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The impact of events in the Slovene high – voltage network on the power quality in the distribution networks

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SUMMARY

This work analyses the impact of different events in Slovene high-voltage network on power quality in the 20 kV and 0.4 kV distribution networks. In order to perform the analysis a simplified dynamic model of the Slovene power system was build in the program package Matlab/Simulink, using toolbox PowerSys. The obtained model is appropriate for simulation of electromagnetic transients in duration up to a few seconds. It contains simplified dynamic models of all main generators and power transformers installed in the Slovene power system, detailed models of 400 kV, 220 kV and 110 kV networks, simplified models of the neighboring power systems and models of important consumers. The 20 kV and 0.4 kV distribution networks are modeled in the details only in the area of interests. Everywhere else, they are represented as constant loads connected to the 110 kV network.

The aforementioned dynamic model was applied to analyze the impact of different events in the Slovene power system on power quality in the 0.4 kV distribution network during transients and in steady states. The power quality in distribution network was analyzed on 0.4 kV busbars in five substations (Cerkno, Škofja Loka, Vevče, Šentjur, Rače) for the following set of events: a switch-off of a 300 MVA (400 kV/110 kV) power transformer in the substation Okroglo; a three-phase short circuit on 110 kV busbars in the substation Kleče; a three-phase short circuit on 20 kV busbars in the substation Rogaška Slatina and a switch-on in a pumping regime of pump-turbine plants Avče and Kozjak which are currently at the design stage. The results obtained show that aforementioned events in some points of Slovene distribution network can cause power quality distortion over that allowed by the power quality standards.

KEYWORDS
Power system – Dynamic Model – Voltage Sag – Simulation – Power Quality .

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1. INTRODUCTION

This work analyses the impact of different events in Slovene high-voltage network on power quality in the 20 kV and 0.4 kV distribution networks. In order to perform the analysis an appropriate dynamic model is needed. It must be appropriate to handle electromagnetic power system transients that appear in the same frequency range as voltage sags treated in [1]-[3]. According to the time frame of various power system phenomena [4], this range must be between 10 μs and a few seconds. An appropriate and simplified dynamic model of Slovene power system is briefly presented in this work. It is applied to evaluate the impact of different events in the power system on power quality in 0.4 kV distribution networks.

2. A SIMPLIFIED MODEL OF SLOVENE POWER SYSTEM

This section gives a short description of a simplified dynamic model of Slovene power system build in the program package Matlab/Simulink using toolbox PowerSys. Initial conditions for simulations are normally determined by calculating load flow.

2.1 Generator model

It is reasonable to use the complete Park's two-axis generator model with considered magnetic nonlinearities of the iron core only in the cases when turbine, excitation system and control models too are included in the dynamic power system model. However, the simplified model of Slovene power system is used for study of electromagnetic transients which appear relatively far away from the generator's terminals. In such cases generator model can be represented with sufficient accuracy by a voltage source with generator internal impedance in series. The generator output power can be adjusted by the amplitude and angle of the voltage source. Of course, the complete Park's generator dynamic model can be used together with turbine, excitation system and control models if their structures and parameters are known.

2.2 Power tranformer model

A variety of three phase transformer models can be used. All of them are composed of connected single phase transformers with two or three windings. Required transformer data are nominal voltages and resistances of all windings and rated power. Iron core losses and magnetically nonlinear iron core characteristic can be included in the model if they are available. In the simplified power system model magnetically nonlinear transformer models are used when magnetically nonlinear iron core characteristic is available. In all other cases magnetically linear models are used. A substantial difference between results obtained by the magnetically linear and nonlinear transformer dynamic models can be noticed only when a switch-on of an unloaded transformer is studied.

2.3 Models of transmission and distribution lines

The transmission and distribution lines are accounted for by π models. They require resistance, inductance and capacity for positive and zero symmetric components sequences per kilometer and length of the entire line.

2.4 Models of transmission and distribution networks and loads

The discussed simplified dynamic power system model contains models of all important generators, transformers, power lines and loads. The 400 kV, 220 kV and 110 kV networks are modeled in details. Lower voltage networks are modeled in details only in the area of interest while everywhere else they are presented as constant loads. In order to achieve the best possible agreement between the measured and calculated results, the exact loading conditions for each individual point of the power system at given instant must be known before simulation is started. Usage of average loading conditions measured for a given time interval in simulations normally leads to disappointing results.

2.5 Considering neighboring power systems

Slovene power system is connected to the neighboring power systems in 13 high voltage points. The short circuit impedance in these points is low due to high apparent power. In the simplified model of Slovene power system the neighboring power systems are accounted for passively by voltage sources connected in series with short circuit impedance in given point. The correct power flow is achieved by appropriate amplitude and angle of the voltage source.

3. MODEL EVALUATION

The proposed simplified dynamic model of Slovene power system was confirmed in two ways. The steady state accuracy of the dynamic model was confirmed through the comparison of calculated results with those obtained by the professional program for steady state analysis and network optimization NEPLAN. The agreement of steady state voltages during normal operating conditions is very good, while the steady state voltages during the three-phase faults can differ up to 4 % in 0.4 kV network. The dynamic response of the model was partially confirmed by the comparison of calculated results with the results of field testing performed on 20 kV in the substation Rogaška Slatina. The agreement between measured and calculated results is very good for the three-phase faults as well as for the line to line and line to ground faults. Thus, the dynamic responses of the model are confirmed for the tested substation and its vicinity, while the entire model is confirmed only for the steady state operation by the results calculated with NEPLAN.

Table 1 shows decrease of voltage RMS values on 110, 20 and 0.4 kV busbars in substation Cerkno caused by a three-phase short circuit in the middle of 110 kV overhead line Divača – Ajdovščina. The results calculated by NEPLAN and by proposed simplified dynamic model are given for the steady state during aforementioned short circuit.

Table 1: Comparison of voltage drops calculated by NEPLAN and by dynamic model on 110, 20 and 0.4 kV busbars in substation Cerkno caused by a three-phase short circuit in the middle of 110 kV overhead line Divača – Ajdovščina.

Substation Cerkno	Dynamic model	NEPLAN	Differences[%]
110 kV	14,6 kV	14,54 kV	0,41
20 kV	2,27 kV	2,27 kV	0,00
0,4 kV	57 V	55 V	3,63

4. RESULTS

The proposed simplified dynamic model of Slovene power system was applied to evaluate the impact of different events on power quality in 0.4 kV distribution networks. Simulations were performed for the following list of events:

1. a three-phase short circuit on a 110 kV busbars in the substation Kleče,
2. a switch-off of a 300 MVA power transformer in the substation Okroglo,
3. a three-phase short circuit on a 20 kV busbar in the substation Rogaška Slatina,
4. switch-on in a pumping regime of pump-turbine plant Kozjak and
5. switch-on in a pumping regime of pump-turbine plant Avče.

The impact of these events on the power quality in 0.4 kV distribution networks is in this work analyzed in the following points:

1. 0.4 kV busbars in the substation Cerkno,
2. 0.4 kV busbars in the substation Škofja Loka,
4. 0.4 kV busbars in the substation Šentjur and
5. 0.4 kV busbars in the substation Rače.

Figure 1 shows results calculated for the three-phase short circuit on 110 kV busbar in the substation Kleče. The three-phase short circuit appears in the time interval between 0.04 s and 0.12 s. The calculated line voltages on 0.4 kV busbar in substations Cerkno, Škofja Loka, Šentjur and Celje are shown in Figure 1. The left hand side of the Figure 1 shows calculated time dependent wave forms of all three voltages, while the right hand side of the same figure shows the time dependent RMS values for voltages in line L1. Only the last type of presentation is used for the presentation of results that follow.

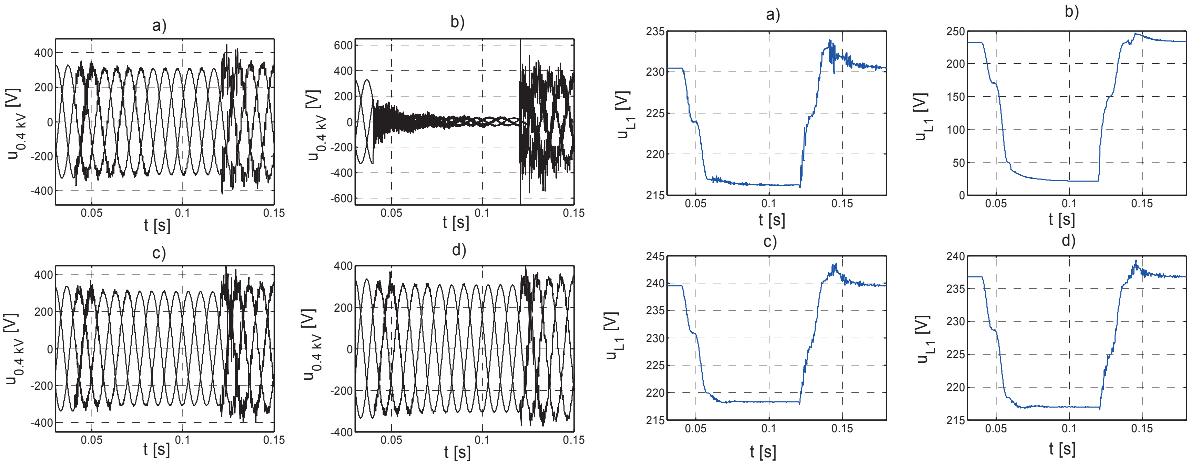

Figure 1: Voltages on 0.4 kV busbar in substations a) Cerkno, b) Škofja Loka, c) Šentjur and d) Rače, during a three-phase short circuit on 110 kV busbar in substation Kleče.

The results presented in Figure 1 show that the three-phase short circuit on 110 kV busbar in the substation Kleče can substantially influence power quality in Slovene 0.4 kV distribution networks. The depth of the voltage sag on 0.4 kV busbar in the substation Škofja Loka, caused by this event, is much higher than it is allowed by the Slovene standard for power quality SIST EN 50160.

The next example shows the impact of switch-off of a 300 MVA power transformer (400 kV / 110 kV) situated in the substation Okroglo. The switch-off appears in the time interval between 0.04 s and 0.12 s. Figure 2 shows time dependent RMS values for line L1 voltage on 0.4 kV busbar in substations Cerkno, Škofja Loka, Šentjur and Celje.

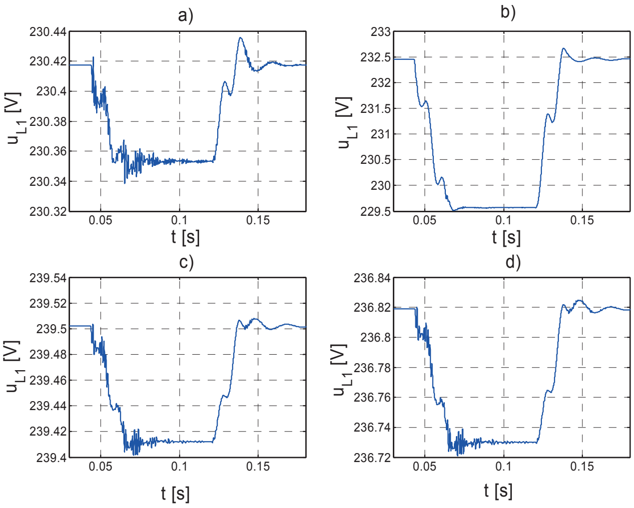

Figure 2: Voltages on 0.4 kV busbar in substations a) Cerkno, b) Škofja Loka, c) Šentjur and d) Rače, during switch-off of 300 MVA power transformer (400kV / 110 kV) in substation Okroglo.

Figure 3 shows time dependent RMS values for line L1 voltages on 0.4 kV busbar in substations Cerkno, Škofja Loka, Šentjur and Celje for the case of a three-phase short circuit on 20 kV busbar in the substation Rogaška Slatina. Again, the short circuit appears in the time interval between 0.04 s and 0.12 s.

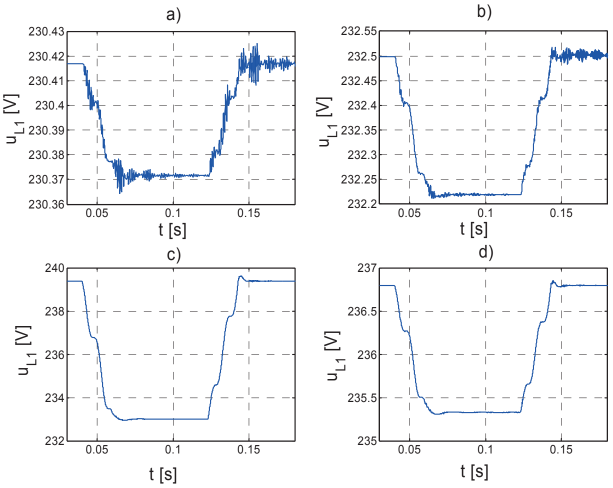

Figure 3: Voltages on 0.4 kV busbar in substations a) Cerkno, b) Škofja Loka, c) Šentjur and d) Rače, for the case of a three-phase short circuit on 20 kV busbar in the substation Rogaška Slatina.

Results presented in Figures 4 and 5 show the impact of pump-turbine plants Kozjak and Avče during their switch-on in the pumping regime. The pump-turbine plant Kozjak is at present at the design stage. It will be build above the Drava valley. The pump-turbine plant Avče is under construction close to the Soča valley. Both pump-turbine plants will use so called var-speed technology to limit the pumping regime switch-on currents. In the simulations, their switch-on is considered as a switch-on of a constant load 180+j30 MVA for Avče and 400+j80 MVA for Kozjak. In both cases the switch-on appears in the time interval between 0.04 s and 0.12 s. The time dependent RMS values for line L1 voltages on 0.4 kV busbar in substations Cerkno, Škofja Loka, Šentjur and Celje are shown in Figure 4 for the pump-turbine plant Kozjak and in Figure 5 for the pump-turbine plant Avče.

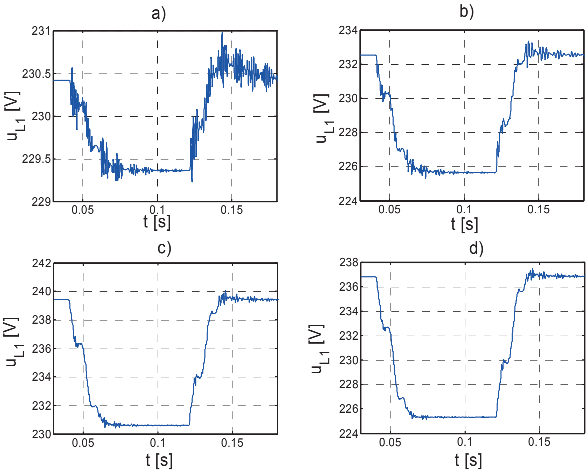

Figure 4: Voltages on 0.4 kV busbar in substations a) Cerkno, b) Škofja Loka, c) Šentjur and d) Rače, calculated for pumping regime switch-on of pump-turbine plant Kozjak.

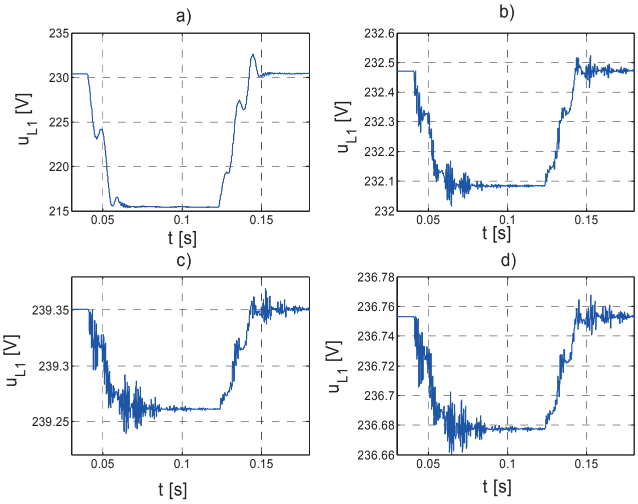

Figure 5: Voltages on 0.4 kV busbar in substations a) Cerkno, b) Škofja Loka, c) Šentjur and d) Rače, calculated for pumping regime switch-on of pump-turbine plant Kozjak.

5. CONCLUSION

A simplified dynamic of Slovene power system is presented in this paper. The proposed dynamic model is appropriate for study of electromagnetic transients in the power system. It is applied to evaluate the impact of different events in the power system on power quality in 0.4 kV distribution networks. The results presented show that the impact of some events presented in this paper on power quality in distribution networks is much higher than it is allowed by the national power quality standard.

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