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EDITORIAL

This first issue in 2019 marks the 68th year of publishing the Journal of Energy. We are especially happy due to the fact that our Journal was included into INSPEC (*Information Services for the Physics and Engineering Communities*) citation database of journals. INSPEC is a bibliographical database published by the Institution of Engineering and Technology from London, and it indexes and contains works from the fields of physics, electrical engineering, computer science, information technology, technical sciences. It comprises more than 18 million records, including more than 10 million articles, more than 4,300 scientific journals (more than 450 of which are open access journals), 14 million conference woks and more than 2,500 conference proceedings, more than 14,000 books, dissertations, reports etc. That is a great motivation for the future work of the editorial board, to achieve better quality of works covering different topics of energy system.

The first paper is a derived version of author's Ph.D. thesis entitled "*Türkiye Enerji Piyasasının Çok Değişkenli Doğrusal Regresyon Analizi ile* İncelenmesi" defended at the Gazi University Institute of Social Sciences. In this paper natural gas, electricity and oil consumption which are the energy sources that the greatest market share of world and Turkey are investigating by using multivariate linear regression model. The conclusion of paper is very interesting. The effects of energy prices in Turkey's energy market didn't meet the classic economic expectations but they developed in accordance with the economic structure of Turkey.

The next very interesting paper is "Fuzzy inference based stability optimization for IOT data centers DC microgrids: impact of constant power loads on smart grid communication over the powerline". In this paper, a 600 V / 380 V DC-DC microgrid that can be used to represent state of the art IoT data center microgrid is modeled using Matlab. Takagi-Sugeno fuzzy inference model is used to establish the domain of attraction of the dc microgrid. It is discovered that the domain of attraction, which represent the stability region of the data center microgrid increases when the dc bus channel capacitance increases.

The paper "Customer empowerment strategy and shaping markets in the production of electricity" analyzes the implementation of the strategy of empowering customers and shaping markets that the E.ON Group, as example, has carried out as a „response" to global transformative trends in the energy market environment by which the former company was divided into two less dynamic and more focused companies into a new or conventional energy world.

In this number of Journal of Energy we have a paper dealing with "Strategic role of oil pipelines in EU energy supply" The oil pipelines have a strategic importance in the energy supply of the European Union (EU), thus the oil pipeline companies hastily modify their strategies by expanding business and becoming more and more transport-storage-energy oriented, and by investing in the flow reversal of oil pipelines and connection pipelines, storage capacities, as well as in enhancement of efficiency and flexibility of oil pipeline and storage infrastructures.

The last paper "Neutral point connections in MV power networks with grounding zigzag transformers – analysis and simulations" deals with treatment of transformer neutral point in middle-voltage (MV) networks which become an important issue with increasing proportion of MV cables in power networks.

This year we are going to work on several special issues from different scientific conferences, and we hope the authors will recognize the quality of publishing works in this journal, which is definitely going to contribute to quality maintenance, but also to the improvement of the journal's quality, which is in the interest of our wide academic community.

Goran Slipac
Editor-in-Chief

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Estimating Demand of Turkish Energy Market: a Multivariate Regression Model[1]

SUMMARY

Energy is a fundamental factor for economic development. Although in recent years there is a development in studies on an energy economics they are focused on specific energy sources. In this study natural gas, electricity and oil consumption which are the energy sources that the greatest market share of world and Turkey are investigating. In this investigation multivariate linear regression model is used. MVR model is a system of linear regression equations having the same set of independent variables. In this model within–equation, linear restrictions are testable on an equation–by–equation basis using a standard F test. The aim of the study is estimating demand of these three energy sources which are mentioned above. For this purpose, the regression model estimated which has a natural gas, electricity and oil consumption as dependent variables and price of these sources, income and population as independent variables by using 2001:01–2010:06 monthly data. Except for oil prices, coefficients of the model are statistically significant in all models. Coefficients are interpreted economically and determined that supply and demand move peculiar to Turkish energy markets despite the general expectations.

KEYWORDS

Turkish Electricity Demand, Turkish Natural Gas Demand, Turkish Oil Demand, Multivariate regression, Energy Demand.

INTRODUCTION

As a one of the energy importer country, Turkey has five primary energy resources as petrol, natural gas, coal, hydroelectricity and renewable energy.

In the last twenty years Turkey went through three crises in 1994, 2000 and 2001, energy consumption fluctuated during these crises and showed a decreasing attitude [1].

While the dominant fuel in energy production was coal in 1950's, its ratio in the total installed capacity which was 52.1% (212,6MW) decreased to 27.4% (348,3MW) in 1960's. Supply for hydroelectricity reached 32.4% in total capacity in the same year. Increase in the natural gas consumption started in 1970's. While the production rate of natural gas, the consumption rate of which was quite low until 1980's, in the energy plants was 1.1% in 1985, it increased to 26.4% in 1999 [2].

The year 1984 is a milestone both for the economy of Turkey and for conducting energy planning and energy demand for next years. The World Bank proposed ETKB (Ministry of Energy and Natural Resources) to use MAED (Model for Analysis of the Energy Demand) and WASP (Wien Automatic System Planning Package) III models developed by IAEA (The International Atomic Energy Agency) to determine the energy and electricity demands [3].

Turkey as a mainly importer in terms of energy resources, met 74% of its energy supply from abroad, above 90% in petroleum and natural gas and about 20% in coal in year 2009. According to the data from 2008, 55.7% of the imported natural gas was used in electricity production, 22.2% was used in the houses and 22.0% was used in industry. Natural gas consumption of Turkey was an annual 35.6 billion cubic meters at the end of 2008, the consumption increased in the electricity sector and similarly decreased in the industry sector [4].

Consumption of natural gas started to be used in 1976. In 2006 it had 28.6% of total supply of primary energy and 52.8% of this supply was

1 This paper is a derived version of author's Ph.D. thesis entitled 'Türkiye Enerji Piyasasının Çok Değişkenli Doğrusal Regresyon Analizi ile İncelenmesi" defended at the Gazi University Institute of Social Sciences, October 2011.

used in electricity plants [5][2].

Electrical energy was first produced in 1906 in Tarsus by the Italian. The plant commissioned in Tarsus was a generator in 2kW capacity connected to a watermill. First major electricity plant in our country was established in Silahtar Ağa, İstanbul in 1913.

Coal, especially Brown coal is the most important local energy resource of Turkey. TTK (Turkish Coal Corporation), sustains its actual monopoly position in coal production, distribution and processing. While 55% of the Brown coal produced in 2003 was produced solely by TTK, only 10% was produced by private companies.

This study aims to estimate natural gas, electricity and petroleum demand for Turkey. The equation to be estimated with this aim is known as demand equation in the literature of economy.

There is wide literature about Turkish energy demand. [3] forecast energy demand of Turkey using Winters' exponential smoothing method and cycle analysis. [6] finds that price elasticity of coal is very low for the period 1987–2002 for Turkey. [7] shows that growth and investment have positive, consumption and prices have negative relationship in Turkey. [8] argues production effect, structural effect and intensity effect by using LMDI(Logarithmic Mean Divisia Index) approach on Turkish sectoral3 energy use then concludes that main source of the total effect is production effect. [9] finds that long–run and the magnitude of price elasticity is considerably larger than the income elasticity in Turkey. [10] investigate the Granger causality of GDP and energy consumption and find that direction of causality is GDP to energy consumption. [11] conclude that fossil fuels will continue to play a major role in the future energy mix of Turkey. Nonetheless Turkish energy system will be depended more on natural gas than on other fuels. Also [12] investigates electricity demand and finds that the price and income elasticity for electricity demand is very low in Turkey and asserts that the electricity market have to be regulated.

In this study, factors of the goods demand quantity of which is to be estimated are determined within the frame of traditional demand theory as the price of the good, the price of substitute goods and income. In this case, general demonstration of the model to be established is presented in the vectorial form as below as D is for demand, P is for price, G is for income, E is for electricity, NG is for natural gas and O is for oil:

[NGD, ED, OD]=f[NGP, EP,OP, G] (1)

It can be shown in vectorial form in (2) and also below:

$$NGD\_{t}=\beta_{01}+\beta_{11}\,NGP_t+\beta_{12}\,EP_t+{}_{13}\,O_t+\beta_{14}\,G_t+\varepsilon 1_t$$
$$ED_t=\beta_{02}+\beta_{21}\,NGP_t+\beta_{22}\,EP_t+\beta_{23}\,OP_t+\beta_{24}\,G_t+\varepsilon_{2t}$$
$$PD_t=\beta_{03}+\beta_{31}\,NGP_t+\beta_{32}\,EP_t+\beta_{33}\,OP_t+\beta_3 4\,Gt+\varepsilon_{3t} \tag{2}$$

GDP or GNP is used as the indicator of income level in the implementations of macroeconomics. GNP data is estimated in four terms by TÜİK(Turkish Statistical Institute) as quarterly data. In this paper monthly data are used therefore Industry Production Index is which is published monthly as income level variable.

The variables are in different measurements, i.e. natural gas consumption was obtained in Terajoule, electricity consumption was obtained in GWs, petroleum consumption was obtained in Kilotone yet to make all the measurements in the same type, all consumption values were converted into Terajoule. Price values were converted into fixed prices by deflating these values with PPI[4] . Also a correction was made on electricity data.

As known, electricity energy is obtained by using other energy sources. Natural gas and petroleum consumption data comprises petroleum and natural gas quantities used in electricity production. This situation causes a correlation among independent variables and also causes the same data to be calculated twice. Therefore, natural gas and oil quantities used in electricity production are excluded from electricity consumption quantities.

The dependent variables are NGD natural gas demand (Turkey, Gross Inland Deliveries (Observed) [in Terajoules] IEA Energy Statistics Ó OECD/ International Energy Agency, 2010), ED electricity demand (EC–EGN–ENP[5]), OD oil demand (Turkey (Total Products Demand as defined in the Oil Market Report [in KT] IEA Energy Statistics Ó OECD/ International Energy Agency, 2010). Independent variables are NGP natural gas price (TÜİK,CPI, Product Name, Natural Gas Fee,TL), EP electricity price (TÜİK,CPI, Product Name, Electricity Fee,TL), OP oil price (TÜİK,CPI, Product Name, Petrol Price, TL), IPI industrial production index (Monthly Industrial Production Index (1997=100), Total Industry, Manufacturing+Mining+Ohters)[6]. Economic expectations for the variables are discussed generally below.

When the price of energy resources increases, consumers alter it with another energy resource which is a substitute. Yet electricity, natural gas and petroleum are not exactly substitutes. An energy source for a machine used both in residents and industry for energy or heating is either cannot be replaced or it takes a long and/or expensive process to replace.

Petroleum is used more commonly in transportation diesel and LPG involved. Along with this, it takes part in production as an intermediate input. Impact of petroleum price on electricity is bidirectional. First impact is substitute impact and the second impact is the one it makes as complementary good. A part of electricity consumption is procured from petroleum and petroleum is a cost for electricity production. Increase in the price of petroleum price causes an increase in the cost of electricity consumption and therefore the more the price for petroleum is, the less the electricity consumption is. Direction of the impact will be determined depending on which of the two impacts is more dominant.

Along with this, there are losses and illegal use while this energy is transmitted to the consumers. Especially in electricity energy distribution, there is a high rate of losses and leaks. [13] mentions some reason of these causes such as there is no investment in this field and maintenance–repair works are not performed periodically. Illegal use in petroleum and electricity constitutes a major problem too.

In the petroleum market, especially since the middle of 2007, various substances have been sold and used in cans instead of diesel oil under the name of 10 number oil. According to [14] report, base oil import of Turkey increased in 210.000 tones between 20052007. According to [15] report, after fixed Special Consumption Taxes collected from certain fuel types were increased by the Ministry of Finance of Republic of Turkey, legal consumption of these fuels decreased and activities carried under the name of 10 number oil etc. considerably increased. It is estimated that market activities caused only by mixing base oils and waste oils in fuels is more than an annual 500 thousand tones and the tax loss caused by this situation is far above 600 million TRY/Year.

In this study, loss and illegal use rates do not take into account, official consumption data are used and the increase in the price is deemed to have a consumption decreasing impact by increasing the rate of illegal use.

MULTIVARIATE REGRESSION MODEL

In this paper multivariate regression model is used. [15] defined multivariate regression model that a system of linear regression equations having the same set of explanatory variables. Author stated that this technique mostly used in demand analysis and empirical asset pricing. If the individual equations of the system are classical regressions is used instead of using multivariate regression linear restrictions are testable on an equation–by–equation basis using a standard F test.

MVR is named as a multivariate regression model in [16], [17], [18], [19], multivariate linear regression in [20], [21], [24] and general linear multivariate model in [23].

In the MVR generalizes the univariate model by allowing more than one dependent variables to be measured on each independent sampling unit. Implicitly the model requires that the same design matrix apply to every dependent variable and every independent sampling unit have the same set of responses variables. The most important key difference is hypothesis testing which is far more complicated than multiple regression model [23].

Test problems in MVR model may also be found in seemingly unrelated regressions (SURE) and simultaneous equations. Also the MVR model can be interpreted as a SURE model with identical dependent variables across equations in other words the SURE model may be nested within an MLR framework, imposing exclusion constraints [24].

In MVR estimated coefficients and standard errors are identical to the estimates obtained from multiple regression model of the individual equations. The advantages of the MVR are in hypothesis testing since heteroscedasticity across equations and contemporaneous dependence of the distur-

2 World Energy Council. Turkish National Committee.

3 Agriculture, industry and service secotors were used.

4 In period 2001:01:2002:12 the data converted to 2003=100 indiced from 1994=100 indiced by authors.

5 EC Electricity Consumption (Turkey Gross Electricity Consumption [in GWs] , TEİAŞ), EGN Electricity Generation Natural Gas: Distribution of Turkey's Gross Electricity Generation by Primary Energy Resources, Natural Gas part (GWs), TEİAŞ, EGP Electricity Generation Petroleum: Distribution of Turkey's Gross Electricity Generation by Primary Energy Resources , Liquids (Fuel–Oil, Diesel, LPG, Naphta) (GWs), TEİAŞ

6 2001:01–2008:01 period 1997=100, 2009:01–2010:05 period 2005=100 indiced series are collected from data source. The period of after 2009:01is converted to 1997=100 indiced series.

bances are explicitly incorporated into the hypothesis tests [25].

Suppose that we have the response of the ith individual (i=1,…,n) is some quantitative measure of dependent variables observed at time points $t_1,\ldots,t_g$. The dependent variables depend on explanatory variables that are shown by . A MVR model for this dependent variables is below

$$Y_{ij}=\beta_{0j}+\sum^{p}_{l=1}\beta_{lj}X_{il}+\varepsilon_{ij} \quad i=1,\ldots,n, \ j=1,\ldots,q \tag{3}$$

In the Equation 3 the coefficients of the explanatory variables depend on j . This accounts for the possibility that the pattern of influence of the explanatory variables may depend on the time of measurement. Also the observations of a given patient at different time points may be correlated. The error variance for the various time points may also be different. These variances and covariances may not be known at all [21]. In order to overcome these kind of problems the model with several dependent variables which is called MVR model is used.

Testing linearity is one of the main problem in MVR model like multiple regression model(MR). The advantage of MVR model over multiple regression model is that significance of independent variables can be tested in all models jointly. If we have collected data about several dependent variables and make separate MR model then we could make separate t tests. If more tests we conduct on the same data, the more we inflate the familywise error rate.

Imagine a situation in which there were three model and we would like to compare one independent variable between these three models separately. If we were to carry out t–tests on every pair of models, then we would have to carry out three separate tests: one to compare models 1 and 2, one to compare models 1 and 3, and one to compare models 2 and 3. If each of these t–tests uses a 0.05 level of significance then for each test the probability of falsely rejecting the null hypothesis (known as a Type I error) is only 5%. Therefore, the probability of no Type I errors is 0.95 (95%) for each test. If we assume that each test is independent then the overall probability of no Type I errors is 0.857 (0.95x0.95x0.95). Thus the probability of at least one Type I error is 0.143(1–0.857) or 14.3%. Therefore, across this group of tests, the probability of making a Type I error has increased from 5% to 14.3%. This error rate across statistical tests conducted on the same experimental data is known as the familywise or experimentwise error rate [26].

The most common tests which could be used to do these joint tests are Wilks' Lambda, Pillai's Trace, Hotelling –Lawley Trace and Roy's Largest Root statistics such as following:.

Wilks' Lambda:

$$\wedge = \prod_{i=1}^{s}\frac{1}{1+\lambda_i} \tag{4}$$

Pillai's Trace :

$$V = \sum_{i=1}^{s}\frac{\lambda_i}{1+\lambda_i} \tag{5}$$

Roy's Largest Root : λ_1 (6)

Hotelling –Lawley Trace is also known as a Hotelling T2 is below.

$$T = \prod_{1}^{s}\lambda_i \tag{7}$$

where s number of variables and is eigenvalues.

[27] point out that the Roy test is weaker than other three test but if there is a one big eigenvalue it will be the most powerful test. Also they indicate that in a big sample Wilk's Lambda, Roy' Largest Root and Hotelling Lawley Trace tests statistics values are approximately same.

Other Model Testing Methods

[27] suggest these four graphs[7] to detect possible anomalies.

Residuals $\hat{\varepsilon}_i$ are plotted against the predicted values $\hat{Y}_i$. The graph is indicated the violating assumptions and has two interpretations and both of them means not equal variance:

a) The relationship between $\hat{\varepsilon}_i$ and $\hat{Y}_i$ may be increasing. A dependence of the residuals on the predicted value. The numerical calculations are incorrect or constant term has been omitted from the model.

b) The pattern of residuals may be funnel shaped. If this is the case, the variance error is not constant and transformation or a weighted least squares approach are required.

Residuals are plotted against independent variables or products of them. A systematic pattern in these plots suggests the need for more terms in the model.

Q–Q plots and histograms used to detect normality in residuals.

Residuals are plotted versus time. Although the assumption of independence is hard to check if the data are naturally chronological, a plot of the residuals versus time may reveal a systematic pattern. For instance, residuals that increase over time indicate a strong positive dependence.

EMPIRICAL APPLICATION

Table 1 shows descriptive statistics of the variables. Range of the consumption variables is quite high, the standard deviation of natural gas demand is 28736 terajoule and it indicates how great the increase in natural gas consumption is. Therefore, it was decided to take logarithm of the consumption variables.

It is seen that the price variables are not high in variance. Also, because the Industry Production Index is an index variable, it is not considered necessary to take logarithms of these variables.

Table I: Descriptive Statistics of Variables

	Variables							
	Dependent Variables				Independent Variables			
	NGD	EC	OD	ED	NGP	EP	OP	IPI
Mean	89128,68	49523,29	10468,11	24748,31	0,0038	0,0017	0,0244	91,2223
Median	90916,5	48610,8	10618,99	24709,14	0,0036	0,0016	0,0268	88,0709
Maximum	152633	66210,48	14418,06	34061,23	0,0087	0,0029	0,0404	127,1
Minimum	41547	34878,6	6154,664	17495,28	0,0011	0,0006	0,0059	61,2451
Std. Dev.	28735,84	8490,41	1296,867	3981,927	0,0017	0,0005	0,0087	18,6819

Before the logarithms of the variables are taken, it is necessary to investigate if they include seasonality or not. Seasonal Stacked Line graphics were used for this. When the graphics were examined it was seen that they included high levels of seasonality. With the effect of seasonality being low in price variables and PIPI, at first all variables are seasonally adjusted. Also, it would be seen from the graphs that the price of electricity was fixed for nearly 62 months. In this period comprising 2002:11–2007:12, the difference between the highest and the lowest price was 0.00242 TRY.

First, all variables were seasonally adjusted using moving averages method then logarithms of the high variable demand series were taken. The seasonally adjusted series are named by adding "MA" to the end of the abbreviation of the series and logarithm of the series are named by adding "L" to the beginning of the abbreviation of the series.

Before the model was estimated, to ensure the requirement that the residuals terms [28] and dependent variables [23] must be un–correlated, natural gas and liquid fuel quantities used in the electricity production were excluded from the electricity consumption quantity and the electricity consumption data from hydroelectricity and thermal plants were obtained. As described above, electricity is a secondary energy source and a part of the electricity is produced from natural gas and liquid fuels.

Table presents results of the MVR model. The model having LNGDMA dependent variable is the natural gas demand model, the model having LEDMA dependent variable is the electricity demand model and the model having the LODMA dependent variable is the petroleum demand model. It is seen that all of the estimated models are statistically significant in %1 significance level. When the R–squared of the models are interpreted, it is seen that the first model has %95 and the second model has %82 coefficient of determination. That the oil model has a low ratio of %29 indicates that either there are more important variables affecting the petroleum consumption or consumption does not move according to the price factors due to the illegal use rate in oil consumption in Turkey.

7 Illustration of graphs can be found in the book.

Table II: Results of the Model

Dependent Variables						
LNGDMA	Variable	Constant	NGPMA	EPMA	OPMA	IPIMA
	Coefficient	10,4046	2,2183	–171,765	33,9871	0,0033
	F=587,1004 F–prob= 0,0000 R–squared = 0,9556					
LEDMA	Variable	Constant	NGPMA	EPMA	OPMA	IPIMA
	Coefficient	9,6282	–27,4213	9,1451	16,9337	0,0012
	F= 132,5032 F–prob= 0,0000 R–squared= 0,8294					
LODMA	Variable	Constant	NGPMA	EPMA	OPMA	IPIMA
	Coefficient	9,3875	21,5037	–194,069	3,2739	0,0003
	F= 11,00698 F–prob=0,0000 R–squared= 0,2877					

Error terms and coefficients should be tested before the estimated parameters of the independent variables are interpreted.

Testing Residuals

The independence of residuals were tested by Breusch Pagan (1980). Table 3 shows that the correlation between residuals is at most 13% that is to show there is no strong dependence between residuals. Also the null hypothesis of the B–P test which refers to the error terms are not related cannot be rejected.

Table III: Correlation matrix of residuals

Residuals of Model:	LNGDMA	LEDMA	LODMA
LNGDMA	1,0000		
LEDMA	–0,0796	1,0000	
LODMA	0,1460	0,0946	1,0000
Breusch Pagan Test		Test Stat.	Prob,
		4,173	0,2434

Joint Significance Test of Coefficients

It is main advantage of the MVR model that we can jointly test the coefficients across models. The results are below:

Table IV: Constant Term — Multivariable Significance Test Results

Test	Statistic	F Stat	Prob
F Testi	21676,50	–	0,0000***
Wilks' Lambda	0,0007	49627,4311	0,0000***
Pillai's Trace	0,9992	49627,4311	0,0000***
Roy's Largest Root	1378,5397	49627,4311	0,0000***
Hotelling–Lawley Trace	1378,5397	49627,4311	0,0000***

*** shows significance level in 1% .

The null hypothesis of constant terms are not significant in the MVR model is rejected in 1% significance level(Table 4).

Table V: NGPMA — Multivariable Significance Test Results

Test	Statistic	F Stat.	Prob.
F Test	2,88	–	0,0394**
Wilks' Lambda	0,9266	2,8248	0,0422**
Pillai's Trace	0,0733	2,8248	0,0422**
Roy's Largest Root	0,0791	2,8248	0,0422**
Hotelling–Lawley Trace	0,0791	2,8248	0,0422**

** shows significance in 5% level.

The null hypothesis of natural gas price variables are not significant in the MVR model is rejected in 1% significance level(Table 5).

Table VI: EPMA — Multivariable Significance Test Results

Test	Statistic	F Stat.	Prob.
F Test	20,74	–	0,0000***
Wilks' Lambda	0,6365	20,3629	0,0000***
Pillai's Trace	0,3634	20,3629	0,0000***
Roy's Largest Root	0,5709	20,3629	0,0000***
Hotelling–Lawley Trace	0,5709	20,3629	0,0000***

*** shows significance level in 1% .

The null hypothesis of electricity price variables are not significant in the MVR model is rejected in 1% significance level(Table 6).

Table VII: OPMA — Multivariable Significance Test Results

Test	Statistic	F Stat.	Prob.
F Test	153.55	–	0,0000***
Wilks' Lambda	0,1913	150,7293	0,0000***
Pillai's Trace	0,8086	150,7293	0,0000***
Roy's Largest Root	4,2260	150,7293	0,0000***
Hotelling–Lawley Trace	4,2260	150,7293	0,0000***

*** shows significance level in 1% .

Table 7 shows that the null hypothesis of oil price are not significant in the MVR model is rejected in 1% significance level.

Table VIII: IPIMA — Multivariable Significance Test Results

Test	Statistic	F Stat.	Prob.
F Test	8,44		0,0000***
Wilks' Lambda	0,8114	8,2849	0,0001***
Pillai's Trace	0,1885	8,2849	0,0001***
Roy's Largest Root	0,2322	8,2849	0,0001***
Hotelling–Lawley Trace	0,2322	8,2849	0,0001***

*** shows significance level in 1% .

At last there is no significant result to omit IPI variable from the model (Table 8).

Also all variables which are used in the MVR model can be tested by multivariate significance tests. In this situation the hypothesis is below:

$$H_0 : \begin{bmatrix} \beta_1 \\ \beta_1 \\ \beta_1 \end{bmatrix} = \begin{bmatrix} \beta_2 \\ \beta_2 \\ \beta_2 \end{bmatrix} = \begin{bmatrix} \beta_3 \\ \beta_3 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} \beta_4 \\ \beta_4 \\ \beta_4 \end{bmatrix} = 0$$

Table 9 : Overall — Multivariable Significance Test Results

Test	Statistic	F Stat.	Prob.
F Testi	4,58x10–5	–	0,0000***
Wilks' Lambda	0,0206	78,8298	0,0000***
Pillai's Trace	1,3599	22,5966	0,0000***
Roy's Largest Root	29,6612	261,1836	0,0000***
Hotelling–Lawley Trace	29,6612	261,1836	0,0000***
*** shows significance level in 1% .			

The four independent variables in three models are significant to be in all models. In conclusion we cannot reject to include any variables into model.

Results of Other Model Testing Methods

1. The residuals against fitted values of models are given below. In the Figure 1, RNG, RE and RO shows natural gas, electricity and oil models residuals respectively and the abbreviation "FIT" in the graphs means fitted values of the series used.

Figure 1 : Residuals Against Fitted Values

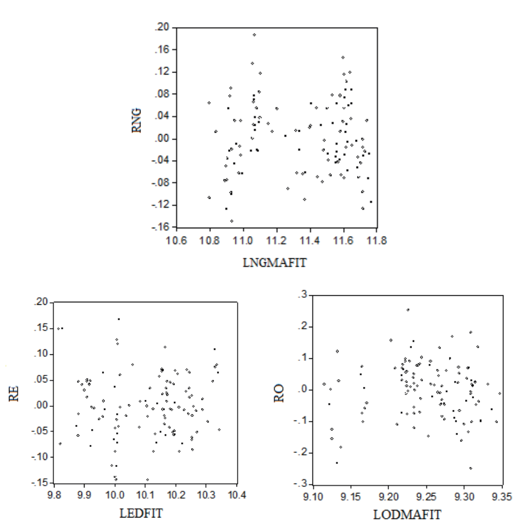

Figure 1 shows that there is no patter between residuals and fitted values.

2. Plotted residuals against independent variables are below and show that there is no pattern as required.

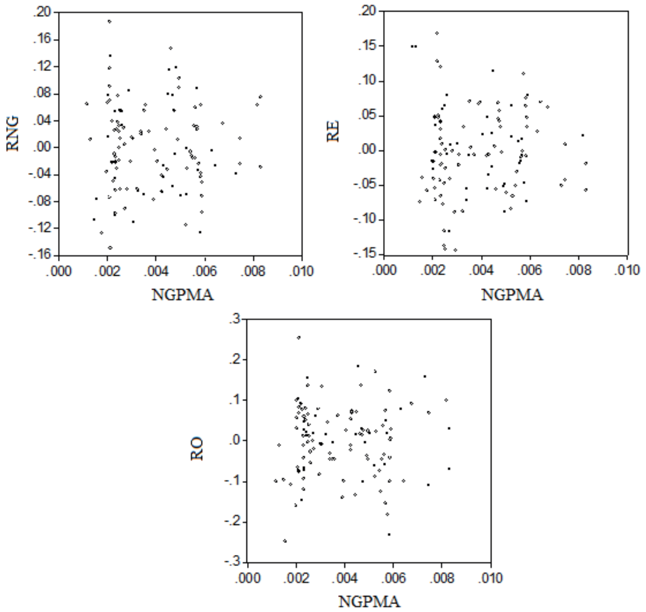

Figure 2: NGPMA — Residuals

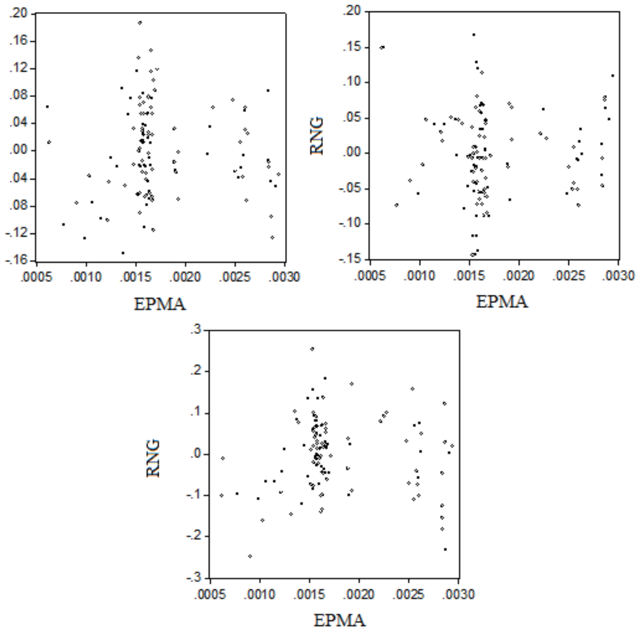

Figure 3: EPMA– Residuals

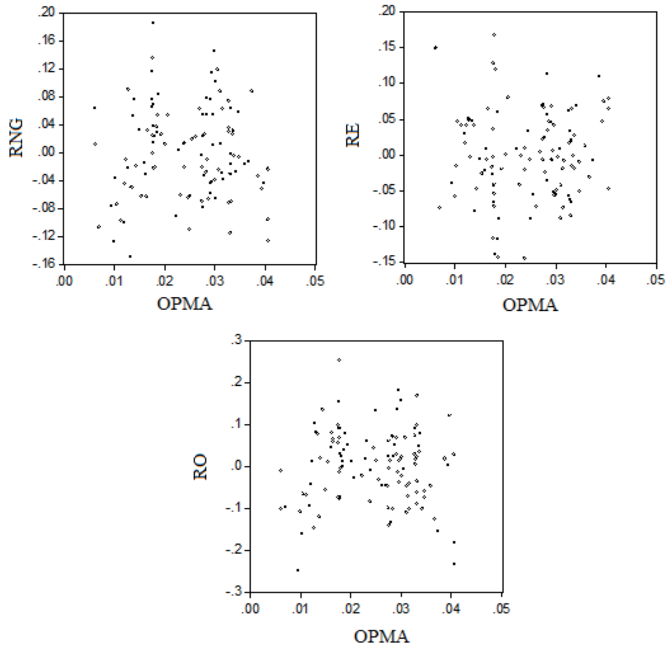

Figure 4 : OPMA– Residuals

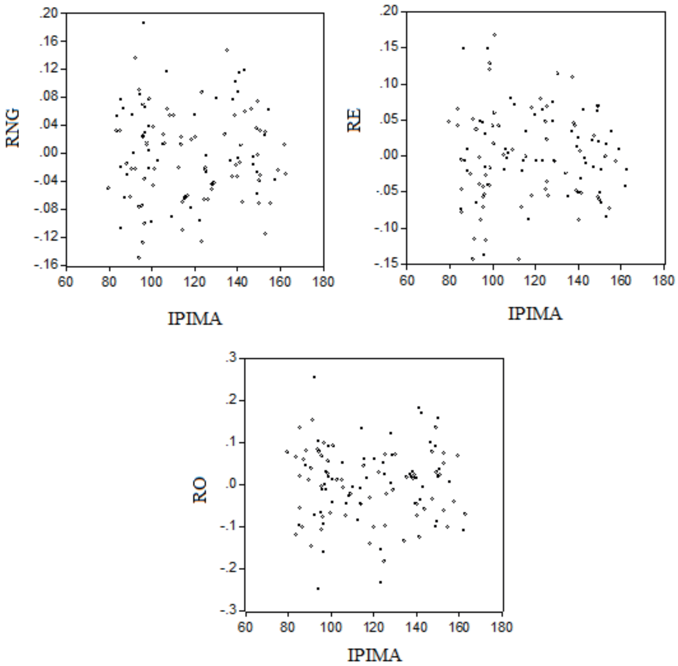

Figure 5 : IPIMA– Residuals

3. Figure 6 shows that the points on a normal Q–Q plot are reasonably well approximated by a straight line thus normal distribution hypothesis is plausible.

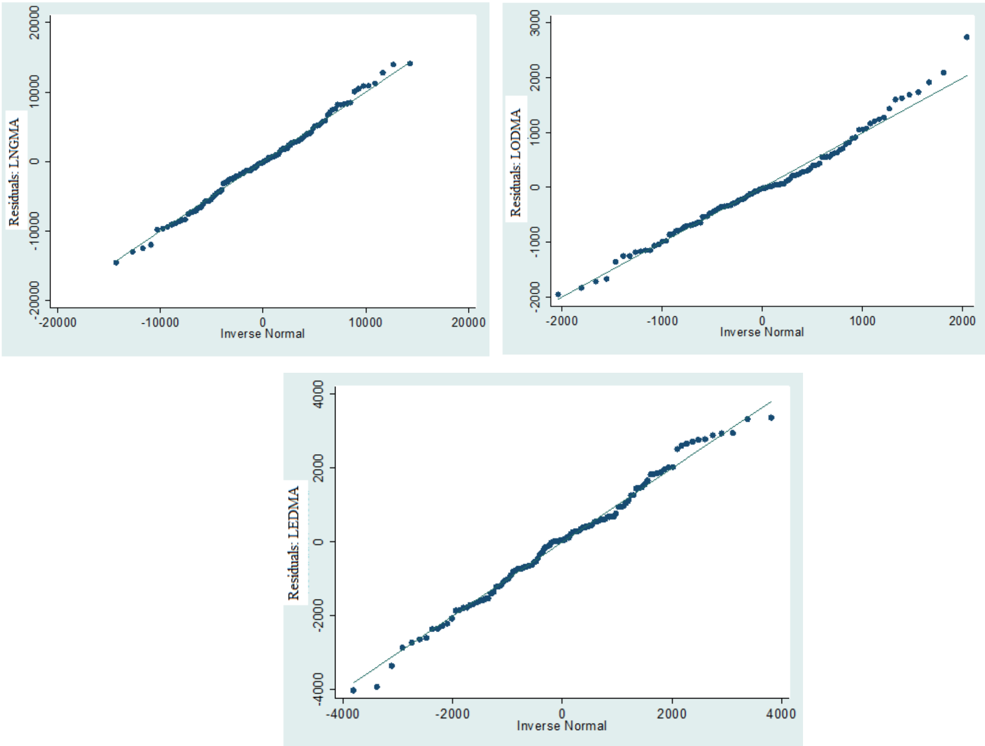

Figure 6: Q–Q plot of Residuals

4. The plots of residuals versus time have no systematic pattern and they show that no dependence on time.

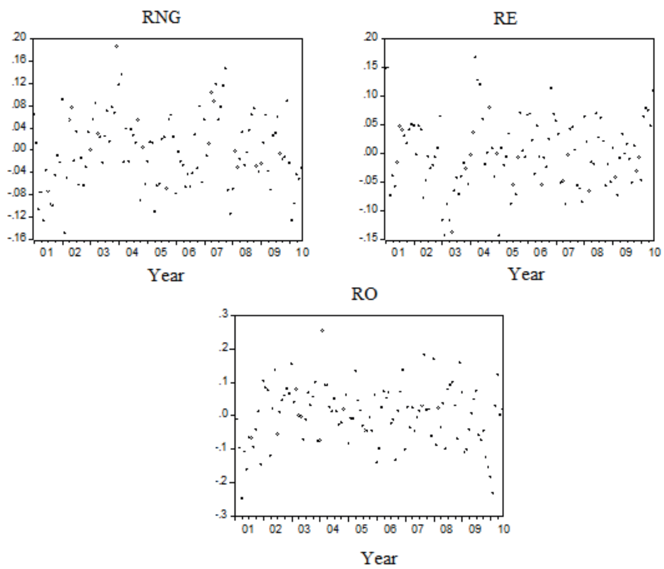

Figure 7: Residuals–Year

Testing Multicollinearity

The Variance Inflation Factor (VIF) is widely used measure of the degree of multicollinearity. If the VIF value is large, usually larger than 10 ([29], [30], [31]) indicate that a importance of multicollinearity.

Table X : VIF Values

Variable	VIF
NGPMA	9,16
EPMA	3,84
OPMA	5,95
IPIMA	7,36

Although Table 10 shows that there is no strong multicollinearity in the models natural gas prize has high VIF value.

After the goodness of fit tests of the model shows that the model statistically significant the model can be interpreted in terms of economics. When the first model in which the natural gas consumption is the dependent variable is examined, it is seen that the relation between the natural gas price and the natural gas consumption is in the same direction. Although a negative directional relationship is expected between price and consumption theoretically, demand increases continuously in terms of the use of natural gas both in residents and in real sector production. Also, because the pricing of natural gas is determined not based on the demand but based on the exchange rate and unit price factors of the natural gas obtained from different countries by the central government, change in demand is not a determinative factor in the price of natural gas.

In addition to these factors, that some part of the natural gas purchases Turkey obtains from abroad is in "purchase or pay" way, considering the annual purchases which will be paid even in it is not purchased, requires the extend the consumption of natural gas. That the natural gas consumption doesn't decrease even if the price of it increases can be explained by this situation. Because nearly the half of the natural gas consumption is used in electricity production and production and consumption values shows an increasing trend every year. Also, thanks to the infrastructure investments realized, number of residents benefiting from the aforementioned energy source is similarly increases. According to the data from BOTAŞ, while 9 cities had Access to natural gas in 2002, this number increased to 61 in 2009.

Although the present consumers decrease the natural gas consumption, the increase in the number of consumers increases the consumption independently. Also, as stated in [32], in spite of the reforms and regulating institution the market structure couldn't be liberalized and it is said that both not being able to strengthen the liberal market structure and not being able to realize the demand–price relationship are effective. Again in [1] study, a positive relation between the natural gas consumption used in electricity production sector and price was detected. It must be considered that nearly the half of the natural gas consumption used in the model established above is used in electricity production. The relation between the price of electricity and natural gas consumption is in reverse direction, in this context there is an important complementary effect between these two energy sources. The determinative factor here can be considered as the effect the natural gas has on electricity as complementary good. When the price of electricity increases, share of natural gas in electricity production decreases.

The results obtained indicate that the electricity and natural gas are not substitutes of each other but they are complementary goods. [33] detected in his study that the electricity price had a negative effect on the total energy demand of service sector and industry sector in the cointegration model estimated for the period of 1985–2004.

Natural gas and petroleum used mainly as a production input for the industry sector can be subject to a substitute effect as using the cheaper one to the extend the production process allows. Also, the relationship between the Liquid Petroleum Gas (LPG) and natural gas is parallel to this. Because LPG pricing is parallel with the raw petroleum pricing mechanism, the changes in petroleum prices in the world markets are more apparent on LPG pricing and the pricing of natural gas (as defined before) is determined by terms and free from market conditions by the central government. It is seen that the petroleum prices have a positive effect on natural gas consumption. Because petroleum and natural gas are used as substitutes especially in industry, it is an expected situation that when the price of petroleum increases the natural gas which is the substitute is preferred by the consumers.

The relation between the natural consumption and the Industry Production Index used as the representative of the income variable in the equation is marked in positive direction as expected. On the other hand it draws attention that the price of natural gas has a negative effect, electricity and petroleum prices have a positive effect and income has the same positive effect on electricity demand.

When considered in terms of the electricity demand (second equation), the increase in the natural gas price decreases the electricity consumption. Energy plants particularly using natural gas as input are determinative and because the price of natural gas used as input is determinative on electricity consumption costs, the increase in the price of natural gas used in electricity energy production decreases the electricity consumption.

Contrary to the expectations the relationship between the price of electricity and electricity consumption is positive. In the periods in which the economies expand, the populations increase thus the energy demand increases, the consumption of electricity, which is used as the primary energy input, increases regardless of the direction the price changes. In addition to this, because of the developments in the technology and enhancements in the purchase power, household people use electrical appliances more and these results in the increase in the electricity consumption in spite of the increase in the price. In this point, it shouldn't be forgotten that the electricity is not in a structure that can be priced in the market and thus the price of which can change in accordance with the changes in the input costs but it is also a "good" the price of which is determined by the public. As in the pricing of natural gas, pricing in the electricity does not change according to the demand increase; it is determined "externally" by the public as a means of policy. Also it should be considered that the price of electricity was hold fixed in nearly 40% of the investigated data period.

Table 2 shows that there is a relationship in the same direction between the petroleum prices and the electricity consumption, petroleum price increases the electricity consumption. İt is known that petroleum prices usually increases in periods on which economies expand and energy demands increase. The consumption of electricity, which is related to the expanding in world economies (incomes of the exporting countries) through the export channel and which is affected by the price changes in the energy market through import in energy consumption increases. This increase occurs also in Turkey's economy in parallel to the global economic expanding periods (when the crisis years which are incidental and occurred only in the domestic economy are excluded from the analysis) both because of the increasing household income and increasing industry and services production. Therefore, increase in the petroleum price and increase in the electricity production occur in overlapping periods. That the electricity consumption in residents does not have a substitute results in no effect of electricity price on consumption. On the other hand, the increase in the petroleum price and income has an increasing effect on electricity consumption. [1] stated that even though the natural gas costs are not determinative on electricity price, its reflection on the costs of the company would be determinative (cost–pass–through) in the estimation of the cost of the electricity produced in the electricity generation plants, in other words, the reason why the relationship between the price and the consumption is not negative as expected in the theory is that the plants generating electricity by burning natural gas sell the electricity they produce without reacting the increase in the natural gas prices on a determined tariff.

IPIMA coefficient indicates that the increase in the income increases the electricity consumption of the individuals (both by using present electrical appliances and by purchasing new electrical appliances).

The results of the last model, which is the petroleum consumption model shows that the relationship between the price of natural gas and petroleum consumption is in the same way and the increase in the natural gas price increases the petroleum consumption. This situation seems to verify the substitute effect between petroleum and natural gas explained in the first equation. Petroleum consumption increases as a result of increase in the natural gas price and the end users (either household people or company sectors) increase their petroleum consumption as a result of this increase.

The relationship between the price of petroleum and petroleum consumption is in the same direction it may be reason of the period of increase in the petroleum demand occurs in the expanding periods of economies thus two variables increase in same term. Petroleum, one of the most important inputs of the production and trade thus demand of this resource increases free from the price. That the IPIMA, coefficient indicating the relationship between the income and the petroleum consumption.

CONCLUSION

In this study, the demands of natural gas, electricity and petroleum, which are the primary energy source in Turkey and in the world, were estimated using MVR model. The aforementioned energy sources were discussed in many studies yet the examinations conducted usually focused on a single energy source. In this study, the three energy resources were investigated together.

Because the three energy sources were the substitutes or the complementary goods of each other, a MVR model used to deal with these variables simultaneously. Therefore a method that was capable of such examination needed to be used. These requirements were met by using MVR model.

It was concluded that there should be different variables to be considered especially in petroleum demand. Yet these variables were to be specific to petroleum demand and wouldn't be used in natural gas and electricity demands, which were the other two models. As expected in all estimated models, the effects of the income variable on the consumption of all three energy resources were in the same direction. When the incomes of the consumers increased, their energy consumptions, which was a part of their social and economic lives also increased.

As a result of the analyses conducted, it was observed that the effects of energy prices in Turkey's energy market didn't meet the classic economic expectations but they developed in accordance with the economic structure of Turkey. In a newly constituting market such as natural gas market, demand and supply increased continuously with an increasing trend and therefore changes in the price didn't have an effect on consumption. In the electricity market, competitive market conditions still didn't develop and production became dependent on natural gas. Therefore the complementary good effect of the natural gas, which actually should have been a substitute energy resource, was higher than its substitute good effect. Turkey, which was among the fastest developing countries in the world used petroleum as a main input in production process and many by–processes of production (such as transportation) and therefore the effect of petroleum prices on its consumption decreased. Also, it is decided that in the petroleum demands occurred due to the illegal use and use of similar goods instead of petroleum, not due to the petroleum prices.

In the light of these findings, it is suggested that the energy market should become a market having a stronger market structure.

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Fuzzy Inference Based Stability Optimization for IoT Data Centers DC Microgrids: Impact of Constant Power Loads on Smart Grid Communication over the Powerline

SUMMARY

Direct Current (dc) microgrids due to their efficiency and energy savings are being deployed to provide power for servers in Internet of Things (IoT) data centers, in more electric aircrafts (MEA), electric ships and in rail systems round the word. In this paper, Takagi–Sugeno fuzzy inference method is used to establish a Lyapunov stability candidate for a 380 V ring bus dc microgrid modeled with Matlab. To determine suitability of using powerline communication (PLC) to monitor stability condition on the 380 V dc microgrid, impact of distortion caused by microgrid constant power loads (CPL) on signals transmitted over the dc microgrid PLC channel is examined. It is shown in this paper that while Lyapunov asymptotic stability is maintained on the dc bus, increasing CPL on the microgrid causes the dc microgrid PLC channel to experience growing signal distortion.

KEYWORDS

microgrid, Lyapunov, fuzzy inference, stability, powerline communication,

MOTIVATION AND INCITEMENT

Worldwide, data centers (such as Google Data Center) consume up to 1.5% of total generated electricity round the world. From the consumed 1.5%, they utilize only about 30% leading to a loss of 70%. Thus, the efficiency ratio of data centers round the world is approximately 30% [1]. The reason for this low efficiency is that data centers are always over–engineered in terms of electricity provision and usage with a lot of redundancies in electric power provision introduced in data center networks. An average data center draws about 25MW of electricity from the grid, hence they present a huge load to the electricity grid. Data centers must be reliable, they must have the exact needed supply of electricity at the right time since most data center equipment are very sensitive. Consider the typical data center power distribution topology shown in Figure 1. AC supply from the electricity mains will be

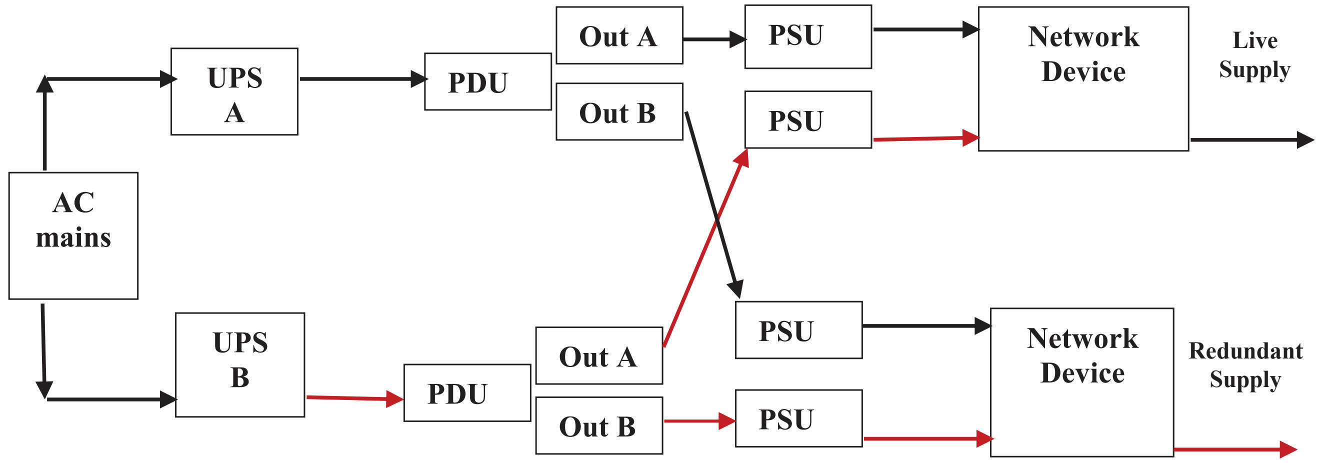

Figure 1. Data centers looses enormous amount of power due to overprovisioning of redundancies.

supplied to the Uninterruptible Power Supply (UPS), and from the UPS to the Power Distribution Unit (PDU). It will be converted to dc power at the Power Supply Unit (PSU) and finally to network servers, switches, huge database computers, and other general network devices. The auxilliary part of the topology (denoted with red arrows) that result to redundant power supply is only introduced to provide added reliability to the network. In most cases, the reducndant power supply is not used, leading to losses of generated electricity. To curtail these enormous losses and to ensure that microgrid stability is maintained, it is envisaged that by installing a communication overlay such as PLC with the power distribution topology, then downstream connected devices will be visible to upstream UPS by means of communication and the UPS can adjust power needs based on the number of connected devices [2]. With PLC, downstream visibility of connected devices will be achieved, thus power consumption efficiency and load balancing can be improved, and the need for redundant power supplies will be progressively phased out in data center topologies. Data center power usage and stability monitoring using PLC has been suggested in [2], but no one have work on its feasibility and ways to make this possible. Also, to reduce the incidence of power losses, and to improve on reliability and efficiency, ring bus dc microgrids are being increasingly used in data centers, MEA, electric ships, rail systems, and autonomous islands more than ever [3]. DC microgrids have significant advantages when compared to alternating current (AC) based microgrids. dc microgrid have fewer conversion stages, leading to lower energy losses. Also. Most renewable energy sources such as photovoltaic (PC) are dc in nature. In fact, dc microgrids are central to the development of smart grid systems [3]. However, for PLC to be a reliable means of monitoring IoT data center stability and power usage, the impact of varying DC microgrid powerline channel power loads on the effectiveness, signal distortion and reliability of PLC must be further studied. This is the main contribution of this paper.

LITERATURE REVIEW

In [4], authors discussed a power quality (PQ) monitoring solution based on PLC. The PLC hardware and software used for PQ monitoring and evaluation is based on the IEEE std. 1159. It is shown that PLC could be applied for power management by the end user. However the effect of PLC channel loads on the PQ monitoring effectiveness of the system designed is not discussed. In [5], changes in key PLC channel characteristics of the channel frequency response (CFR) is used to observe the PQ of the powerline. In [6], PLC is used as a communication link between a smart meter and a central server. The central server can be used to monitor the power usage of a smart meter. In [7], PLC is used for monitoring and supervision of feeder equipment for medium voltage substation automation. In [8], PLC is used for monitoring Electrocardiogram (ECG) and Electroencephalogram (EEG) signals in order to reduce the cost associated with big health data transmission in healthcare platforms. However, in all of the research works considered, the impact of varying PLC channel loads on the effectiveness of PLC is not examined.

CONTRIBUTION AND ORGANIZATION

In this paper, we have examined the stability of a low voltage dc microgrid that could satisfy the energy needs of a small autonomous system such as aircrafts, IoT data centers and electric ships when channel loads are varying on the powerline channel of the dc microgrid. A 380 V dc bus ring is modeled using Matlab due to many research work that reports on the merits of deploying 380 V dc for data centers and autonomous power systems worldwide [1] — [3], [9], [10]. Small and large signal stability issues are examined for the modeled 380 V dc microgrids when IoT cloud servers or data center servers acting as CPL are increasing on the dc bus. Stability is also examined when an energy source is experiencing large signal voltage transients on the microgrid. Impact of CPL loads on distortion experienced by basedband signals sent over the dc bus when the dc bus is used as a communication channel is also examined. Special emphasis is placed on dc microgrids that are providing power for IoT cloud servers and data centers in this paper due to the energy demands of such data centers and the impact of the demands on power systems that support them worldwide. Our contribution in the paper, to the best of our knowledge is the first known attempt at understanding the relationship between dc microgrid stability, varying CPLs and amount of signal distortion that they can cause of PLC signals transmitted on dc microgrid channels.

Section two of this paper discussed problem of circulating current, electromagnetic interference (EMI) and dc bus line impedance problem on the 380 V dc ring bus microgrids. Small signal stability issues using Bode plots are discussed extensively. In section three, modeling approach for the 380 V dc ring bus microgrid used in this paper is discussed. In section four, the Takagi–Sugeno (TS) fuzzy inference method used to establish a Lyapunov candidate to ensure stability of the microgrid is discussed. Stability of the 380 V dc ring bus microgrid is discussed as well. In section five, impact of CPL on distortion of signal communicated using PLC on the dc bus of the microgrid is examined. Section six is conclusion of the paper.

CIRCULATING CURRENT IN LVDC RING BUS MICROGRID

A representation of the ring bus LVDC microgrid considered in the work is shown in Figure 2. In this configuration, there exist several upstream line–regulating converters (LIR) that are connected to different energy sources which in most cases are renewable energy sources. LIR converters could be ac–dc or dc–dc, but the LIR converter discussed in this paper are Buck dc–dc converters. There also exist several point of load (POL) converters that are connected to loads. The LIR converters considered are Buck converters and they are stepping down a high voltage 600 V (considered in this paper) to a lower voltage, 380 V. On the modeled dc microgrid, only dc–dc Buck converters are considered for both LIR and POL converters. Similar work that considered ring bus Microgrids are reported in [10] and [11]; however, both works considered LIR and POL buck converters that have similar parameters. This is not quite close to real life since in most cases, Microgrids are populated with converters that that have quite different configurations and parameters.

E. Oyekanlu, Fuzzy Inference Based Stability Optimization for IoT Data Centers DC Microgrids: Impact of Constant PowerLoads on Smart Grid Communication over the Powerline, Journal of Energy, vol. 68 Number 1 (2019), p. 11–21

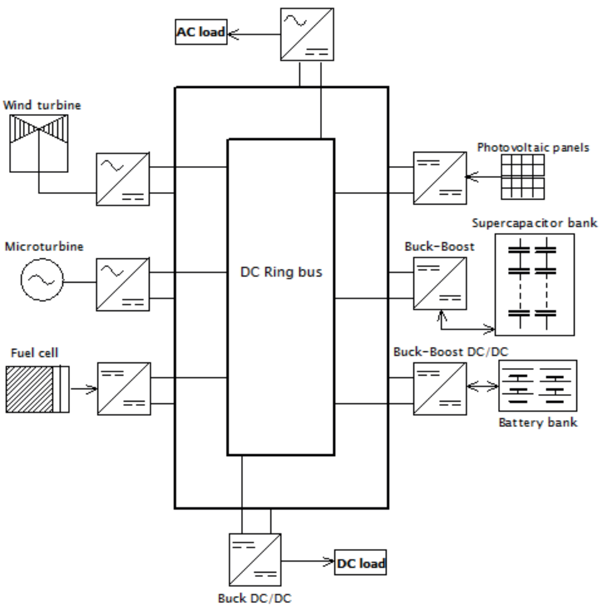

Figure 2. Low Voltage LVDC ring bus model

In addition, most work in literature always consider constant power high bandwidth loads (CPL) as the worst–case load that could jeopardize stability and make control effort in Microgrids to be difficult. However, report in [12] and [13] have reveal new set of complex impedance low bandwidth loads that could exist because of changing converter parameters and other systemic nonlinearities that can exist on the microgrid in any instance. In addition to stability challenges that can result from changing converters bandwidth, problem of circulating currents can also jeopardize stability and power quality on dc microgrids. Power quality issues are very important for IoT cloud server, aircrafts and electric ship loads using dc microgrids. When dc–dc converters are connected on microgrids for load sharing, problem of circulating current always exist. It is often a direct result of poorly regulated dc voltage and complex impedance that exist on the dc bus. For a multi–converter microgrid, the flow of circulating current among converters is as shown in Figure 3.

Circulating current can exist between converter 1, 2 and 3. Converter 1 (Conv 1 in Figure 3) and 2 are LIRs while converter 3 is a POL converter. Indeed, circulating current flow (indicated by arrows and dotted lines) could exist among all the converters on the microgrid as shown in Figure 3.

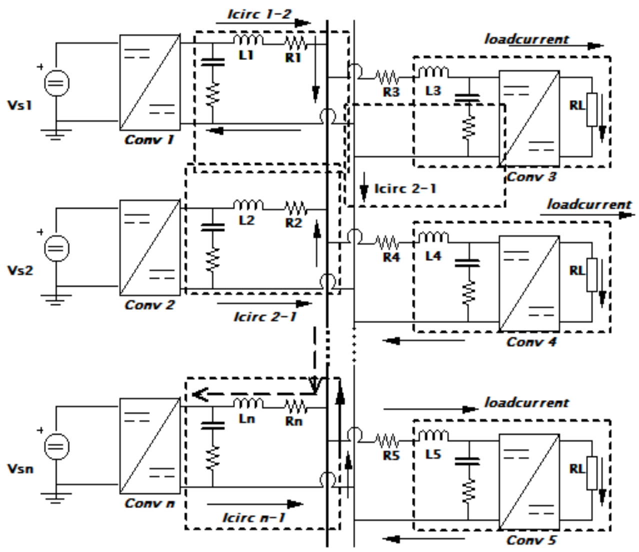

Figure 3. Circulating current problem among a multi-converter system

As reported in [14], Kirchhoff voltage law (KVL) and Kirchhoff current law (KCL) can be used to analyze the amount of circulating currents that can exist on the microgrid. Using KVL, an assessment of converter output currents between converter 1 and 2 when complex line impedance is considered can be given as:

$$I_1 = \frac{(Z_2 + Z_L)\,V_{S1} - Z_L\,V_{S2}}{Z_1 Z_2 + Z_1 Z_L + Z_2 Z_L} \tag{1}$$

$$I_2 = \frac{(Z_1 + Z_L)\,V_{S\,2} - Z_L\,V_{S\,1}}{Z_1 Z_2 + Z_1 Z_L + Z_2 Z_L} \tag{2}$$

Source voltages can be expressed as

$$V_{s1} = I_1 Z_1 + I_L Z_L \tag{3}$$

$$V_{s2} = I_2 Z_2 + I_L Z_L \tag{4}$$

and the difference between (3) and (4) is

$$V_{s1} - V_{s2} = I_1 Z_1 - I_2 Z_2 \tag{5}$$

The circulating currents between converter 1 and 2 can be expressed as when $Z_1 \neq Z_2$

$$I_{\,circ\,1} = -I_{\,circ\,2} = \frac{V_{S1} - V_{S2}}{Z_1 + Z_2} = \frac{I_1 Z_1 - I_2 Z_2}{Z_1 + Z_2} \tag{6}$$

Also, when $Z_1 = Z_2$

$$I_{\,circ\,1} = -I_{\,circ\,2} = \frac{(I_1 - I_2)\,Z_1}{2\,Z_1} = \frac{(I_1 - I_2)}{2} \tag{7}$$

The circulating current for the n parallel converters from converter 1 to all other converters when (when is given by

$$I_{\,circ\,1} = \frac{I_1 Z_1 - I_2 Z_2}{Z_1 + Z_2} + \frac{I_1 Z_1 - I_3 Z_3}{Z_1 + Z_3} + \cdots + \frac{I_1 Z_1 - I_n Z_n}{Z_1 + Z_n} \tag{8}$$

$$I_{\,circ\,1} = \sum_{k=2}^{n} \frac{I_1 Z_1 - I_k Z_k}{Z_1 + Z_n} \tag{9}$$

also, the circulating current for n parallel converters from converter 1 to all other converters when is given by

$$I_{\,circ\,1} = \frac{I_1 - I_2}{n} + \frac{I_1 - I_3}{n} + \cdots + \frac{I_1 - I_n}{n} \tag{10}$$

$$I_{\,circ\,1} = \sum_{k=2}^{n} \frac{I_1 - I_k}{n} \tag{11}$$

Both results above in (8) and (11) could be [14] extended to the case for converters 2, 3, ..., n, for $I_{circ\,n}$.

EMI and Line Impedance Problems on DC Microgrids

Apart from circulating currents, other issues that can affect stability is the existence of line electromagnetic interference (EMI) and excessive line impedance, both of which if not confined within tolerable limits can jeopardize individual converter's small signal stability and hence the entire microgrid large signal stability. To limit EMI and input impedance to individual converters, damped input filters are always used. There are several possible input filter configurations to choose from [15], and the configurations are mainly based on the mode of damping employed to reduce the filters output impedance. Filter output impedance are a major consideration if both small and large signal stability of the microgrid are to be preserved. Middlebrook criterion [15] states that for stability to be maintained, then the magnitude of filter's output impedance, i.e., ZoutputFilter in Figure 4(a) must be less than the magnitude of the converter's input impedance ZinputConverter; i.e.,

| |ZoutputFilter| | << | | ZinputConverter (12)

For Middlebrooks criterion to be met, then filters must be damped. Reason is that, for undamped input filter in Figure 4a, at resonant frequency f0, that is, when:

$$f_o = \frac{1}{2\pi\sqrt{LC}} \quad (13)$$

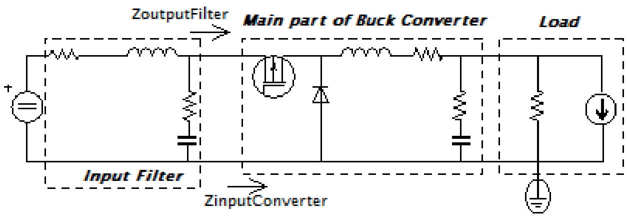

Figure 4a. Undamped filter with Buck converter.

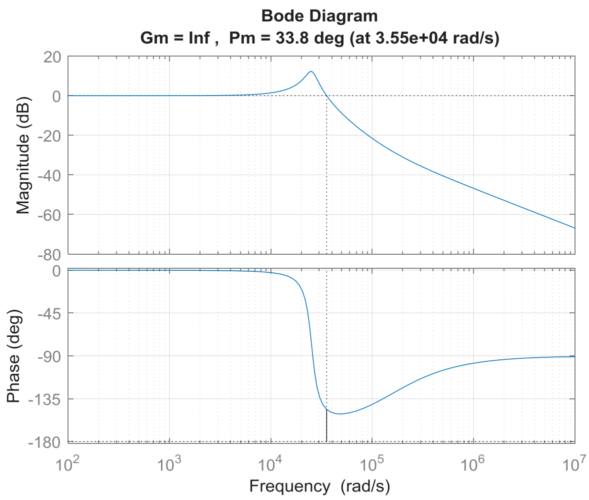

Figure 4b. Small Signal Bode plot for undamped input filter.

ZoutputFilter will approach infinity [15]. Since this work focuses on stability issues and distortion suffered by signals transmitted on dc microgrid channels, then it is instructive to examine different input filter configurations and how those configurations impact small signal converter stability and overall large signal system–wide stability. Major existing input filter topologies [15], [16], [17], that are examined include undamped input filter, parallel damped input filter (Figure 5a), series damped input filter (Figure 6a).

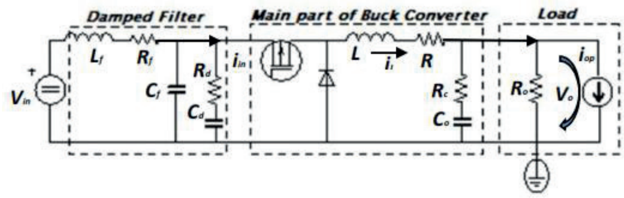

Figure 5a. Parallel damped filter

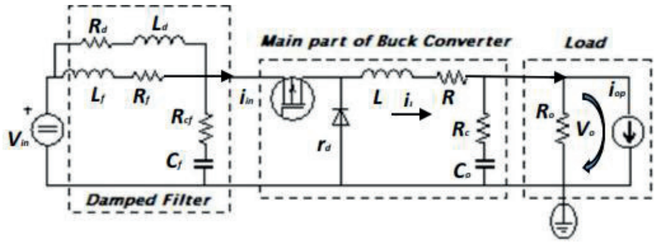

Figure 6a. Series damped filter

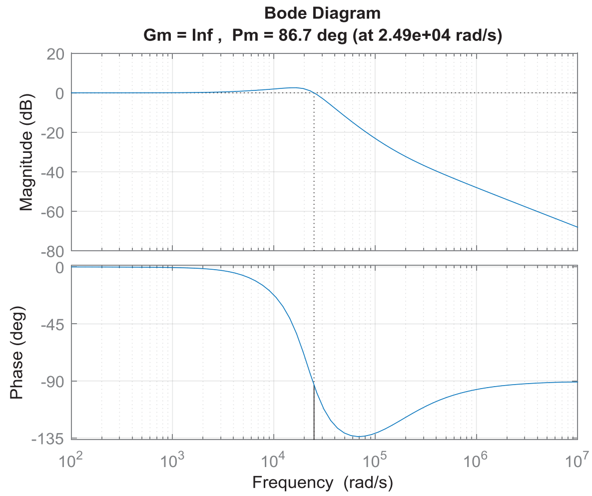

Figure 5b. Small Signal Bode plot for parallel damped input filter.

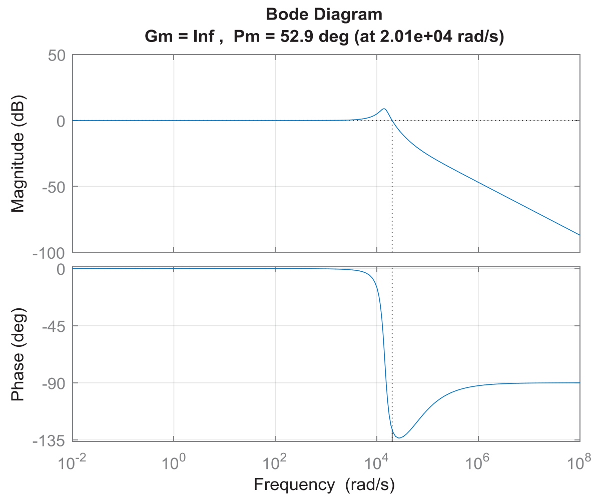

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Figure 6b. Small Signal Bode plot for series damped input filter.

For each configuration, bode plots are generated. The phase margin of bode plots is an indication of the limit of phase variation that can be attained at crossover frequency before dc microgrid stability is lost. The gain margin also indicates the limit of gain variation attainable at crossover frequency before stability is jeopardized. For most systems, a phase margin of 60–degree or more is always desired. Thus, as shown in Figure 4b, undamped input filter will adversely affect microgrid stability because of its poor phase margin of 33 degree. Stability result for a parallel damped configuration is shown in Figure 5b where it is show that the phase margin is well above the 60–degree threshold. The phase margin of the series damped filter of Figure 6b is lower than the 60–degree threshold. This indicate that the series damped filter may not yield a good stability performance if it is used on the microgrid.

DC RING BUS MICROGRID MODELING

The ring bus microgrid considered in this paper is modeled as a contiguous series of pi bus (Figure 7) sections [10], [18]. Based on the segmenting approach discussed in [18], a breakpoint is introduced on the microgrid bus as shown in Figure 8. Each pi segment is also modeled as a filter and is added with the EMI–limiting

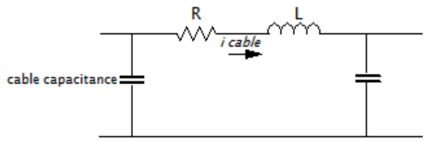
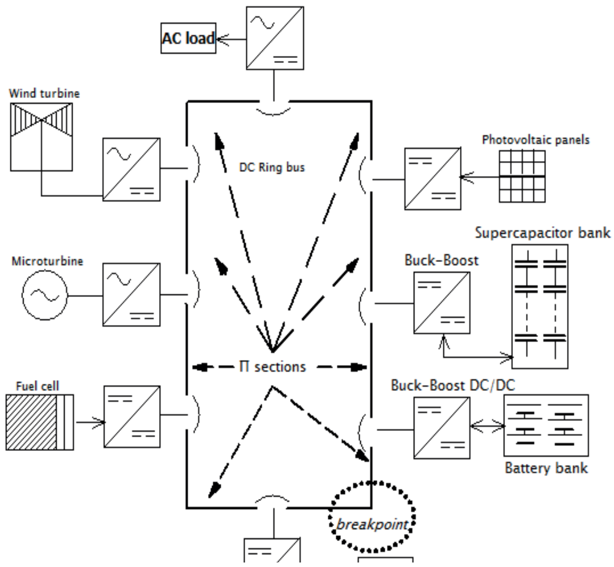


Figure 7. Pi section model of transmission line used to segment the dc bus in Figure 2

damped input filter already existing with each converter as shown in Figure 9a. The result is a multiple section input filter with a good 180–degree phase margin bode plots shown in Figure 9b.



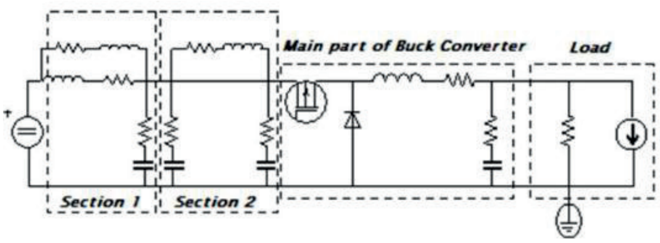


Figure 9a. Multiple section input filter representing EMI filter and pi section lines

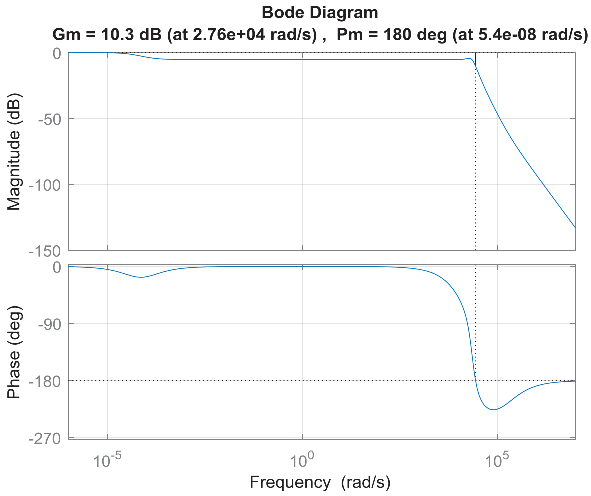


Figure 9b. Bode plot of the resulting multiple section input filter

FUZZY INFERENCE DC MICROGRID LYAPUNOV LARGE SIGNAL STABILITY REGION ESTIMATION USING TAKAGI–SUGENO INFERENCE METHOD

To estimate the stability region and the impact of CPL distortion on signals exchanged over the dc bus of a microgrid having CPL, a pi section of the dc ring bus microgrid having one–source and one CPL shown in Figure 11 is used. This is similar to the approach used in [21], [22], [23], [25]. The generalized load impedance model on dc microgrids given in [12], [13], [20] is

$$Z_L(s) = \frac{\sum_{i=o}^{m} b_i \; s^i}{\sum_{i=o}^{n} a_i \; s^i} \qquad b_i \, a_i \, \varepsilon \, R \tag{14}$$

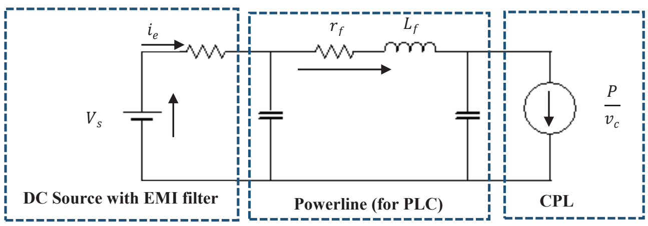


Figure 11. Model of a dc microgrid with one source, PLC and a CPL (one-load) used in this study

The constants m and n in (14) are the numerator and denominator orders, and and are load coefficients. For downstream close–loop POL converters, the input impedance in view of load impedance of (14) will produce:

(15)

$$Z_i(s) = \frac{\sum_{i=o}^{m} b_i \left[n_3 s^{i+3} + n_1 s^{i+1} + n_0\right] + \sum_{i=o}^{n} a_i \, n_2 \, s^{i+2}}{\sum_{i=o}^{m} b_i \; d_2 \; s^{i+2} + \sum_{i=o}^{n} a_1 \left[d_1 \, s^{i+1} \, d_0\right]}$$

The load model can be used to understand the nature of different loads that could exist on the DC Microgrid. The generalized load model (15), could be used to represent CPLs, constant impedance loads, first order lag loads and other load types that could incidentally exist because of faults on the microgrid or the changing nature of the dc converters having varying parameters.

E. Oyekanlu, Fuzzy Inference Based Stability Optimization for IoT Data Centers DC Microgrids: Impact of Constant PowerLoads on Smart Grid Communication over the Powerline, Journal of Energy, vol. 68 Number 1 (2019), p. 11–21

Takagi–Sugeno Fuzzy Inference Method

The Takagi–Sugeno (TS) fuzzy inference model is a very good universal approximator for nonlinear systems [19] such as a one–source and a CPL load model of the dc microgrid of Figure 11. In TS fuzzy inference models, a nonlinear system could be decomposed into a subset of linear subsystems of the type = $\dot{x}(t) = A_i \dot{x}(t) + B_i u(t)$. These linear models whose local behavior is defined by the i[th] fuzzy rule are interconnected by nonlinear scalar functions, and are a convex sum of the original nonlinear system [21]. Lyapunov theorem can then be applied to establish stability or other wise of the TS fuzzy inference model.

For each susbystem $\dot{x}(t)$ of the whole model, a premise for $i = 1, 2, ..., q$; where q is the number of nonlinearity (for example, operating point) is established. Each subsystem is further linked to a weigthed activation function that will determine the membership degree of the linear subsystem in the whole fuzzy model of the nonlinear system. The decision space of the whole nonlinear system is partitioned into a fuzzy inference rule based space of the form: for rule R^i: if $z_1(t)$ is activated by F^i_1, ..., and $z_q(t)$is activated by F^i_i, then the system can be modeled by

$$\begin{cases} \dot{x}(t) = A_i\, x(t) + B_i\, u(t) \\ y(t) = C_i\, x(t) \end{cases} \tag{16}$$

In (16), , , and are constant matrices. The weight attributed to the rule of each subsystem of the linear fuzzy model is given as

$$\omega_i = \omega_i(z(t)) = \prod_{j=1}^{q} F_j^i(z_j(t)), \quad i = 1, 2, ..., \tag{17}$$

and the weights given in (17) can be normalized using

$$h_i(z(t)) = \frac{\omega_i(z(t))}{\sum_i^r \omega_i(z(t))}, \; i= 1, 2, ..., r \tag{18}$$

which verifies the property convex sum

$$\sum_i^r h_i(z(t)) = 1,\; h_i(z(t)) \geq 0\; \forall t \tag{19}$$

For the whole nonlinear model, the fuzzy inference model for the whole nonlinear dc microgrid system can be represented as

$$\begin{cases} \dot{x}(t) = \sum_i^r h_i(z(t))\; A_t\, x(t) + B_i\, u(t) \\ y(t) = \sum_i^r h_i(z(t))\; C_i\, x(t) \end{cases} \tag{20}$$

The TS theorem leads to a generation of the Lyapunov function *V(x)* that allows the determination of the domain of attraction for a given operation point. The existence of a Lyapunov candidate based on the TS model shows that the given operation point is asymptotically stable. The resulting fuzzy inference model showing this asymptotic stability can then be represented as a system of linear matrix inequality (LMI) which is an optimal convex solution of the Lyapunov stability criteria. The feasibility of the LMI of the converter is established by solving LMI equations in (21) to obtain a matrix M that is positive definite according to Lyapunov criteria.

$$\begin{cases} M = M^T > 0 \\ A_1^T.M + M.A_1 < 0 \\ A_2^T\, M + M.A_2 < 0, ..., A_i^T\, M + M.A_i < 0, \;\; for \;\; \forall_i \in \{2, ..., r\} \end{cases} \tag{21}$$

Existence of a positive definite M establishes the feasibility of the fuzzy models generated. A large signal Lyapunov candidate solution can then be constructed based on the M matrix generated [19], [23]. The large signal domain that shows the domain of stability of the microgrid based on the rated power and the load type is then determined. The existence of M is based on satisfying two conditions. First, all local linear subsystem must be stable. For this to be possible, the matrices in (21) must be Hurwitz. Secondly, if $A = \sum_{i=1} A_i$ is Hurwitz, then a Lyapunov function, which proves the stability of the linear local model must also exist.

For the dc microgrid model shown in Figure 11 with CPL (p/v_c), a suitable operating point for the CPL defined by inductor current and capacitor voltage with constant load power can be represented [21] as

$$\begin{cases} i_{eo} = \dfrac{V_e - v_{co}}{r_f} = \dfrac{p_s}{v_{co}} \\ v_{so} = \dfrac{V_e + \sqrt{V_e^2 - 4\, p_s\, r_f}}{2} \end{cases} \tag{22}$$

A change of variables $x^1 = i_e - i_{eo}$ and $x_2 = v_s - v_{co}$ provide avenues by which the system can be studied at its operating points. Using these change of variables, the system in Figure 11 can be linearized and studied at its operating points, leading to

$$\begin{cases} \dot{x}_1 = \dfrac{-r_f}{L_f}\, x_1 - \dfrac{1}{L_f}\, x_2 \\ \dot{x}_2 = \dfrac{1}{C}\, x_1 + \dfrac{p_s}{Cv_{co}} \dfrac{x_2}{v_{co} + x_2} \end{cases} \tag{23}$$

The system in (23) with its nonlinear part $\left(\dfrac{p_s}{Cv_{co}} \dfrac{x_2}{v_{co} + x_2}\right)$ can be represented as

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} \dfrac{-r_f}{L_f} & -\dfrac{1}{L_f} \\ \dfrac{1}{C} & f(x_2) \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = A(x_2) \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \tag{24}$$

In (24), $f(x_2)$ represent the system nonlinear part $\dfrac{p_s}{Cv_{co}} \dfrac{x_2}{v_{co} + x_2}$. The nonlinear part can be studied within an upper and lower fuzzy inference boundary represented [21] as

$$f(x_2) = f_{max}\; F_1^1(z) + f_{min}\; F_1^2(z) \tag{25}$$

In (25), the upper and lower boundary of the dc microgrid nonlinear activation function $f(x_2)$ lies within the domain of the fuzzy inference rule with activation functions $F_1^1(z)$ and $F_1^2(z)$ that verifies the convexity property

$$\begin{cases} 0 \leq F_1^1(z) = \dfrac{z - f_{min}}{f_{max} - f_{min}} \leq 1 \\ 0 \leq F_1^2(z) = \dfrac{f_{max} - z}{f_{max} - f_{min}} \leq 1 \end{cases} \tag{26}$$

Thus

$$\begin{cases} f_{min} = \dfrac{p_s}{Cv_{co}} \dfrac{1}{v_{co} + x_{2max}} \\ f_{max} = \dfrac{p_s}{Cv_{co}} \dfrac{1}{v_{co} + x_{2min}} \end{cases} \tag{27}$$

The two local models resulting from the single nonlinear function of the system can be represented with two rules using the activation functions F_1^1 (z) and F_1^2 (z) ; and they are respectively represented [21] as

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix} = \begin{bmatrix} \frac{-r_f}{L_f} & -\frac{1}{L_f} \\ \frac{1}{C} & fmax \end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} = A_1\begin{bmatrix}x_1\\ x_2\end{bmatrix} \qquad (28)$$

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix} = \begin{bmatrix} \frac{-r_f}{L_f} & -\frac{1}{L_f} \\ \frac{1}{C} & fmin \end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} = A_2\begin{bmatrix}x_1\\ x_2\end{bmatrix} \qquad (29)$$

To further clarify the method of TS fuzzy inference model, value of the nonlinear part of the dc microgrid can be deduced using a TS membership function. The membership function (*M*) of the TS fuzzy inference model can be represented as shown in Figure 12.

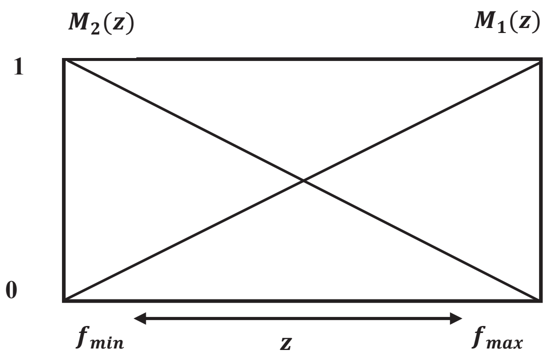


Figure 12. Takagi-Sugeno Fuzzy Inference Formulation

TS membership function can be derived such that for the nonlinear part of the dc microgrid equation in (23), membership function can be written as already discussed in (25), leading to

$$Z = f(x_2) = f_{max}\ M_1(z) + f_{min}\ M_2(z) \qquad (30)$$

where

$$M_1(z) + M_2(z) = 1 \qquad (31)$$

and F_{max} and F_{min} are computed based on

$$x_2 \in [x_2min \quad x_2max] \qquad (32)$$

The fuzziness of the TS method implies that if z is in the positive (+) region of the TS membership model shown in figure 12, then and the matrix of the dc microgrid can be evaluated as shown in (28). If z is in the negative region of TS membership of figure 12, then dc microgrid can be evaluated as shown in (29). Using this fuzzy method, value of the nonlinear system part can be deduced, and stability of the system evaluated. The stability domain of the dc microgrid system is simulated for a data center microgrid with a 380 V dc bus supplying data center cloud server acting as CPLs. The data center dc bus is assumed to have a 600 V input voltage from renewable energy sources [3] (such as PV arrays). System parameters [3] are shown in Table 1. Using the LMI model in (21) and systems parameters in Table I, a Matlab procedure for obtaining M as discussed in [26] is used to obtain the needed matrix M for the dc microgrid system shown in Figure 11.

Table I. 600 V/ 380 V DC–DC Data Center Microgrid Study Parameters

Parameter	Value
V_{in}	600 V
DC Bus Voltage (V_{bus})	380 V
Bus Capacitance (varied)	200 µF, 300 µF, 400 µF and 500 µF
Data Center Server CPL (varied)	400 W, 800 W, 1200 W and 1600 W

The obtained matrix M for a 400 W cloud server center CPL and its associated Lyapunov candidate [23] is

$$M = \begin{bmatrix}105.3 & 0.056\\ 0.056 & 0.015\end{bmatrix} \qquad (33)$$

$$V(x) = 105.\ 3\ x_1^2 + 0.112x_1x_2 + 0.015\ x_2^2 \qquad (34)$$

The domain of attraction for the system using varying dc–bus capacitance and varying cloud server loads modeled as CPLs are shown in Figure 13 and Figure 14 respectively. Since acceptable level of dc bus capacitance for dc microgrid is still an area of research study worldwide [3], [27], [28], the impact of allowed capacitance values for the 380 V dc microgrid on the dc bus link is shown in Figure 13. It is shown that the size of domain of attraction, and hence system stability increases with increasing dc bus capacitance. For CPLs, the system domain of attraction indicate that system stability will be jeopardized when server loads, acting as CPLs increases on the dc microgrid.

The system domain of attraction decreases when CPLs increases on the dc bus. To explicitly show this effect, the upper limit of each server load domain of attraction is traced out on the voltage axis as shown in Figure 15, and the relationship of the domain of attraction and server loads is explicitly plotted and shown in Figure 16. The existence of a Lyapunov candidate for the modeled system ensures that the system is large–signally stable [21], [23], even when the system is experiencing large variation in input voltage. The system will maintain stability when voltage variation being experienced by the system falls within the stability margin of the domain of attraction. The asymptotic stability of the modeled 600 V / 380 V dc microgrid is verified by varying the input voltages *V*in of the system as shown in Figure 17.

In Figure 17, it is shown that when the system input voltage (blue) is varied by reducing it to 550 V in time 0 to 0.2 s, 0.5 to 0.7 s, 1 to 1.2 s etc., the output voltage (red), on dc bus supplied to the cloud server system is stable at 380 V dc. This asymptotic stability implies that the existence of Lyapunov candidate resulting from the LMI based TS fuzzy inference model makes the system to be stable in the large signal sense when the input voltage is experiencing large signal variations by decreasing in steps of 50 V from 600 V to 550 V for many time steps of the simulation.

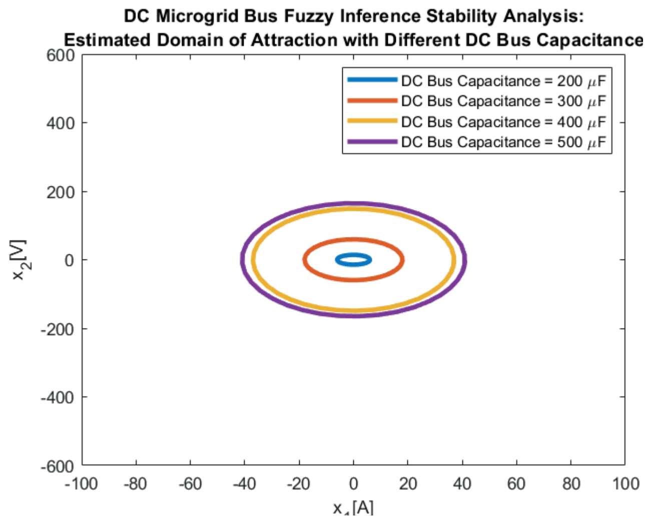


Figure 13. Domain of attraction of the 600 V / 380 V data center dc microgrid using varying dc bus capacitance

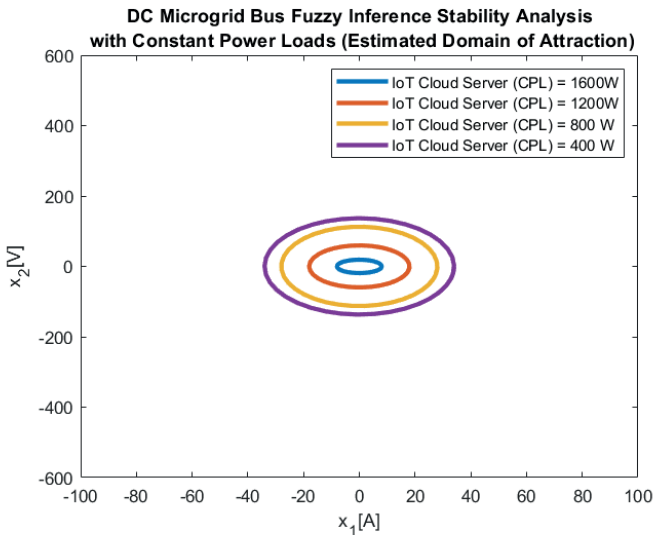


Figure 14. Domain of attraction of the 600 V / 380 V data center dc microgrid with varying data center server loads modeled as CPLs

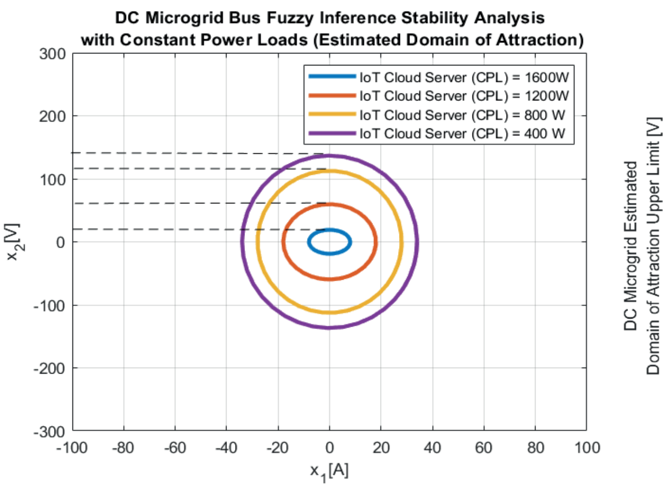


Figure 15. Domain of attraction of the 600 V / 380 V data center dc microgrid with varying data center server loads modeled as CPLs (enlarged voltage axis)

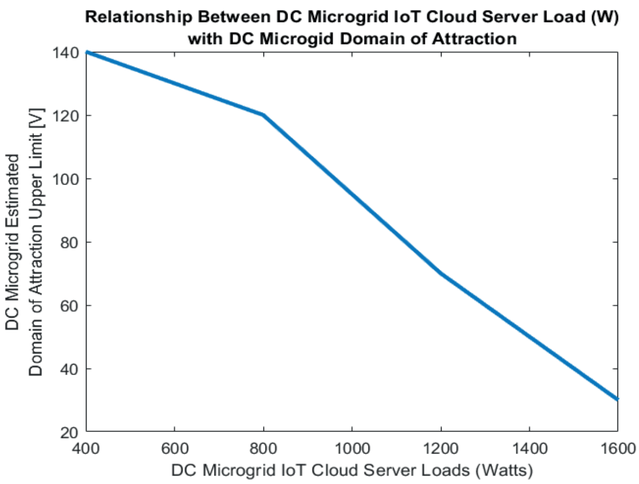


Figure 16. Comparison of the upper limit of the dc microgrid IoT cloud data center server load with upper limit of the stability domain

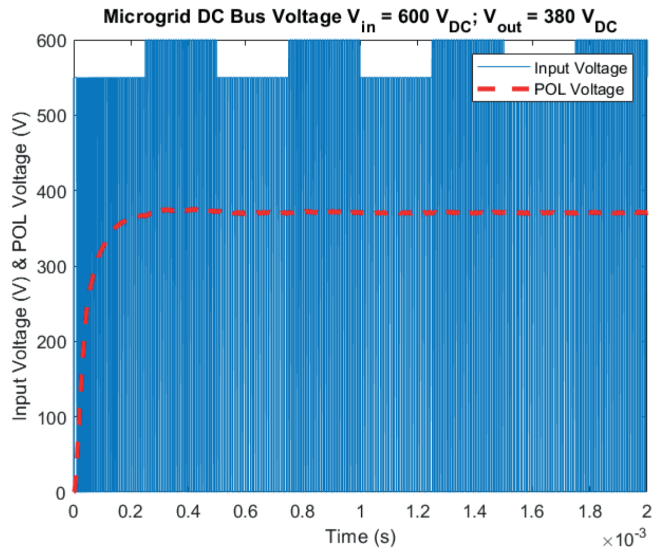


Figure 17. Existence of stable Lyapunov candidate ensures that the 600 V / 380 V dc microgrid is asymptotically (large signal) stable even when system input voltage experience perturbations

IMPACT OF DC MICROGRID IoT SERVER CPL ON DC MICROGRID POWERLINE COMMUNICATION

For communication purpose, the dc bus microgrid powerline can be modelled as a linear time invariant (LTI) system, and generally for LTI systems [25], [29], the group delay is a useful measure of amplitude and time distortion of signals generated by such channels [25], [29]. Suppose that x is the input signal to the LTI dc bus powerline channel having impulse response h[n], then the channel output y[n] is,

$$\mathrm{y[n]} = \sum_{k=-\infty}^{\infty} x[k]h[n-k] \qquad (35)$$

which can also be represented using the discrete time Fourier transform identity as,

$$\mathrm{Y}(e^{j\omega}) = \mathrm{H}(e^{j\omega})\ \mathrm{X}(e^{j\omega}) \qquad (36)$$

(36) implies that the magnitude of the PLC channel and the input has multiplicative effect while their phases have additive effects [25], [29] leading to,

$$|\ \mathrm{Y}(e^{j\omega})\ | = |\ \mathrm{H}(e^{j\omega})\ |\ |\ \mathrm{X}(e^{j\omega})\ | \qquad (37)$$

$$\angle \mathrm{Y}(e^{j\omega}) = \angle \mathrm{H}(e^{j\omega}) + \angle \mathrm{X}(e^{j\omega}) \qquad (38)$$

In (37), $\mathrm{H}(e^{j\omega}) = \mathrm{H}(e^{j\omega})\ |\mathrm{H}()|\ e(j^{Ø(\omega)})$, and in (38), $\angle \mathrm{H}(e^{j\omega}) = Ø(\omega) = \arg[\mathrm{H}(e^{j\omega})]$. Thus, the phase delay $\tau_p\ (\omega)$ of the LTI channel is represented as,

$$\tau_p(\omega) = -\frac{Ø(\omega)}{\omega} = -\frac{\arg\,[\mathrm{H}(e^{j\omega})]}{\omega} \qquad (39)$$

Also, the group delay (ω) of the DC powerline LTI channel can be represented as,

$$\tau_g(\omega) = \mathrm{grd}[\mathrm{H}(e^{j\omega})] = -\frac{d}{d\omega}\{\arg[\mathrm{H}(e^{j\omega})]\} = -\frac{d}{d\omega}Ø(\omega) \qquad (40)$$

In other to evaluate the level of distortion that CPLs could generate on the dc microgrid bus powerline, the dc microgrid system of Figure 11 is simplified as shown in Figure 18 so as to represent a medium length and medium voltage dc bus powerline system [30], [31]. The inductance parameter of Figure 18, aptly represent a medium () length powerline such as the dc microgrid bus under consideration [30], [31], [25].

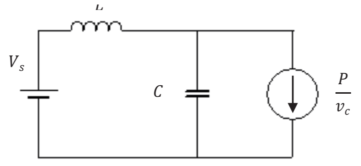


Figure 18. Simplified model of the dc microgrid powerline communication channel. A medium length, medium voltage transmission line channel is used to represent the PLC channel here.

This dc bus model in Figure 18 is a model of a second order low pass filter [32] and its transfer function can be represented [33] as

$$H(s) = \frac{\omega^2{}_o}{s^2 + \frac{\omega_o}{Q}s + \omega^2{}_o} \tag{41}$$

By using KCL, the transfer function of the dc microgrid in (35) and Figure 18 can be represented as

$$\frac{V_{out}}{V_{in}} = \frac{\frac{1}{LC}}{s^2 + s\frac{v_C}{PC} + \frac{1}{LC}} \tag{42}$$

=

The transfer function in (42) is used to evaluate the rate of signal distortion that will be experienced by a transmitted signal when CPLs exist on the microgrid dc bus PLC channel. A 39.5 mH inductance value [21], [23] and 500 µF capacitance value is used for simulation. The in (42) is the 380 V dc bus voltage. *P* is the IoT data center load modeled as CPL for the dc bus microgrid. CPL power (*P*) ratings used to represent IoT server loads on the dc bus channel are 400 W, 800 W, 1000 W, 1200 W and 1600 W respectively. The rate of a baseband sine wave signal distortion as a function of delay samples using the dc bus channel parameters discussed is evaluated using Matlab and results are shown in Figure 19 to Figure 24.

As shown in Figure 19 to Figure 24, the width of the filter passband is decreasing as more CPLs exist on the dc bus PLC channel. This signifies that lesser samples of the baseband channel signal will experience equal amount of distortion as more CPLs exist on the microgrid dc bus channel. As dc bus channel CPL increases, increasing samples of any signal transmitted on the dc bus channel will experience different amount of delay, leading to more signal samples arriving distorted at the receiving end.

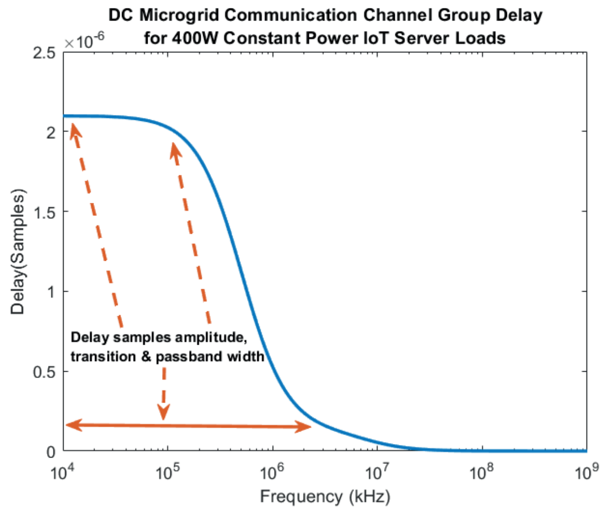


Figure 19 Group delay distortion caused by 400 W IoT server CPL load on dc bus microgrid channel

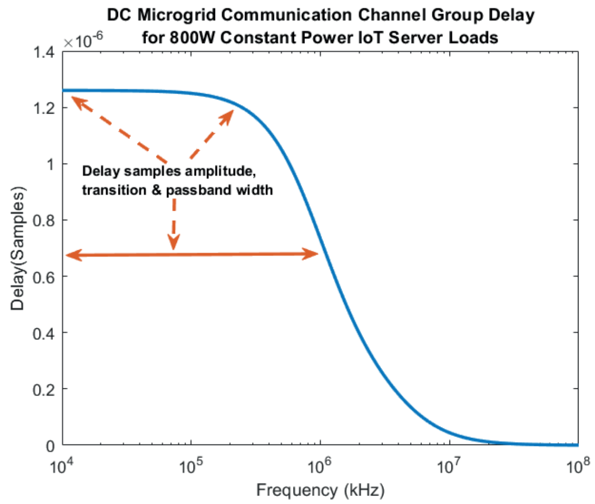


Figure 20 Group delay distortion caused by 800 W IoT server CPL load on dc bus microgrid channel

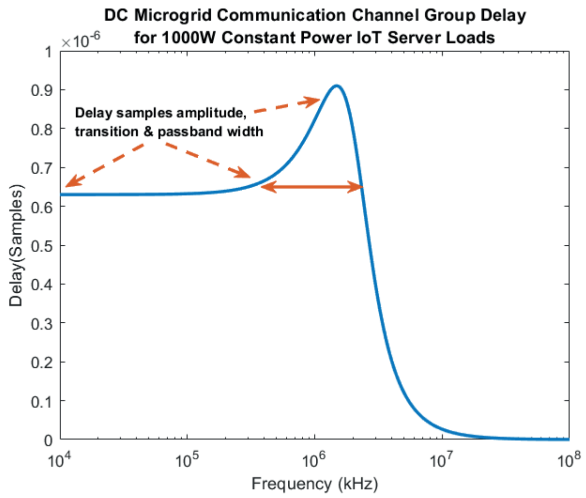


Figure 21 Group delay distortion caused by 1000 W IoT server CPL load on dc bus microgrid channel

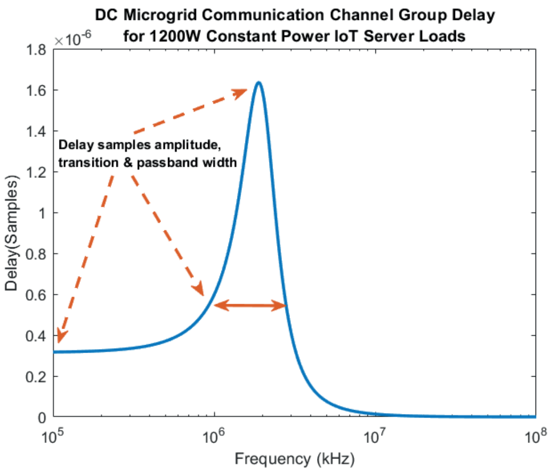


Figure 22 Group delay distortion caused by 1200 W IoT server CPL load on dc bus microgrid channel

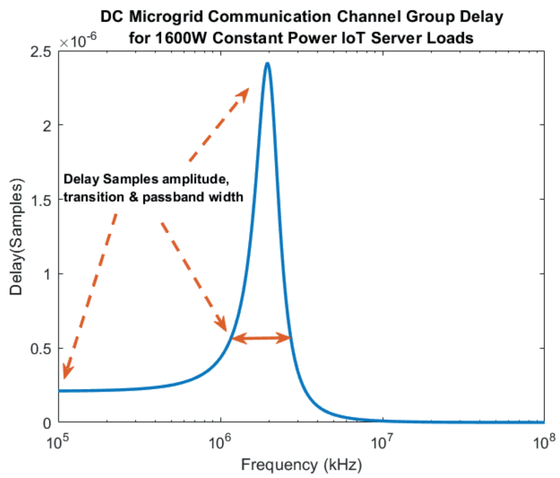


Figure 23 Group delay distortion caused by 1600 W IoT server CPL load on dc bus microgrid channel

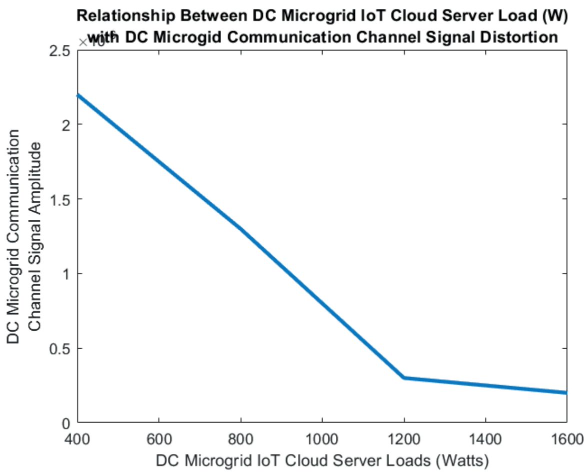


Figure 24 Baseband signal amplitude decreases as microgrid dc bus CPL loads increases.

It can also be deduced using Figure 24 that the amplitude of the baseband signal decreases progressively as more CPL exist on the dc bus channel, leading to more transmitted signal distortion. Also, as more CPLs exist on the dc bus channel, there is increasing abruptness from the filter's passband to stopband. The more abrupt a transition from the passband to stopband, the greater the delay distortion that a transmitted signal will experience across the transition band [34].

CONCLUSION

In this paper, a 600 V / 380 V DC–DC microgrid that can be used to represent state of the art IoT data center microgrid is modeled using Matlab. Takagi–Sugeno fuzzy inference model is used to establish the domain of attraction of the dc microgrid. It is discovered that the domain of attraction, which represent the stability region of the data center microgrid increases when the dc bus channel capacitance increases. This signifies enhanced system stability. The domain of attraction also decreases with increasing CPL IoT server loads on the dc bus channel. This signifies reducing system stability. PLC is being considered as a future means of monitoring the dc bus microgrid such that the power usage efficiency and stability of the data center microgrid can be improved. In this paper impact of varying CPLs such as data center IoT cloud servers on signals transmitted on the dc microgrid bus PLC channel is evaluated. Our contribution in this paper, to the best of our knowledge is the first reported evaluation of the stability and measurement of the PLC channel signal distortion of the 380 V dc microgrid when CPLs on the dc bus is varying. It is discovered that more CPLs on the PLC channel will lead to increased signal distortion on the dc bus channel when PLC is used as means of communication on the channel. Hence, to be able to use the powerline of the dc microgrid as a means of monitoring the dc microgrid stability and energy utilization, effects of varying CPLs on PLC channel must be considered. Future work in this area will include research work on delay equalizers that can be used to reduce signal distortion rate when the dc microgrid powerline is used as a means of communication, monitoring stability and energy utilization on the microgrid dc bus channel.

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Customer Empowerment Strategy and Shaping Markets in the Production of Electricity

SUMMARY

A large number of energy companies in the world today a faced with global transformative trends which devastatingly affect their business results. Therefore, energy companies in the world were very slow in investing and adopting renewable energy sources and become significantly overcapacitated by coal and gas fired power plants which are now unprofitabile due to low marginal costs of renewables and their priority dispatching into a power system. Also increasing the share of renewable energy sources in the structure of electricity generation, the decline in primary energy prices (fossil fuels) the stagnation of consuption and the surplus of supply in relation to electricity demand caused a drop in wholesale electricity prices by half compared to 2008. Furthemore, the operation of coal fired power plants is burdened with carbon dioxide emissions. As a result, there has been a significant reduction in revenues, falling stock values andthe collapse of credit rating of many energy companies in the world. This article analyzes the implementation of the strategy of empowering customers and shaping markets that the E.ON Group has carried out as a „response“ to global transformative trends in the energy market environment by which the former company was divided into two less dynamic and more focused companies into a new or conventional energy world. This strengthens the competitiveness of all previous business activities due to stronger focus on the development of necessary skills and process. Furthemore, from on investor perspective it has been shown that the risk profiles associated with conventional energy production differ from those related to the new energy world, ie the activities covered by the business portfolio of the E.ON Group, and the activities covered by the business portfolio of the Uniper Group attract different types of investors.

KEYWORDS

Customer empowerment strategy, Schaping markets, Global transformative trends, Renewable energy sources, Customer solutions

INTRODUCTION

Energy companies from both sides of the Atlantic, face a big question of their own survival in the environment of the new environment and energy policy [5]. Therefore, faced with the dilemma of failure or sucess, the decommissioning or transition to new innovative business models. Utilities are experiencing an unprecedented change in their operating environment, which requires a broad reinvention of business models. Historicaly, a centralized and grid–conected power generation structure positioned utilities in the center of power system, with a culture focused on regulators and mandates rather than innovation and customer service expectations. This utility business model is now profoundly questioned by the accelerated deployment of distributed energy resources and smart grid technologies, as well as profound changes in market economics and regulatory frameworks. This is global trend, to which utilities and regulators around the world seek to find adequate solutions.

GLOBAL TRANSFORMATIONAL TRENDS IN THE ENERGY MARKET

Global trends in power market landscapes show that approaches to business model inovation will be diverse [5]. Utilities operate under different regulated or deregulated market models, varying ownership structures and in a complex value chain of generation, transmission, system operations, distribution and retail sales. Market models differ in their degree of regulation and competition in the value–chain, framed by varying policy and regulatory settings [8]. Ownership structures vary from 192 investor–owned utilities (IOUs) serving over 73% of all US customers, to 2009 publically owned municipal utilities (14% of US customers) and 871 electric cooperatives (13%). Regulated markets dominate most of the Southeast, Northwest, and much of the West (excluding California). Here, verticaly integrated monopoly utilities cover the entire value chain with oversight from a public regulator. New business models in regulated markets require regulatory changes to provide more performance–based incentives for greater efficiency and innovation.

In 24 US states, such as California, Texas and most states in the Northeast, deregulated markets have opened up generation for competition from independent power producers. 15 of these states and Washington D.C. have also introduced retail choice, which allows residental and/or industrial consumers to choose their supplier. The role of utilities in deregulated markets is focused on owning, maintaining and operating distribution infrastructure, and depending on their business model, on procuring and marketing power for retail sales. Deregulated markets provide more competitive pressure and more flexibility business model innovation.

German energy transition, has forced the electric industry into a pole position for developing new business models, as the market has now a large number of citizens and energy cooperatives that produce electricity [1]. In Germany, the power market is fully deregulated and characteried by a high degree of diversity, with four large integrated utilities and obout 900 regional and local municipal utilities. The energy transition, in conjuction with the Renewable Energy Act that introduced feed–in tariffs in the early 2000's, has forced electric industry into a pole position for developing new business models, as the market has now a large number of citizens and energy cooperatives that produce electricity. The German Energeiewende is transforming the energy system of Europe's most populated and industry–heavy country from traditional coal and nuclear to energy efficiency and renewable energy. Germany is commited to phasing out nuclear by 2022, and targets a minimum share of 50% renewable power by 2030 (80% by 2050), and 50% reduction of primary energy consuption by 2050 (compared to 2008), particulary in building sector. The main drivers for this transition are: 1. Germany's objective to reduce its energy import dependency and its reliance on dirty coal and nuclear, 2. Germany's ambition to fight climate change, 3. Germany's aim to stimulate technology innovation and employment in a green economy. As renewables become increasingly cost–competitive, there is no doubt that the Energiewende is here to stay. The following figure shows the share of energy consuption in Germany.

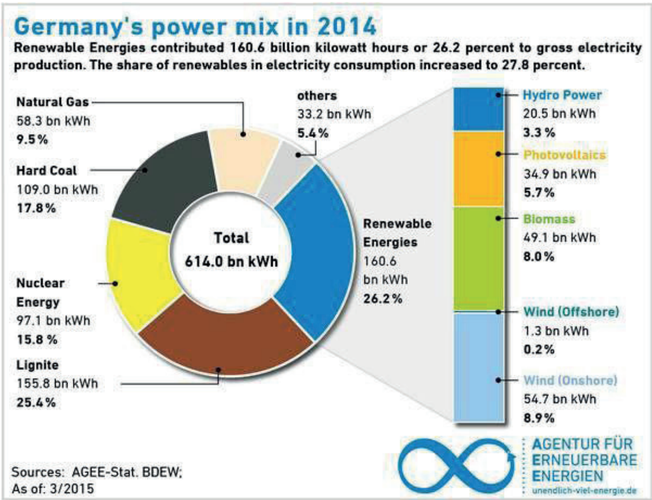
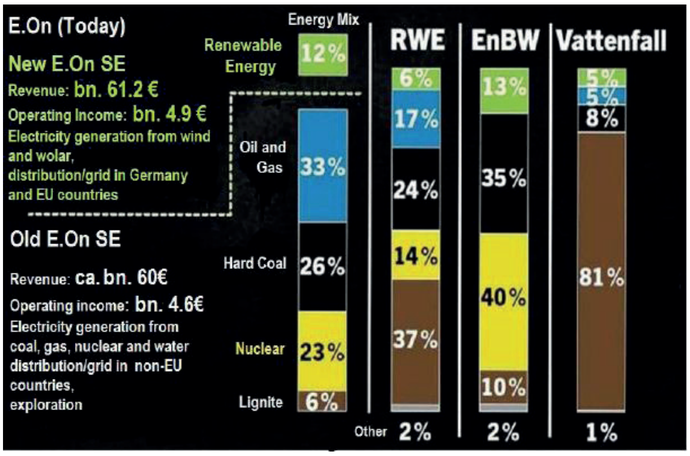


Figure 1. Electricity consuption shares in Germany [13]

The above figure shows that the structure of electricity generation in Gernmany has significant share of renewables (26.2%), than energy from coal and lignite (43.2%), nuclear energy (15.8%) and energy from natural gas 9.5%. This figure also shows that energy produced from renewables is divided on hydro power (3.3%), photovoltaics (5.7%), biomass (8%), wind onshore (8.9%) and wind offshore (0.2%).

Energiewende affected Germany's three utility groups in a different way [5]. The four large centralized utility conglomerates, the 'Big4' (figure 2) were the worst hit. Having dominated the market for a long time, E.ON, RWE, EnBW and Vattenfall owned and operated about 80% of Germany's generation capacity, predominantly centralized fossil–and fossil–fueled power plants. They reduced the historically prominent role of the local municipal utilities to mere re–distributers of electricity. The generation share of the 'Big4' has however, dropped to 47% since 2011, when the German government decided on a nuclear phase–out by the year 2022 and eight reactors were immedistely taken off the grid. Understimating the improwing economics for renewables and the persistence and dynamics of the Energiewende policies the four large centralized utility conglomerates were very slow in investing in and adopting renewables, and now own only 5% of Germany's installed capacity [4]. Instead, they invested heavily in coal and gas–fired power plants in the mid–2000's. The folowing figure shows generation mix of the German 'Big4' electricity conglomerates.

Figure 2. Earnings German „Big 4" electricity conglomerates (2013 mlrd. €) [32]



The above figure shows earnings of German „Big4" electricity conglomerates and shares in their energy production. This has left them with significant overcapacities that are now unprofitable due to the low marginal costs of renewables and their related merit order advantage of lowest cost power sources being dispached first. Renewables have caused whole–sale power prices to drop by half and peak premia by almost four–fifths, erasing the utilities „bread–and–butter" revenue [5][9]. „ What at the time may have look like a prudent business decision to protect investor interests, in hindsight has to be qualified as clear mistake of the „Big4": leaving the „small–sized" business with decentralized renewable energy to others, in particular to citizens and renewable energy cooperatives" [12]. The German generation market is now highly fragmented and localized with over 50% of the supply companies being owned by citizens, rural communities or by regional and local municipal utilities. The same trends is occuring in the retail sales market. With over 900 electricity suppliers, this market is very fragmented and competitive, and retail market share of the „Big4" has been continously decreasing to below 44% in 2013, down over 10% since 2011. As a result „Big4" have lost 70% of their market capitalization since 2008 on average and carry huge liabilities [28].

The following figure shows the lost market capitalization, share price of selected German Utilities.

Figure 3. Share Price of selected German Utilities vs. DAX 2006–2015 ODS [34] (Index May 2006 = 100%)

The above figure shows a significant fall in stock prices German „Big4" electricity conglomerates from 2008 to 2015 year. This crisis has trigered significant reorganization plans and write–offs and an intense search for new business models [5] [4]. Germany's largest utility E.ON announced plans to get rid of its core business of commodity–driven conventional power generation by 2016, which will be part of a new „Uniper" company. E.ON itself will focus entirely on renewables, distribution and smart energy services. E.ON's strategy is by far the most radical one, stripping the company down to a fraction of its former business and completely changing its nature. RWE, Germany second largest utility, has announced considerable layoffs, the closure or sale of generation assets and of other parts of company, as well as a stronger focus on new business fields and costumers. Germany third's largest utility EnBW, which is almost fully publicly owned by the state of Baden–Wuerttemberg, has to shut down 40% of its fleet due to nuclear phase–out and is thinking along the same lines as E.ON, focusing entirely on renewable energy generation, distribution and energy services. For political reasons, the Swedish energy giant Vattenfall is considering selling its coal facilities and eventually exiting the German power market altogether.

Regional utility service companies have adapted well to the Energiewende [5]. These mid–sized regional utilities, such as MVV Energie in the Mannhein region, Mainova in the Frankfurt/Main region and SWM in the Munich region, cover all competitive functions of the electric value chain either directly or through partners. They represent over 8% of German retail sales, and are either investor–owned (with a considerable share of public shareholders) or fully publically owned. They have focused on meeting their clients' needs and expectations through investments in renewable energies and offer inovative energy services. Many of them inteligently use cogeneration to rely on power and heat for balancing their budget. They use their size, local proximity and emotial ties to their customers to their competitive advantage. They focus on quality of service instead of excesive price competition with discount retailers. Being decentralized in their structure and focus, regional utilities are well positioned to respond to the increasingly distributed power generation and consuption that the Enegiewende asks for.

Local municipal utilities are preparing for vast changes in their business models after a period of significant downturn that resulted from the previously dominant market position of the „Big4" and from increased competition by new discount retailers. While municipal utilities constitute the majority (700) of Germany's 940 local distribution system operators (DSOs) and its over 1100 retail supliers, they are higly dependent on buying power from the „Big4". Many local municipal utilities are struggling with a lack of investment capacity and with adopting new business culture that focuses more on energy services than kWh–sales. Despite these challenges, a „re–municipalization" trend is noticeable in Germany [5] [3]: communities and cities such as Hamburg are buying back expiring local grid operating concession, which they had previously sold to the „Big4" [3]. Since 2005, over 120 local municipal utilities have been founded. In adition to the traditional utility industry, as Fratzscher (2015) states, an increasing number of communities have taken over their own energy supply [5]. In Germany, 146 communities and regions, ranging from 1000 to 1 milion inhabitans, are implementing 100% renewable energy strategies: major cities such as Frankfurt and Hannover, smaller cities like Scwabisch–Hall, or even smalltowns like Schonau. Several of them are already fully energy independent in their power and heat supply. The EU undertakes significant efforts to strengthen these so–called „100% renewable energy conmmunities". In the USA also a growing number of communities are engaging in distributed energy generation: 56 villages, cities and counties across the country are considered as „Green Power Communities". Consequently, in USA as in Germany, utilities face a convergence and acceleration of very similar transformative trends related to changing technology, policy and market developments. The following trends will profuondly alter the current power market landscape and require business model innovation on both sides of the Atlantic. Next few years will be a decisively pivotal period for utilities to adapt and reinvent their future rather than being drawn into a „vicious cycle from distruptive trends" or, as others call it the „utility death spiral" [7]. Below are 7 global transformative trends in power market landscape.

Supply will be increasingly decentralized

This future state imply relocation of generation from high voltage to low voltage [6]. Even if market share of renewable generation is still comparatively limited,, small–scale distributed capacity represented about one third of new global investments in clean energy in 2014, approx. US$ 80bn [5] [18]. Overall, renewable energy (excluding large hydro) made 48% of the new power capacity added globally in 2014, the third succesive year in which this figure has been above 40% [22]. This investments are still strongly driven by government mandates and policy incentives, such as feed–in tariffs or quota systems (renewable Portfolio Standards). However, decreasing costs particulary for onshore wind and solar photovoltaics (PV), continue to improve the economics of renewables even without incentives. The following figure shows US Solar Photovoltaic (PV) Installation and Average System price in period from 2000 to 2013.

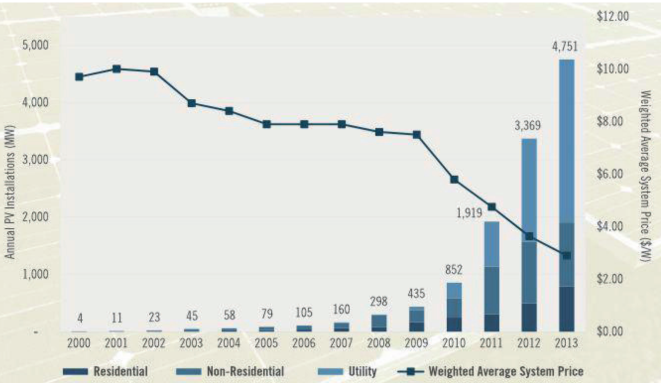


Figure 4: US Solar Photovoltaic (PV) Installation and Average System Price (2000–2013) [24]

As a global trend, the national average price of an installed PV system in the USA decreased by 63% between 2010 and 2014, reducing costs for residential rooftop system to US$ 3.48 per watt [5] [27]. While decentralized large scale wind projects by indenpendent power producers initially led the way in the USA and now account for 65,900 MW, customer–sited distributed generation, particularly rooftop solar, has significantly increased — a trend expected to accelerate as costs for PV decrease further [16]. The US added about 6,201 MW of PV in 2014, totaling 18,300 MW, a 30% increase over 2013 and more than 12 times the amount installed five years earlier [27]. In Germany, thanks to the Energiewende, decentralization is well advanced: in 2014, 157 TWh (of 610 TWh in total) were generated from decentralized renewable sourced, accounting for almost 28% of domestic electricity consumption [17].

On both sides of the Atlantic, many incumbent utilities are still slow in adapting to this trend of competitive renewables and prefer to stick with their accustomed model of centralized and large — scale, fossil and nuclear — fuel generation. For majority of US utilities, renewables still constitute just 0.1–3% of retail sales. Only the utilities that serve sunny or windy states and/or are forced to by ambitious state policy mandates have renewables accounting for 12–21% of their retail sales. In Germany the „Big4" still only own 5% of the renewables capacity.

Increasingly favorable market and regulatory conditions will lead to an acceleration of this trend towards decentralization of electric supply (and demand). This will pressure utilities to profoundly change their centralized way of thinking and doing business. However, it will also increase the financial pressure for these utilities to make significant investments in grid infrastructure and system operations to enable the integration of distributed and variable renewable energy generation.

OECD energy demand will continue stagnating or declining

„Why demand growth is out, energy efficiency is in, and the important implications of the two" one can ask a question [6]. While the economic slowdown has been the main reason for declining electricity demand since 2008, better energy efficiency measures, particularly from stringent building codes and appliance standards, will decrease the importance of kWh sales of utility business drivers [5]. In Germany, electricity demand has declined since 2011, and energy efficiency, expressed as final energy comsuption per unit of real GDP, has increased annually by 1.67% on average since 1990 [15]. The US EIA foresees electricity growth of only 0.9% annually until 2040 [30].

Moreower, distributed and auto–consumed elecricity will decrease the power demand cake even further. Many individual power producers will still need some grid electricity to balance the variability of their renewable energy system or to sell excess power back to the grid. However, complete grid defection, where customers will fully disconnect from the grid, could increase with the growing adoption of customer–sited distributed storage. In Germany, grid defection is on the rise, with more and more retail customers consuming their self–generated power. Today, around 25,000 companies are already self–sufficient and produce roughly 9% of Germany's total energy capacity for their own usage. Continously slow economic growth in OECD countries and the rising but slow adoption of electric vehicles will not reverse the trend of lower power demand in the mid–to long– term.

Decreasing revenues from declining demand, will thus continue to impact utilities on both sides of the Atlantic [5]. With already eroded credit ratings, utilities' cost of capital risks will rise even further. In the US, credit rates decreased from AA on average in the 1980s to BBB today, with threat of slipping to non–investment grade ratings [7]. This level deteriorates utilities' financial metrics and reduces their access to low–cost capital to enhance the energy system.

The distribution grid will become a smart, interconnected and interactive platform

This future imply that grid management complexity increases in the contest data needs, physics, unpredictability and also that grid increasingly become a back up machine [6]. In adition, smart meters and smart grid technologies, which provide digital processing and communications to the power grid, fundamentally change the dynamics of the lower–voltage distribution systems (below 60 kV) by alloving a two–way flow on information and power [5]. The power grid used to be a unidirectional system where only the utility delivered electrons to the consumer. Increasingly, the increase of distributed energy supply and demand from renewables, demand response, batteries and electric vehicles will make the grid an integrated and multi–directional platform that interconnects a variety of devices, consumers and producers. This platform will be the basis for a new way of thinking about the power sector. 43% of the US households are already equipped with smart meters [1]. The following figure represents smart meter deployments, planned deployments and proposals by investor–owned utilities, large public power utilities and some cooperatives in USA.

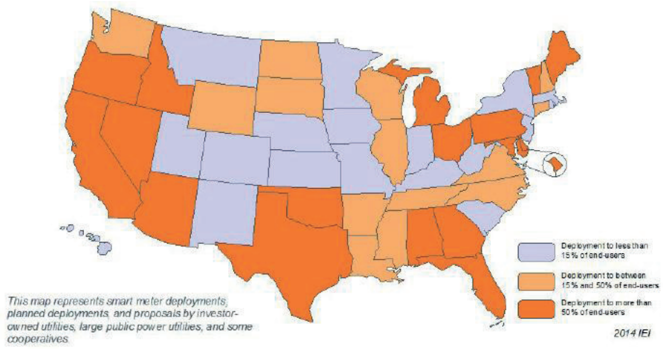


Figure 5: Smart meter deployments in USA (2014) [26]

The above figure shows that more than 50% households in California, Texas, Florida and NewYork have smart meter deployments. Moreover, in Germany, smart meters are still less deployed [5] Discussions are ongoing about how to set the institutionaland regulatory framework to develop the distribution grid into a smart, interconnected and interactive platform [23]. Data collection and analytics, smart and interconnected devices, and time–of–use price signals will allow advanced energy management and smarter energy use „reducing utilities" even further. For utilities this means that, in addition to lower sales, they will be confronted with rising costs to implement these new technologies. Given utilities' deteriorating financial metrics, these investments will become more risky and difficult to realize.

Customers will become active power agents

Customers will increasingly become active power agents–consuming, generating and balancing power — and will have to be situated at the heart of utility operations, in other words, customer become part of supply curve [6]. Technology changes, particularly in the rooftop PV sector, as well as regulatory modifications will revolutionize their role from passive kWh consumers to customers of diversifed energy products and services, and eventually even to proactive „prosumers" who produce, consume and trade power at the same time. Thanks to the favorable feed–in tariff policy and priority access to the grid for renewables, Germany already has a large number of such active prosumers: individuals and farmers own 46% of its 72,900 MW renewable energy capacity, commerce and industry own 14% [14] [5]. In the USA, the PV uptake has been considerable with a total installed capacity of 18,300 MW and another 8,500 MW expected in 2015, of which most rapid growth is anticipated in the residental market. Moreover, generational mentality changes will create new customer expectations: the „millennials generation" born after 1982 and one third of the adult population in 2020 wants products and services that meet the criteria of the three „C"s: cheap, convenient and cool [2]. Utilities will hence need to even actively engage customers on an individualized basis with an emphasis on personalized and tailored marketing, communication, and product and service packages. To do so, they will need to change their mindset from selling one commodity to captive customers towards offering more service orientation. Partnership particularly with innovative data analytics providers will help better explore customer expectations and design customer–centric services. The approach to tailored service packages in the wireless communication industry can serve as an example.

Innovative market entrants will increase competition in the power sector

In the USA as in Germany, innovative and agile providers of energy services up to and behind the meter will continue expanding their market position, service–oriented offerings will proliferate [19]. Up to the meter, for example, third party developers offer leasing services for residential PV or storage systems. Behind the meter, many energy service providers help commercial customers to save energy or to make money from reducing their demand during peak times. These new market entrants will explore and even further expand customer needs and fill the gap with new services. This will accelerate grid defection and endanger utilities than hold on to operating under the old business model of exclusively centralized generation.

The regulated utility business of providing basic power to customers will be relatively shielded from competitors. The electric marketplace will remain regulated to ensure that utility customers and service providers are protected from the lack of competition where utilities are granted exclusive service teritories and monopolistic structures persist, such as for transmission. Utilities will nevertheless want to convince regulators to tap more into the market–based business of providing new energy services up to and behind the meter, and benefit from growth opportunities. This service market, however, is very competitive. Utilities, which as per their original monopolistic model are not used to face competition, may avoid the risk of being outcompeted by etablishing innovative partnership with agile competitors.

System optimization will require significant investments and regulatory changes

System optimization takes two dimensions: market design to remunerate power flows and flexibilization services, and tehnical optimization of grid infrastructure and system operations to manage and balance the power system. These two dimensions of system optimization keep industry, regulators and policy makers busy on both sides of Atlantic [5]. Firstly, revenue generation and long–term investment decisions will be profoundly influenced by the future market design if utilities are to be paid for just providing electrons in energy–only markets or if they are also to be remunerated in capacity and ancillary services markets for reserving generation capacity in case it is needed to balance demand and supply. Secondly, and as the other side of the same coin, tehnical optimization of system operations and infrastructure will continue to require significant regulatory adjustments and substantial regional planning for more flexible grid management and the integration of distributed energy resources. Huge investments are needed to upgrade or replace aging or overhauled generation, transmission and distribution infrastructure. In the USA for example, investor–owned utilities are expected to invest $100 billion in annual capital expenditures over the next few years, with more being spent on the distribution system and less on generation [1]. These investments pose tremendous stress on financially strapped utilities. Beyond low interest rates, the solution will require innovative financing and regulatory models to allow utilities to realize these investments.

Germany is facing considerable challenges to optimize its system and to ensure the required investments in grid infrastructure. Heated debates on the appropriate market design and on transmission expansions are ongoing on the federal and state level as well as in industry and civil society [35].

Energy policy and environmental regulation push towards cleaner power generation

34% of carbon emissions in the USA and 33% in Germany are attributed to the power sector [5]. As the evidence of climate change and the need for greater resiliency against its impacts become a publically supported reality, energy policy is seen as the key instrument to tackle climate change and to address geopolitical considerations.

In the USA, the proposed Clean Power Plan gives states flexibility to choose their measures for achieving pre–defined emission reduction targets. Moreover, state mandates and policies as well as market–driven carbon reduction mechanisms, such as the regional Greenhouse Gas Initiative (RGGI) for power generators and California's cap–and–trade system, will keep on encouraging a shift in generation mix. Despite its world largest coal reserves, the USA gears towards replacing significant parts of its coal fleet with lower–carbon gas–fired generation, which benefits from more operational flexibility and presently low fuel prices, as well as with renewables.

Just as in Germany, ambitious government targets on the German and EU level call for cleaner power generation. In addition, the European Emission trading Scheme (EU ETS) pushes energy generators to reduce their emissions. For utilities on both sides of Atlantic, investing early in low–carbon generation capacity helps avoid compliance costs to meet increasingly stringent environmental and energy policy and regulation.

Business Model Innovation will be Lifeline for Survival in a Reinvented Clean Energy Future, against the backdrop of the convergence of these multiple distruptive trends, utility executives on both sides of the Atlantic want to adapt; yet it is still largely unclear how [5] [31]. Examples in the USA and Germany show that sound business can be derived from pursuing new business models that embrace two key features: a more distributed and integrative approach to generation and/or distribution, and greater customer and services orientation when it comes to retail sales. This analysis focuses on deregulated power markets so as to alolw for a better comparison between Germany and the USA.

A more distributed and integrative approach to generation can play out on two levels: either as decentralized utility–scale generation (large grid–connected wind or solar farms, or flexible and fast–ramping gas–fired plants) or as distributed customer–sited generation (rooftop PV, small off–grid wind turbines, on–farm biogas digesters, etc.). Government mandates and policies as well as falling technology costs for renewables and low natural gas prices in the USA favor the deployment of both decentralized and distributed generation over large–scale centralized power generation from coal or nuclear.

CUSTOMER EMPOWERMENT STRATEGY AND SHAPING MARKETS IN THE PRODUCTION OF ELECTRICITY (EXAMPLE OF E.ON)

As its states in first chapter, energy companies invested heavily in coal and gas–fired power plants in the mid–2000's, and this has left them with significant overcapacities that are now unprofitable due to low margin costs of renewables and their related merit order advantages of lower cost power sources beingdispatched first. At the other words this companies were operating with losses, and as a result German the „Big4" have a lost 70% of their market capitalization since 2008 on average and carry huge liabilities. This crisis has trigered significant reorganization plans and write–offs and an intense search for new business models. This article analyses E.ON Group's response to global transformative trends in energy market enwironment. Consequently, E.ON Group is divided into two very focused and dinamic companies, one of which is focused into a New world of energy and other into a conventional world of energy. In other words, using Diferentiation strategy E.ON Group develops new business model innovation in generation power, shapes expectations of customers and design energy market

Strategy for future, new trends, new opportunities

This strategy has represented by the E.ON SE on the Press Conference in Decembar 1, 2014 [10]. New strategy of E.ON Group, will involwe dividing broad portfolio of business into two very focused, publicly listed companies. This will better position both companies with strategic opportunities: to grow, to secure jobs, and to create value. E.ON will focus entirely on renewables, distribution networks, and customer solutions and thus on the building blocks of the new energy world. This is the logical consequence of E.ON's commitment to be for their customer's partner of choice and to be best in class in terms of customer satisfaction in all markets. The following table shows split of E.ON into two focused publicly listed companies.

Table 1. E.ON to split into two publicly listed companies [10]

E.ON	
E.ON	Uniper
Endpowering customers	Shaping markets
New energy world	Conventional energy world

Uniper focus on conventional energy world. Well then, E.ON will spin off their conventional generation, global energy trading, and exploration and production businesses into a new, independent company, which will play a key role in ensuring supply security for the transformation of energy systems and in reshaping conventional energy markets. The spin off will involve transferring a majority of the New Company's capital stock to E.ON's shareholders. In addition, they intend to sell the shares of the remaining minority stake gradually over medium term. In conjuction with the new setup, E.ON has sold his entire business in Spain and Portugal to Macquarie, an Australin investment firm, for an enterprise value of €2.5 billion. In addition, board of management is evaluating the sale of E.ON's activites in Italy and will conduct a strategic review of it's exploration and production business in the North Sea. Thanks to their clear setup and missions, both E.ON and the New Company Uniper, will be superbly positioned to play a leading role in their respective businesses and markets and both will be solidly financed, will secure jobs, and will have prospects for creating new jobs in the future [10]. In addition, Board of Management setting up his company that significantly different, because European and global energy markets have undergone a dramatic transformation, as a glance at the changes in the energy value chain indicates.

„Until not too long ago, the structure of energy business was relatively straightforward and linear. The value chain extended from the drill hole, gas field, and power station to transmission lines, the wholesale market, and end–customers. The entire business was understood and managed from the perspective of big production facilities. That is the conventional energy world familiar to all of us. It consist big assets, integrated systems, bulk trading, and large sales volume. Its technologies are mature and proven. This world of energy still exists and will remain indispensable. In the last few years, however, a new world has grown up alongside it, a world characterized above all by tehnological innovation and individualized customer expectations. The increasing tehnological maturity and cost–efficiency and thus the growth of renewables constitute a key driver of this trend. More money is invested in renewables than in any other generation technology. Far from diminishing, this trend will actually increase" [10].

Moreover, the costs of some renewables technologies, such as onshore wind farms, have sunk to parity with, or below, those of conventional generation technologies, and that is expected that other renewables technologies could become economic in the foreseeable future [10]. Renewables aren't just revolutionizing power generation. Together with other technological innovations, they're changing the role of customers, who can already use solar panels to produce a portion of their energy. As energy storage devices become more prevalent, customers will be able to make themselves largely independent of the conventional power and gas supply network. The proportion of customers that want to play a more active role in designing their energy supply is growing steadily. Above all, they want clean, sustainable energy that they can use efficiently and in a way that conserves resources. At the same time, the Internet of Things has arrived in the energy business, creating new opportunities for innovative data–based products and services [10].

The growth of renewables is also changing the role played by distribution networks, which no longer simply transport electricity to customers [10]. At times, the renewables feed–in in E.ON distribution networks in Germany already surpasses their customers' consuption. E.ON's networks are becoming smarter and can also along with transmitting electricity, transmit and process data. Distribution networks, which serve as energy hubs, are integral to the new energy world. This new world, which is emerging around customers and their changing needs, is fundamentally different from the conventional energy supply system which is based on large–scale systems. The decisive success factor in the new energy world is customer proximity. Small distributed equipment such as, solar panels, micro CHP units, and battery storage devices are just as much as part of this world as increasing interconnectivity. This new energy world is still in its infancy, but it will grow faster than the conventional energy world. Both worlds will remain viable for long time to come but they need each other[10]. That's why, despite their fundamental differences, both have their own development and growth opportunities. These are precisely the opportunities bord of management intend to size. Today's E.ON has a broad portfolio of operations and businesses that straddles both energy worlds. It's seen for some time now that E.ON's businesses are characterized by different value drivers, opportunities, capabilities are charaterized by different value drivers, opportunities capabilities, and ways of thinking. The differences between operating big power stations and developnig innovative customer solutions are obvious. E.ON's Board of Management has now come to conclusion that it will become increasingly difficult for a company with a broad portfolio to be successful and grow in both the new and conventional energy world [10]. The main objective in the conventional energy world is to make a meaningful contribution to supply security. Big, efficient assets at favorable locations and with a low cost base represent the key success factors. The new company Uniper will have them, along with outstanding capabilities in engineering and in global energy trading. The new energy world, by contrast, is characterized by speed, agility, innovation, and digitalization. E.ON's Board of Management is convinced that energy companies will have to focus on one of the two energy worlds if they want to be successful in the future. That's why E.ON's Board of Management is going to divide their current businesses into two companies, each of which has the right setup and the right strategy for its particular world. The following table shows dividing E.ON's current business portfolio into two companies. E.ON Group for new energy world and Uniper for conventional energy world.

Table 2. Dividing current business portfolio to E.ON and Uniper [10]

E.ON	Uniper
Renewables	Upstream
Distribution	Global Commodities
Customer solution	Power Generation

The above figure shows that E.ON will focus on renewables distribution networks, and customer solutions. Uniper's focus is Upstream, Global Commodities and Power Generation. E.ON will consist primarily from their regional units' distribution and sales businesses in eight european markets, E.ON Climate & Renewables' wind and solar activities, E.ON Connesting Energies' distributed–generation and energy–efficiency business, E.ON's steak in Enerjisa, their joint venture in Turkey. About 40,000 of E.ON's 60,000 employees currently work in these businesses. With roughly 33 milion sales customers and 26 million network customers in Europe and Turkey, the future E.ON will have a superb platform for establishing and expanding new end–customers business. With a total system lenght of more than 1 million kilometers, E.ON is already one of Europe's largest operators of electricity networks and in many regions is an innovation leader. With about 4.5 GW of renewables capacity (primarily wind capacity in the United States and Euroipe), E.ON ranks among the biggest and most experienced players in the global renewables business.

The future of E.ON's three core business–renewables, energy networks, and customer solutions–fit together and reinforce each other, creating a business portfolio with stable earnings and strong growth potential. Building on this portfolio, by 2020 board of management intend to make E.ON the leading provider of customer oriented energy solutions, which will enable us to meet customers' increasing demand for greater autonomy and a more active role in the energy world. E.ON's Board of Management intend to make innovative approaches to developing each of the three core businesses. For this purpose, they'll increase investment budget for 2015 by about €500 million in addition to the already planned €4.3 billion. They'll further expand wind business in Europe and in other selected target markets and strengthen solar business. They'll upgrade energy distribution networks in Europe and also in Turkey and make them smarter so that customers can take adventage of new products and services in areas like energy efficiency and distributed generation.

New company Uniper will focus on conventional power generation, global energy trading, and exploration and production. It will consist of E.ON Generation's thermal and hydro fleet, E.ON Global Commodities' trading business, E.ON Exploration and production, E.ON Russia's power generation business, and their stakes in Yushno Russkoye gas field in Russia, in the Nord Stream pipeline, and in Eneva in Brazil. The new company will have its headquarters in Germany's Rhine–Ruhr region. Tomorrow's energy world will continue to need a stable, secure energy supply and access to global markets for energy products. Uniper's core businesses are geared precisely toward meeting these fundamental needs. A strong natural gas portfolio–which encompasses the exploration and production business, gas transport pipelines to Europe, long–term gas procurement contracts, and substantial storage capacity in Germany–will make the Uniper one of the biggest players in the natural gas business. With more than 50 GW of installed capacity, Uniper will be a leading power producer in Europe and Russia. Now, Uniper is Europe's fourth–largest power producer and its largest operator of technologically advanced gas–fired power plants. In recent years Bord of Management has systematically optimized E.ON's generation fleet and dramatically reduced his production costs. From an operational standpoint, they has therefore laid the fundation for sustainable profitability, particularly if policymakers create the necessary regulatory framework for supply security. E.ON's power and gas operations will continue to rely on his trading unit as their interface with global commodity markets and European trading platforms. Trading unit transforms E.ON's power production and gas portfolio into trading products that is markets to customers across Europe and increasingly, around the world. It has trading officies in Asia and North America, ensuring its access to growth markets outside Europe. And it has one of the largest gas–storage portfolios in Europe. Policymaker's efforts to reduce the import risks of Europe's gas supply give gas storage facilities a substantial strategic significance. Uniper's strong positions in the power and gas business will enable it to play a key role in ensuring supply security in the United Kingdom, Germany, Sweden, Russia, and many other countries. The fundamental transformation of Europe's power generation market creates opportunities to reshape this market. Being one of Europe's largest power producer will position the Uniper well to serve as a catalyst and platform for the consolidation of Europe's generation market. Its recognized capabilities will make it a sought–after partner in global energy trading and as a service provider for third parties. Now and in the short term, the conventional energy business faces significant challenges. But Uniper is superbly positioned to seize future opportunities. Many European countries are developing a new market design that will better reflect the growing significance of renewables and the altered role of conventional generation. It isn't a question of whether but rather when they will adopt a new market design, because the current situation is simply untenable. A market design that pays appropriate compesation for generating capacity that ensures supply security will create opportunities for Uniper. In addition, European countries continue to support the EU Emissions Trading Scheme and have already taken tangible steps to revitalize it. A recovery of carbon prices would substantially improve the prospects for Uniper's technologically advanced gas–fired power plants. Finally emerging countries will continue to have a significant demand for conventional energy. Over the medium term, this will create opportunities in markets outside Europe for strong power–generation and trading companies. The business portfolio of E.ON in its new setup and the business portfolio of the Uniper differ considerably in terms of growth, risk, and cash–flow profile [11]. And that each company will face different strategic challenges and will therefore have different requirements for capital. The new setup will create two attractive stocks, each of which will appeal to different investor groups. The future E.ON will offer its investors a balanced risk profile with clear growth opportunities and a large proportion of regulated and quasi–regulated business with relatively stable earnings.

„All of our current capital–market liabilities will remain with E.ON, giving E.ON SE's lenders a strong counterparty that willcountinue to have an investment–grade rating. If E.ON's rating changes in conjuction eith the new. It will be set up with a strong net financial position, ensuring that it too can obtain a solid investmnent–grade rating. Existing provisions for the dismantling and disposal of nuclear and conventional assets will be fully covered in the Uniper's balance sheet. Because it won't have any capital–market liabilities and thanks to its solid financing, publically listed company Uniper, will be financially robust. Board of Management is convinced that the new setup will offer our current shareholders additional value potential" [11].

In view of these strategic developments, the company's restructuring, and the related foreseeable uncertainties, the Supervisory Board agreed to the E.ON Board of Management's proposal that the company should aim to pay a fixed dividend of €0.50 per share for both the 2014 and 2015 financial years. The dividend proposal applies regardless of issues such as the possible consequences of portfolio streamlining, and accounting treatment of the new setup, and the outcome of the pending court cases regarding Germany's nuclear–fuel–tax. As part of the process of preparing the annual finacial statements and the new medium term–plan, the E.ON Board of Managemnent recently tested the the Group's assets for impairment. E.ON expects to record additional impairment charges of about €4.4 billion in 2014, primarily on its operations in Southern Europe and on generation assets. Althought not cash–effective, the total impairment charges will result in E.ON reporting a substantial negative net income for the 2014 financial year. Board of Management expect EBITDA to be between €8 and 8.6 billion and underlying net income to be between €1.5 and €1.9 billion. Because Uniper's business do not yet constitute a corporation, this year and next year they lay legal foundation for them to be combined. This will involve bringing together under a new parent company those business units that will belong to the Uniper. They will then spin off the Uniper by transferring a majority of its capital stock to E.ON's shareholders. Moreover, they intend to sell the shares of remaining minority stake on–market over the medium term, enhancing E.ON's financial felxibility for future growth investments. New strategy gives their employees good prospects for the future in two superbly positioned and attractive companies [10]. It also offers E.ON's stockholders attractive investment opportunities in two companies with sharper profiles, a high degree of earnings transparency, and improwed earning prospects. E.ON wil offer their customers the innovative holistic energy solutions they expect. That is what the future E.ON will stand for. And Uniper will play key role in ensuring a reliable energy supply.

–„*The two companies' business operations will make a significant contribution to the communities and countries where they operate. E.ON will propel the transformation toward a clean, sustainable energy supply, and Uniper will hepl provide the backup for this process and play an active role in the consolidation and restructuring of conventional energy world. All these elements are encompassed by the name for new strategy: Empowering customers. Shaping markets [10]."*

Two energy worlds, each with significant opportunities

The formerly integrated world of energy supply is dividing into two different energy worlds, convential and new energy world [10]. Renewables and distributed generation are becoming more prevalent. New energy technologies are spreading fast, and customers increasingly demand innovative solutions. Smart grids are creating a data highway for the energy system, and digitalization is moving rapidly foward. They believe this new energy world will grow rapidly. Alongside this new world, the established energy world continues to exist and transform itself. It's still needed to secure the power and gas supply by providing access to global energy markets. Increasingly, it's needed to serve as a stable backup for intermittent renewable and distributed energy sources. The two worlds call for very different business approaches, require different capabilities and skills, and attract different investors. Each has its own development and growth opportunities. The purpose of strategy is to enable to seize these opportunities.

Why not remain one company for both energy worlds?

In their exposition E.ON's restructuring concept give picturesquely explanation new strategy:

„A generalist is no longer the right player for the energy markets of today and tomorrow. Markets are becoming more fragmented, customer needs more individualized, technological trends more diverse. This more fragmented energy world calls for specialists who are experts in their particular segment. Being able to plan, build and operate large and complex assets has little in common with offering innovative customer solutions. Just as trading commodities and energy products on global markets has little in common with operating smart grids. It's like soccer and team handball: both are about putting a ball in a goal. But not even the top soccer teams in E.ON countries, not Bayern Munich or Chelsa, not Zenit Saint Petersburg or IFK Goteborg would stand a chance against a professional handball team. The rules, skill sets, the formations, the tactics: all are simply too different. And so it is with the two energy worlds. Both are about supplaying customer with energy. But the succes factors specific to each are becoming increasingly different. We're experts in many areas. And we need to demonstrate this expertise even more than in the past. That's why we're combining our capabilities according to whether they fit with the established or the new energy world. This will enable us to deploy these capabilities more effectively so that we can take advantage of growth opportunities. It will also enable us to avoid confusing our customers, enterprise partners, and stakeholders, who may wonder whether we're focusing more on energy efficiency and distributed solutions or on bulk generation trading. We need to seize this opportunities. Otherwise, others will do it first. If E.ON continued to be single company but focused on one of two worlds, their operations in the other world would effectively be demoted to noncore businesses, giving them limited prospects as part our company. Sooner or later, we've have to divest them. That's why the only right course to take is also the name of our transformation project „One2two: best in both worlds." [11]

The One2two project will ensure the creation of two attractive and financially solid companies capable of optimally deploying their people's many strengths and skills. The aim is for booth companies to start from a very good position and to be, as the project motto puts it, the „best in both worlds". Well then, E.ON Group is divided into two very focused and dinamic companies: New E.ON focused into a new world of energy based on business model inovation, empowering customers and Uniper focused into a conventional world of energy, based on security of supply and significant reduction of costs.

Uniper focus: the established energy world

The primary objective in the established energy world is to make an effective contribution to the security of the power and gas supply. The key success factors in this world are to have powerful and efficient assets at good locations, to maintain the highest safety and environmental standards, to have a low cost base, and to have a portfolio of market based gas import contracts and the partnership that go with them [11]. Going forward, they state that Europe will continue to have a substantial need for conventional power generation, a reliable gas supply, and energy trading companies with global reach. Renewables are as fickle as the weather. Fossil fueled power plants provide an important backup service: they ensure grid stability and supply security. This service needs to recieve fair compensation. Althought the details will differ by country, across Europe there there will be new market designs with mechanisms for compensating assets that ensure supply security. Outside Europe, the growing demand for energy can't be met cost–effectively without conventional energy sources. Countries in these regions urgently need companies that can plan and build power plants and operate them efficiently, that can develop gas pipelines, and that can provide a reliable supply of power and gas. These countries want to grow their economies in order to increase prosperity and reduce poverty. For this, they need a stable, diverse, and cost–effective energy supply. Uniper's knowledge and capabilities can play an important role here, not only for their assets, but also for project partners and for third parties. Now, plan is that Uniper will be an established leader for an established world. The established energy world is undergoing continual transformation as well. It calls for state of the art assets that are optimally integrated into the energy system, can help ensure supply security, and have competitive cost position. Uniper's three core business: conventional power generation, global energy trading and exploration and production will enable it to operate successfully in this world.

Generation: Uniper's generation fleet ranks among the most competitive in Europe, giving it a strong position in the ongoing market consolidation. Its power stations, which are located near consuption centres, will have excellent chances in a competitive energy marketplace and in emerging capacity markets. In addition, its technologically advanced gas–fired power plants will benefit from rising carbon prices, which will result from the revitalization of the emissions trading scheme. And its hydroelectric stations deliver stable earnings. Germany's nuclear–fuel tax will expire at the end of 2016 (and possibly earlier, depending on court rulings), which will give Uniper's nuclear power stations in Germany good earnings prospects until the country phases out nuclear power in 2022. It goes without saying that Uniper will meet its responsibilities for the retirement of these assets. Uniper will have almost 10 GWh of generating capacity in Russia and will be a significant foregn investor in that country's energy market. These power plants are located in fast growing regions, where they're needed to meet rising energy demand.

Global trading: Uniper's global trading units connects its power and gas operations with global commodity markets and European trading platforms. It optimizies Uniper's power production and gas portfolio and markets them to customers across Europe and increasingly, worldwide. It has offices in Asia and North America, giving it access to growth markets around the world. It also has one of the largest gas storage portfolios in Europe.

Exploration and production: Uniper's E&P business owns a stake in Yuzhno Russkoye, one of the largest gas fields in Russia. This valuable investment is of strategic significance for Europe's gas supply. Uniper's E&P business in the North Sea is under strategic review. Uniper will be able to build on existing, proven synergies between generation, trading, and the midstream gas business. Even in markets with low commodity prices, these businesses continue to generate good earnings. In short the established energy world will ensure reliability and supply security as the energy transformation moves forward. Uniper has indispensable businesses, a wide range of outstanding technological capabilities, and exciting business prospects.

E.ON focus: new energy world

The emerging new energy world is oriented toward customers' changing needs. Customer proximity is the key success factor end, energy efficiency is the watchword. Small–scale distributed energy solutions rooftop solar panels, micro CHP units, and battery storage devices are as much a part of this world as increasing connectivity and the ongoing growth of renewables. Customers want sustainable energy solutions.

At the same time, the role of distribution networks is changing. Electricity no longer flows in just one direction (from power plants to customers). Networks are becoming smarter, enabling them to transmit dana as well as electricity. As energy and data hubs, distribution networks are essential infrastructure for new energy world.The trend toward an Internet of things has reached the energy business, creating new opportunities for innovative, data–based products and services. This future imply that grid management complexity increases in the contest data needs, physics, unpredictability and also that grid increasingly become a back up machine [6]. E.ON is bringing, the new energy world to life using strategy based on three fundamental market trends and the corresponding growth businesses: the global growth of renewables, the increasing significance of smart distribution networks for a cleaner energy world, and the increasing individuation of customer needs [10]. E.ON's goal is to be leading provider of energy solutions and to be customers' partner of choice for innovative energy solutions. To achieve this aim, it will focus on three core businesses: renewables, energy networks, and customer solutions. The interplay between these businesses will enable E.ON to develop solutions tor the new energy world, such as sustainable solutions for cities and custom–tailored offerings for industrial customers.

Customer solutions: About 33 milion customers in Europe and Turkey already rely on E.ON's competitive products and services. E.ON is working with European and American startups to design cutting–edge energy solutions. Program is nurturing businesses ideas developed by his own employees and by people outside company. Going forward E.ON intend to enhance his position as a pioneer in innovative customer solutions.

Energy networks:E.ON's 26 milion network customers give him a broad platform for establishing and expanding new end–customers businesses. With a total system lenght of more than one million kilometers, E.ON is already one of Europe's largest network operations and in many regions an innovation leader. It intend to upgrade distribution networks and make them smarter so that customers can take advantage of new products and services in areas like energy efficiency and distributed generation.

Renewables: With about 4.5 GWh of renewables capacity (primarily wind capacity in the United states and Europe), E.ON already rank among the biggest and most experienced players in the global renewables business. Two more large offshore wind farms will become fully operational this year, further underscoring his pacesetting role offshore wind. E.ON intend to further expand his wind power business in Europe and other selected target markets and strengthen solar business. In a short, E.ON's focus in the new energy world will be enhancing their customer orientation, developing and deploying new downstream business models and products, and leveraging the digital transformation. E.ON's Board of Management will strengthen and reposition the E.ON brand, expand his international wind business, establish substantial solar, battery–power, and energy efficiency businesses, surpass regulatory cost benchmarks in his distribution business.

THE UNIPER GROUP AFTER THE SPIN–OFF TAKEN EFFECT

Once the spin off takes effect, the Uniper Group will become a legaly and economically independent group in the energy sector [25]. Uniper SE will become the ultimate parent company of the Uniper Group, which will be one of the important players in the areas of conventional energy generation and energy trading in Germany, Europe and Russia, with generating capacity of approx 40 GW in the 2015 financial year and adjusted EBIT of about € 801 million (2014: € 826 million, 2013: € 1,048 million) and revenues of € 92.12 million in 2015 financial year (2014: € 88.23 million, 2013: € 94.75 million). The Uniper Gruop will principally operate in areas of electricity generation, and electricity gas, coal, freight, liquefied natural gas and oil trading, in gas storage facilities and in the course of participations in gas infrastructure. In addition, it will also trade carbon allowances. Its customers will be wholesale and business customers in the first instance, which also include, among others, network operations, municipal utilities and other energy distribution companies.

Table 3. Schematic overwiew of the segments and activities of the Uniper Group [25]

Uniper Group				
Segments				
	European Generation	Global Commodities	International Electricity Generation	Administration/ Consolidation
Activities	Hydro power Nuclear Power (Sveden) Fossil Generation Other	Electricity Gas Yuzhno Russkoye Gas Field Coal&Freight/Liquefied Natural Gas/Oil	Russia Brazil	

Based on adjusted EBIT, the Uniper Group's operating business will focus on Germany, Russia and Sweden. Furthermore, the Uniper Group is active in particular in Great Britain, France and the Benelux countries as well as in the USA. The operating activities' future focus will also depend on whether and to what extent the Uniper Group intends implements any measures for portfolio optimisation. For this purpose, group–wide optimisation programmes will be implemented, among others. Corresponding measures are being examined comprehensively at present, with the aim to complete such measures by 2018. The measures will probably encompass three components, namely cost reductions, the analysis of capital exenditure and the further optimisation of current assets. In addition, the Uniper Group intends to make portfolio sales worth at least € 2 bn for debt repayment purposes. The criteria applicable to a portfolio sale are limited overlaps and synergies with the remaining portfolio and the reduction of cluster risks in the overall portfolio. In total, these measures will lead to a reduction in the number of employees of the Uniper Group. Uniper's portfolio is very focused and consist attractive assets across Europe and Russia with diversificate revenues.The following figure represents stakes in EBITDA of Uniper's business areas:

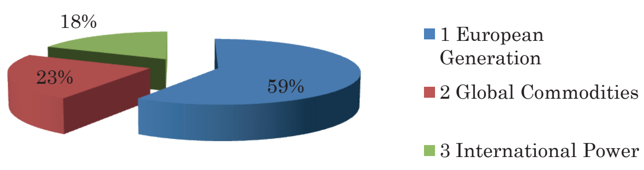


Figure 6. EBITDA Uniper's segments for 2015 [29]

The above figure shows stakes in EBITDA of Uniper's business areas and it presents that 59% of EBITDA is European Generation, 23% of EBITDA is Global Commodities and 18% of EBITDA is International Power. European Generation consists Hydro Power, Fossil Generation, Nuclear Power in Germany, Sweden, United Kingdom and other countries. Global Commodities's revenue comes from the electricity and gas trade. International Power refers to Generation in Russia and Brazil. Now, it is one of largest European generators with 31 GW of own, mostly dispatchable generation capacity with diversifed base across technologies and main markets.

Some indicators of Uniper's 2016 first half results

When the spin off takes effect the Uniper Group will become a legally and economically independent group in the energy sector oriented to a conventional energy world. The prospectus of Uniper First half results of 2016 was publiced at 22–nd August 2016. The following figure represents Net Income of Uniper Group in first half of 2015 and 2016.

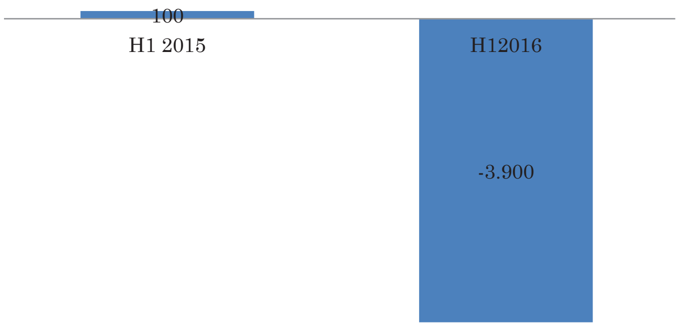


Figure 7. Net Income Uniper Group (million €) [29]

The above figure shows that in first half of 2016 there was significant fall of Net income in regards to same period in 2015, in other words, reasons of Net loss are Impairments European Generation, Impairments Gas Storage and Provisions of Onerous Contracts Gas Storage. The following figure represent drivers of Net loss.

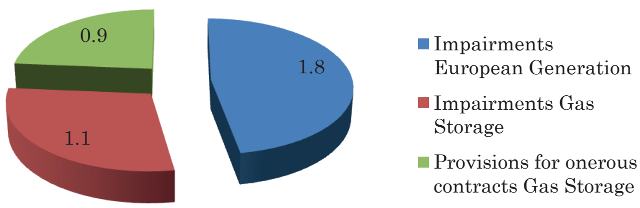


Figure 8. Net loss drivers of Uniper Group (bn €) [29]

The above figure shows that significant negative effects in Uniper's European Generation and gas storage impact bottom line. Total impairment provisions for onerous contracts was €3.8 bn. Impairments in European Generation were €1.8 bn. It takes into account discussions in several European countries with respect to early shut downs for coal plants or the introduction of additional levies on carbon, and it has been taken into account scenario analysis with different lifetimes of the plants. Impairments in Gas Storage were €1.1 bn. It takes into account that Gas summer/winter spreads have narrowed and sucurity of supply is no more appropriately rewarded by the market. Provisions for onerous contracts Gas Storage were €0.9 bn. It takes into account valuation reflects a changed assessment in terms of the sustainable market outlook for onerous contracts for gas storage Europe. However, Global Commodities drives positive H1 2016 Group EBIT(DA) performance, and following table represent this first half results:

Table 4. EBITDA Uniper Group H1 2016 [29]

EBITDA (mil. €)			
mil. €	H1 2015	H1 2016	+/– %
European Generation	515	406	–21
Global Commodities	420	1.165	>100
International Power	150	5	–97
Admin/Consolidation	–85	–36	–58
Total	1.000	1.540	+54

Table 5. EBIT Uniper Group H1 2016 [29]

EBIT (mil. €)			
mil. €	H1 2015	H1 2016	+/– %
European Generation	195	120	–38
Global Commodities	334	1.095	>100
International Power	106	–39	<100
Admin/Consolidation	–90	–41	–54
Total	545	1.135	>100

The above tables shows that EBITDA and EBIT results in first half 2015 and 2016 financial year. Conclusion is that Global Commodities drives positive H1 2016 Group EBIT and EBITDA performance.Well then, Global Commodities with its good results surpassed losses of the European Generation and International Power.

THE E.ON GROUP AFTER THE SPIN OFF

After the spin off has taken effect and the Deconsolidation Agreement has been implemented, Uniper SE, previously part of the E.ON Group, and its subsidiaries will form the independent Uniper Group, and thus cease to be members of the E.ON Group [25]. However, when the spin off takes effect, E.ON SE will hold an indirect stake of 46.65% in Uniper SE's share capital. As a result of the spin off, the E.ON Group will focus its business operations on the Energy Networks, Customer Solutions and Renewables.

Table 6. E.ON Group's business areas and activities after spin off [25]

E.ON Group					
Business areas	Energy Networks	Customer Solutions	Renewables	Non Core	Group Management
Aktivities	• Germany • Sweden • Central Europe East & Turkey	• Germany • Great Britain • Other	• Onshore wind/ Solar • Offshore wind/ other	Preuseen Elektra Uniper	Group Management Business services

The above table shows fundamental business areas of the new E.ON Group: 1. Energy Network with its assets in Germany, Sweden and Central Europe countries and Turkey, 2. Customer solutions in Germany and Great Britain, 3. Renewables which consist Onshore wind and Solar and Offshore wind. In addition E.ON Group consist Non Cor activities and Group Management.

Some E.ON Group's financials in the first half of 2016

E.ON Equity story 2016 approachable on [20] published Group financials in first half of 2016 year. The following figure represent Group's Business areas contribute to EBIT in 2015 financial year.

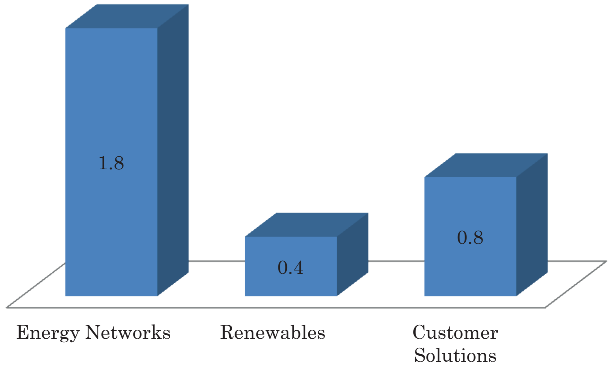


Figure 9. E.ON's Business areas contribute to EBIT in 2015 (bn €)[20]

Energy Networks is the stable earnings backbone. Positive driver for Energy networks in 2016 was start of new regulatory period in Sweden, and negative driver were one–off effects in 2015 especially from provision release in Germany. Renewables and Customer Solutions growing in 2016. Renewables's contribute to EBIT was 13%, Customer Solutions's contribute to EBIT is 27% which make contibution to E.ON's EBIT of 40%. Consequently, E.ON group is focused to new energy world because new business areas in energy value chain contribute to EBIT 40%. Moreower, Energy Networks earnings include additional components focused to new energy world. Renewables have earnings increase from new capacities, for 2016 driven by full–year contribution from offshore windfarms Amrumbank and Humber. Customer Solutions growth through increased customer focus. Positive Customer Solutions' drivers for 2016 are margin expansion and reduced costs outside Germany and normalized weather in Sweden. Negative driver for 2016 was one–off in 2015 from provision release in Germany. Total Core EBIT was €2.6 bn including Corporate Functions/other with loss €0.4 bn.

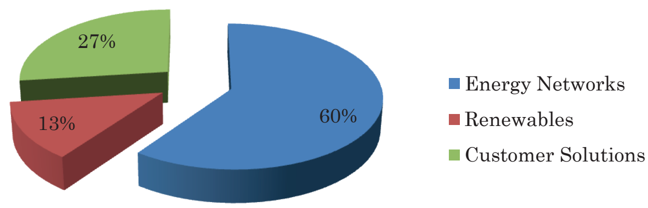
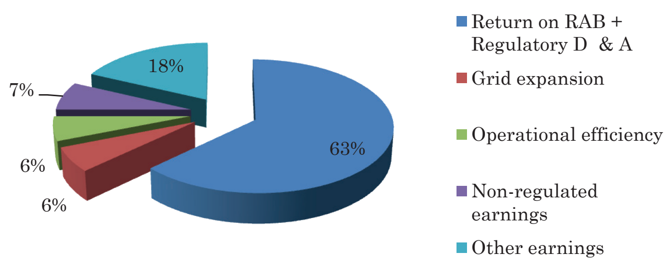


Figure 10. E.ON's Business areas contribute to EBIT in 2015 (%)[20]

The above figure shows that Energy Networks 60% contribute to E.ON Group's EBIT, Customer Solutions 27% contribute to EBIT and Renewables 13% contribute to Group's EBIT. Consequently, Customer Empowerment Strategy and Shaping Markets 40% contribute to E.ON Group's EBIT, in other words 40% E.ON Group's earning form part of new energy world with shapinh customer's expectation and shaping markets by diferentiation strategy. In addition, 37% Energy Networks earnings include additional components which following figure represent:

Figure 11. Additional components contribution to E.ON Energy Networks EBITDA (%) (2015) [20]



The above figure shows that Grid expansion 6% contribute to E.ON Goup's Energy Networks EBITDA, operational effeciency 6%, non–regulated earnings 7% and other earnings contribute to E.ON Goup's Energy Networks EBITDA 18%.

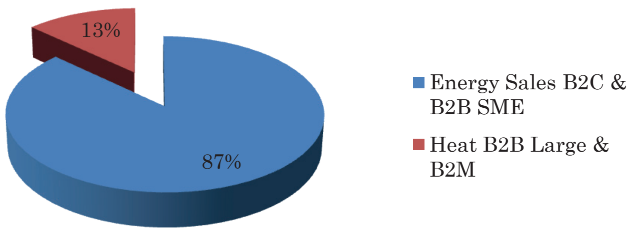


Figure 12. Segments contribution to E.ON Customer Solution EBIT (%) 2015 [20]

The above figure shows that segment Energy Sales 87% contribute to E.ON's Business Area Customer Solutions EBIT, while segment Heat contribution is 13%. Taking in consideratation contribution E.ON's Business Area renewables, comes to a conclusion about significant E.ON Group's earnings in all three bearable pillars of new energy world.

CONCLUSIONS

A large number of energy companies in the world today a faced with global transformative trends which devastatingly affect their business results. Therefore, energy companies in the world were very slow in investing and adopting renewable energy sources and become significantly overcapacitated by coal and gas fired power plants which are now unprofitabile due to low marginal costs of renewables and their priority dispatching into a power system. Also increasing the share of renewable energy sources in the structure of electricity generation, the decline in primary energy prices (fossil fuels) the stagnation of consuption and the surplus of supply in relation to electricity demand caused a drop in wholesale electricity prices by half compared to 2008. Furthemore, the operation of coal fired power plants is burdened with carbon dioxide emissions. As a result, there has been a significant reduction in revenues, falling stock values (for example German's „Big 4" have lost 70 of their market capitalization) and the collapse of credit rating of many energy companies in the world. The crisis has trigered significant reorganization plans and write–offs and an intense search for new business models.

This article analyses E.ON Group's response to global transformative trends in energy market enwironment. As a result of changes in the market environment, the traditional energy value chain is fragmenting into a increasing number of different market segments, one of which is grouped into a new world of energy and other into a conventional world of energy. Consequently, E.ON Group is divided into two very focused and dinamic companies, one of which is focused into a new world of energy and other into a conventional world of energy. New world of energy is based on renewables, decentralized energy generation, customer solutions and smart grids. Conventional world of energy refers to generating power throught large–scale plants on coal and nuclear fuel. New E.ON Group focused into a new world of energy, as a response to global transformative trends in energy market enwironment, implemented Customer Empowerment Strategy and Shaping Markets, in other words using Diferentiation strategy develop new business model innovation in generation power. Consequently, E.ON shapes expectations of customers and design energy market. Now, E.ON Group realize sucessful global diferentiation which which is look at in shaping markets, by empowering customers which become active partners in distributed generation power, at the other words E.ON become lider in new energy world. Other divided company is focused on conventional world of energy and realize Cost Management Strategy to reduce costs and increase competitiveness. The company's separation also involved shortcoming that are reflected in loss of sinergy and economies of scale as well as other costs incurred during the separation. However, E.ON's and Uniper's Board of Management concluded that positive effects of the division will overcome this disadvantage.

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Strategic Role of Oil Pipelines in EU Energy Supply

SUMMARY

The oil pipelines have a strategic importance in the energy supply of the European Union (EU), especially given the fact that in the next two decades the crude oil will continue to be a dominant energy source, accounting for approx. 30% of the primary energy consumption, along with a reduction in the petroleum product consumption and growth in renewables.

Europe has a widespread network of oil pipelines of approx. 22,5 thousand kilometres (without Russia), connecting refineries to import oil ports or to land–based crude oil sources. The refineries of the Central Eastern Europe are supplied mainly from the Druzhba oil pipeline. Recently, these refineries have diversified their crude oil supply routes and sources, by sea imports from the North Sea, the Middle East, Canada and others (Poland) or by the TAL — IKL oil pipelines (Czech Republic) and the JANAF oil pipeline (Hungary, Slovakia and the Czech Republic). Given the insufficient diversification of crude oil supply precisely of the Central Eastern European region, particularly the landlocked countries (and refineries respectively), the EU has envisaged, among the projects of common interests, also six connection oil pipelines with terminals. At the same time, they are the only pipelines planned to be constructed in Europe and financed by the oil companies' funds.

The oil pipeline companies hastily modify their strategies by expanding business and becoming more and more transport–storage–energy oriented, and by investing in the flow reversal of oil pipelines and connection pipelines, storage capacities, as well as in enhancement of efficiency and flexibility of oil pipeline and storage infrastructures.

KEYWORDS

EU energy strategy, security of supply, oil pipelines, JANAF

INTRODUCTION

Our times are characterised by great changes. We are witnessing numerous predictions related to the energy and the energy strategies of the Republic of Croatia, the EU and the worldwide, asking ourselves a reasonable question is this to be a century of abandoning oil?

In the 20th century, oil ceased to be just a "black sludge" and becomes the paradigm of our times, inseparable from politics, economics, geopolitics and similar. An aspiration to rule over oil–rich sources and corridors becomes a fundamental geopolitical and economic force of the modern age.

Today, the oil is still strongly present, with high share in the energy consumption, and along with the powerful multinational giants Exon Mobile, BP, Chevron, Gazprom, Rosneft, ENI, Total, Shell, as significant pillars of the economy. But, "renewable energy is the fastest growing source of energy, contributing half of the growth in global energy supplies and becoming the largest source of power by 2040" [1].

The Republic of Croatia is a part of that global world and has an exceptionally important geostrategic position as Mediterranean and transit country, especially for the oil supply of the countries of South–Eastern and Central Europe.

As part of the European oil pipeline network, JANAF and the Republic of Croatia are an important part of the EU energy policy.

OIL IN ENERGY STRATEGY OF THE EU AND REPUBLIC OF CROATIA TO 2030

Strategic objectives

European Union

An important guideline of energy policies and trends in the energy consumption refers to the issue of climate changes and successfulness of implementation of international agreements, especially the *Agreement to voluntarily limit the greenhouse gas emissions*, signed in Paris in December 2015 (the Paris Agreement) during so–called *Conference of the Parties (COP21)*. The Agreement came into force on 4 November 2016 and was ratified by Croatia on 17 March 2017. The Agreement aims to limit temperature increases below two degrees Celsius compared to pre–industrial levels, compelling future efforts to limit temperature increases to 1,5 degrees. The key long–term goal is to remove, by the middle of this century, the greenhouse gas emission produced by man.

The European Union (EU) is the leader of global climate movement and, in accordance with the agreed goals, has determined the own targets of the 2030 energy policy. Documents such as *A policy framework for climate and energy in the period from 2020 to 2030* [2] and so–called *Winter Package* [3] foresee a 40% cut in greenhouse gas emissions compared to the 1990 levels and at least a 27% share of renewables in the total energy consumption. A preferable target is also an energy efficiency increase of at least 30%. It will affect a further trend of decrease in crude oil and petroleum products consumption and the oil industry activities in general. Therefore, the oil companies have already commenced with the implementation of their diversification strategies in other business activities, especially into the renewables, yet also in other markets with growing energy consumption.

Besides, for the oil industry, especially for an oil pipeline and storage infrastructure, it is essential that the EU strategic documents [4] foresee a long–term security of the energy supply through diversification of supply sources and transit routes, thus taking account of the oil–related security and required production and transportation infrastructure.

In compliance with the strategic energy objectives, the *European Energy Security Strategy* [5] foresees the actual implementing measures, such as, to:

- discuss with industry and the Member States how to diversify crude oil supplies to EU refineries with the aim of reducing dependency on Russia;
- identify EU–wide strategic assets in the oil value chain and coordinated action to ensure that consolidation of the EU's refinery capacity occurs in a manner that improves the EU's energy source diversification;
- propose instruments for implementing the strategic infrastructural priorities that will enable competitiveness, environmental sustainability, as well as supply security.

The EU policy is actually realised through the projects of common interest (PCI) [6], representing one of the methods of establishing nine priority energy corridors and three thematic areas, aimed at the more efficient connection of European energy networks, enhancement of supply security, and especially promotion of competitiveness and development and reduction of energy prices.

In order to speed up a successful implementation of PCIs, the 2013 energy infrastructural package, which also includes the *TEN–E Regulation* [7], specified, inter alia, the following: accelerated permitting procedure, reduction of administration costs for project promotors; possibility of receiving a financial support in accordance with the *Connecting Europe Facility (CEF)* [8]. In accordance with the set regulatory framework, the European Commission adopted the first PCI list of 248 projects. The second PCI list of 195 projects (108 related to electric power supply, 77 to gas, *6 to oil and* 3 to advanced networks) was adopted on 18 November 2015, while the third list was adopted on 23 November 2017.

It needs to be highlighted that PCIs are especially intended to strengthen the oil supply security by *oil pipeline connection projects* in Central Eastern Europe given the fact that certain countries are land–locked without sea access and that they import the oil predominately from one direction, i.e. by the Druzhba oil pipeline from Russian direction. Therefore, the PCIs related to oil pipelines are anticipated only for that region within the priority corridor of the *Oil Supply Connection in Central Eastern Europe* (abbr. OSC). At the same time, they represent the only new pipelines planned to be built in Europe, while the PCI entitled *JANAF–Adria Oil Pipelines* is realised by their promotors, MOL, Transpetrol and JANAF.

A special part of the EU oil supply security is the *system of compulsory stocks* of crude oil, which are intended to be available in cases of emergencies or crisis and to be allocated quickly where needed. The EU Member States need to maintain the compulsory stocks equal to at least 90 days of net oil imports or 61 days of consumption, while during the crisis the European Commission is responsible for organising consultations between the EU Member States on placing stocks on the market, except in a very urgent sitution. [9]

Most of the EU countries have already formed the compulsory stocks, even beyond the minimum levels, among which the least was formed by Lithuania (87–day consumption) and the most by the Netherlands (179–day consumption), (as at 22 January 2013) [10]. According to the information by the Croatian Compulsory Oil Stocks Agency (HANDA), Croatia has "available reserves sufficient for the regular supply of crude oil and petroleum product markets" [11]. JANAF's transportation and storage capacities represent an important part of the compulsory stocks system since the crude oil is stored at the Omišalj and Sisak Terminals, while the petroleum products are stored at the Žitnjak Terminal in Zagreb.

Republic of Croatia

In compliance with European strategic guidelines and obligations defined in the *United Nations Framework Convention on Climate Change* (UNFCCC), *Paris Agreement and similar,* the Republic of Croatia is among the first EU members to prepare a *Proposal of Low–Carbon Development Strategy of the Republic of Croatia by 2030, with a view towards 2050* [12]. The key targets to be achieved until 2030 are the following: to reduce the emissions by 7% in sectors outside the ETS (Energy Trade System) compared to the 2005 emissions and to strive towards more ambitious emission reduction. The figures and goals related to the renewables, energy efficiency, CO2 emissions and sectoral goals are specified for the period until 2030 and 2050 in the document entitled *Analyses and Basis for Energy Strategy of Republic of Croatia, Draft of White Paper* [13].

Having in mind the trends of petroleum product consumption, it is important to look at the supply security from the aspect of enhancement of petroleum product production, especially taking into consideration that the Croatian refineries have access to the crudes coming from numerous sources and directions, i.e. the Mediterranean, the Druzhba oil pipeline and national oil fields, whose production is planned to be increased. Next to the refineries, the capacities for storing the compulsory oil stocks are located (at the JANAF's Terminals at Omišalj, Sisak and Zagreb), which also contributes to the energy supply security.

More concrete strategic directions for the future development of the Croatian oil industry shall be defined in a new Energy Development Strategy, planned to be adopted in 2019. Some of the fundamental goals of the oil sector indicated in the 2009 Strategy [14] and some scientific papers [15],[16] will most probably be defined in a new Strategy. They are primarily related to:

- enhancement of supply security of domestic crude oil and petroleum product markets,
- alignment of energy infrastructure with actual requirements in terms of safety and security and environmental protection,
- enabling technological development of energy activities in the oil sector,
- enhancement of crude oil and petroleum product compulsory stocks system.

New Strategy should recognize a *strategic and economic importance of transit and export potentials of transport and storage of crude oil and petroleum products*, along with better utilisation of competitive advantages of sea position, with the aim of more intensive diversification of routes and sources of crude oil and petroleum product supply for the countries of Central and South–Eastern Europe. Furthermore, in order to enhance the supply security, it is necessary to give a strategic and economic significance to the activities of exploration and production of oil and gas, as well as to the oil refining.

Trends in EU and Croatian oil industries

Petroleum product consumption and import dependency

In the last 15 years, the oil consumption in the *EU Member States (EU28)* has decreased from 660 mil. tons in 2000 to 580 mil. tons in 2015, along with the reduction of share in the total primary energy consumption from 38,2% to 34,8% (Figure 1.), and therefore, a conclusion can be reached that those trends were moderately in decline, which nevertheless had a strong impact on the oil industry.

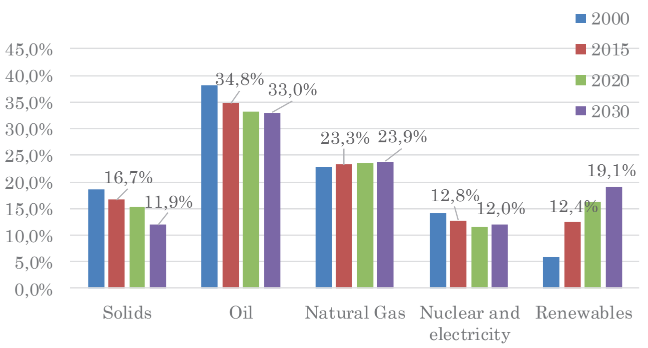

Figure 1. Structure of primary energy consumption of EU28

Source: Calculated based on: European Commission. EU Reference Scenario 2016, Energy, transport and GHG emission, Trends to 2050, European Union., Annex 2, p. 144 [17]

However, a high dependency on imports of crude oil, semi–products and petroleum products of about 96% (Table I.), as a result of decrease of domestic production of crude oil, primarily from the North Sea, and of petroleum products in European refineries, influences the (un)certainty of energy supply to consumers. Thus, one of the strategic directions of the energy policy is to reduce an oil share in the primary energy consumption to significantly lower levels of 33% as predicted by the reference scenario. According to such scenario, a further reduction of oil consumption is foreseen by approx. 67 mil. tons in 2030 compared to 2015, and by 147 mil. tons respectively compared to 2010.

Table I. Oil import dependency EU–28

000 tons EN	2000	2015	2020	2030
Primary energy consumption	1.726.889	1.666.602	1.639.428	1.554.388
Oil consumption	660.025	579.805	545.752	513.151
Oil share in total primary energy consumption	38,2%	34,8%	33,3%	33,0%
Net oil import	532.226	556.140	532.001	513.151
Oil import dependency	80,6%	95,9%	97,5%	100,0%

Source: Calculated based on: European Commission. EU Reference Scenario 2016, Energy, transport and GHG emission, Trends to 2050. European Union, 2016, Annex 2, p. 144 [17]

Croatia consumes 3,7 mil. tons of petroleum products, i.e. approximately the same as in 2010, although with forecasts of a moderate drop to 3,3 mil. tons until 2030. The import dependency related to consumption of crude oil and petroleum products of about 70% (Figure 2.) is more favourable than at the EU level.

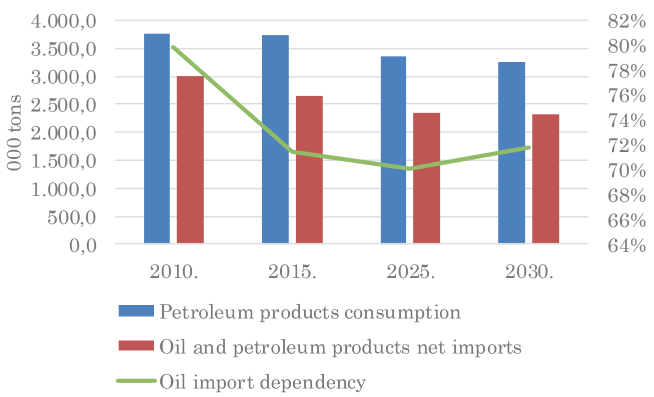

Figure 2. Consumption of petroleum products and import dependency of the Republic of Croatia

Source: Energy Institute Hrvoje Požar (EIHP), "Crude oil and petroleum product market of the users of the JANAF transportation system with estimates of crude oil transport until 2035", Zagreb, October 2016 [18]

How to obtain greater oil supply security?

The security of crude oil supply can be increased through diversification of import routes and sources and through the growth of domestic production of crude oil and its exports being greater than petroleum product imports.

According to the forecasts for EU28, the oil production should amount to only 48,2 mil. tons in 2030, as compared to 70,8 mil. tons in 2016 and 156,6 mil. tons in 2001, [17]. Therefore, the *European Energy Security Strategy* [5] foresees a development of utilising the conventional oil and gas sources in Europe on traditional production fields (e.g. on the North Sea) and newly–discovered fields (e.g. on the Eastern Mediterranean and the Black Sea), entirely in line with the legislation on energy and environment protection. It needs to be pointed out that European oil companies are actively involved in explorations and production of oil and gas in the countries rich in hydrocarbon reserves, although these activities are faced with numerous challenges (e.g. Syria and some countries of the Middle East, North and West Africa and others).

The greatest oil import in Europe in 2016, which amounted to 500 mil. tons, was realised from Russia, i.e. approx. 35,5%, then 12,9% from the West African countries, 12,3% form the Caspian region, 10% from Iraq and others (Figure 3.).

Along with the growing trend of petroleum product import, which amounted to 200 mil. tons, even 44,5% of the same came from Russia, 16,7% from the USA, 6,9% from India, 6,3% from the Saudi Arabia etc.

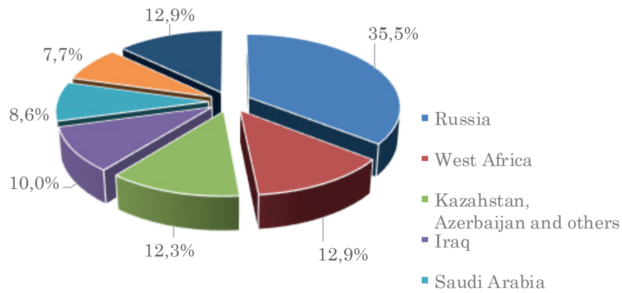

Figure 3. Main oil import routes for Europe

Source: Made based on: BP Statistical Review of World Energy, June 2017 [19]

Given the fact that the import dominance from one route is considered as a fundamental strategic matter of security, the EU policies and activities are directed to the more intensive diversification of supply routes and sources. Namely, about 90% of crude oil is imported into Europe by sea, which gives a desirable flexibility of choices among crude oil sources and directions. Although the transportation costs are changeable, they represent a smaller part of the value as compared to oil, thus enabling an import from distant regions. Most refineries are located on the seaside and thus have direct access to oil through import from the countries of great consumers. The land refineries are supplied by the oil pipelines whose initial points are major ports and/or oil pipelines that are connected to the oil fields on the land.

The refineries of Central Eastern Europe (Poland, Eastern part of Germany, Slovakia, Czech Republic and Hungary) are supplied mainly from the Druzhba oil pipeline. Recently, Polish oil companies have diversified their oil supply, by import from the Middle East countries, Canada, the North Sea and others. To a smaller extent, yet along with the growing trend, Hungarian and Slovakian refineries, since 2013, have been supplied from the Omišalj direction by the JANAF oil pipeline, while the Czech refineries are partially (30%) supplied by TAL pipeline and IKL connection pipeline [20], and there are plans for the transport to be conducted by the JANAF pipeline.

Refineries, predominately supplied from the Druzhba oil pipeline, are vulnerable in case of the supply interruption. Therefore, they need the alternative supply routes that should be provided through some of the following EU oil pipeline projects of common interest [21]:

- Adamowo–Brody pipeline: pipeline connecting Brody (Ukraine) and Adamowo Tank Farm (Poland);
- Bratislava–Schwechat–Pipeline: pipeline linking Schwechat (Austria) and Bratislava (Slovakia);
- JANAF–Adria pipelines: reconstruction, upgrading, maintenance and capacity increase of the existing JANAF and Adria pipelines linking the Croatian Omišalj seaport to the Southern Druzhba (Croatia, Hungary, Slovakia);
- Litvinov (Czech Republic)–Spergau (Germany) pipeline: the extension project of the Druzhba pipeline to the refinery TRM Spergau;
- Cluster Pomeranian pipeline (Poland), including the following PCIs: construction of oil terminal in Gdańsk and Expansion of the Pomeranian pipeline: second line on the Pomeranian pipeline linking Plebanka tank farm (near Płock) and Gdańsk handling terminal;
- TAL Plus: capacity expansion of the TAL pipeline between Trieste (Italy) and Ingolstadt (Germany).

For certain countries (Austria) the PCI Bratislava–Schwechat–Pipeline should represent the second oil supply route through the Druzhba pipeline since at present they realise their imports only through the TAL–AWP oil pipelines from Trieste. Through the realisation of this project, Austria would import less oil by TAL, thus allocating the capacities of this oil pipeline for greater transport for the Czech Republic, yet opening another (3rd) supply route for Slovakian and Hungarian refineries.

At the same time, they represent the only newly planned oil pipelines in Europe. Namely, approx. 22,5 thousand km of oil pipelines run through Europe or approx. 4% of the entire global oil pipeline network [22] and they are mainly 40–55 years old. For comparison, Russia has 80,8 thousand km, and the USA have 240,7 thousand km of oil pipelines.

The implementation of the planned PCI oil pipelines proceeds very slowly, and until now, the only constructed ones are:

Százhalombatta — Šahy (Hungary–Slovakia) oil pipelines and subsea oil pipeline Krk Island–mainland within the project of *JANAF–Adria Pipelines*; and

Gdansk Terminal, 1st phase (375.000 m3 storage tanks for crude oil storing) within the PCI *Cluster Pomeranian pipeline* (Poland).

It is especially important to emphasise that, since 2013, when the project of *JANAF–Adria Pipelines* was adopted on the 1st PCI list, the diversification of supply routes and sources has been realised for Hungarian and Slovakian refineries. It is pointed out that the refineries of these countries in the first years of the 1990s imported up to 4 mil. tons of crude oil. In 2016, the diversification from the sea direction, i.e. Omišalj, amounted to around 12% of the total oil imports, with the trend of growth. By the end of 2016, a *Framework Transportation Agreement* was signed with the Czech Unipetrol. Its realisation provides the Czech refineries with the third oil import route, from Omišalj direction.

Challenges and opportunities and strategic development projects of oil sector, especially as regards oil pipeline and storage activities

The energy and climate policy and trends of oil consumption reducing strongly affect the oil activities. For that reason, the oil companies attempt to find new markets and buyers, improve the range of services and to diversify its activities to the field of storage, but also to the non–oil activities (renewables, electric power supply, petrochemical industry and others), upon which their further development will depend, as well as their existence.

In such process, they will face numerous *challenges, together with opportunities for further development,* such as:

- Global refinery and petrochemical sector outside Europe grows, while new high–technology refinery and petrochemical complexes from the Middle East and Asia expand the imports in Europe. Besides, the import from the USA also grows, considering that the US refineries take the advantages of a significant increase in domestic oil production and construction of oil pipelines and storage capacities over the last years.
- On the global level, further overcapacity of refineries is expected, which implies competition strengthening, new shutdowns (in Europe, 24 refineries since 2007) and others. European refineries are also less complex compared to new Asian refineries and 40 and more years old with a focus on gasoline configuration. The ones, which have competitive advantages based on volumes, locations and complexity, will survive.
- Regulation and local policies of the refining, and the EU oil sector are additionally burdened by the companies' operating expenses (substantially more than in Asian countries and the US), besides their importance in the security of energy supply, to consumers of around 35%.
- Further integration of oil companies is foreseen (with the aim of increasing the competitiveness and responses to ever stronger challenges) through both vertical (along with the petroleum–gas–petrochemical chain) and horizontal integrations.
- Refineries change their business operations management from the refinery driven concept towards supply chain integration, with the refining being more oriented to a combination of crude oil grades taking account of sales of the most profitable products.
- The upstream activities related to oil (and gas as well) are faced, due to the energy and climate policy and the EU legislation, with numerous restrictions affecting a further decrease in the European production, although the domestic production represents one of the key pillars of both the supply security and the import independence. On the other hand, the stimulated production grows in the US and other regions and therefore, the imports of crude oil and petroleum products, in many aspects, contribute to weakening the European oil sector and thus to the economy and its competitiveness. The development of the renewables could not make up for the negative economic effects arisen from the decrease in activities of the oil operations, especially with less developed European states.
- The oil trading companies wish and intend to integrate and/or develop more oil and compatible activities, invest in the development of oil infrastructure in less developed regions, expand the market and locations of crude oil and petroleum product production as well as storage (e.g. JANAF's Omišalj Terminal, Ploče Terminal and others).
- The oil pipeline companies develop new business for their more successful performance offering more and more to oil companies also storage, possibilities of transport of several crude oil grades from a greater number of routes and other services. At the same time, they represent an important part of the supply security system in crisis and emergencies, since they store the compulsory stocks of crude oil and petroleum products.

Having in mind the fact that in the next two decades the considerable crude oil quantities will be consumed and that the oil will remain a dominant energy source, *strategic directions of European oil companies* should, among other things, be related to:

- investments in the capacities modernisation, their maintenance, environmental protection and safety of humans and facilities;
- construction of capacities in the chain from exploration, production, distribution and consumption on new locations, especially in the regions rich in hydrocarbon reserves, in less developed countries with emerging economies and petroleum product markets;
- construction of European connection oil pipelines in accordance with the EU policies and projects of common interest (see point 2.2.2.), yet in other parts of the world as well.

On their way to contributing to a low–carbon economy, oil companies develop projects contributing to the reduction of greenhouse gas emissions, thus ensuring long–term successful business operations and growth [23]. Such activities and projects will be presented in the continuation of the paper, particularly for some major oil companies, like Shell, Exxon Mobile end others, as well as for some medium– sized oil companies in the Central and South Eastern Europe, such as MOL, NIS, etc.

Following new energy climate policies, the activities of *Shell* company are directed to [24]:

- construction of wind power plants in North America and Europe of 1.000 MW capacity, yet also to expanding the operations related to natural gas that will replace the coal in thermal plants;
- investments in biofuels (e.g. JV Raizen in Brazil) and explorations in the second generation of biofuels;
- pilot projects of using LNG in transport;
- development of the first broad network of hydroelectric vehicles in Germany;
- enhancement of technologies of CO2 capture and storage, in which Shell is the leader;
- researches as regards use of traditional oil and gas based fuels in vehicles, along with green and clean technology (Shell Technology Venture);
- reduction of emissions and continued efforts in improvement of energy efficiency.

British Petroleum [25]**,** assisted by a number of institutes, develops a complex, interactive and sustainable programme "Energy Sustainable Challenge", studying and researching the relations between natural sources and the energy supply and demand. The model also comprises the research on the future of biomass to be used at different CO2 emission regimes and technological scenarios, which would give to the policy creators more strategic understanding on bioenergy and its potential influences.

British Petroleum is focused on investments in low–cost and low–carbon biofuels. The biofuels are mixed with the gasoline or diesel without significant engine modifications or major changes to the existing distribution systems. A Brazilian company produces biofuels from sugarcane together with the production of around 640 mil. litres of ethanol and employment of 6.000 people. The sugarcane waste is further used for the electricity production of up to 170 GWh, and in new plant even up to 340 GWh annually.

ExxonMobil [26] contributes to greenhouse gas reduction through the following strategic projects and activities:

- reduction of emissions from its own operations;
- development of the next generation of technologies intended for CO2 separation, compression and underground injection;
- finances and researches related to biofuels;
- advancement of technologies as regards vehicles and fuels, including enhancement of plastic parts and use of hydrogen fuel cell in vehicles and others.

OMV [27] sees the answers to challenges in the future through investing in development and exploration of new energy and technology sources, as well as directly through enhancement of efficiency of energy source utilisation.

With the aim of achieving this goal, the company is focused to creating an appropriate infrastructure for ensuring the mobility of hydrogen as fuel, indirect conversion of electricity into hydrogen and direct conversion of solar energy into hydrogen, then to producing the advanced biofuels for diesel and kerosene substitution, as well as to chemical recycling of plastic waste.

Specifically, it means to:

- create a national network of 400 stations for hydrogen fuel cell filling for electric cars in Germany, until 2023;
- explore and develop the advanced biofuels, such as the use of micro seaweed for competitive production of aviation fuel;
- produce a synthesis gas from CO2 and water, which would represent a renewable energy source, and, at the same time, would be neutral from the emission aspect;
- focus on gas as cleaner fossil energy source for the electricity production, as well as on carbon and water management in order to achieve eco–efficiency along with the reduction of greenhouse gas emissions and efficient water management and use.

KEY ROUTES OF CRUDE OIL SUPPLY, EUROPEAN OIL PIPELINE NETWORK AND JANAF'S STRATEGIC POSITION

The EU holds small oil reserves, only about 0,3% of the global reserves, and low falling production, and therefore it is a major oil importer with 88% dependency of the total consumption (Figure 4.). The overall oil consumption in 2016 amounted to 13,9% [19], of the total global consumption that places the EU on the second place in the world, right after the USA. In Europe, only the Great Britain, Denmark, Norway, Italy and Romania have significant oil production.

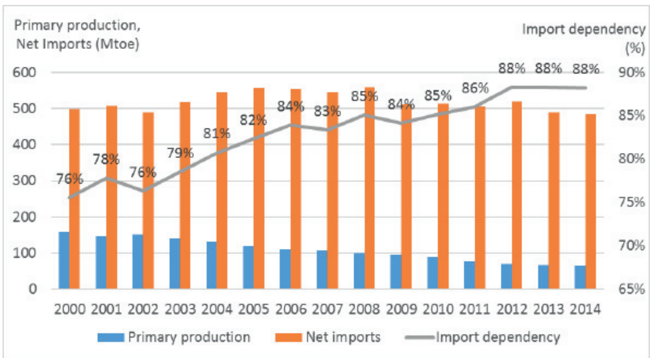

Figure 4. Crude oil production and net imports in Europe (2010–2014)

Source: Cambridge Econometrics: A Study on Oil Dependency in the EU, July 2016 [28]

The main supply routes of oil imports for Europe are: from the Norwegian oil fields, through the Norpipe oil pipeline; from the Middle East countries, Africa, Caspian region, Russia and America by sea to the oil ports on the North Sea and the Mediterranean; and from the Russian direction by the Druzhba pipeline.

Therefore, only Russian and Norwegian crude oil is transported into Europe by oil pipelines (about 20% of the total imports), while the remaining quantities arrive by tankers to the oil terminals and the sea ports like Rotterdam in the Netherlands, Le Havre and Marseille in France, Hamburg in Germany, London and Teesside in England, Trieste in Italy, Omišalj in Croatia, etc. [28].

The main oil pipelines transporting crude oil to Europe and within Europe can be classified into four categories: [29]

- Norwegian oil pipeline, Norpipe,
- Russian oil pipelines,
- Caspian oil pipelines,
- *European oil pipeline network (added by authors).*

Norpipe

Norpipe oil pipeline was constructed in 1975, after the discovery of oil fields in the North Sea in the 1960s. Its starting point is in the territorial water of the Norwegian Sea, and through the British Sea arrives at the Teesside Port in England, having the length of 354 kilometres (km). The pipeline transports crude oil from the Norwegian oil fields of Ekofisk, Eldfisk, Embla, Tor, Valhalla, Hod, Ule Gyda and Tamber, as well as from several British oil fields. The pipeline capacity used to be 45 million tons (MT), and today is reduced to 39 MT.

Druzhba pipeline

Druzhba represents the major supply oil pipeline for Europe, and it is the largest among the Russian oil pipelines (Figure 5), forking into the North and South branch, having the total capacity of 64 MT. With its length of approx. 5.100 km, it is considered the world longest oil pipeline.

Figure 5. Druzhba Pipeline, Baltic Pipeline Systems 1 and 2 [30]

The initial pipeline point is Tatarstan in Russia, where the crude oil is collected from the Western Siberian oil fields, the Urals and the Caspian lake, and it proceeds to Mozyr in Belarus, where it forks into the North and South branch. The current flowrate through Mozyr in Belarus amounts to approx. 64 MT [31]. The North branch runs through Belarus and Poland, supplying the Plock refinery in Poland and the Schwedt and Leuna refineries in Germany. In Germany, the Druzhba pipeline is connected to the Rostok Port by means of the MVL pipeline. In Poland, the North branch is connected, by means of the Plock–Gdansk oil pipeline, to the Polish oil terminal in Gdansk. The pipeline south branch forks into Druzhba 1, extending to Bratislava in Slovakia and Prague in the Czech Republic, and Druzhba 2, extending to Szazhalombatta with a possibility of supplying Hungary directly, as well as Croatia, Bosnia and Herzegovina and Serbia by means of the JANAF pipeline. Druzhba 1 and Druzhba 2 are interconnected through the oil pipeline between Šahy in Slovakia and Szazhalombatta in Hungary.

Baltic Pipeline System 1 (BPS–1)

Another major oil pipeline system is the Baltic pipeline, transporting the crude oil from Russian oil districts in the Western Siberia and Tyumen–Pechora in the west direction to the newly constructed port of Primorsk on the Baltic Sea, having the export capacity of 76,5 MT (Figure 5.). BPS provides Russia with a direct access to the North European markets, thus reducing the dependency on routes extending through the Baltic countries, Belarus and Poland.

Baltic Pipeline System 2 (BPS–2)

The second route of the Baltic pipeline connects Unecha and the Baltic port of Ust–Luga. BPS–2 (Figure 5.) has the total designed capacity of 30 MT, amounting to 36 MT with the capacity expansion made in 2017. Thus, Russia is enabled to supply the crude oil directly to the users in Poland and Germany, without being dependent on transit states. It is important to emphasise two issues regarding the Baltic oil pipelines — ports frozen even up to two months per year and price difference as regards the crude oil supply, compared to the Druzhba, of about USD 3 per barrel. Nevertheless, Russia sees it as minor problem compared to what it has gained by the Baltic pipeline system.

Caspian Pipeline Consortium (CPC)

The CPC pipeline is 1.511 km long and transports the Caspian crude from the Tengiz and Karachaganak fields, as well as from new huge offshore field of Kasaghan (light crude of high quality) to the Black Sea port of Novorossiysk on the Russian coast (Figure 6.). It represents the main export route for the Kazakh crude, and in 2018, the capacities were increased from 28 MT to 67 MT. By the end of 2018, 5.400 tankers were loaded and 580 MT of crude oil was transported, while only in 2018 the transport reached 55 MT [32]. The CPC pipeline is the only oil pipeline that runs through the Russian territory, and that is not in the majority ownership of Transneft, company which is the operator of the Russian oil pipeline system, but it is 24%–owned by the Russian Federation. Other owners include: Kazakh national company KazMunaiGaz, Chevron CPC, LUKARCO B.V., Mobil CPC, Rosneft–Shell, and others.

Figure 6. Caspian pipelines [33]

Baku–Tbilisi–Ceyhan (BTC)

The BTC oil pipeline transports crude oil from the Azeri–Chirag–Deepwater Gunashli (ACG) field and the condensates from the Shah Deniz field, through Azerbaijan, Georgia and Turkey to the Port of Ceyhan on the Mediterranean. The oil pipeline transports both Turkmen and Kazakh crude. It was constructed in 2006. It has the total length of 1.768 km. Upon expansion made in 2009, and by use of DRA (drag reducing agents), the pipeline capacity amounts to 60 MT. By the end of 2018, BTC has transported around 417 MT of crude oil, while in the Port of Ceyhan 4.085 tankers were reloaded [34].

European oil pipeline network

The oil entry points to the EU Member States on the land part are located on few locations: Teesside in the United Kingdom, Adamowo (Polish–Belarusian border), Budkovce (Slovakian–Ukrainian border), Fenyestlikte (Hungarian–Ukrainian border). Thus, three of four oil pipeline entries on the EU territory continue to the Druzhba pipeline (Figure 7. and Table II.).

Figure 7. European oil pipeline network

Table II. Major European oil pipelines

Oil pipelines	From - to	Year of construction	Length (KM)	Capacity (MT)	Transport in 2016 (MT)
TAL	Trieste-Karlsruhe	1967	754	54	41,4
AWP	I/A border-Swechat	1967	420	11	8,1
SPSE	Fos sur Mar (Marseille)-Karlsruhe	1962	769	36	22,0
MOL	U/H border - H/Cro border	1963	848	23	7,0
NWO	Wilhelmshaven-Koln	1958	391	15,5	18,1
NDO	Wilhelmshaven-Hamburg	1983	144	11,5	4,8
MVL	Plock-Spergau	1963	365	22,5	21,8
TRANSNAFTA	Sotin-Pančevo	1979	154	6	2,9
RRP	Rotterdam-Wesseling	1960	323	22	16,0
MERO (Družba, IKL)	S/Cz border - Litvinov	1965, IKL 1996	505, IKL 170	9, IKL 11,5	9,0
TRANSPETROL	H/S border - S/Cz border	1962	1.032	20	11,0
JANAF	Omišalj - Sotin - Gola	1979	631	24	7,2

Source: Energy Data Base, JANAF

Note: I–Italy, A–Austria, U–Ukraine, H–Hungary, S–Slovakia, Cz–Czech Republic, Cro–Croatia

NWO is the first major European pipeline, constructed in 1958. The pipeline capacity amounts to 22 MT, having the diameter of 71 cm and the length of 391 km. It supplies four refineries in Germany and in 2016 its transportation quantities amounted to 18,1 MT. In total, the pipeline transported one billion tons of crude oil, and 19.000 tankers were reloaded. It accounts for 20% of the share of the total German supply.

Soon after NOW, the *Rotterdam–Rhine Pipeline (RRP)* was constructed, with the diameter of 60 cm, and the length of 300 km. Then, the pipeline has been extended by 150 km up to the area around Frankfurt. Today, the pipeline length is 479 km and it connects Rotterdam and the German district of Ruhr, while its maximum capacity is 16 MT.

South European Pipeline (SPSE)

SPSE was put into operation back in 1962. It connects Lavera (French port), through Strasbourg, to Karlsruhe (Germany). It is 782 km long, with the diameter of 86 cm and the maximum capacity of 36 MT. The greatest crude oil transport amounted to 43 MT (in 1973). The present transportation level reaches about 23 MT of crude oil annually. Afterwards, in Karlsruhe, the pipeline connects to the Rhine–Danube Pipeline (RDO), it is 280 km long and connects the Karlsruhe and Ingolstadt refineries.

Trans Alpine pipeline (TAL)

The Transalpine Pipeline (TAL) connects the Port of Trieste in Italy with Ingolstadt in Germany, and on its route, it supplies with crude oil five refineries in Austria and Southern Germany. TAL transports crude oil for the Schwechat Refinery (OMV) in Austria, by means of the AWP connection pipeline, then for Bayernoil refineries of Vohburg and Neustadt, MIRO refinery of Karlsruhe, Esso refinery of Ingolstadt and OMV refinery of Burghausen (by the OMV pipeline) in Germany, and further through the Czech IKL connection pipeline supplies the Czech refineries of Kralupy and Litvinov, near Prague. In 2016, the transport by TAL amounted to 41,4 MT, while the number of tankers unloaded in the Port of Trieste reached 499. [35] The pipeline length amounts to 754 km, while its tank farm storage capacity in Trieste amounts to 2.033.000 m3 and in Ingolstadt to 350.000 m3.

MERO pipeline

The Czech Republic has two refineries, Kralupy and Litvínov. The Litvinov Refinery is supplied by crude oil from Russia and is designed for refining the crude oil of REB grade. The Kralupy Refinery refines mostly the low–sulphur crudes supplied from the Middle East and other sources, and delivered by the TAL and IKL pipelines [28]. The Czech section of Druzhba (South Druzhba) has a capacity of 9 MT, while the other oil pipeline route, Ingolstadt–Kralupy–Litvínov pipeline (IKL), which takes the crude oil from TAL, has a capacity of 11,5 MT/annually. The IKL pipeline was constructed in 1996, as an alternative to the Druzhba pipeline [36]. The operator of both pipelines is the Czech national oil transportation company MERO.

Transpetrol pipeline

Transpetrol is the operator of the 1.032 km long oil pipeline, in Slovakia, which supplies the Bratislava Refinery and serves for transit towards the Czech refineries in Kralupy and Litvinov. The main supply pipeline of the refinery is a part of Druzhba, and on the Slovakian territory, is almost completely reversible. Its capacity is 20 MT/annually, and currently, more than half of capacity is used for the supply of Slovakian and Czech refineries. The other crude oil supply route comes from the Omišalj direction, by the Croatian JANAF pipeline, the Hungarian Adria pipeline and the Šahy–Szazhalombatta pipeline (Slovakian–Hungarian pipeline).

MOL pipeline

The pipeline is 848 km long, and its total capacity amounts to 23 MT. The pipeline system is operated by the Hungarian oil company MOL [37]. It is connected to other pipelines in the surrounding region on three points and can be supplied by crude oil from two directions (Druzhba and JANAF/ Omišalj). It supplies the refineries in Hungary and also serves for crude oil transit towards Slovakia and the Czech Republic. All crude transported by the Druzhba pipeline is of Russian origin, while the Adria branch, coming from the JANAF direction, transports the crudes from Africa, Iraq, Kazakhstan and others. At the same time, that route is of strategic importance since it enables the diversification of sources and security of supply, as well as higher refining profitability. In February 2015, MOL and Slovakian Transpetrol have, by constructing a new pipeline, expanded the capacity of the Szazhalombatta — Šahy pipeline section from 3,5 MT to 6 MT, which should contribute to substantially higher security of supply by the import of greater crude oil quantities from the Omišalj direction.

JANAF pipeline and its strategic importance in crude oil supply of South Eastern and Central Europe

JANAF has been a significant storage pipeline with storage capacities for crude oil supply of the South Eastern and Central European countries for almost forty years now (since 1979). For foreign refineries, it transports about 65% of the total oil quantities, with a growing trend. The crude oil is transported for six (6) countries and nine (9) refineries in Croatia, Bosnia and Herzegovina, Serbia, Hungary, Slovakia and soon also in the Czech Republic (Figure 8.). It is a respectable market of around 30 mil. tons of petroleum product consumption.

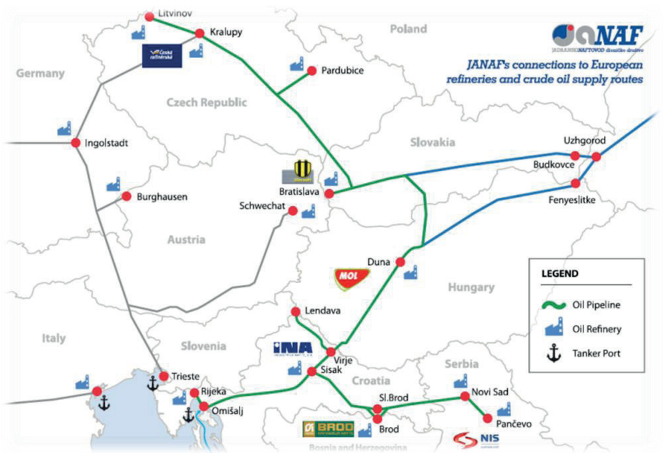

Figure 8. JANAF's connection to global oil sources and European oil pipeline network

The initial point of the oil pipeline system is on the coastal Terminal and Port of Omišalj, located on the island of Krk on the North Adriatic. The pipeline runs through the entire Croatian territory in the length of 631 km. The storage capacities are also located throughout Croatia on four locations — Omišalj, Sisak, Virje and Zagreb. Nowadays (at the beginning of 2019) JANAF has 1,94 mil. m3 of storage tanks available for crude oil storage and 222.000 m3 storage tanks available for petroleum product storage. The storage tanks are, to the largest part, located on the Omišalj Terminal, which represents a strategic part of the Mediterranean oil market. In the last five years, the crude oil and petroleum products storage capacities doubled. Thus, one of the strategically important goals has been achieved, namely the diversification of business operations towards storage, which today accounts for approx. 40% of the company's operating revenues. The crude oil is stored at the Omišalj Terminal by major international oil companies, such as Vitol, Glencore, MOL, and soon also by other companies.

The successful achievement and implementation of the development and business strategy is enabled owing to the enhancement of the environmental protection and security of transport and storage, by investing into modernisation of the oil pipeline and storage system (new SCADA system, electric power supply system, and others), pipeline rehabilitation, storage tanks repairs and overhauls, and others.

In accordance with the objectives of the EU and Croatian energy policies, JANAF has a special importance as regards the enhancement of the security of crude oil supply. The EU has recognised precisely that strategic role of the JANAF pipeline through the project of common interest (PCI), *JANAF–Adria Pipelines,* whose aim is to diversify the supply routes and sources, through the crude oil import precisely from the Omišalj direction.

In that respect, the encouraging results have been achieved, and thus, since 2013, the oil transportation has been restored again for Hungarian and Slovakian refineries, and the same is also expected for the Czech refineries. At the same time, they represent the markets on which JANAF can increase the market share and where there are possibilities of further growth for oil transportation. The possibilities of the transportation growth are also observed with the refineries in Croatia, Bosnia and Herzegovina and Serbia, given the fact that these countries foresee an above–average growth of the economy and living standard.

The *subsea pipeline Krk island–mainland* that recently has been put into regular operation (August 2017) and that replaced the crude oil transport conducted in the last 38 years through the Krk bridge, will contribute to the supply and transport security.

It is important to emphasise that the recent construction of facilities for improving the operations and capacity utilization at the Omišalj Terminal, as well as of the storage tanks, has created new business and development opportunities for JANAF, local communities and the Republic of Croatia. Thus, Omišalj obtains the brand of the *Adriatic Centre for storage of crude oil and petroleum products* with storage capacities for crude oil of 1,4 mil. m3 and for petroleum products of 80.000 m3.

In order to respond to ever greater challenges, JANAF intensively cooperates with oil companies and is headed towards the development of new services (bio–fuels and additives adding, crude oil blending, and others) in order for the oil companies to be able to import crude oil from the Omišalj direction, to process several crude oil grades and to conduct their business operation more successfully.

Moreover, JANAF considers a possibility of gradual transition into more complex company, which implies a potential development of projects related to renewables (solar, etc.) yet also of projects related to the local community, with the aim of the company's further growth, as well as its contribution to realization of the policies related to the climate and low–carbon economic development, and especially to enhancing the security of the energy supply.

MAJOR PLAYERS IN EUROPEAN OIL SUPPLY

The business operation and development of the European oil industry are conducted within the framework and under the influence of major oil companies, to mention just a few: Royal Duch Shell, British Petroleum, Total, Rosneft, Lukoil, ENI, Glencore, Vitol, Trafigura and others. In the Central Eastern Europe, the largest oil and gas companies that are in the process of globalisation and growing (spreading their businesses on the new markets, buying new companies, entering into new non–oil activities) are OMW, PKN Orlen and MOL. (Tables III. and IV.).

Table III. Revenues of some of the major integrated oil companies in the 2014–2016 period (in mil. USD)

	2014	2015	2016
Shell	421.105	264.960	233.591
British Petroleum	214.730	145.890	135.630
Total	212.018	143.421	127.925
Rosneft	95.679	89.541	86.724
Lukoil	122.800	85.360	71.160
ENI	98.218	72.286	55.762

Table IV. Revenues of some of the major European trading oil companies in the 2014–2016 (in mil. USD)

	2014	2015	2016
Glencore	221.073	170.497	152.948
Vitol	270.000	168.000	152.000
Trafigura	126.200	97.200	98.100

Royal Dutch Shell [24] is an Anglo–Dutch multinational oil company, established in 1907, by merging Royal Dutch and Shell Transport & Trading. Shell is a vertically integrated company with the activities in almost all areas of the oil and gas industry. It operates in over 70 countries worldwide and employs around 90.000 employees. Royal Dutch Shell produces 3,7 million barrels of crude oil per day and sells 57,1 million tons of liquefied natural gas per year. In 2016, its revenues amounted to USD 233,6 billion.

With the crude oil discovery in Persia back in 1908, begins a story of one of the most significant companies in the world — *British Petroleum* [25]. Until 1954, the company was called Anglo Indian Company, when it changed the name to BP. Its registered office is in London, it operates in over 70 countries and employs around 75.000 employees. Its 2016 revenues amounted to USD 135,6 billion. The company produces 3,3 million barrels of crude oil per day.

Total [38] was founded after the First World War, when the French Prime–Minister, Raymond Poincaré refused to form a partnership with Royal Dutch Shell. Total was founded back in 1924, under the name of Compagnie française des pétroles (CFP). At that time, the company's primary activity was the oil production in the Middle East. The successful management of the company over the last 100 years has resulted in Total being the fourth largest producer of oil and gas, operating in over 130 countries. It employs around 100.000 employees and is a leading company in the liquefied petroleum gas industry. The company has 16.400 filling stations and 4 million clients daily.

Rosneft [39] is a major Russian oil company with its registered office in Moscow. It was founded in 1993, as cartel composed of several hundred smaller companies and organisations that operated in the former Soviet Union. At the beginning of 2001, with the economic growth, the company's growth and successful performance were achieved owing to the accepted strategy that enabled the development of geological explorations, an increase of hydrocarbon production, development of refining capacities and entry on new markets. In 2016, the company produced 210 MT of crude oil, condensates and gas, and has over 2.962 filling stations and 18 refineries, of which 13 are located in Russia.

ENI [40] is an Italian oil company of global characteristics, operating in 71 states and employing 33.000 employees. E. Mattei founded the company in 1953, in order to make it an international one. With growing hydrocarbon production, the record production of 1,82 million barrels per day was achieved in 2018. ENI owns the refineries in Italy and Germany, whether they are 100%–owned or partially owned by ENI. They are the first in the world to convert the refinery (in Venice) into a biorefinery, and they plan to do the same with the refinery in Sicily.

Lukoil [41] is also a vertically integrated oil and gas company, whose production accounts for more than 2% of the entire global oil production and for 1% of hydrocarbon production. The company was founded in 1991 and since then, it has become one of the strongest players in both Russian and European markets. Lukoil produces 1,3 million barrels of crude oil per day and has 5.390 filling stations. The company's registered office is in Moscow, and it employs over 100.000 employees.

Glencore [42] is an Anglo–Swiss multinational company founded in 1974, whose activity relates to the trading of crude oil and petroleum products, as well as other commodities. At the same time, Glencore is the largest Swiss company and major world trader. It employs around 150.000 employees in over 50 countries worldwide.

Vitol Group [43] was founded back in 1966. The company is a major independent energy trader, with revenues amounting to USD 153 billion in 2016. The company controls 250 supertankers and other vessels that transport up to 350 million tons of crude oil annually. It employs more than 5.000 employees worldwide.

Trafigura [44] is also among the leading global companies for commodity trade. It was founded in 1993, having its registered office in Switzerland. In 2016, the company's revenues are realised in the amount of USD 98,1 billion. The company employs more than 4.000 employees.

The company which is also relevant for European oil supply is *Transneft* [45] an operator of the majority of the oil pipeline system of the Russian Federation. It was founded in 1993. It transports about 90% of crude oil and 30% of petroleum products produced in Russia, by the oil pipeline which is approx. 70.000 kilometre long. The company's revenues in 2016 amounted to USD 12,6 billion.

Among major global oil and gas companies in Central Eastern Europe, the following ones need to be mentioned, *OMV*, *PKN Orlen and MOL Group*.

OMV [27] is an Austrian global oil–gas–petrochemical company with the total revenues of USD 22,8 billion, employing 22.544 employees in 2016 and operating in 30 states. It was founded in 1956. Its significant complex refinery capacities (17,8 MT) are located in Austria, Romania and Germany. Moreover, it operates the network of 2.000 filling stations in 10 countries. It produces 311 thousand barrels of oil equivalent per day, of which 90% in the EU Member States.

PKN Orlen [46] is a Polish integrated oil–gas–petrochemical company with 22.000 employees and USD 21,7 billion of revenues realised in 2016. It owns the refineries in Poland (Plock), Lithuania and the Czech Republic (Kralupy and Litvinov), 2.679 filling stations (Poland, Czech Republic, Germany, Lithuania). It has access to the Druzhba pipeline and the ports of Butinge and Gdansk. The company performs the activities of oil and gas exploration and production in Poland and Canada, as well as in Germany. It produces 32,4 MT of petroleum products and 5,4 MT of petrochemical products.

MOL Group [37] is a Hungarian integrated oil and gas company. MOL was founded in 1991. It operates in more than 30 countries and employs 25.000 employees. Its total revenues amounted to USD 12,6 billion in 2016. It produces around 112 thousand barrels of oil equivalent per day. MOL Group has, within its structure, also the refineries in Hungary and Slovakia (complex and competitive) and in Croatia, as well as in Italy (distribution centre) that produce up to 417.000 barrels of petroleum products per day. MOL Group manages over 1.600 filling stations located in 10 countries Europe wide.

It is significant for all oil and gas companies that they intensively diversify their business operations to non–oil activities, mainly to renewables, electric power supply, automotive industry, petrochemical industry and others. Furthermore, owing to the energy efficiency programmes, technical and technological advancements and similar, they reduce the CO2 emissions and contribute to the realisation of the climate change policies.

CONCLUSIONS

The entire resources of the planet that we live are limited. Thus, the question of finding the alternatives imposes by itself. In the modern world, there is a constant struggle for control over the oil and gas reserves. Just to mention that 2/3 of oil reserves and 1/3 of natural gas reserves are found on the Middle East.

A dominant question of major forces concerns the preservation of influence in these areas. In such global relations, the Republic of Croatia holds a geostrategic position as a Mediterranean and transit country. Thus, the efforts are undertaken to successfully respond to numerous challenges related to providing the sources of the Croatian economy growth. Therefore, the development of oil and storage activities is essential, as well as the establishment of strategic partnerships in oil sector together with the more efficient use of infrastructure and corridors.

The European oil pipeline network was constructed in the 1960s, except for the JANAF and IKL pipelines that were constructed afterwards. The oil pipelines are generally considered as the most cost–efficient and the safest mode of crude oil transport, with a high–reliability level and low maintenance costs. With reference to consumption trends of oil and other energy sources, as well as realized and expected technical and technological achievements, especially in the field of energy efficiency and renewable energy sources, transportation and similar, but also to the oil and gas industry, it is obvious that the pipeline transportation of oil will be used in the decades to come.

The oil pipelines represent the fundamental energy infrastructural facilities of the energy supply security of the EU and the Republic of Croatia. They link the refineries with the import oil ports and land oil sources. Therefore, through the EU legislation and actual projects, the construction of six (6) connection oil pipelines with terminals as the EU projects of common interest, is encouraged and anticipated. Until now, only JANAF, MOL and Transpetrol as project promoters have independently realized the common project entitled *JANAF–Adria Pipelines*, aimed at crude oil supply from the Omišalj direction in the Central Eastern European countries, which today dominately import the crude oil from one direction, i.e. the Druzhba pipeline and Russia respectively. PCI pipelines are, at the same time, the only new oil pipelines planned to be built in Europe as opposed to, for instance, the USA, Canada, Russia, China, etc. In this respect, JANAF plays an important role, since it provides, to the countries of Central and South Eastern Europe, a possibility of crude oil imports from the Omišalj direction, and thus from numerous routes and sources, and from the Druzhba pipeline as well.

Given the fact that until 2030, a significant share of crude oil is foreseen of 30% in the primary energy consumption, the oil pipeline and storage companies, as well as other oil companies, have a social responsibility as regards the oil supply security, which can be achieved only by investments into modernizations, reconstruction and upgrades of the existing capacities, yet also into new operating activities and markets, in order to achieve further companies growth and ensure funds for maintaining the facilities in the circumstances of reduced oil activities.

The oil and gas companies intensively diversify their business operations to non–oil activities, mainly to the renewables, electric power supply, automotive industry, petrochemical industry and others. Furthermore, owing to the energy efficiency programmes, technical and technological advancements and similar, they reduce the CO2 emissions and contribute to the realisation of the climate change policies.

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Neutral Point Connections in Mv Power Networks With Grounding Zigzag Transformers — Analysis And Simulations

SUMMARY

Treatment of transformer neutral point in middle–voltage (MV) networks become an important issue with increasing proportion of MV cables in power networks. As consequence, overall capacitance of MV network is increased and moreover earth fault currents magnitudes. In MV networks with feeding transformer winding in delta connection (isolated networks), that earth fault current increase requires forming of artificial ground point — a neutral connection point on a three–phase ungrounded power system. Grounding transformer use, in zigzag or delty–wye connection, is common, well–known solution for constructing neutral connection in power systems. Physical characteristics of grounding transformers, protection principles, short–circuit calculations with symmetrical components and simulation techniques are presented in this paper. Characteristical operational modalities of MV power networks are also revieved on practical examples.

KEYWORDS

Neutral point, grounding transformer, earthfault, simulation, PSCAD

INTRODUCTION

Depends on neutral point treatment of feeding transformer in MV networks (isolated, grounded, grounded with resistance or petersen coil), fault with ground means earth fault or one–phase short circuit [1]. Basic criterion for transformer neutral point grounding is magnitude of capacitive earth fault current. Boundary values of earth fault currents [2] are (until quoted values arc fault can extinguish without relay tripping of faulted feeder):

Ic = 20 A (Un = 10 kV)
Ic = 15 A (Un = 20 kV)
Ic = 10 A (Un = 35 kV)

If capacitive earth fault magnitudes exceed this values, establishing a neutral connection point is necessary. In practice, change of neutral point treatment of feeding transformer leads to common problem with grounding resistance of neighbouring substations in means of allowed touch and step voltages. Magnitudes of earth fault currents are determined with capacitances of MV power network, i.e. with length of MV cables in the power network.

Criterions for neutral point treatment of feeding transformer are:

- magnitude of capacitive earth fault currents
- voltage level
- magnitudes of inner overvoltages
- relay protection efficiency and selectivity
- possibility of decreasing equipment isolating level

- conditions of earthing components in power network
- specific soil resistance
- reliability of supply

If feeding transformer winding is delta connected, neutral connection point i.e. artificial neutral — is constructed with grounding transformers usually in zigzag connection. Such grounding point is usually carried out in combination with earthing resistor as short–circuit limiter. Advantages in such operation modality of MV power networks are:

- Limiting of inner overvoltages
- Elimination of intermitent earth faults
- Limitation of 3rd harmonics of magnetic flux in earthing transformers
- Efficient work of relay protections for single phase earth faults

Fault elimination is facilitated in MV network with neutral connection point but bigger magnitudes of earth faults (single phase short circuits) causes danger potentials and unallowable touch and step voltages in substations.

GROUNDING TRANSFORMERS FOR NEUTRAL CONNECTIONS IN MV POWER NETWORKS

Earthing transformer construction

A grounding transformer is usually zig–zag transformer without secondary winding, used for establishing a neutral connection to the ground in a three phase ungrounded power systems [1]. Earthing transformer for neutral connection is positioned near the power feeding transformer in the substation, directly connected on MV busbars. Usually, grounding transformer is builted in zigzag connection. Basic principle of connecting earthing transformer in substations is presented on Figure 1.

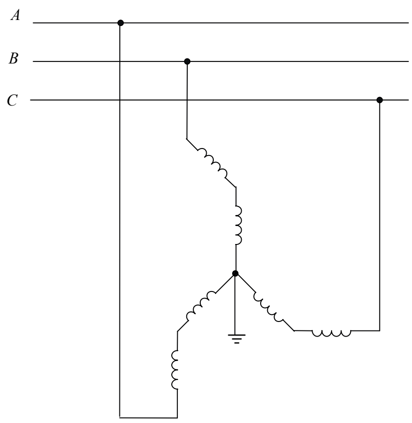


Figure 1: Principle of zigzag earthing transformer connection

Earthing transformer construction and winding connections should ensure following properties: small impedance in steady state (without faults in power network or big load impedance asymmetries) when small magnetising currents flows through the windings. When ground fault occurs in power network, grounding transfomer impedance should be small in order to easily conduct fault current into the ground. Every phase turn consist of two parts in which phase shifted voltages are induced. Six equal half–windings are spooled on three limbs such that every winding spans on different limb with half–windings spooled in opposite direction (Figure 2). Thus, amperturns in phase half–windings are mutually balanced and earthing transformer divide single–phase fault current on three equal components. These currents are equal, not just on magnitudes, but in phase angles [1]. Spooling and construction of earthing transformers are outlined on Figure 2. Connections of half–phases tends to cancel currents of 3rd harmonics — practicaly there is not 3rd harmonics of magnetic flux. Flux can be closed between zigzag turns with big magnetic resistance and considerable amount of ampere–turns would be nedeed i.e. magnetizing primary current must have big magnitude.

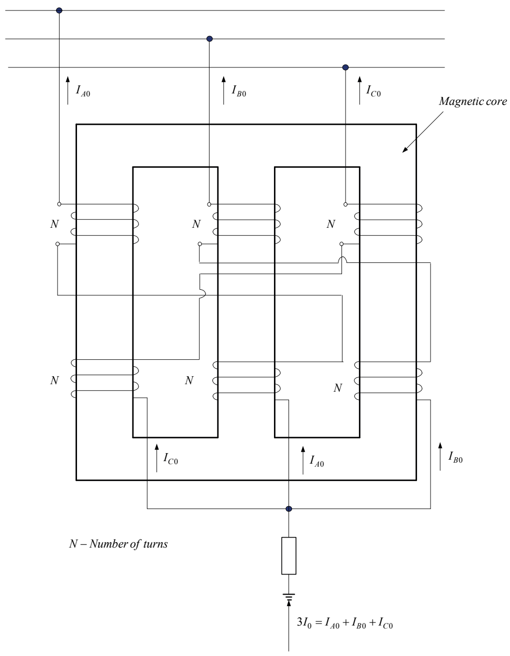


Figure 2: Winding connections of the zigzag grounding transformer

After grounding transformer installation, single phase to ground fault in power system means one–phase short circuit. In order to limit short–circuit currents a grounding resistor usually is connected on neutral leads of grounding transformer. Resistor limits fault currents up to 400 A [1], in praxis most often up to 300 A. Single phase to ground short–circuit distribution inside the grounding transformer is outlined on Figure 3.

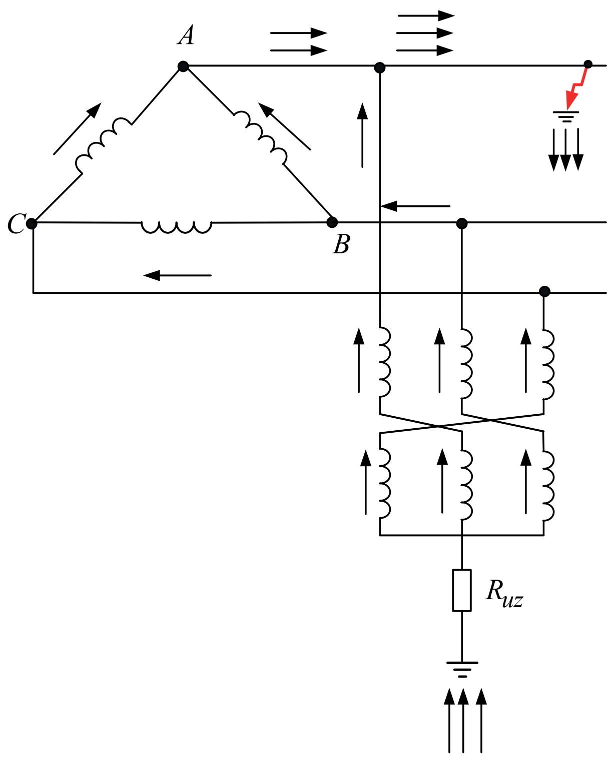


Figure 3: SLG short–circuit distribution inside the grounding transformer

Evidently from Figure 3 is that overall fault current flows through earthing resistor *R*. Fault current divides in manner that one third of fault current flows through every winding of earthing transformer. Characteristic for SLG faults in power networks with grounding transformers for ground path connection is that two thirds of fault current flows through one phase while remain flows through other phases.

Protection of the Grounding transformers for artifficial neutral connection in substations

Grounding transformer for neutral point connection is installed usually in vicinity of feeding transformers in substations. Consequently, overall configuration is protected with differential protection (Figure 4). Depend of speciffic applications, current transformer is added with earthing resistor with independent overcurrent protection. In protection parametring fault current distribution should be considered as presented on Figure 3. Protection principle of characteristic feeding transformer 110/2x10.5/36.75 kV, 20 MVA, YNyn0d5 is outlined on Figure 5.

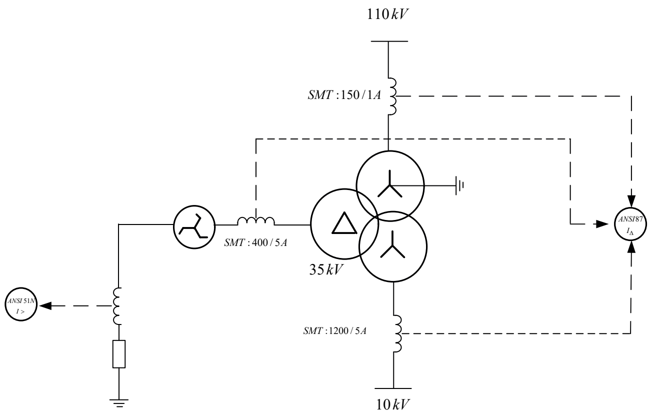


Figure 4: Protection principle of characteristic feeding transformer

Fault currents have much bigger magnitudes then earth fault currents in unearthed networks and overcurrent protections efficient trips the circuit breakers in small time intervals — in order of magnitudes of short circuits. That is safer operational mode of power MV networks, especially from from the point of operational personell safety with consideration of equations for calculation of allowed step and touch voltages in substations [4].

Short circuit calculations with symmetrical components in power networks with earthing transformers

For the analysis with symmetrical components of MV power networks with grounding transfomers, sequence networks should be determined along with calculations of impedances of network elements. Construction of symmetrical components networks will be illustrated on MV power network configuration presented on Figure 5, with SLG fault on 35 kV busbars.

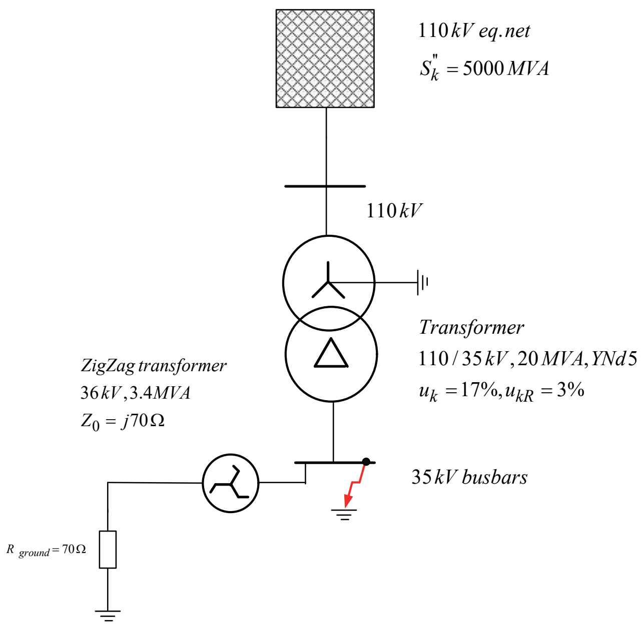


Figure 5: Typical MV power network with zigzag grounding transformer for example of short–circuit calculation with symmetrical components

Configuration for neutral connection of ungrounded MV network consist of grounding transformer with resistor for limiting short circuit currents and allows flow of SLG fault current to the ground. Consequently, equivalent zero sequence network of grounding transformer with resistor have connections as presented on Figure 6.

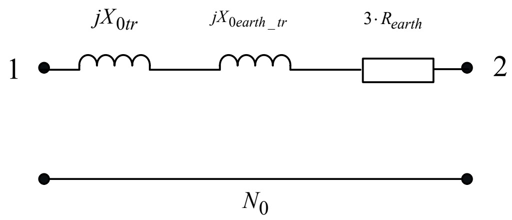


Figure 6: Zero sequence connection of grounding transformer in combination with short circuit limiting resistor

Considering Figure 6 schematic, connection of direct, inverse and zero sequence networks for SLG calculation for MV power network from Figure 5 is outlined on Figure 7:

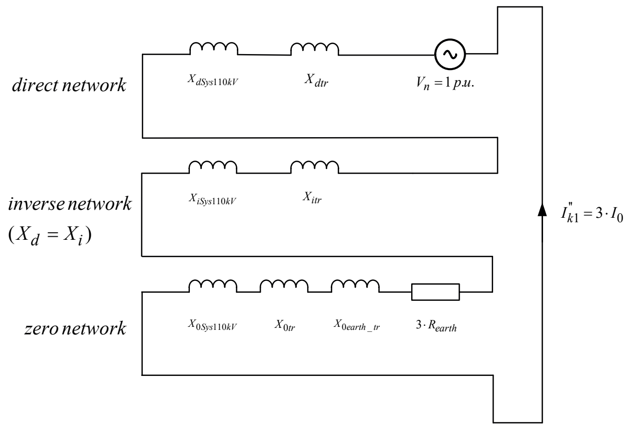


Figure 7: Connection of direct, inverse and zero sequence networks for SLG calculation for MV power network from Figure 5

According to the Figure 7, short circuit current calculation is carried out for MV power network from Figure 5. Impedances of network elements are determined and calculations are performed according to the IEC 60909 standard [7]:

Active 110 kV power network:

$$Z''_{110kV} = \frac{c \cdot U_n}{S''_k}$$

$$X_{110kV} = 0.995 \cdot Z''_{110kV} = j0.842765\,(35kV) \quad (1)$$

Feeding transformer 110/35 kV, 20 MVA:

$$Z_{tr} = \frac{u_k}{100} \cdot \frac{U_n^2}{S_n} = j10.4125\,\Omega$$

$$R_{tr} = \frac{u_{kR}}{100} \cdot \frac{U_n^2}{S_n} = 1.837\,\Omega$$

$$X_{tr} = \sqrt{Z_{tr}^2 - R_{tr}^2} = 10.24908 \quad (2)$$

With correction factor for transformer:

$$K_T = 0.95 \cdot \frac{c_{\max}}{1 + 0.6 \cdot x_T} = 0.984461$$, calculated on 14 MVA (3)

Feeding transformer reactance is:

$$X_{tr} = K_T \cdot X_{tr} = j10.08924\Omega \quad (4)$$

:

Single line to ground short circuit is:

$$I_{k1} = 3 \cdot I_f = \frac{\sqrt{3} \cdot c \cdot U_n}{\left| X_{eqd} + X_{eqi} + X_{eq0} + 3 \cdot R_{earth} \right|} = 285.20\,A \quad (5)$$

Simulation model of SLG on power network from Figure 5 is presented ON Figure 8:

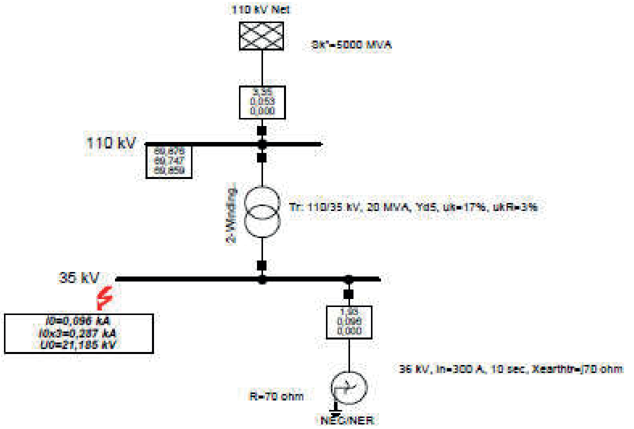


Figure 8: Computer simulation — SLG fault on 35 kV busbars

It is evident that difference between calculation and simulation case is under 1%

Earthing transformer dimensioning

Earthing transformer dimensioning is carried out on a way that rated voltage is equal or bigger with feeding transformer winding in power network where artifficial ground point is builded [1]. In typical sample substation, common feeding transformer rated data are: rated volteges 110/2x10.5/36.75 kV, rated power 20 MVA, winding connections Y0yn0d5. For such rated data, earthing transformer rated voltage is choosen. Rated power of earthing transformer is determined with phase voltage and short–time allowed current. In most of the practical application, that fault current is limited on 300 A for 10 seconds time period.

$$S_n = \frac{38kV}{\sqrt{3}} \cdot 300A \cdot \frac{1}{\sqrt{3}} = 3.8\,MVA \quad (6)$$

Grounding transformer in zigzag connection have bigger number of turns. That allows that phase voltage can be for smaller and as consequent decreasing rated power cost saving can be accomplished.

MODELING OF MV NETWORKS WITH ARTIFICIAL GROUND POINT

Grounding transformer in zigzag connection modeling

Model of MV ungrounded power network with grounding zigzag transformer for ground connection is built in order to demonstrate physical characteristic of such networks. Figure 9 represents a principle of modeling grounding zigzag transformers. Model is built from three monophase transformer with connections in half–windings which corresponds with physical connections on Figure 2.

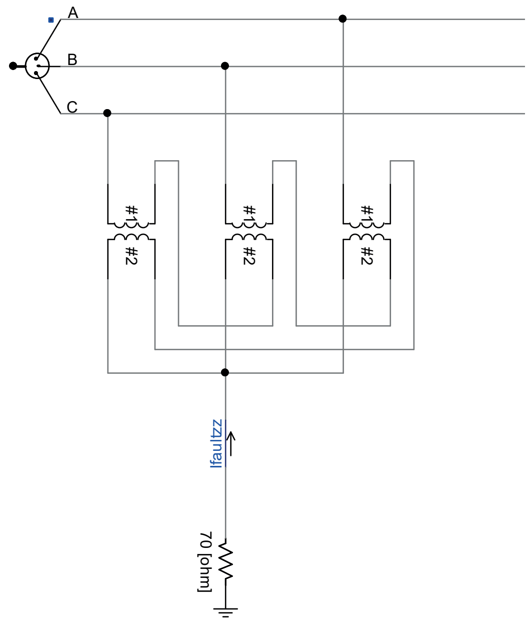


Figure 9: Model of grounding zigzag transformer for artifficial ground point

Based on formed grounding transformer simulation model, simulations for characteristic operational modalities of MV power networks are carried out. For every operational mode analysis of grounding configuration is performed.

Normal (symmetrical load) operation of MV power network

For the illustration of physical principles of artifficial ground point connection operation, simulation model [5] of 35 kV power network is developed based on typical 110/35/10 kV substation equipment data taken from [6]. Underground power cables capacitances are simulated with concentrate capacitances connected on MV busbars. In considered substation, 36.75 kV winding of feeding transformer is delta connected, earth fault currents reached the allowed maximum values and ground connection for this isolated network must be formed. Artifficial ground connection point is formed with grounding transformer (Figure 9) along with grounding resistor for limiting short circuit currents. Normal operation of 35 kV power network without faults and with symmetrical loads is modeled according data taken from [6] and presented on Figure 10.

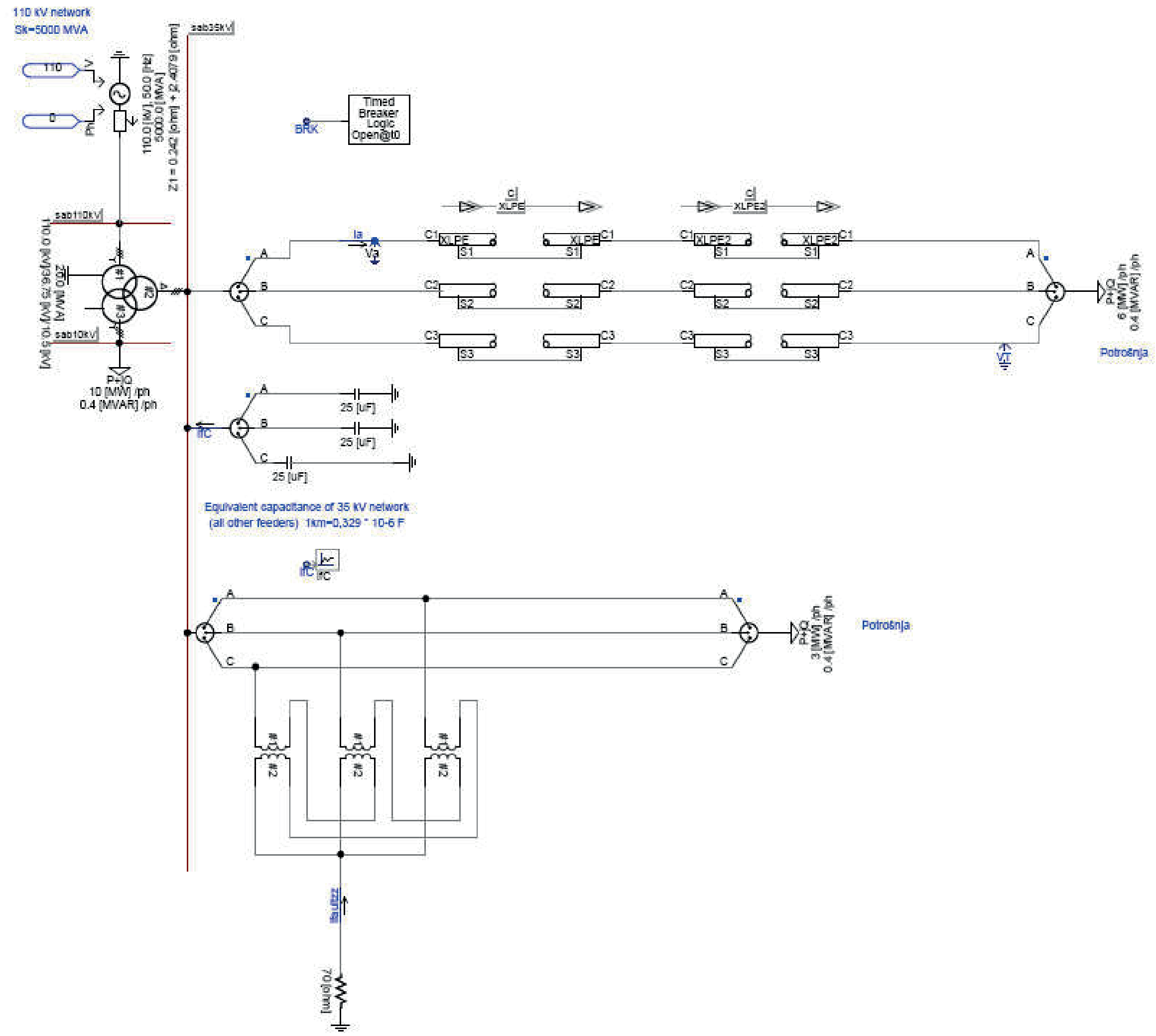


Figure 10: Simulation model of 35 kV power network with grounding transformer neutral point connection — symmetrical loads

Current through earthing resistor in normal operation of MV power network without asymmetrical loads and faults is presented on Figure 11. Magnitude of current through earthing resistor is under 1A (caused with stray capacitances) which prove correctness of simulation model for assumpiton — small magnetising current and big impedance of earthing zigzag transformer in normal network operation.

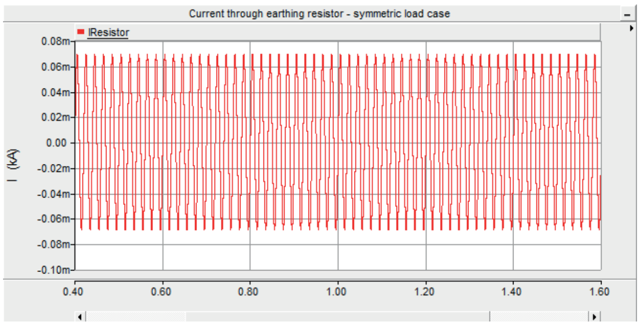


Figure 11: Current through earthing resistor — normal operation of MV power network

Asymmetrical load in MV network

In practice is very rare to find symmetrical loaded MV power network. That's reason for installation of higly asymmetric load in observed MV network (different load phase resistances) in order to examine grounding transformer in such operational mode (Figure 12).

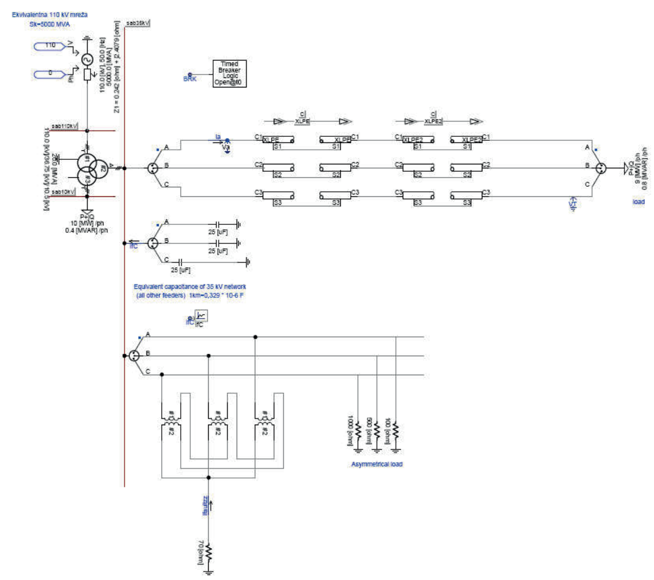


Figure 12: Simulation model of 35 kV power network with grounding transformer neutral point connection — asymmetrical loads

Current which continuously flows through grounding resistor is presented on Figure 13.

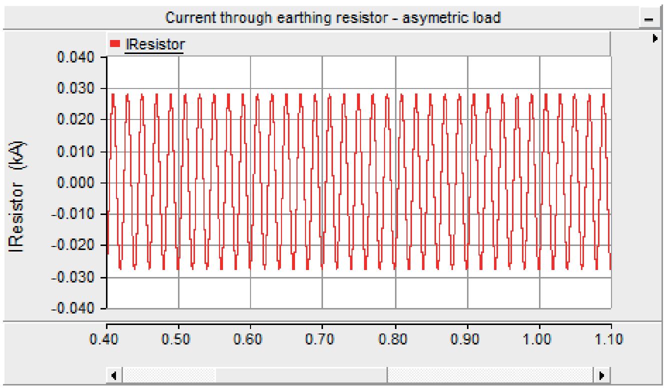


Figure 13: Current through earthing resistor of artiffICial ground point — higly asymmetrical loads

For high asymmetric load current magnitude is 26 A which is permitted continous current for earthing resistor. Phase currents in grounding transformer for the asymmetrical load case are presented on Figures 14 — 16.

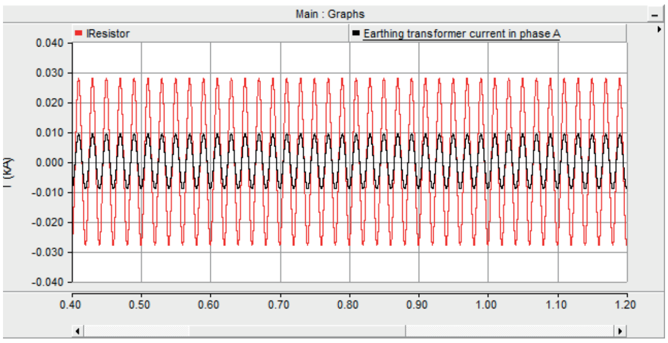


Figure 14: Earthing resistor current of artiffICial grounding point connection and grounding transfomer phase A current

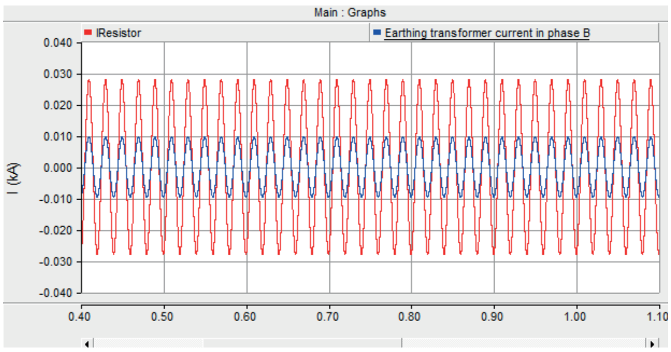


Figure 15: Earthing resistor current of artiffICial grounding point connection and grounding transfomer phase B current

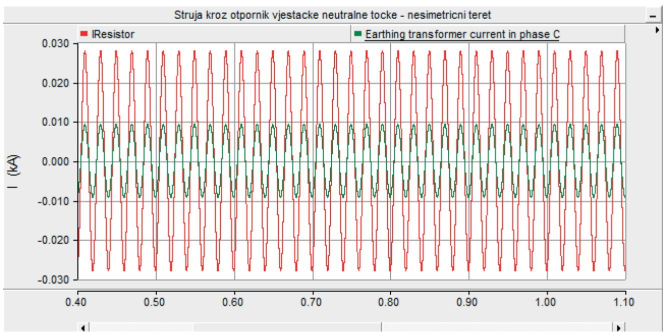


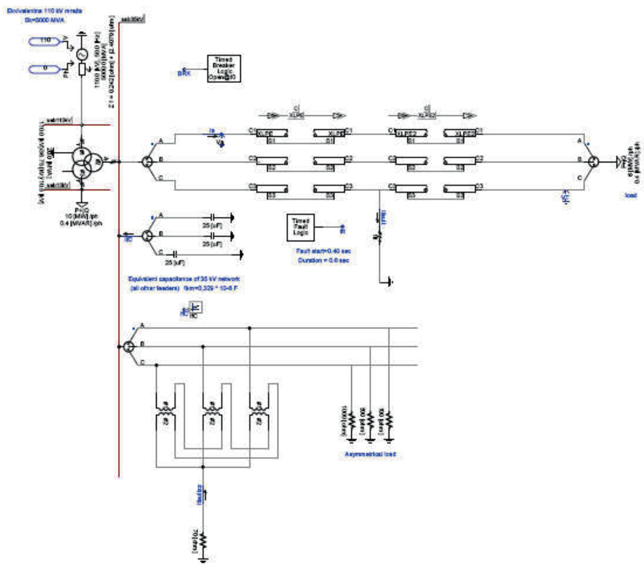
Figure 16: Earthing resistor current of artiffICial grounding point connection and grounding transfomer phase C current

Current distribution per phases of grounding transformer is evidently uniform, current magnitudes and phases are equal, which proves of another assumption for grounding transformer characteristics. Also, magnitudes of phase currents through earthing transformers are under 10 A which is permitted rated value.

Single–phase to ground (SLG) fault in 35 kV network

Earth fault or single–phase to ground (SLG) fault (depend on network grounding type) is the most common fault type in MV power networks. For assumed SLG fault is simulated in sample substation with configuration outlined on Figure 17. SLG fault is apllied on one phase of underground power cable, at 0.4 seconds at distance of one kilometer from 35 kV busbars.

Figure 17: Simulation model of 35 kV power network with grounding transformer —



SLG fault on underground power cable

Simulation results are presented on Figures 18 — 20.

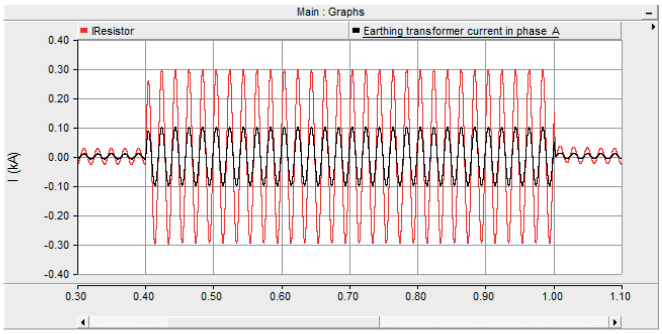


Figure 18: Earthing resistor current of artifICial grounding point connection and grounding transfomer phase A current — SLG fault

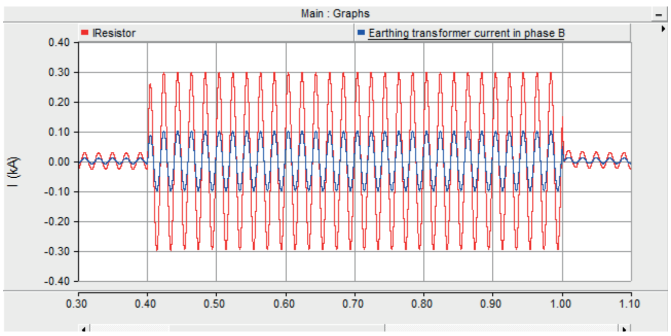


Figure 19 Earthing resistor current of artifICial grounding point connection and grounding transfomer phase B current — SLG fault

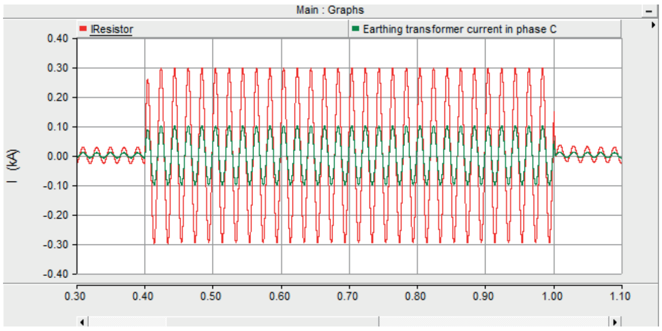


Figure 20 Earthing resistor current of artificial grounding point connection and grounding transfomer phase C current — SLG fault

Even for the case of SLG fault, current distribution per phases of grounding transformer is evidently uniform. Furthermore, current magnitudes and phases are equal, which is another prove of grounding transformer characteristics. With Fourier analysis harmonic decomposition contribution of third harmonic of magnetic flux in earthing transformer is obtained and presented on Figures 21 (Fourier's decomposition of phase C flux) and Figure 22 (detailed view of flux oscillations by harmonics in magnetic core of earthing transformer during the SLG fault).

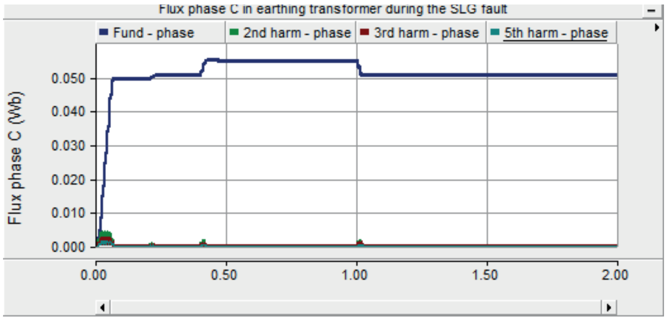


Figure 21: Harmonic decomposition of magnetic flux of grounding transformer

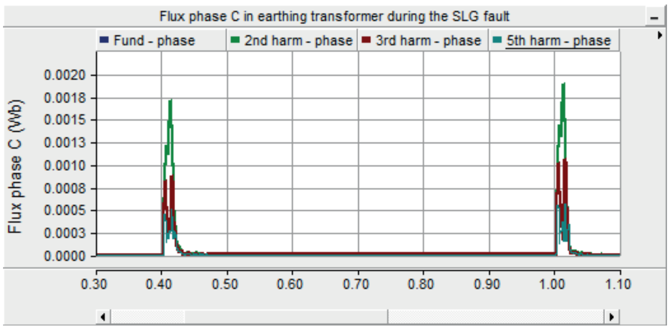


Figure 22: Detailed view of flux oscillation by harmonics during the SLG fault

As quoted, connections of half–phases tends to cancel currents of 3rd harmonics — practicaly there is not 3rd harmonics of magnetic flux.Fourier analysis of magnetic flux in grounding transformer shows that 3rd flux harmonic minor which is another confirmation of grounding transformer characteristics.

CONCLUSION

Use of grounding transformer is common in everyday practice. With increasing proportion of underground cables in MV power networks overall network capacitance is increasing and moreover earth fault currents magnitudes. In MV isolated networks that earth fault current increase requires forming of artificial ground point — a neutral connection point on a three–phase ungrounded power system. Grounding transformers physical characteristics along with their acting in the power networks protection principles and modeling are examined and presented in this paper. Also, characteristical operational modes of MV networks with artificial ground connection (MV power network with symmetrical and asymmetrical load, single–phase to ground fault) necessary for understading of working principles of MV networks are elaborated with detailed simulation cases.

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