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EDITORIAL

Dear colleagues and colleagues,

a special edition of the *Journal of Energy* magazine is in front of you. The International Conference Medit Maint 2018 (May, 2018.) has presented a number of extremely interesting professional and scientific papers. The Editorial and Review Board has selected four especially interesting papers for publication in the special edition of *Journal of Energy* magazine based on the theme and excellence.

The work of young and experienced engineers and scientists is coming from neighboring Bosnia and Herzegovina under the title *Application of Spectral Current Analysis in Predictive Maintenance of Electric Motors*. Distinguished colleagues Saša Nikolić and Radoš Čalasan, in this really interesting work, address the possibilities offered by a spectral analysis of current and voltage in the maintenance of electric motors. Namely, the Motor Circuit Analysis (MCA) and Motor Current Signature Analysis (MCSA) are innovative non-invasive methods that enable diagnostics and evaluation of electric motor and machine status.

Very interesting and current work in the field of thermography called *Infrared thermography in maintenance of building applied photovoltaics* is signed by colleagues from town of Osijek - Hrvoje Glavaš, Držislav Vidaković, Željko Jeršek and Zorislav Kraus. This interdisciplinary work is so interesting that it is hard to distinguish from it. Therefore we refer to it as a whole and we recommend it for a compulsory and complete reading, both for designers, engineers and businessmen, as well as for scientists.

The paper entitled *Technical-economic aspects of the construction of small hydropower plants in the energy market environment* is signed by colleague Ivan Krnić. In this topical work, the technical aspects of construction and operation of small hydropower plants in the power system in the market environment are being discussed. In this context, a concrete example is the mission and vision of the construction of a small hydro power plant. Namely, as a result of the changes in the market environment of energy companies and of the political and regulatory decisions of the European Union, which put great emphasis on renewable energy sources and decentralized energy production, there is a division of the traditional energy value chain into an increasing number of market segments, creating opportunities for new specialized players. This creates competition in all phases of the value chain.

Every high-quality construction starts with the pencil of an experienced designer, which is once again proved by renowned colleagues Robert Raguž, Ante Mladinić, and Mario Nosić. In the technical aspect of the reconstruction of 35 kV and 10 (20) kV plants, they have analyzed, for example, the problem of reconstruction of shrunken transformers in the conditions of an increased number of electricity consumers. TS POSTIRA is designed to maintain the existing building gauge and to incorporate modern equipment with increased power.

HDO (Croatian Maintenance Society) associate Krešimir Brandt rounded off the theme with topics of the Conference MeditMaint 2018, which was devoted to new technologies for property maintenance and management at the European and global level. The lectures were attended by lecturers and participants from Croatia, Slovenia, Bosnia and Herzegovina, France, Luxembourg, Lithuania, Belgium, United States and Australia. Professors Dr. Igor Kuzle and Dr. Nedjeljko Štefanić from University of Zagreb and the guests from abroad Joel Levitt (Springfield Resources, USA), Frederick Beghain (EASA, Luxembourg), David Kreft (Mersen, France), Paul Daugalis (Hugaas, Lithuania), and Prof. Jadranka Polović and Sc. ing. Siniša Brajković from Croatia. Among other things, it was concluded that the Croatian economy is seriously stagnating in the global competitiveness agenda. In the future this can have far-reaching consequences. Today, competitiveness is closely related to the processes of automation, digitization and the use of information and communication technology in production. The long-term vision of the development of production, called Industry 4.0, is based on connecting online technologies, management, industrial drives and separate machines...

I hope you will find something interesting and useful for yourself in our small selection of themes and works. If we motivated you to publish your professional or scientific research in one of the following issues in the *Journal of Energy* magazine, we have fulfilled our mission.

Yours sincerely

Marija Šiško Kuliš
Editorial of the Special Edition of the *Journal of Energy*

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Motor Current Signature Analysis in Predictive Maintenance

SUMMARY

The aim of this paper is to draw attention to the possibilities offered by spectral analysis of current and voltage in the predictive maintenance of the electric motor. Motor Circuit analysis (MCA) and Motor Current Signature analysis (MCSA) are innovative and non-invasive methods that enable diagnostics and assessment of the condition of the electric motor. The main advantage of the method is that the test is carried out during the normal motor operation, without downtime. All motor defects can be detected at the earliest stage. This enable planning the overhaul according to the condition which can make significant savings. Advanced MCSA analysers enable diagnostics of electric motors that are powered either via a soft starter, frequency inverter or directly from mains. So, it is possible in a simple and reliable way make an condition assessment of frequency inverters. In addition, it is possible to detect faults of driven machine, like misalignment, imbalance, blade faults, belts, bearings issues etc. Theoretical basis and tests that are carried out are explained in the paper..

KEYWORDS

Predictive maintenance, Spectral analysis, MCA, MCSA

INTRODUCTION

In order to achieve market competitiveness, there is a constant pressure to reduce maintenance costs and prevent unplanned production losses, leading to loss of production, increased maintenance costs, and financial losses. In recent years, *online* maintenance strategies are in use. However, with such maintenance, the operator makes the final decision when it will stop the equipment and enter it for overhaul. Also, these *online* monitoring systems are mainly based on monitoring mechanical parameters, that is vibration and analysis of vibration spectra. When it comes to pure mechanical systems, this approach gives good results. However, when it comes to complex systems that include an electric motor, this approach is not enough. Namely, it may happen that measuring vibration determines the defect of the system and incorrectly estimates the cause.

A typical example is the occurrence of a second harmonic in a vibration spectrum that does not have a mechanical cause.

Symbols			
P	Number of motor poles	*%FLA*	Percent of full load, A
f	Mains frequency, Hz	*fp*	Pole pass frequency, Hz
f_{sync}	Synchronous speed, Hz	*f ecc*	Frequency of eccentricity, Hz

On the other hand, it is true that electrical defects are manifested through the occurrence of certain harmonics in the vibration spectrum, but their occurrence can therefore only be detected when the damage reaches a serious extent.

The essential thing for a spectral analysis of an electric motor's current is that each failure of the electric motor modulates the flux of the motor, creating the rotating components of the flux which further produce characteristic current components that superimpose the basic harmonics. By detecting and separating these current components, an electric motor defect can be detected, such as a rotor bar damage, an inter-turn short circuits of the stator winding or eccentricity of the rotor. Measurement is performed during normal operation of the engine, without stopping and interrupting the production process. It does not matter how far the measuring point is from the motor. By measuring from the distribution cabinet, the status of the circuit current (MCA) is additionally performed.

Defects that can be detected through components in the electric motor current spectrum are [1], [2], [3]:

- Damage to the rotor bars,
- Static eccentricity,
- Dynamic eccentricity,
- Damage to the core,
- Stator winding defects,
- Damage to the bearings,
- Missalignment / imbalance,
- Loose foundation,
- Problems with the working machine.

Spectral analysis of the motor current can detect these defects at a very early stage, preventing further secondary damage and complete failure of the electric motor. Damage to the rotor bar will affect the vibration spectrum of the engine, but since the vibrations are traditionally measured on bearings and since for each electric motor there is a different mechanical stiffness between the electromagnetic forces caused by breaking the rotor bar and the place where vibration is measured, this further complicates the attempt to quantitatively define level of damage through vibration analysis. Vibrations caused by damage of rotor bars are a secondary effect and often the damage reaches a serious level before it is detectable in the vibration spectrum.

Due to all this, spectral analysis of motor currents and online monitoring can serve for quality monitoring of the condition of the electric motor and maintenance according to the condition.This system, along with online vibration monitoring, can completely prevent unplanned downtime of the electric motor and thus reduce the maintenance costs to a minimum.

THEORETICAL BASIS

The electric current signal is ideally the right sinusoid with a frequency of 50Hz, which of course depends on the frequency of the power supply network. A graphic, current signal can be presented in the time and frequency domain.

Figure 1. An ideal time diagram of the current and its spectrum is shown. It is noted that there is only one component in the spectrum, which is the basic harmonic at a frequency of 50Hz. All other components in the spectrum are equal to zero. In practice, the current signal is »contaminated« by a number of components having different causes. In addition to harmonics on the integers of the fundamental frequency, subharmonics occurs in the spectrum of the current. Separating and identifying these subharmonics is key to evaluating the health of the motor.

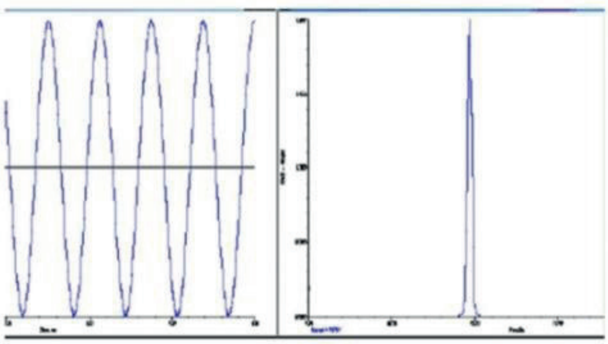
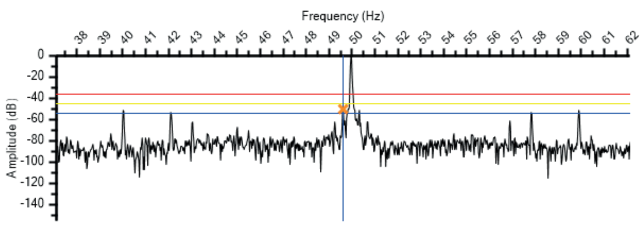


Figure 1. An ideal sinusoidal signal and its spectrum

During the motor operation, several components, or harmonics, will appear in the current spectrum. The current spectrum will consist of several



peaks including the component on the network frequency and its harmonics. This is known as the *Motors Current Signature*. The analysis of these harmonics after the amplification and processing of the signal allows detection of various electric motors faults.

Figure 2. Spectrum of real current signal

Certain harmonics are always present in the network voltage as a result of harmonic network pollution. However, these harmonics are negligible. In contrast, other harmonics are generated by various electrical and mechanical defects. All errors cause a change in the internal distribution of flux, which further generates harmonics in the motor current. It should be noted that the spectrum also includes inter-harmonics, which can not be detected by standard spectrum analyzers. Kako se harmonici karakteristični za određene defekte pojavljuju u strujnom spektru a ne i u naponskom, onda se upoređivanjem strujnog i naponskog spektra mogu izdvojiti harmonici koji su posledica defekta a ne zagađenja napajanja.

MEASUREMENT SETTING

The basic instrumentation system for measuring the spectrum consists of:

- Current transformer CT for signal measurement,
- A resistive shunt mounted at the CT outlet,
- Spectrum Analyzer.

Figure 3 is a schematic representation of the basic measurement setting.

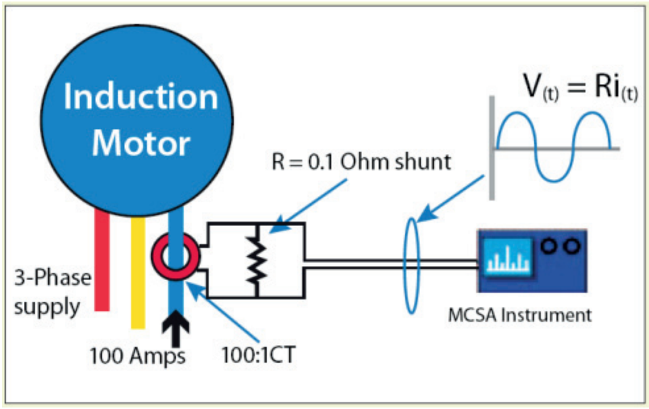


Figure 3. Instrumentation setup

The system can also include voltage measuring transformers VT, if it is a medium voltage motor. Depending on the real situation in the plant, the current transformer can be a type of clip-on and is mounted on one phase of the motor, or if a current measuring transformer is already installed in the plant, which is usually the case with large motors, then a probe is mounted on secondary current transformer. It is noted that only one current transformer is sufficient to analyze the spectrum of only one phase of the motor. The main reason for this is that each defect produces a rotating component of a flux that intersects all three phase windings of the motor and induces in it an appropriate component of the current that represents the occurrence of the defect. For a successful spectral analysis, standard commercial current transformers are sufficient. Although one phase analysis phase is sufficient, it is better to measure all three phase currents for a complete analysis.

After acquisition of the current signals, FFT is performed for separating the spectral components. The motor condition is evaluated through a series of tests in which the engine elements are evaluated individually[4]. These tests are described below.

OVERVIEW OF BASIC TESTS

Rotor evaluation test

In the Rotor Evaluation Test, an analysis of the current spectrum is performed in order to determine the condition of the rotor and to detect possible damage. The spectrum is shown in the coordinate system Hz-dB. The main component of the current is displayed at a frequency of 50Hz and with a weakening of 0dB. All other components of the spectrum are shown by the weakening in relation to the basic harmonic. The weakening is expressed in decibels (dB).

The greater the attenuation, the component's amplitude is smaller. In this test, the spectrum of the current around the basic harmonic is observed. The frequency of the pole pass is identifying (pole pass). If the component of the spectrum is at a distance from the basic harmonic below the 54 dB line 54 dB, then the rotor is considered to be in good condition, with no signs of damage and increased resistance. If these symmetric components are in the range between 45 dB and 54 dB, this means that there are signs of initial damage and places with increased resistance on the rotor bars and end rings.

This situation still does not require urgent intervention. It is necessary to monitor the development of defects and in case of progression to react in time, before the fatal damage of the rotor bars. The level of the spectral components at distancesfrom the base accordion, which is larger, that is, the attenuation of less than 35dB, indicates significant damage to the rotor bars or end rings and requires the urgent stopping of the motor and inspection of the rotor in order to detect and correct the defect.

Figure 4 shows the rotor evaluation spectrum for rotor with defect.

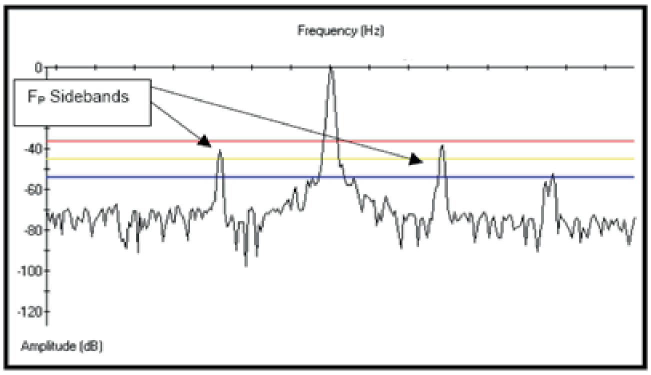


Figure 4. Rotor evaluation spectrum

Figure 5. shows a rotor with damaged rotor bars.

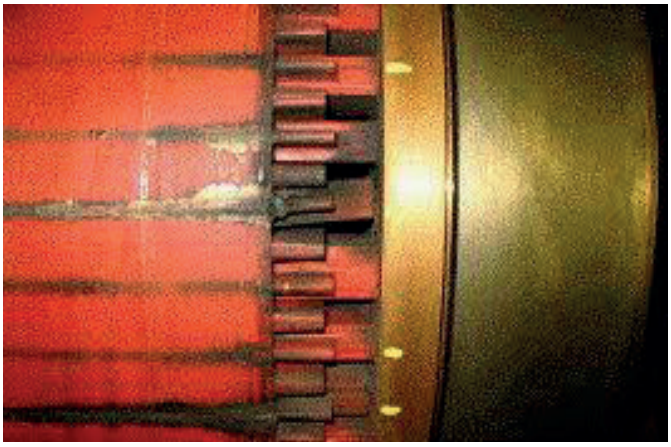


Figure 5. Rotor with broken bars

Rotor bars damage is a common practice case in cage motors. It is most commonly caused by an excessive number of direct or too frequent startups. It is very important to detect damage of the rotor bars in time, until the bar is lifted from the slot, which necessarily leads to severe or even irreparable damage of the complete engine.

Air gap evaluation test

An ideal electric motor has a uniform air gap between the stator and the rotor. In practice, this is usually not the case. The eccentricity of the air gap can be caused both factory faults, as well as the consequences of exploitation, assembly errors, etc. Of the factory defects, it is often the case of an oval rotor or stator, and as a result of mounting errors, especially in large engines where the bearings are not mounted in the bonnet, most often there is a misalignment of rotor and stator. Two type of eccentricity are existing. That are static and dynamic eccentricity. In static eccentricity, the minimum air gap is always at the same place on the stator edge. In contrast, in dynamic eccentricity, the point of minimum air gap moves during rotation of the rotor.

Figure 6. shows an illustration of an electric motor with an eccentricity of the air gap.

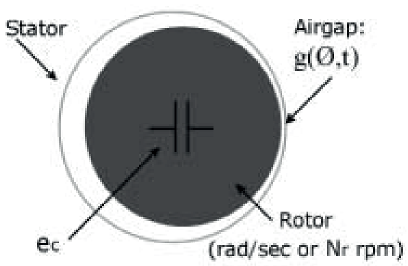


Figure 6. Air gap eccentricity

The consequence of eccentricity in an electric motor is the emergence of strong radial forces acting in the direction of the smallest air gap (*Unbalanced Magnetic Pull*). Mechanical vibrations occur at 2x frequency. These vibrations cannot be removed by balancing the rotor. For large motors, manufacturers allow the eccentricity of the rotor to be up to 5%.

By spectral analysis of the current of the electric motor, the existence of the asymmetry of the gap between the rotor and the stator can be easily and reliably determined. Figure 7 shows the part of the current spectrum of the electric motor with the presence of eccentricity.

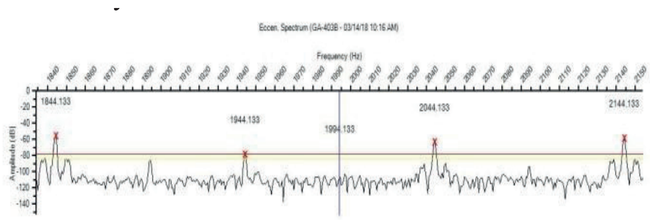


Figure 7. Eccentricity spectrum

Eccentricity indicators are four characteristic components in the spectrum at a distance of 100Hz. In the case of eccentricity, all four components exceed the permissible limit. The frequency of eccentricityis proportional to the number of bars in the rotor and is equal to the product of the number of bars and mechanical velocity in Hz.

STATOR WINDINGS EVALUATION TEST

This test is used to assess the state of the stator winding and the connecting circuit. A detailed analysis determines the condition of the winding and the connecting circuit. Calculation of the following parameters is performed:

- Voltage imbalance,
- Current imbalance,
- Impedance imbalance,
- Power factor imbalance
- THD,
- *Crest* factor,
- Positive, negative and zero current components

By analyzing the obtained results, it is possible to assess with certainty the state of the stator winding and the connecting circuit. Quantitative and qualitative analysis of these parameters determines the location and level of damage. The relation of current and impedance imbalance shows whether the fault in the connecting circuit is in the form of a point with increased resistance or is a failure in the stator windings. Also, in this test, an evaluation of the frequency regulator is performed, if present. The regularity of switching in the power block is checked. It also determines the level of higher harmonics that the regulator injects into the network, which affects the work of other devices.

Test for evaluation of mechanical parts

Mechanical defects modulate the flux of the motor that further induces the components of the current at the appropriate frequency. The problem is that the levels of these components are negligible in relation to the level of the basic harmonic and its multiplications. Therefore, in this test, the signal is separated at a 50Hz frequency band and its harmonics, making the components caused by mechanical defects visible and allowing analysis of hidden signals that are the result of a repeated load variation. Spectral analysis further determines what this load variation means and enables us to identify potential faults with the balance of the rotor, the centering of the motor shaft and the working machine, belts, bearings, gears, pumps, compressors and other mechanically generated anomalies.

Each mechanical component associated with an electric motor has its own frequency. On the Demodulation Spectrum, it is necessary to identify the increased harmonics corresponding to the frequency of the mechanical circuits associated with the working machine. The increase indicates a problem in that part.

In Figure 8, a demodulation spectrum for a motor that has a centering error is shown.

It can be seen in the figure that the uncertainty of the motor and pump rotor causes the components to emerge in the power spectrum at mechanical and double mechanical speeds. There are no significant components in this motor that would represent other defects. In the beginning part of the spectrum masked by the noise lie the components corresponding to the frequency of passing the bearings, the pump blades ...

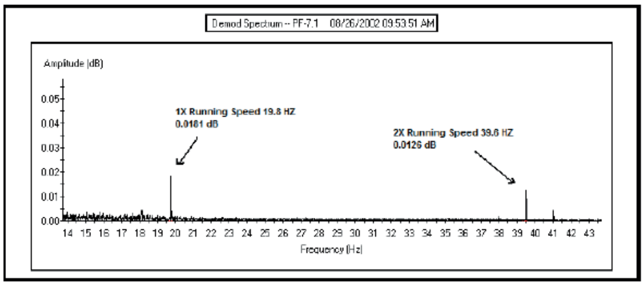


Figure 8. Demodulation spectrum

Figure 9. shows the spectrum of the same motor after centering.

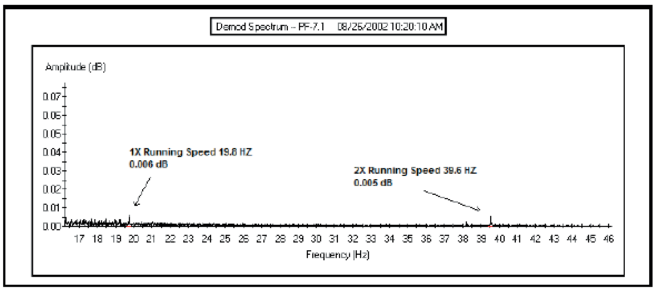


Figure 9. Demodulation spectrum after alignment

For precise identification of mechanical problems, knowledge of specific system elements data is needed. Thus, to assess the condition of the bearings it is necessary to know the type of bearings, the number of balls, the passage rate of the balls, the inner and outer paths, etc. To assess the condition of a gear unit, you need to know the number of gears and teeth of each gear and the like. Therefore, when interpreting the results obtained through the Demodulation Spectrum, it is good to consult a specialist in mechanics. By working together, a precise and reliable assessment of the condition of the mechanical circuits associated with the electric motors is obtained.

CONCLUSION

Motor Current Signature Analysis this is an innovative method that allows a thorough analysis of the condition of the electric motor. The advantage of this method is that testing is carried out during the normal operation of the motor and there is no need to stop and interrupt the production process. In our area, this method is very little represented in the process of electromotor maintenance. However, in the United States it has become a standard in the last few years. The savings that can be achieved by applying this method in the predictive maintenance of the electric motor have been recommended as a standard procedure applied in the industry. As it has become usual for us to measure the vibrations routinely, as a standard maintenance procedure, MCSA has become the standard method for testing electric motors in the US industry. Producers of advanced MCSA analyzers are still few and are all from the USA. However, the importance of this method is becoming increasingly evident in Europe and the manufacturers of these analyzers are slowly turning to our market.

The method of spectral analysis of currents, as a diagnostic method and tool in predictive maintenance does not exclude the method of vibro-diagnostics. On the contrary, this method compensates for the defects in vibro-diagnostics in the analysis of complex systems and a good combination of these methods, it is possible to accurately and reliably evaluate the state of all rotary machines driven by an electric motor.

As vibration measurement has become a widely accepted method for assessing the condition of mechanical circuits, so will the spectral analysis method of electric motors to find their place in predictive maintenance. The confirmation of this is the continuous improvement of advanced analyzers and the increasing interest of companies, which have so far solely engaged in the production of vibration analyzers, to conquer this technology and manufacture their own analyzers.

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1 Statements expressed in the paper are author's own opinions, they are not binding for the company/institution in which author is employed nor they necessarily coincide with the official company/institution's positions.

Infrared Thermography in Maintenance of Building Applied Photovoltaics

SUMMARY

Photovoltaic Systems (PV) are the most widely used renewable energy source in the Republic of Croatia but with a modest share in the total energy balance. EU energy policy encourages PV installation in building elements such as facades, roofs or separate constructions with the aim of achieving zero-energy buildings. Whether an integrated or stand-alone system during their lifetime requires periodic maintenance. In a normal operation, it is necessary to carry out a visual inspection twice a year before and after the winter period to determine the condition of the equipment, connecting lines and supporting structures. In the case of a significant deviation from the normal production, the inspection must be done as soon as possible. Most commonly, the problems of the unmaintained system cannot be perceived as long as the PV system is in an operational state. Dropping of dust, bird droppings or shading over a longer period may lead to system components being damaged and to necessary repair costs that can be prevented by regular maintenance procedures, including regular surface cleaning of photovoltaic panels. Infrared thermography is a fast method of detecting heat sources due to shading or defective photovoltaic module elements. The paper provides visual examples of thermal spots that can be observed during the infrared thermographic inspection of photovoltaic systems, as well as a review of their impact on the system.

KEYWORDS

Infrared thermography, Photovoltaic systems, Maintenance

INTRODUCTION

INTRODUCTION

Photovoltaic systems are the most commonly used form of renewable energy source (RES) integrated into existing buildings. Its application is encouraged by the Energy Performance of Buildings Directive (EPBD II). Directive 2010/31/EU on the energy performance of buildings requires that from 31 December 2018, all new public-use buildings to be zero energy buildings, and from 31 December 2020, all new buildings should be nearly zero energy buildings. Zero-energy Building (ZEB) is a building that meets energy needs from renewable sources to meet its own annual energy needs, thereby reducing the use of non-renewable energy in the residential sector, [1]. The most commonly used renewable energy source in the Republic of Croatia is the photovoltaic system, [2].

Table I. RES Power Plants with which HROTE has concluded an Electricity Purchase Contract under the Tariff System and whose plants are in the incentive system; - Grid-connected Power Plants - Status as at 31 December 2016, Source [2]

Nr	RES power plants	Number of power-plants	Total power (kW)	Average power (kW)	Share in total number	Share in total RES power
1.	Solar power plants	1,219	49,479	41	94.2 %	7.7 %
2.	Hydro power plants	11	3,885	353	0.9 %	0.6 %
3.	Biomass power plants	12	25,955	2,163	0.9 %	4.1 %
4.	Biogas power plants	26	30,435	1,171	2.0 %	4.8 %
5.	Landfill gas power plants	2	5,500	2,750	0.2 %	0.9 %
6.	Wind power plants	18	412,000	22,889	1.4 %	64.3 %
7.	Cogeneration plants	6	113,293	18,882	0.5 %	17.7 %
8.	Total of RES power plants	1,294	640,547	495	100.0 %	100.0 %

Table I shows that photovoltaic systems represent the most common renewable energy source in the Republic of Croatia with over 94 % of the total number of RES installations. In total power, PV participates with only 7.7 %. The advantage of photovoltaics is that their production (if we neglect maintenance) depends solely on insolation, which in spite of stochastic nature is predictable and independent of energy prices.

Designations			
AM	Air Mass	IR	Infra Red
ε	emissivity	LID	Light Induced Degradation
EVA	Ethylene Vinyl Acetate	RES	Renewable energy source
PV	Photovoltaic	PID	Potential induced degradation
STC	Standard Test Condition		

INTEGRATION OF PHOTOVOLTAIC SYSTEMS ON BUILDINGS

Photovoltaic systems on existing buildings are usually laid using an aluminum pre-fabricated structure that, in the case of a sloping roof, is fixed to the roof-mounted supports underneath the roof cover to ensure unobstructed precipitation of rainwater. In the case of flat roofs, the construction is fixed to the concrete slabs (Figure 1) or plastic trays filled with stone aggregates in the case of a flat roof where the fixture with the screws is not possible (the first example in the Republic of Croatia, Konzum maxi Sopot 2011). When constructing new buildings, it is increasingly common to integrate panels to a wooden roof structure, (Figure 2), or to use a cover with integrated photovoltaic cells (Figure 3).

Figure 1. PV panels on the flat roof, picture source Končar d.d.

Figure 2. Photovoltaic panels on the roof of a new building, [3]

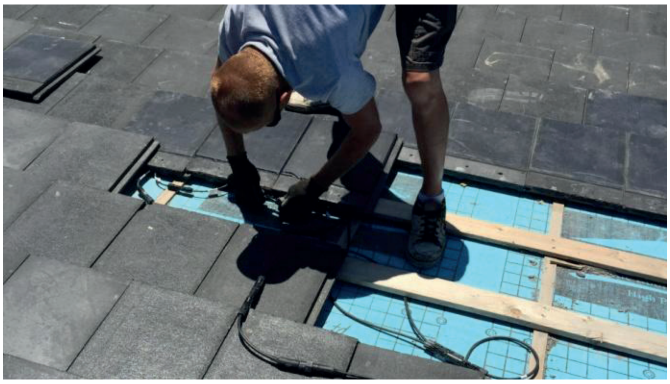

Figure 3. An integrated solar cell in roofing, [4]

The main problem of the integrated cover is reduced efficiency due to an increased panel working temperature (0.3-0.5 % and more per 1 °C increase of the temperature) due to reduced ventilation and inability to access the connection points. Reduction of the power due to the increase in working temperature is not so pronounced with panels integrated into façades of buildings, Figure 4.

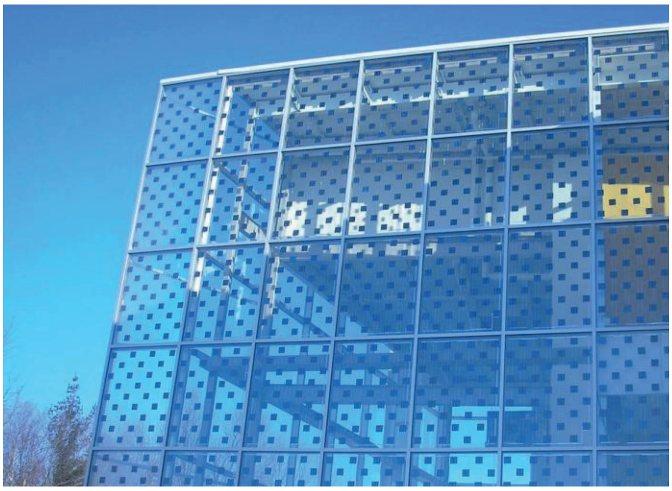

Figure 4. Photovoltaic elements integrated into the façade, [5]

For façade elements, the problem is the inability to achieve an optimal angle of sunlight because they are positioned according to architectural expression.

PV PANEL TESTING

Technical problems affecting the PV panels

Photovoltaic power plants have a life span of 25 to 30 years but photovoltaic modules are usually covered by a 20-year warranty. Cells power production typically decreases 1 % of nominal capacity per year. Numerous damages can occur during the life cycle. One of the most significant studies [6] shows the representation of all the technical problems that can affect the photovoltaic panels (Figure 5).

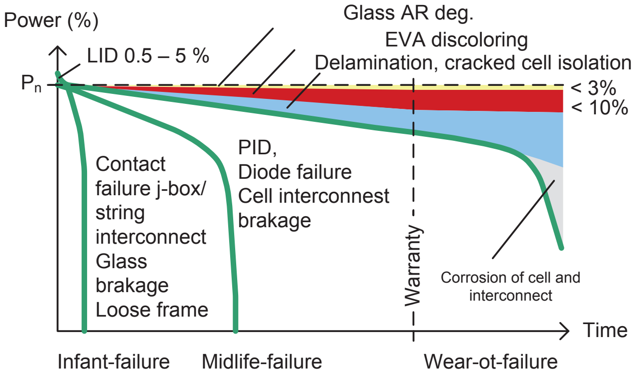

Figure 5. Causes of failure on PV panels, [6]

Figure 5 shows that the plastic used for laminating photovoltaic cells Ethylene Vinyl Acetate (EVA) significantly contributes to the reduction of the panel capacity while the glass cover as a seemingly sensitive material represents a relatively reliable component. This is especially important in façade applications because they have to choose higher quality materials that will not cause color change or delamination.

The usual PV panel testing methods

The first photovoltaic panel testing is carried out by the manufacturer after certain stages of the production process, lamination, and housing in the frame. The finished product is tested on a known lightsource and is released for sale. Basic test in standard circumstances, so-called STS is conducted under 1000 W/m² radiation at 25 °C and air mass AM 1.5 corresponding to Europe; (for Equator AM is 1). The work conditions after the installation change considerably in relation to laboratory conditions and the tests are usually carried out in three ways:

- measuring current-voltage conditions,
- infrared thermography and
- photoluminescence observed in infrared (IR) and near IR spectrum.

Equipment for electrical testing of photovoltaic systems requires several thousand euro investments, and the measurement and the measurement results depend on the momentary amount of radiation that changes significantly over time. Based on the results, conclusions about the malfunctions of individual cells or diodes can be made. Localization of the fault is much faster performed by IR thermography due to thermal inertia causing measurement result do not depend on rapid changes in radiation. The main condition for the IR analysis is insolation of at least 500 W/m2, [7]. Photoluminescence is a process when the inversion voltage of a few hundred volts is applied to the panel system when the panels begin to emit the light we detect in the near IR part of the spectrum with the camera and in the IR part of the spectrum by IR thermal camera. There are two international standards for testing PV, IEC 62446 and IEC 60904:

IEC 62446-1:2016 Photovoltaic (PV) systems Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection,

IEC 62446-3 Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance – Part 3: Photovoltaic modules and plants – Outdoor infrared thermography,

IEC 60904-12 Ed1.0 Photovoltaic devices - Part 12: Infrared thermography of photovoltaic modules International and

IEC 60904-14 Photovoltaic devices – Part 14. Outdoor infrared thermography of photovoltaic modules and plants.

IR THERMOGRAPHY PV PANELS

Thermal patterns on PV panels

The PV panel analysis with an infrared thermal camera leads to the detection of different thermal patterns. The apparent temperature varies depending on the recording parameters. The most accurate values are obtained by analyzing the plastic back of the panel, which in the case of PV systems on buildings can often not be carried out.

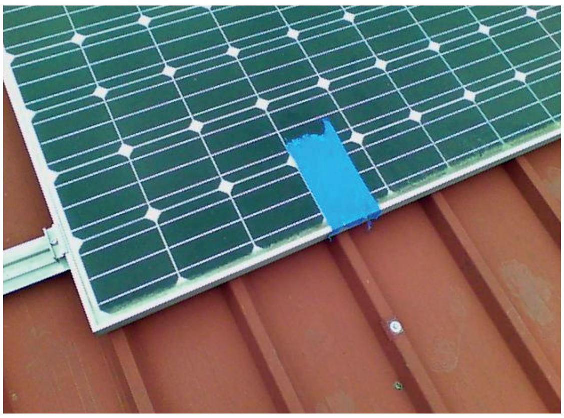

Figure 6. Shading of the panel cell

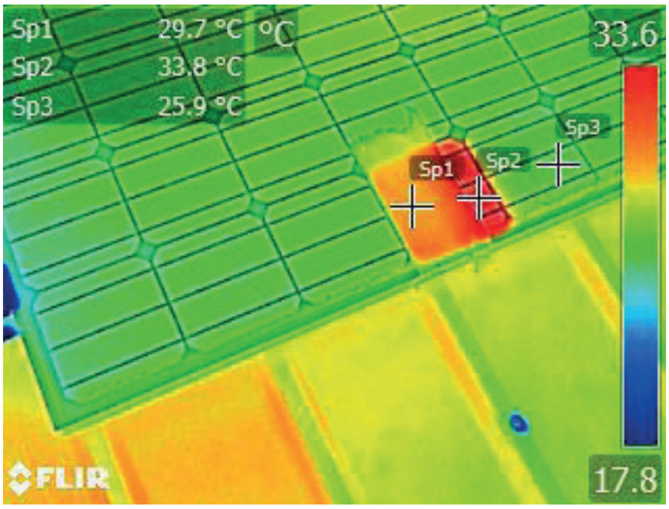

Figure 7. The thermographic pattern of the panel cell

The example of shade cell in Figure 6, does not generate electromotive force and represents resistance to the flow of current from the other cells of the series, resulting with heat dissipation shown in Figure 7. The analysis was made with the FLIR E6 infrared thermal camera resolution of 160 x 120 pixels, 45 ° × 34 ° field of view, operating temperature range from -20 °C to 250 °C, noise equivalent temperature difference or NETD <0.06 °C, refresh rate of 9 Hz and accuracy of ± 2 % or 2 °C of reading, with a set emissivity of $\varepsilon = 0.85$ characteristics for glass. Despite the high emissivity of glass, the problem of reflection of IR radiation is not negligible, as indicated in the paper [7].

Figure 8. The surface of the panel covered with bird droppings

Shading of the PV panel does not have to be obvious in the visible part of the spectrum to be noticeable with an infrared thermal camera in the infrared part. Figure 8 shows the surface area covered with bird droppings. On the corresponding thermogram, a 1.6 °C apparent temperature increase can be observed (Figure 9).

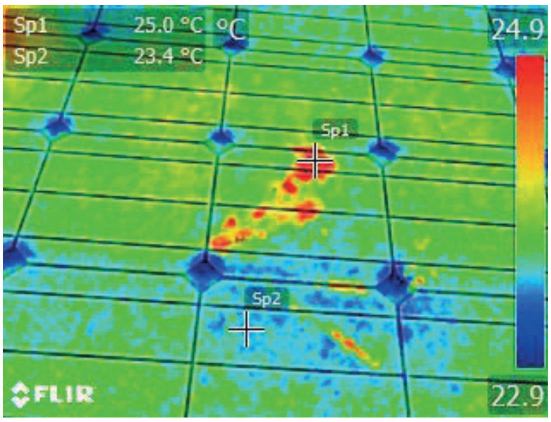

Figure 9. The thermal pattern reveals the position of the bird droppings

Bird droppings and accumulation of dust on panels lead to a decrease in production, but also to the different thermal stresses of individual cells, which cause cracking between the cells or the cells themselves. Therefore, periodic cleaning of the panel surface is important not only to maintain the production but also for the reliability of the system.

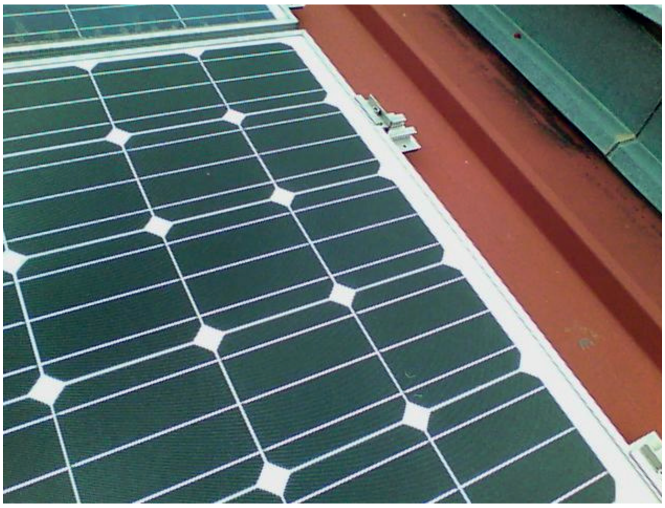

Figure 10. The side of a PV panel where the connection box is located

The PV panel cells are connected in the connection box by wires. The box is located at the bottom of the panel. Figure 11 shows the characteristic thermal pattern of the connection box. Because of the thermal resistance of the connection box, the place where the box is located is 1.7 °C warmer than the rest of the panel.

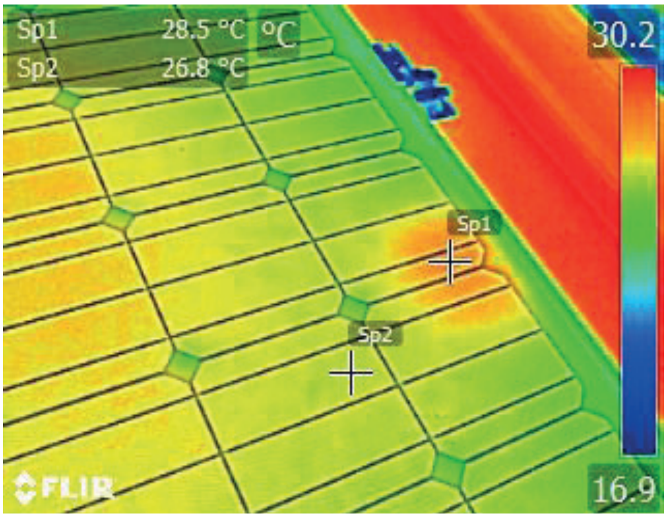

Figure 11. The thermal pattern of a PV panel connection terminal

A temperature difference of the individual parts of the panel, so-called hot spots, seen on previous examples does not necessarily mean malfunction. Often at the location of the connection box increased temperature can be seen and therefore, for the correct conclusion based on infrared thermal inspection, it is necessary to have knowledge about the panels operation as well as basic training in the field of IR thermography. In the field of electrical engineering, there is no single technical standard for assessing the correctness of electrical installations based on infrared thermography. The methodology mainly focuses on the analysis of the temperature difference between similar components often neglecting loads of individual components. That is why there are more organizations that have developed their own maintenance methodology over the years. One such organization is the International Electrical Testing Association (NETA) whose criteria are set out in Table II. [8]

Table II. Recommended maintenance procedures based on the temperature difference, [8]

Priority	The temperature difference (Delta-T) based on comparisons between	Recommended action	
	Similar components under similar loading	Components and ambient air temperatures	
1	> 15 °C	> 40 °C	Major discrepancy; repair immediately
2	-	21 – 40 °C	Monitor continuously until corrective measures can be accomplished
3	4 – 15 °C	11 – 20 °C	Indicate probable deficiency; repair as time permits
4	1 – 3 °C	1 – 10 °C	Possible deficiency; warrants investigation

The above examples (illustrated in Figures 9 and 11, with temperature differences of 2 and more °C) according to Table II require observation. In the case of a connection box, the pattern will not change, but in the case of the bird droppings pattern disappears with the appearance of the first rain or PV panel cleaning. In Fig. 12, the panel temperature can be read at 24.6 °C and at the point of hotspot 41.2 °C. This is a temperature difference of almost 20 °C, which leads to the conclusion that the panel will most likely be replaced (Figure is an example from the FLIR Tools software).

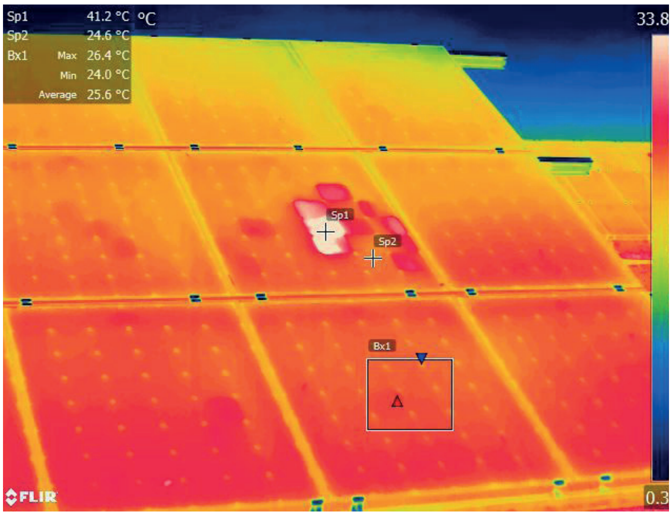

Figure 12. Thermal hot spot pattern, Source: FLIR Tools

Consequences of lack of PV panel maintainence

Monitoring the condition of the equipment is indispensable because defective equipment can lead to significant negative consequences. Figures 13 and 14 show the consequences of the defective PV system.

Figure 13. The consequence of fire on photovoltaic system, example [9]

Figure 14. The consequence of fire on photovoltaic system, example, [10]

CONCLUSION

Photovoltaic systems on buildings represent the simplest way to meet the EU energy policy in terms of archiving zero energy buildings goals. Ensuring a nominal lifetime of the photovoltaic system of 20 years and more requires continuous supervision and maintenance in other to PV system perform its function of electricity production. Infrared thermography is a fast, non-contact method of photovoltaic system inspection. Usage of IR thermography in maintenance can lead to problem prevention while still in development and do not pose a severe threat to the system. The problem is localized quickly, and the greatest advantage is that the procedure can be carried out in the operational state without turning off of the power plant.

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Tehnical-economic Aspects of Construction of sSmall Hydro Power Plants in the Energy Market Environment

SUMMARY

As a result global trends in the energy market environment and of the political and regulatory decisions of the European Union, which put great emphasis on renewable energy sources and decentralized energy production, there is division of the traditional energy value chain into a increasing number of market segments. In these newly established market segments opportunities are created for new specialized players, which leads to competition in all phases of the value chain. Small hydropower plant also represent an essential renewable energy source. This article elaborate tehnical economics aspects of construction and operation of small hydropower plants in energy market environment. In this context, a concrete example is given of the mission and vision of the construction and operation of a small hydro power plants in energy market environment.

KEYWORDS

Renewable energy sources, decentralized energy production, small hydropower plant

INTRODUCTION

Energy companies from both sides of the Atlantic, as Susanne Fratzscher (2015) states in her paper, face a big question of their own survival in the environment of the new enwironment and energy policy. 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. Small hydropower plant also represent an essential renewable energy source. This article elaborate tehnical economics aspects of construction and operation of small hydropower plants in energy market environment

Figure 1 shows that in the structure of electricity generation in Germany renewable energy sources contribute significantly to 26.2%, coal and lignite coal and lignit power plants 43.2%, nuclear power 17.8%, and gas power plants 9,5%. It can also be seen that the energy produced from renewable sources consists of hydroelectric plants 3.3%, solar energy 5.7%, biomass 8%, offshore wind 0.2% and onshore wind 8.9%.

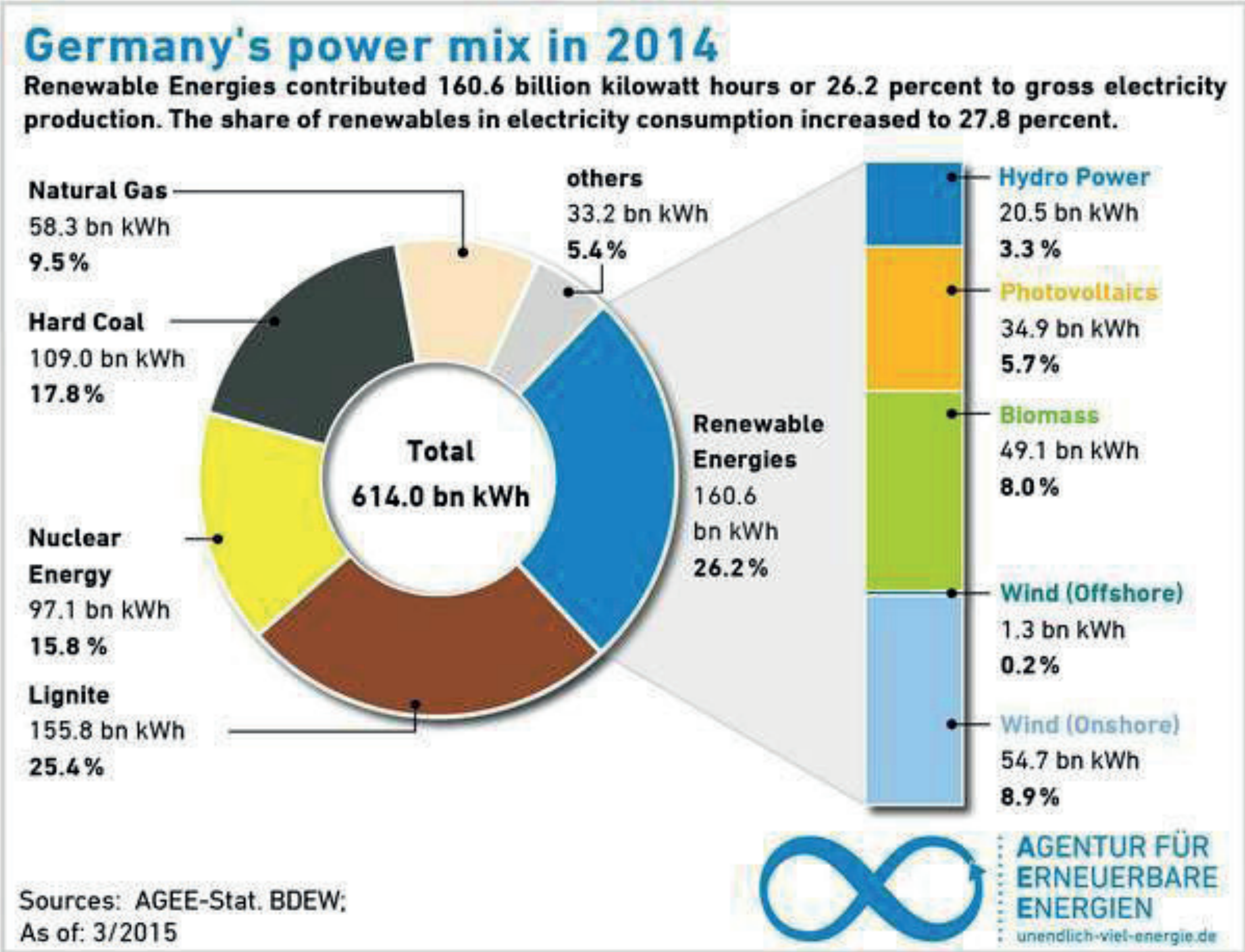

Figure 1. the share of electricity consumption in Germany [4]

SMALL HYDRO POWER PLANTS AS AN ESSENTIAL PART OF RENEWABLE ENERGY SOURCES

Energy supply will be increasingly decentralized. Humayun Tai (2013) states that this future state imply relocation of generation from high voltage to low voltage. Even if market share of renewable generation is still comparatively limited, as Fratzscher (2015) states and call on Bloomberg New Energy Finance (2015), small-scale distributed capacity represented about one third of new global investments in clean energy in 2014, approx. US$ 80bn. 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% (Frankfurt School – Unep Centre/BNEF 2015). 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 and solar photovoltaics (PV), continue to improve the economics of renewables even without incentives. The main reason for the construction of small hydro power plants is to enable the energy exploitation of the biological minimum water, which enables more precise flow regulation. By realizing such projects it is planned to increase the annual electricity production, optimize the use of water from accumulation, and thus provide additional GWh electricity from renewable sources. A small portion of the electricity produced by small hydro power plants is used to supply their own consumption, while the remaining electricity is delivered to the distribution grid via an accounting metering point that registers all the electricity delivered to the grid as well as the one used by the hydro power plant for its own consumption. Existing energy facilities are often used in the realization of such projects. Energy resources of river and water of the biological minimum are used, which, in accordance with water management conditions for hydroelectric plants, are constantly emitted from the reservoir lake into the natural river basin. These projects usually build a water catch on the existing bottom drainage on the right or left bank of the river. Furthermore, for small hydropower plants, it is planned to provide the status of eligible electricity producers, thus gaining the incentive price (premium), thus making the subject projects more economic and cost-effective, especially considering that energy policy and regulation environmental protection pushes towards the production of clean energy. Fratzscher (2015) states that 34% of carbon emissions in the USA and 33% in Germany are attributed to the power sector. 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.

The goals of building small hydro power plants

Small hydropower plants are considered to be sources of electricity that have a beneficial role to play in sustainable development, energy savings, increased energy security, and diversification of electricity sources. This future imply, as Humayun Tai (2013) states, that grid management complexity increases in the contest dana needs, physics, unpredictability and also that grid increasingly become a back up machine. In this context, the optimization of the power system 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. Fratzscher (2015) states that these two dimensions of system optimization keep industry, regulators and policy makers busy on both sides of Atlantic. 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. From the point of view of production planning and the necessary regulatory constraints for balancing the power system, small hydro power plants are highly desirable because of the predictability of electricity production and little influence on the scope of the regulatory reserve or balancing energy engagement. The fundamental energy input of small hydro power plants is the production of electricity with little impact on nature and the environment. Small hydropower plants are of great interest to the Republic of Croatia because their use has achieved developmental and energy objectives in the field of renewable energy sources. Also, for the assumed commitments of the Republic of Croatia to cover 20% of gross direct electricity consumption by renewable sources by 2020, the production of electricity from such sources is encouraged, thus making this project even more important. The basic aim of the construction of small hydro power plants is to solve the problem of discharge of the biological minimum and to use the basic drip regulator in accordance with the projected parameters. The construction of small hydro power plants enables more flexible operation of the main aggregates and enables the optimum use of water from accumulation according to the requirements of the hydro power system. Furthermore, the construction of small hydro power plants increases operational reliability and certainty and reduces the cost of regular annual maintenance. The construction of small hydropower plants achieves the following goals: solving the problem of discharge of the biological minimum, the energy utilization of the biological minimum water, increase of the total annual production of the hydro power plant, optimum use of water from the reservoir, more efficient operation of the main aggregates in the hydroelectric plant, additional water discharge by the basic tunnel, reducing the cost of regular annual maintenance of the existing equipment, an additional possibility of regulating the water discharge of the biological minimum, automation of aggregates and existing equipment with the introduction of process automatics, remote control, regulation and control of water discharge of the biological minimum, contribution to the realization of the investment plan of the power utility company and the overall investment cycle of production economical facilities and development of supporting industry, significant financial effects for the owner and the local community, the contribution of Republic of Croatia to the fulfillment of the commitments undertaken on the share of electricity generation from renewable sources, due to the more precise regulation of the water of the biological minimum, there will be a favorable influence on the plant and animal world in the downstream river. A small hydro power plant can, according to current legislation, acquire a status of a privileged electricity producer and retain the right to incentives in the future. Also, it is important to point out that these projects are highly competitive and without incentives, and electricity generation should not be a problem because of the growing demand for such sources. The reason lies in the fact that the electricity generation from this plant is relatively inexpensive, the life span is long and maintenance costs are minimal (an investment program for the construction of small hydropower plant Peruća).

3. Estimate the costs and revenues of small hydro power plants

At this point, an estimate of the costs of construction and estimation of the future revenues of a small hydro power plant is provided. The revenue estimate is made in accordance with the applicable legislative framework on the use of renewable energy sources. Furthermore, the status of eligible (privileged) electricity producers and the exercise of the right to a guaranteed preferential purchase price have been taken into account (Economic analysis of the construction of small hydro power plant Prančevići August 2014).

3.1. Estimation of the costs of operation and maintenance of small hydropower plants

The annual costs of operation and maintenance of small hydro power plants consist of the following components: regular and emergency maintenance (assumed in the amount of 1% of total investment, maintenance costs increased with a rate of 0.5% per annum), the reimbursement for the use of space (according to the »Decision on the amount of reimbursement for the use of premises using electricity production facilities«,(NN 84/2013 i 101/2013) for small hydro power plants with installed power greater than 1 MW is 0,01 kn/kWh and is paid for the delivered electricity). The water use fee (according to the »Regulation on the amount of the water use fee« is »5% of the price of one kWh, the realized average electricity price produced on the threshold of all hydroelectric power plants of an individual power company. In the past few years, the Croatian Electric Power Company paid for it on the basis of the average price of electricity produced at the hydro power plant treshold of about 15 lp/kWh. It is not expected that this will change significantly in the future, and the average cost of electricity produced in the budget is annually corrected only for the assumed inflation rate. Concession fee (in accordance with the »Decision on granting concession for the use of water power for the production of electricity to the Croatian Electric Power Company for HE Peruća" (NN 76/1998) is "1% of the realized average price of electricity produced at the hydro power plant threshold in each year of use.") As a small hydro power plant will only generate revenues through the sale of electricity, the concession fee is calculated in the amount of 1% of the realized income in each year. Administrative work and costs of guiding a small hydro power plant (it is assumed that a worker will be hired directly or indirectly) for performing technical and administrative tasks with a gross salary of 15000 kn. The cost of the electricity downloaded from the grid in the amount of 20.000 kn per year, based on estimates of the electricity consumption of the main project are also included in this item. This item is not expected to change significantly in the future and is revised annually in the budget for an assumed inflation rate of 2%. Based on the above, the operating costs of small hydro power plant Prančevići are given below.

Component	Operating costs	Annual Costs (kn/year)
Maintenance costs		338.269
Usage fee	10 kn/MWh	90.000
Water utility fee	7,5 kn/MWh	67.500
Concession fee	1% of gross income	87.937
Administration and management		150.000
Total (first year)		733.707

Table 1. Estimation of operating costs of small hydro power plant Prančevići [6]

The table above shows the estimate of the operating costs of small hydro power plant Prančevići in the first year of operation. The total operating costs amount to HRK 733,707 and consist of maintenance costs of HRK 338,269, usage fee of HRK 90,000, water utility fee of HRK 67,500, concession fee of HRK 87.937 administration and management of HRK 150.000.

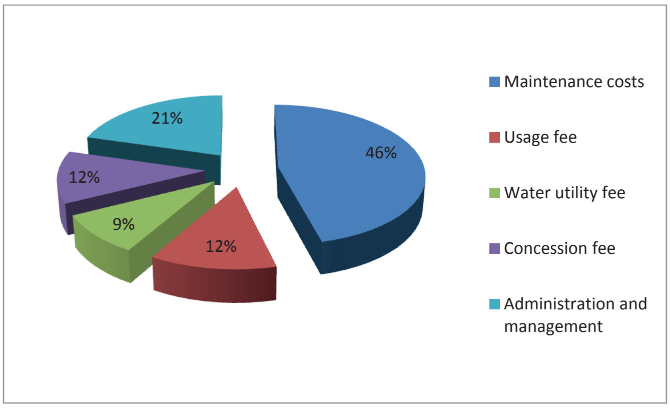

Figure 2. Shares of components in operating costs of small hydroelectric power plant Prančevići [6]

Figure 2 shows that most of the operating costs are maintenance (46%), administration and management participate with 21%, 12% usage fees, 12% concession fees and water utility charges 9% of the total operating costs of small hydro power plants.

Estimates of revenues from electricity sales

The annual revenue of a small hydro power plant is realized by selling electricity to the market. The estimate of annual revenues is made on the basis of the net annual electricity production budget and the expected electricity price trends during the analysis period. According to the current tariff model, small hydro power plants belong to a group of production plants, production facilities of installed power up to 5 MW, hydro power plants with installed power greater than 300 kW up to 2 MW. For this group, the incentive price was set at 0.93 kn / kWh. The purchase price in the financial analysis was calculated as follows: for the period of the Electricity Purchase Agreement (the first 14 years), the incentive price of electricity was HRK 0.93 / kWh and corrected at the annual inflation rate of 2.5%.The following figure shows the movement of electricity prices in the market.

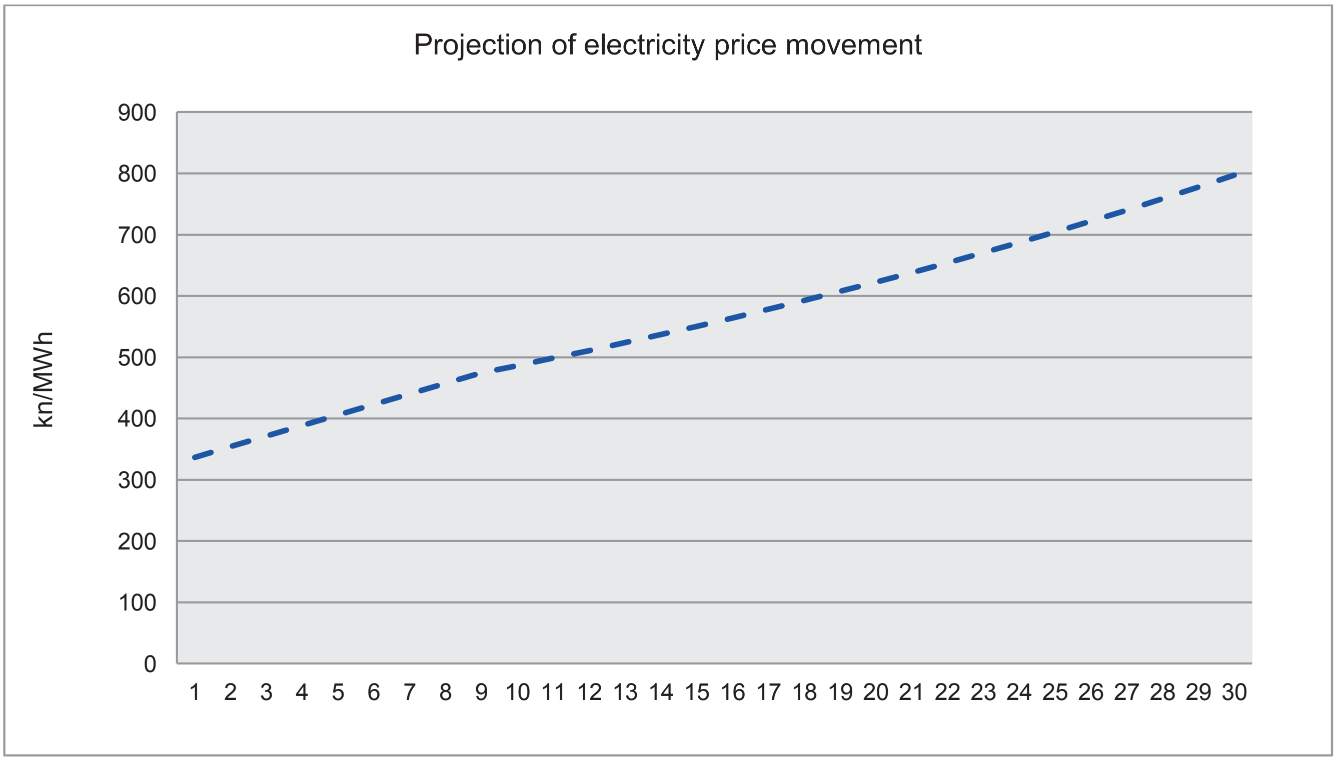

Figure 3. Projection of electricity price movement on the market kn/MWh (2022-2051) [9]

In the period after the expiration of the Electricity Purchase Agreement (from the fifteenth year onwards), according to the Electricity Market Act, the obligation of the Transmission System Operator or the Distribution System Operator has been established for the collection of the total produced electricity from eligible electricity producers. Thus, one can count on free access to the electricity grid and the sale of total electricity produced in the energy market.

Table 2. An estimate of the revenue from the sale of small hydro power plant Prančevići [6]

Year	Net electricity production (MWh)	Purchase price of electricity (kn/MWh)	Gross annual income (kn)
2016	9.000	977,1	8.793.731
2018	9.000	1.026,5	9.238.914
2020	9.000	1.078,5	9.706.634
2023	9.000	1.161,4	10.452.983
2026	9.000	1.250,7	11.256.719
2029	9.000	1.346,9	12.122.256
2030	9.000	574,8	5.173.057
2033	9.000	628,1	5.652.739
2037	9.000	706,9	6.362.207
2040	9.000	772,5	6.952.156

Estimated market price of electricity for each year is determined on the basis of the reference market price increased by the estimated increase in electricity prices. For the reference market price of electricity, an estimate of the average market price of electricity on the stock exchange in the past 3 years is taken and increased by 10%, which is 50 EUR / MWh. It is also accounted for by an average annual growth rate of electricity price of 3% per year, which is slightly above the estimated inflation rate. In the table above is an estimate of the revenues of electricity sales. The table above shows revenues for years where the "green" part represents an incentive purchase price of electricity while the "red" part represents the market price of electricity. The incentive price of electricity is corrected yearly for the annual inflation rate, while the market price of electricity increases for the estimated electricity price.

WEIGHTED AVERAGE COST OF CAPITAL (WACC) IN THE CONSTRUCTION OF SMALL HYDRO POWER PLANTS

In methods for calculating the cost of capital investment projects (Vidučić 2002), certain cash flows are assumed, ie risk-free projects. Cash flows of risk-free projects using the net present value method can be discounted at a zero interest rate. However, for risky cash flows it is necessary to determine the appropriate discount rate (required rate of return). The approach to using it depends on whether the company is funded solely by its own capital or its use and borrowing (leverage), as well as on the project's risk as compared to the company's risk. For companies funded solely by their own capital, the appropriate discount rate is the cost of permanent capital. For companies that use and borrowing the appropriate discount rate is the total cost of capital ie Weighted Average Cost of Capital (WACC). According to the WACC approach, the sum of expected cash flows from the project is discounted at cost of capital, which is determined as the weighted average of the combination of sources from which the company plans to finance.

WACC of small hydropower plants vs WACC renewable energy sources E.ON

At this point, a comparison of the Weighted Average Cost of Capital in the operation of small hydro power plants and Weighted Average Cost of Capital of E.ON energy company operating across Europe. Therefore, instead of using the WACC approach, the German regulator publishes a permitted return on equity (common equity). For existing investments, the return on equity (before corporation tax and after the commercial tax) is 7.14%, while in the case of new investments the return on equity 9.05%, assuming 4% of the debt price and the ratio 60/40 debt / own capital. According to the mentioned operating pro forma WACC in Germany in the amount of 5.9% was derived by weighting the share of existing assets (WACC 5,7%) and new assets (WACC 6,5%). WACC for business operations in Sweden amounted to 4.5%, and is the real WACC before tax. Current WACC of 4.5% in Sweden are disputed at the Court for Network Operations. The average expected rate of inflation in Sweden is 1.6%. Furthermore, based on the model of financing and business risk, the cost of capital (WACC) for the construction of small hydro power plants is also estimated and it is 5%.The next figure shows the equivalent of Weighted Average Costs of Capital (WACC) by countries in Europe where E.ON Group operates and equivalent of Weighted Average Cost of Capital (WACC) for a small hydro power plant Prančevići.

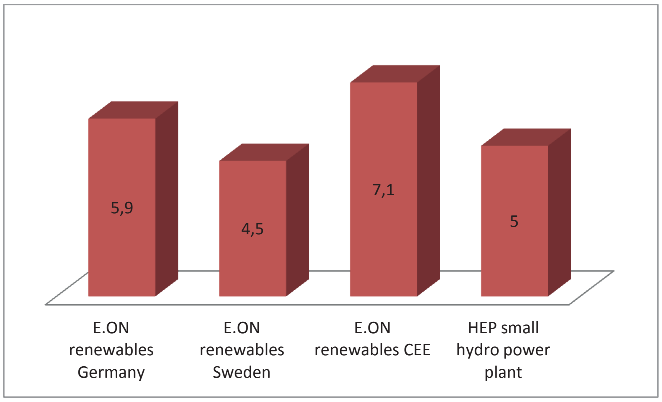

Figure 4. Weighted Average Cost of Capital WACC E.ON vs WACC small hydro power plant Prančevići [7] [6]

Essential parameters for a technical economic analysis

The input parameters required for financial analysis are revenue and expense, together with other technical and financial parameters required for the calculation and analysis of discounted cash flows. Operating costs are shown in Table 1, the estimated revenue for the entire planned period is shown in Table 2. An overview of the estimated values of the other input parameters is shown in the following table.

Common input parameters	Unit	Amount
Number of aggregates		1
The power of the aggregate	MW	1,15
Total installed power	MW	1,15
Inflation rate	%	2,5
Annual rate of increase in electricity prices	%	3
Profit tax rate	%	20
Amortization rate	%	5
Depreciation charge (% of investment costs)	%	100
Weighted Average Cost of Capital (WACC)	%	5
Incentive purchase price of electricity (first year)	kn/MWh	977
The duration of the incentive purchase price	god	14
Market price of electricity (first year)	kn/MWh	380
Annual growth in maintenance costs	%	0,5
Interest rate	%	
Loan repayment time	god	
Cost of borrowing	%	
The period observed in the analysis	year	25

Table 3. Other input parameters [6]

According to Article 12 of the “Income Tax Act” (NN 177/04, 90/05, 57/06, 146/08, 80/10, 22/12, 148/13), amortization of tangible fixed assets is recognized as tax expense. It is calculated on the basis of the cost of procurement (depreciation base) using a linear method using annual depreciation rates. A small hydro power plant belongs to a group of long-term assets“1- construction objects and ships of more than 1000 gross tonnage (BRT)”, for which the annual depreciation rate of 5%. Under the cost of procurement is considered to be all the costs of placing the assets in use. Therefore, in the case of small hydro power plant Prančevići, this is the total investment cost. Accordingly, depreciation for a small hydro power plant has been calculated linearly for 20 years in the amount of 5% of the total investment value.

COST-EFFECTIVENESS ANALYSIS OF SMALL HYDROPOWER PLANTS PRANČEVIĆI

Funding is assumed using only own resources and in that case lose the elements of credit (project financing). The analysis uses the cash flow projections (economic flows) for the observed period and the projections of the profit and loss account. The calculated net profit is increased for amortization and thus the cash flow is obtained. The free cash flow is discounted at a discount rate that for those companies that are funded exclusively with their own equity, is equal to the cost of permanent capital, while for the companies that use the debt, the appropriate discount rate is Weighted Average Cost of Capital (WACC). In the case of a small hydro power plant with a basic variant without discounting (DR = 0), two variants of discount rates were used, namely DR = 5% and DR = 10%. Based on the financing model and business risk, the Weighted Average Cost of Capital (WACC) is estimated, and it is 5%. Thus, in the case of small hydro power plants, the relevant discount rate is 5%. Below are shown calculations of the financial indicators of building a small hydroelectric power plant Prančevići. The following table (Table 4) represents the economic flow of small hydro power plant Prančevići. Two years have elapsed from the total 26-year analysis period: the first year of work for which the electricity price incentive for the eligible producer and fifteen years of work are worth the electricity market price.

Table 4. Economic flow of small hydropower plants Prančevići [6]

Indicators of financial analysis	2016 Incentive price	2030 Market price
Purchase price kn/MWh	977	575
Annual electricity production (MWh)	9.000	9.000
Gross annual income (kn)	8.793.731	5.173.057
Operating Annual Costs – OPEX (kn)	733.707	960.715
Gross profits – EBITDA (kn)	8.060.025	4.212.342
Amortization (kn)	1.691.346	1.691.346
Operating profit – EBIT (kn)	6.368.678	2.520.996
Profit tax (kn)	1.273.736	504.199
Net profit	5.094.943	2.016.796
Net profit + Amortization	6.786.289	3.708.143
Free cash flow	6.786.289	3.708.143

The table above presents the projection of the cash flow, ie the economic flow of the small hydroelectric power plant Prančevići. In this respect, the processing was initiated from the beginning of the 14-year incentive price period for the eligible electricity producer, and for the fifteen years of operation, ie the first year for which the market price of electricity was increased by the average rate of increase of electricity price in the observed period. The period from 2016 to 2040 was observed. Using the economic outlook and projection of the profit and loss account, discounted cash flows and cumulative flows are produced. With variant without discount (zero discount rate), two variants of the discount rate of 5 and 10 percent were used. The following figure shows the cumulative cash flows for all three variants.

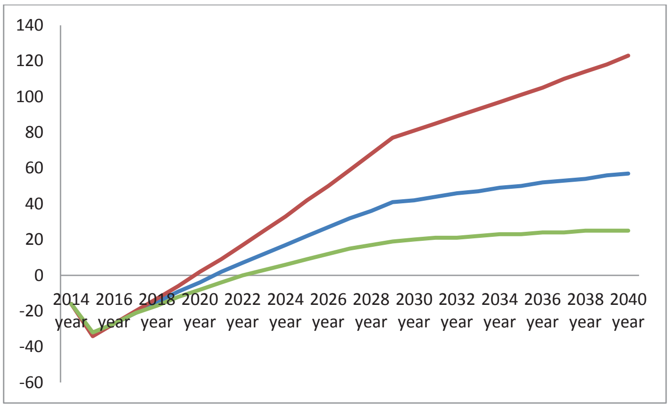

Figure 7. Cumulative discounted cash flows DR = 0, DR = 5%, DR = 10% small hydro power plant Prančevići [6]

The above figure shows the cumulative cash flow for the zero discount rate, a discount rate of 5% and a discount rate of 10%. In the case of non-discounting, the cumulative cash flow is positive in the fifth year of the business, with a discount rate of 5% in the sixth year of operation, with a discount rate of 10% in the eighth year of the business. The assessment of the viability of the investment of the construction of a small hydro power plant is obtained through the calculation of the discounted free cash flow. The result of the underlying analyzes and calculations are the basic financial indicators: Internal Rate of Profitability, Net Present Value and Time of Return on Investment. These financial indicators are shown in the following table.

Indicators of financial viability	
Internal rate of return (IRR)	19,26%
Net present value (NPV) - discount rate 0%	122.851.370 kn
Net present value (NPV) - discount rate 5%	56.897.681 kn
Net present value (NPV) - discount rate 10%	25.424.047 kn
Time of Return on Investment - discount rate 0%	5 year
Time of Return on Investment - discount rate 5%	6 year
Time of Return on Investment - discount rate 10%	8 year

Table 5. Indicators of financial viability of small hydropower plant Prančevići [6]

The above table shows that the financial ratios are exceptionally good as reflected in the high internal rate of profitability, the high net present value, the short investment return time, taking into account the most unfavorable discount rate of 10% which is really too high for this type of low risk project. The relevant discount rate for a small hydro power plant is 5%.

CONCLUSION

The project is competitive and market-oriented as the demand for electricity is growing. The project has good economic indicators that guarantee good profitability and return on investment. Realization of the project uses existing energy facilities, exploits the natural potential of the Cetina River, while the installation of new equipment extends the lifetime of the existing equipment which has not been used optimally so far. Financial analysis has resulted in positive indicators of profitability: the internal rate of return of the project is 19% and meets the condition of profitability, ie significantly higher than Weighted Average Cost of Capital (WACC). Net present value (NPV) of the project with a discount rate of 5% is HRK 56,897,681. Time of Return on Investment is five years, and the discounted period of return is 8 years, which is acceptable. It can be concluded that such projects are economically and financially justified, acceptable and desirable for investors. The project is market-oriented and competitive, given that the electricity price in the European electricity market is growing, and there is growing demand for renewable energy sources. With its production, hydro-electric and power parameters, small hydro power plants with expected annual electricity generation of 9,000 MWh, it is imposed as a durable and reliable and above all an environmentally friendly renewable source of electricity. Such energy sources are of great interest to the Republic of Croatia because their use increases the utilization of existing hydro power plants and the use of their own natural energy resources, reducing the dependence on energy imports and the impact of fossil fuels on the environment in the long term. With the increase in electricity prices, cumulative economic effects and other significant uses of investment in the construction of small hydro power plants are growing, and they are energy economically viable. It should also be emphasized that the character of such renewable energy sources contributes to overall social acceptance. However, this kind of intervention in the area carries certain environmental and financial risks. Ecological risk is the possibility of contaminating river water streams when constructing and using small hydropower plants. The stated risk is planned to be minimized through the organization of work and the application of strictly prescribed environmental standards. Another ecological risk is a possible failure on the equipment of a future energy facility, which would limit the discharge of the biological minimum water stream into the river. Its possible negative impact is planned to be prevented by by-pass pipeline. Together, both ecological and economic risk pose a demand for managing water accumulation. The connection of the pressure pipeline to the basin tunnel requires good preparation and a few days empty of the water tunnel, which limits the release of the biological minimum only through the operation of the aggregate and depends solely on their availability. In order to reduce the risk of such an event, it is necessary to manage the accumulation of water in such a way that a moment of fitting small hydroelectric power plants to the supply system is in such holes of lakes when it is possible to discharge the biological minimum water through the overflowing klapa. The financial risk is certainly a consequence of the mentioned environmental risks, and especially the last mentioned, because the matching of the term plan with conditions in the reservoir lake does not have to coincide, and fostering their coincidence may have demands for a completely different accumulation management. This may have negative financial effects for water accumulation users or Investors. The financial risks of the project for the construction of small hydro power plants are as follows: electricity prices at the international and domestic electricity market, possible change of water supply conditions, capital cost, investor business, company environment and unplanned cost of project participants. given the low probability of occurrence of any of the risky events, taking into account the previously conducted analysis, it can be concluded that such projects are economically and financially justified, acceptable and desirable for investors.

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Technical aspect of reconstructions of 35 kV and 10 (20) kV plants with an example

ABSTRACT

At the beginning of the electrification of Dalmatia in the middle of the last century, a large number of 35/10 kV substations were built, in which 35 kV and 10 kV plants were installed inside cells (vertical partitions, so called ''monijerka''). Since the substation TS 35/10 kV POSTIRA was put in operation, only the necessary repairs have been made for the maintenance of the substation. A growth in the number of consumers caused by an increasing construction of residential and commercial buildings required a reconstruction of the substation's equipment. The reconstruction of TS POSTIRA is designed in a way to maintain the existing dimensions of the premises while incorporating modern equipment with increasing strength. During the execution of the works, a special engagement of all the participants in the construction was necessary due to the reconstruction of the substation without interrupting supply of customers (part of the plant was constantly under voltage). This paper presents solutions and the method of reconstruction of TS 35/10 (20) kV POSTIRA.

KEYWORDS

Substation,Reconstruction, Stages of implementation, Primary equipment, Professional paper

INTRODUCTION

The substation 35/10 kV POSTIRA was built in 1954 with the installed power of substation 4 + 4 MVA. The building of the substation is built as a free-standing building on two floors, a ground floor and a first floor (within which the equipment is distributed), beside which are located power transformers.

Over the years, there have been substantial changes in 10 kV electrical network of the island of Brač. Primarily, reconstructions of the existing network and construction of new parts of the 10 (20) kV network were performed. By increasing the number of consumers, the load reached the power Smax = 7.72 MVA (96.5% Sn), and in the event of failure of one of transformers it was not possible to ensure the continuity of supply of all consumers, i.e. to meet the criteria n-1. Apart from the previously mentioned, the substation was technologically outdated, so a thorough reconstruction of the substation was necessary.

The reconstruction included a replacement of existing transformers (4 + 4 MVA) with transformers of (2x8 MVA) power and a replacement of 10 kV plant and measurement and protection equipment and the implementation of remote-control equipment for the substation. The 35 kV plant was not completely replaced because the existing newer vacuum switches, which replaced the old oil ones, were retained during the maintenance of the plant.

The reconstruction concept of TS (substation) is defined in a way that the entire 35 kV plant is located on the upper floor with deeper cells, while the existing busbars of 35 kV plant on the ground floor are dismantled.

After dismantling the 10 kV plant located on both floors, a new 10(20) kV plant was installed, consisting of 16 factory-fitted switch modules, located on the ground floor of the building. Due to the dimension, SF6 gas insulted switching blocks (type switching block KSMA 24 of the manufacturer Končar-EASN) have been selected.

Reconstructions of 35/10 kV substations are in fact problematic, primarily due to the fact that the work is performed while a part of plant is under voltage. For this reason, the reconstruction of the TS 35/10 kV POSTIRA has been carried out in stages with the maximum coordination of the contractors, supervisors and designers, and with special care for the implementation of the work safety.

DESCRIPTION OF THE CURRENT STATE

The existing 35 kV plant is divided on two floors. On the ground floor are 35 kV busbars, made with round Cu conductors (Ø13 mm), associated bus disconnectors and a sectional metering field.

On the upper floor are 35 kV open-type cells with vertical wall partitions and consist of seven bays:

- =H1 line bay reserve
- =H2 measurement bay
- =H3 transformer bay
- =H4 line bay Dugi Rat
- =H5 transformer bay
- =H6 line bay Nerežića
- =H7 line bay reserve

Image 1 35 kV plant

The 10 kV plant was also located on two floors, designed with single sectioned busbars on the ground floor and switchgear positioned in vertical walled partitions on the first floor. It was composed of two transformer bays, a home bay, 5 line bays and a measurement bay.

On the first floor, next to the cells of 10 kV plant, there is also a secondary equipment and protective relays of the obsolete type.

The auxiliary supply voltage is 24V =.

Image 2 10 kV plant and protective cabinets for installations before reconstruction

The layout of the ground floor and the first floor of the existing TS 35/10 kV POSTIRA is given in Images 3 and 4.

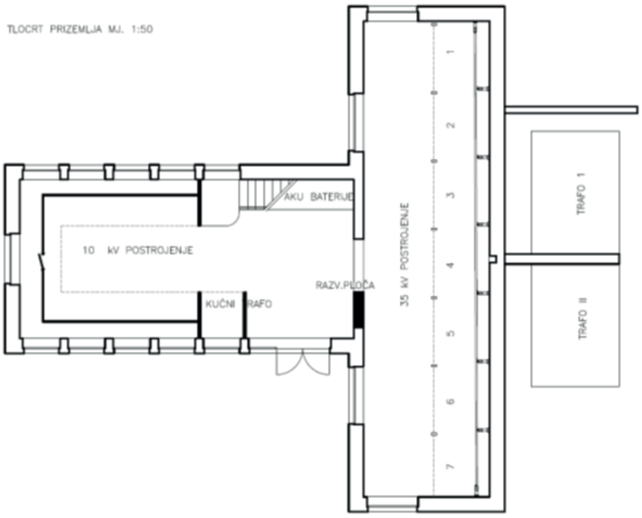

Image 3 The layout of the plant (the ground floor's plan) before reconstruction

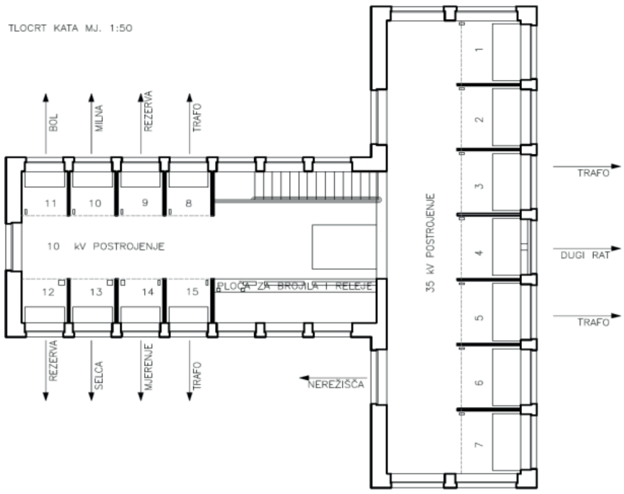

Image 4 The layout of the plant (the first floor's plan) before reconstruction

STAGES OF RECONSTRUCTION

First stage of reconstruction

Preparatory works

The work began by dismantling the home transformer and its re-installation in the already prepared concrete foundations outside the building, to ensure the supply of secondary equipment that will continue functioning until a new setting is mounted.

Image 5 Home transformer

Works on 35 kV plant

35 kV transformer bay =H5 and line bay (Nerežišća) =H6 were enclosed by insulation dividers to protect workers from accidental touching of the live parts and to safely enable the supply of transformer T2, which at this stage takes over the task of power supplying the transformer.

10 kV cables from line bays, of the section supplied by the T1 transformer, are connected by a block-joint system to line bays of the second section which will provide temporary power supply.

After the preparatory work was completed, a dismantling of old 35 kV and 10 kV non-powered plants could be commenced.

On the first floor were reconstructed 35 kV bays: measuring bay (= H2), transformer bay (= H3) and line bay TS DUGI RAT (= H4). There was an upgrade of vertical partition walls between the bays so that a depth of 220 cm was obtained, unlike the previous 180 cm. New 35 kV busbars were mounted on 35 kV support insulators on partition walls. Also, the replacement of disconnectors and current and voltage measurement transformers was performed. On the ground floor were disassembled existing busbars, bus insulators and connections between bus insulators and busbars of the unpowered part of the section.

The particularity of this work is that the two floors facility was transformed into a 35 kV plant where the complete equipment is placed on one floor, which allows a better view of the plant and facilitates the operating interventions.

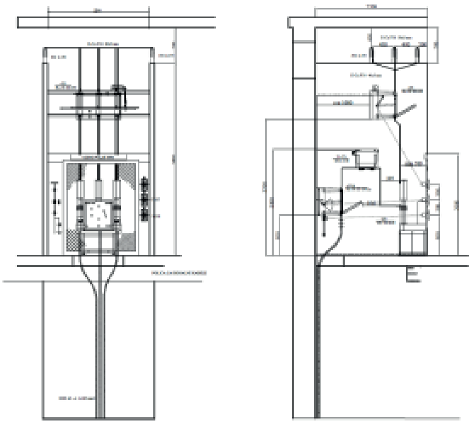

Image 6 Front view and section of 35 kV line bay after reconstruction

Works on 10(20) kV plant

After disassembling a part of 10 kV plant on the first floor, which was not powered, a safety cabinet and a remote-control system cabinet were installed.

In the floor of the ground floor, after disassembling cells of a part of the 10 kV plant, excavation of the KB channels and installation of U steel profiles were performed. In these works, it was important to level U profiles where the switch blocks 10 (20) kV were set.

The 10 (20) kV plant mounted in the first stage consists of 8 factory-fitted switchgear blocks. They were insulated with SF6 gas, rated current 1250 A, 16kA / 1s and equipped with primary and secondary equipment (terminals of bays, measuring terminals).

At this stage, switching blocks are installed:

- 1 transformer bay =J5
- 3 line bays =J1, =J2, =J3,
- 1 compensation bay =J4
- 1 measurement bay =J7
- home transformer bay =J6
- section bay =J8

Image 7 Works on the new 10(20) kV plant

Works required for reception of a power transformer

In addition to works within the building, works on the exterior of the plant have been carried out as well, including the adaptation of the transformer base for the reception of the transformer of 8 MVA power, the drainage surface, transformer oil drainage channel and oil well.

A transformer +T1 type 9NTBN 8000-38x, manufactured by Končar, was set on the adjusted base.

Connecting lines 35kV

The connecting line between the power transformer and support insulators located on the bracket-console was made of a flat copper conductor (E-Cu F 30, dimensions 40x10 mm) to which a 35 kV cable was connected (type XHE 49-A 1x185 mm2, 20/35 kV) and was laid all the way to the 35 kV transformer bay (bay = H3) in built concrete channels.

Cable terminals outside the 35kV plant are the POLT-42E / 1XO-ML-5-13 and within the plant the POLT-42E / 1XI-ML-5-13«, manufacturer Raychem.

Image 8 Bracket of support insulators, surge arresters and cable terminals on a 35 kV side of the power transformer

Connecting lines 10(20) kV

Connecting line from the 10 (20) kV side of the power transformer to the support insulators located on the bracket-console was made with a flat copper conductor (E-Cu F 30, dimensions 50x10 mm) to which a 10 (20) kV cable was connected (type 3 XHE 49 1x240 mm2, 12/20 kV) and was mounted up to the 10 (20) kV transformer bay (bay = J5) in built concrete channels.

Cables on both sides end with cable terminals, inside of the 35kV plant are of the type POLT-24D/1XI-ML-4-13 and outside of the plant are of the type POLT- 24D/1XO-ML-5-13, manufacturer Raychem.

Image 9 Bracket of support insulators, surge arresters and cable terminals on a 10 (20) kV side of the power transformer

Protective relays

A protection of the 35 kV bay was located centrally, in the protection on the facility's upper floor, while the protection of the 10 (20) bay of the plant is distributed on bays. Protection relays of the 10 (20) kV bay were installed on the door of the cabinet where the secondary equipment of the respective field is kept.

Protection relays are microprocessor relays, series RET 541, REF 541 and REF 543, manufactured by »ABB«.

Image 10 Protection cabinet of the 35 kV plant

Second stage of reconstruction

After completing the first stage, the built-in and tested equipment was put under voltage, thus ensuring the conditions for carrying out the work of the second stage.

The following works have been performed in the second stage:

- installation of the 35 kV transformer + T2

- reconstruction of 35 kV transformer bay (=H5) and a 35 kV line bay TS Nerežišća (=H6).

- installation of the second part of the 10(20) kV plant of 8 module switches (trasformer bay = J12; line bays =J11, =J13, =J14; compensation bay = J15; measurement bay =J10; section bay = J9)

- plant for neutral point earthing

Equipment for earthing neutral points of power transformers on the 10 kV side of the substation is foreseen to start working when the network conditions are created, and until than TS POSTIRA will work with an isolated neutral point.

The particularity of this phase of reconstruction is the connection of junction bays = J9 and = J8, performed by a cable type XHE 49 3x2x (1x240/25 mm2) 20 kV mounted in a pre-built channel.

T-connectors were built in connection bays (Dual Cable Kit type D) in order to connect the cable type XHE 49 1x240 mm2 (U0 / U = 12/20 kV) to the conductor isolator of the connection bay (connector type K676LRA-P2-K-240(K)M-11-2 EUROMOLD).

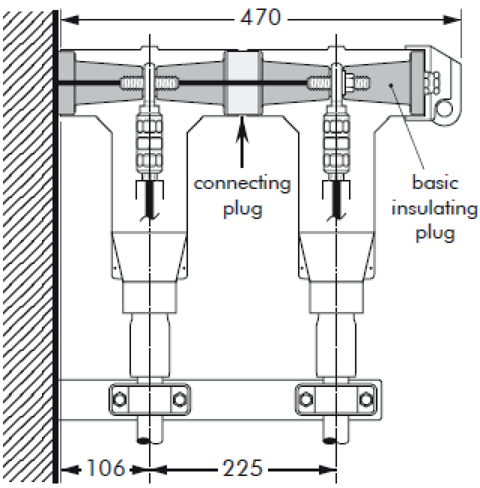

Image 11 Appearance of the connector for connecting the cable to the connection bay

Cabling

Along with works on substation POSTIRA, works on 35 kV and 10(20) kV cabling were performed.

Cabling 35 kV

The TS POSTIRA is powered in two ways: by a submarine cable from substation 110/35/10(20) kV DUGI RAT and by power line from substation 110/35 kV NEREŽIŠĆA.

The input of a cable from substation DUGI RAT is fixed in a way that the existing cable type IPHO 13 Cu 3x50 mm2 in the substation circle was replaced with a new cable type XHE 49-A 1x185 mm2 20/36 kV by using a transitional cable joint type EPKJ-36B/1XU-3SB-DE 10.

A part of the 35 kV power line from the substation NEREŽIŠĆA is cabled from the last pillar in front of the TS POSTIRA up to the substation. On a 35 kV pillar, the transmission of the power cable to the cable was performed using the appropriate cable terminals and surge arresters.

The cable is placed in a cable channel up to the wall in front of the substation. In the wall of the substation, holes 150 mm in diameter have been drilled with built-in PVC pipes. The edges of the aperture were later rounded to avoid damaging cables while installing them. The cable inside the substation is mounted following the wall up to the line bay Nerežišća, on the first floor of the substation.

Image 12 Openings for 35 kV cables

Cabling 10(20) kV

The substation POSTIRA has three 10 (20) kV outputs, out of which one is a cable put (line bay POSTIRA) and two outputs for overhead lines (line bay NEREŽIŠĆA and line bay PUČIŠĆA.

In the area of the substation, the existing cable type IPO 13 3x150 mm² from the line bay POSTIRA was replaced by a new cable type XHE 49A 3x1x185/25 mm² and a transitional cable joint type TRAJ 24/1x120-240-3SB was built in.

Image 13 Making of cable joint

The power line 10 (20) kV from VP NEREŽIŠĆA was cabled with a cable type XHE 49A 3x1x185 / 25 mm² to the edge of the particle where on the path of the existing power line was constructed a concrete pillar SB 1600/12, 12 m high, where the crossing from cables to power lines was installed. The pillar is equipped with a tightening console and tightening glass insulators and with a console and surge arrests HDA-12 M-NFF.

The power line 10 (20) kV from VP NEREŽIŠĆA was cabled with a cable type XHE 49A 3x1x185/25 mm² all the way to the existing wooden ''A'' pillar which was worn out and at the place where a new concrete pillar SB 1600/12, 12 meters high, was constructed. The pillar is equipped with a tightening console and tightening glass insulators and with a console and surge arrests HDA-12 M-NFF.

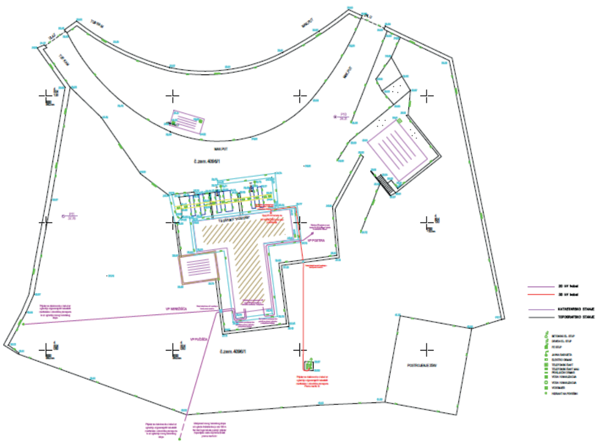

Image 14 Cabling situation

CONCLUSION

After the reconstruction of the substation TS 35/10 (20) kV POSTIRA, the criteria n-1 was satisfied. Greater reliability was ensured with modernization of 35 kV and 10 (20) kV and with the plant protection system.

When reconstructing existing buildings, a problem of predefined space is common, which often does not meet the need for new equipment. Therefore, we have to point out that for the 10 (20) kV plant were selected gas insulated blocks which are smaller in relation to the air-insulated switching blocks, thus allowing an increase of number of 10 (20) kV line bays from the existing five to the required nine (according to a single-pole scheme-image 15).

After reconstruction of TS POSTIRA, a remote controlling is possible from two existing remote-control centers: a distribution center DP Elektrodalmacija Split and a Center for plant management Brač. According to the new concept, center for plant management (CUP) will be a remote terminal of the central system in distribution center DP.

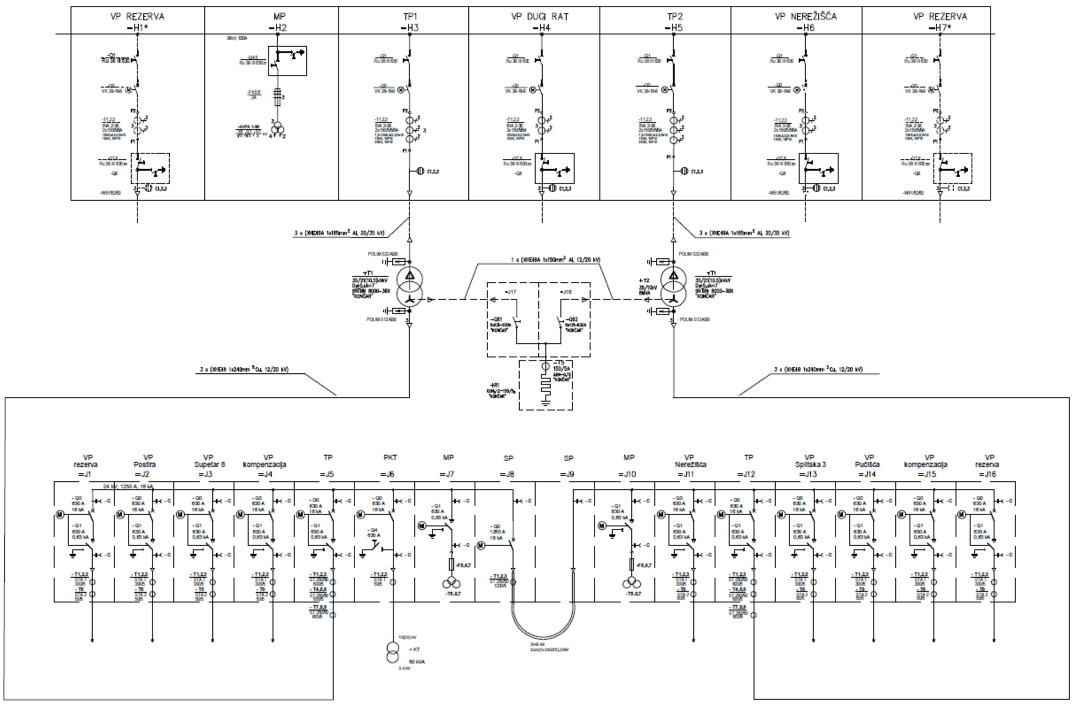

Image 15 Single pole scheme TS POSTIRA after reconstruction

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