Impact of photovoltaic power plants on voltage stability of power system

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***Abstract*—This paper deals with the impact of Photovoltaic Power Plants (PPP) on remote voltage control (DRN). Paper also considering the assessment of DRN quality as a change of delivered reactive power. The impact of PPP on DRN is modelled on Slovak power system model in program MODES. Results shows significant impact of RES on voltage stability.**

***Keywords*— Photovoltaic power plant, remote voltage control, quality assessment**

I. Introduction

The obligation to purchase all the power from renewable energy source (RES) caused a significant increase in the share of resources in the power system, which is very hard to regulate. Another drawback of RES is the variability of electricity production depending on weather conditions. This is particularly true for Photovoltaic power plants (PPP) whose mandatory electricity production depends on solar radiation. Sudden changes in weather - the transition of clouds, which cause a significant change in the delivered power from PPP are problematic. These changes are difficult to predict and in order to ensure the stability of the power system (PS), it is necessary to ensure an equivalent reserve power as a regulatory reserve.

In 2017 renewable energy represented 17.5 % of energy consumed in the EU, on a path to the 2020 target of 20 %. The share of total installed capacity is about 9 percent, while PPP has a share of 6.2% of the total installed capacity. Total installed capacity of PPP in Slovakia is 630 MW as of 31 December 2017. In the same year, the maximum share of RES output to cover daily load diagram of was 13,7%, which in absolute terms represented a maximum production of 300 MW from PPP. This phenomenon results in the need to ensure sufficient regulatory reserve, which TSO is obliged to hold to ensure the system's performance stability [3]. This significantly increases the risk of instability in the event of an unexpected system failure. The task of the thesis is to create a model of the PS SR in the MODES program, on which the dynamic events that can be realized in the system will be tested. The effect of PPP on the system voltage results from increased active power production and thus an increase in node voltage. Part of the PS SR system model are three-winded transformer with HRT Three-winding transformer model.

- In the PS SR model, triple winding TR models were used for all system transformers in the system. Fig. 1 is a three-winded TR replacement scheme used in MODES:
- Neglecting of mutual scattering magnetic fluxes between windings,
- Neglect of saturation,
- Magnetic conductivity (or Magnetic inductance) is quadratically dependent on the number of TR turns.

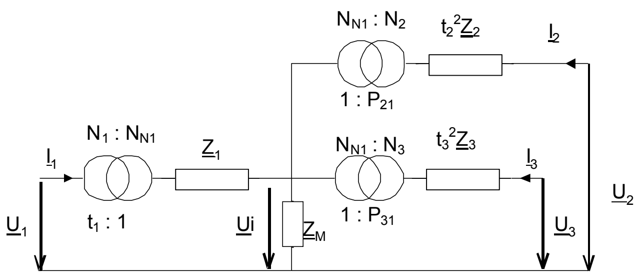

Fig. 1. Triple winding TR models

The advantage of the wiring shown in Fig. 1 is that the individual impedances Z, have constant parameters found at the nominal number of turns. Since the variation of the tap change (number of turns) varies, it is appropriate to define the tap change winding first. In the diagram, ideal TRs are used for which (1) and (2) apply for voltages and currents depending on the number of turns N.

$$\frac{U_1}{U_2} = \frac{N_1}{N_2} \quad (1)$$

$$\frac{I_1}{I_2} = \frac{N_2}{N_1}; \quad (2)$$

1. Calculation of individual parameters of the substitution scheme is according to [1]. Three-turn TR enable automatic tap-switching (HRT).

2. Transformer tap switching

Transformers that are part of the network can maintain the voltage at a specified interval by switching TR taps under load. The switching is controlled automatically by the voltage level regulator - HRT, whose characteristics are given by the network model type parameters described below.

The principle of operation of the TR branch control is as follows. If the voltage deviation in the monitored node is greater than the specified value (ε_{INT}), the TR tap changeover command is executed immediately. If the regulated voltage deviates from the entered value by UNEC insensitivity, the tap turns with a delay of T_{ACT} (modelling the self-switching delay) and the time T resulting from the HRT characteristic.

After switching the HRT, the activity of the HRT is blocked for T_{BLOCK} time to ensure that the transient events are complete and the switching mechanism is ready for further HRT activation. When the voltage drops below U_{BLOCK} (which is part of the HRT controller type parameters), the HRT operation is blocked so that the operating state of the network is not further impaired by further voltage reduction.

Voltage regulation resp. the reactive current flow is thus effected automatically by switching TR taps.

II. Assessment of DRN Quality as a Change of Delivered Q

For comparison, the same scenario and conditions were modeled in the PS SR system to verify remote voltage regulation (DRN) activity. The change in the Q balance in the system was achieved by connecting a choke. The choke with power Q_{TL} = 45 MVA was connected to tertiary winding TR T401Lem at time t_{TLON} = 500 s to verify the operation and correctness of automatic switching of TR taps.

The waveform of the nodes for the case of activated (nodes with TAP - solid curve) and deactivated (dashed curve) HRT is shown in Fig. 2. Voltage change in node Voľa at 220 kV voltage level is U_{VOL220} = 0.66 kV after connection of reactor, in Lemešany node at the same voltage level it is ΔU_{LEM220} = 1.45 kV in case of deactivated HRT.

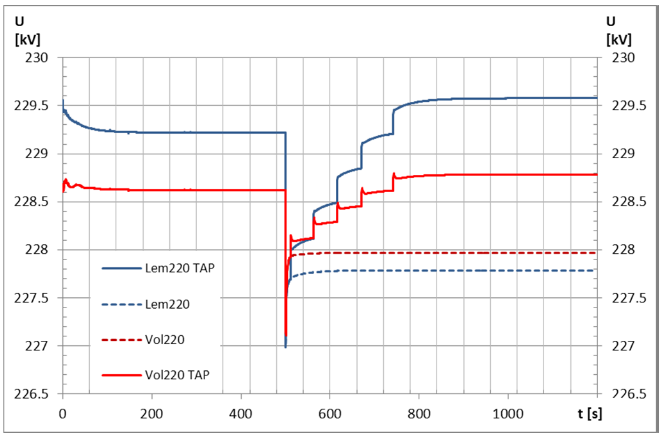

Fig. 2. Voltage curve in Lemešany (Lem) and Voľa (Vol) nodes in case of reactor connection at 500 s.

The quality assessment of DRN is carried out at PS pilot nodes. According to [5], the PS SR pilot nodes are at a voltage level of 400 kV at Sučany, Bošáca, Križovany, Lemešany, Velké Kapušany, Veľký Ďur, Gabčíkovo, Liptovská Mara and Stupava substations. DRN quality evaluation was performed at pilot nodes at 400 and 220 kV voltage levels. DRN operates in 2 modes. The first is to maintain the pilot node voltage at a predetermined value. The predefined value can be adjusted by dispatcher The second mode is to keep the voltage on level to minimize losses in the power system.

The DRN quality evaluation was performed over a period of 30 minutes (1800 seconds). The change of the specified voltage was achieved by the intervention according to the scenario at the time t_K = 600 s. On the HRT on TR $T_{Kriz401}$, the scenario entered the change of the required voltage at the L_{em220} node by -0.2 µs, which is U = 1.6 kV.

The diagram of the required and actual voltage in the Ktiz220 node is shown in Fig. 3. The voltage in this case is regulated only by the HRT automatics, that is, by switching TR taps under load. The blue interval indicates the required node voltage stabilization time at the required time.

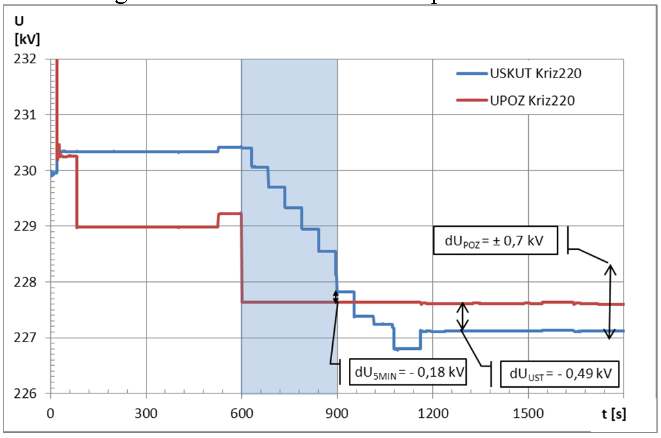

Fig. 3. The course of the setpoint and actual voltage value at the Kriz220 node

The difference between the actual and the setpoint voltage at the node at 5 minutes after the change of the setpoint voltage is dU_{5MIN} = 0.183 kV. The results of the DRN quality evaluation analysis at the pilot nodes at the 220 kV voltage level are shown in Table Tab. 1. The ΔU_{DRN} values marked in red do not comply with the DRN quality assessment condition. Fig. 4 represents ΔU_{DRN} values for individual minute integrals during the 30-minute simulation.

TABLE I. Results of Assessment of DrN Quality in Pilot Nodes 220 kV

t[s]	ΔU_{DRN} Kriz220	ΔU_{DRN} Lem220	ΔU_{DRN} Suc220
60	3,13714	3,11637	0,99909
120	0,59210	0,68939	0,67948
180	0,00024	0,00413	0,00032
240	0,00133	1,98670	0,00371
300	0,00060	0,21495	0,00374
360	0,00034	0,01230	0,00073
420	0,00122	2,08069	0,00392
480	0,00047	0,01930	0,00109
540	0,06208	0,20718	0,00799
600	0,00061	0,67053	0,00368
660	17,48703	0,02250	0,06804
720	2,48647	0,04027	0,06959
780	2,04266	0,04064	0,05752
840	1,30331	0,03005	0,03821
900	0,89056	0,20733	0,02961
960	1,29175	0,22388	0,03080
1020	1,33765	0,01318	0,00803
1080	0,13665	0,03979	0,01416
1140	0,00593	0,02279	0,00556
1200	0,43002	0,08558	0,06399

1260	0,43061	0,03767	0,05815
1320	0,00069	0,15323	0,00516
1380	0,00387	0,21223	0,00758
1440	0,40847	0,03522	0,05651
1500	0,41008	0,24115	0,05127
1560	0,00113	0,22568	0,00354
1620	0,03088	0,01095	0,00827
1680	0,43054	0,24729	0,05863
1740	0,41015	0,21457	0,05443
1800	0,00149	0,01405	0,00085
Un	220	220	220
UN/100	2,2	2,2	2,2

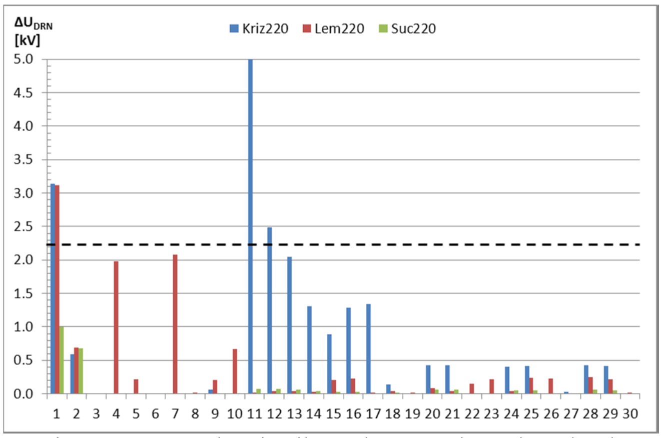

Fig. 4. ΔU_{DRN} values in pilot nodes at 220 kV voltage level

The voltage waveform in all pilot nodes at 220 kV and 400 kV voltage level is shown in Fig. 5 and Fig. 6.

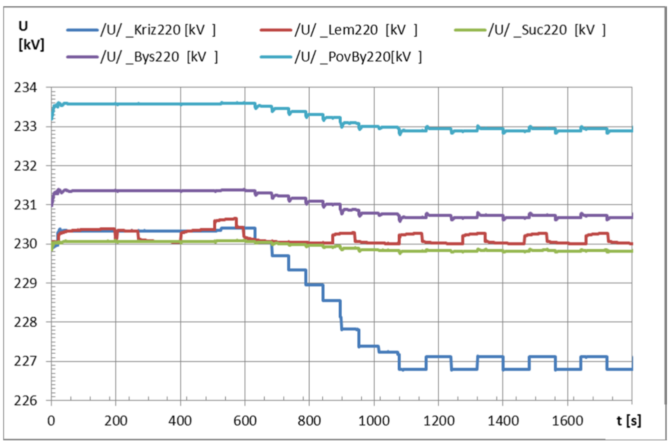

Fig. 5. Voltage waveform in PS of SR pilot nodes at 220 kV voltage level

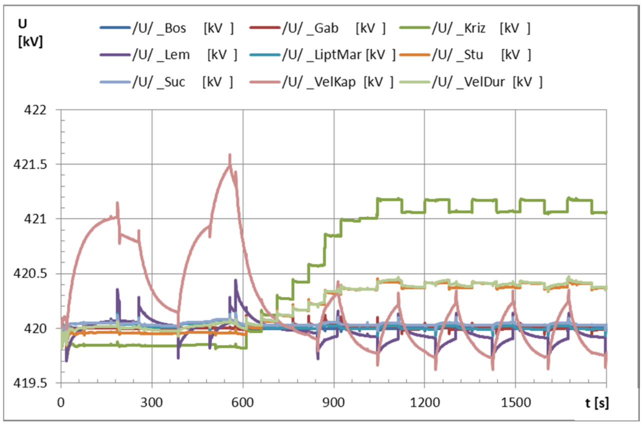

Fig. 6. Voltage waveform in PS SR pilot nodes at 400 kV voltage level

III. Impact of PPP on Remote Voltage Regulation (DRN) Quality

For the purpose of modelling the effect of PPP on node voltage, the PS SR model was supplemented with a part of the distribution system. The power from the PPP_Medz block, which is equivalent to the production from PV in the Central Slovakia distribution system (DS) with installed power P_{PPP} = 314 MWp, was partially replaced by several smaller sources representing individual PV plants operating in the distribution system whose output is brought to 22 kV voltage level and TR 110/22 (which is modelled with substitute parameters R, X, B) and a cable duct with parameters connected to the Intermediate Point. Subsequently, the voltage at 22 kV network nodes was monitored. Up to 110 kV network is through modelled TR 110/22 kV. The diagram of the supplemented DS is shown in Fig. 7

Reactive power of regulators of newly created small PV plants worked in two modes:

- Constant voltage mode,
- constant reactive current mode,

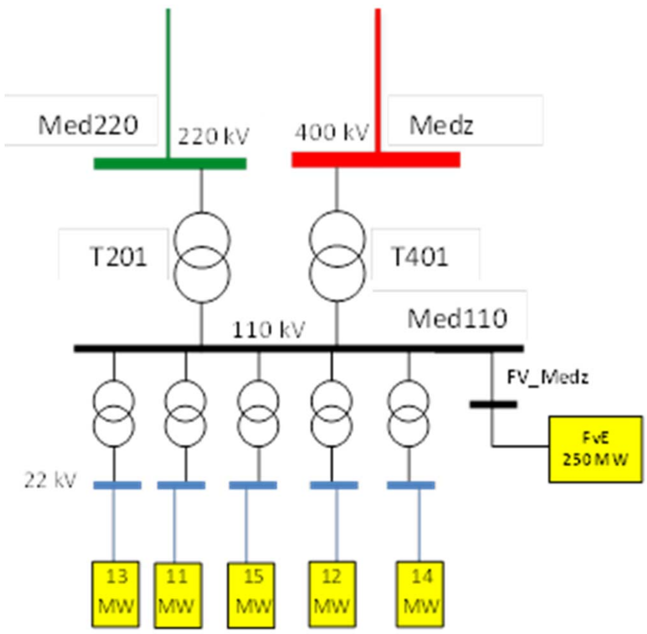

Fig. 7. Single-pole diagram of PPP connection to Medzibrod substation

The voltage waveform in the 22 kV DS nodes with the PPP output power is for the Q controller in the reactive power control mode in Fig. 8. Primary voltage control - Q / U control at the point of block output is in this case switched off by setting the controller Q. The voltage deviation of 10% from the initial value (23.4 kV) is shown in the graph by a horizontal dashed line. This value is not reached even at maximum power PPP. For comparison, the graph shows the voltage curve in the node at the 110 kV level ($U_{FV\ Medz110}$), to which PPP from DS and the original PPP are connected.

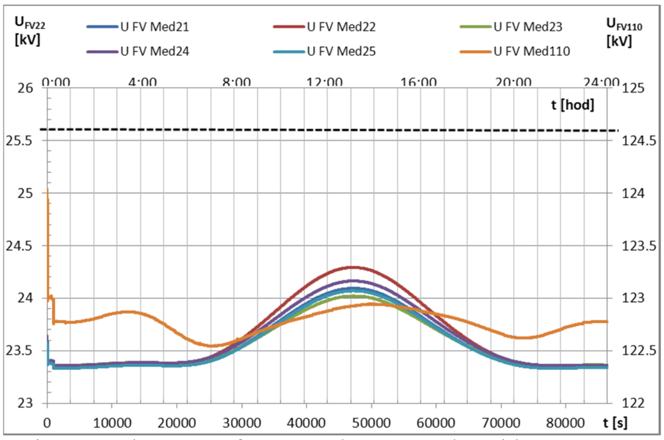

Fig. 8. Voltage waveform at 22 kV PPP nodes with constant Q control mode

In this control mode, the reactive PPP current supplied is constant regulated by the voltage change in the node.

In the voltage control mode, the reactive power supplied changes (Fig. 9). The voltage in the nodes at the 22 kV voltage level is constant, only the voltage changes beyond TR at 110 kV. The course of reactive power is shown in Fig. 10.

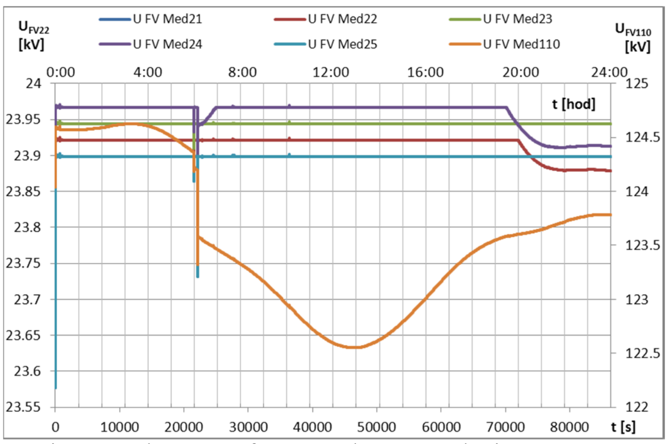

Fig. 9. Voltage waveform at 22 kV PPP nodes in constant U control mode

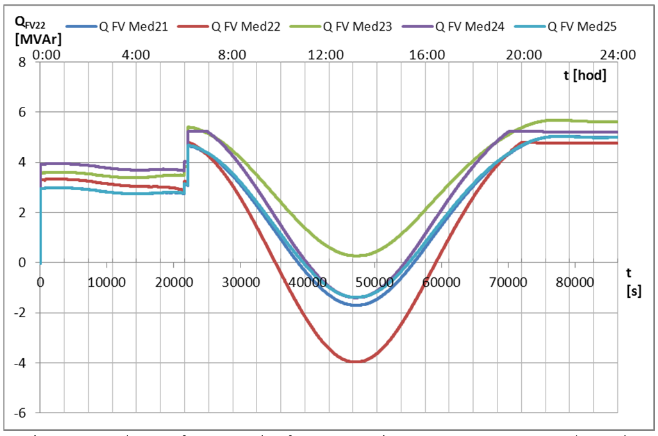

Fig. 10. Flow of Q supply from PPP in constant U control mode

In the case of voltage control mode, the reactive power supplied or the power is supplied. Taken from PPP varies within the range set in the type parameters of the controller. In this case, the Q range was set to ± 4.67 MVAr. This value of Q did not reach and therefore the voltage value was kept constant. Step change Q resp. U was caused by a change in the TR branch.

During analysing the effect of PPP on DRN quality, pilot node voltages were monitored at a 220 kV voltage level (Lem220, Kriz220, Suc220). The pilot node tension was monitored in four different cases

- No PPP connected to the grid,
- connected only PPP in RO SVK (P_{FVESK} = 630 MWp),
- connected only equivalent PPP in SZKE ($P_{FVESZKE}$ = 18.2 GWp),
- all PPP connected.

The course of the voltage deviation in the node from the set point (230 kV) during 24 h at the Leme220 node is shown in Fig. 11. The equivalent of PPP, which represents production from PPP in the regional DS, is delivered to the Leme110 node. The voltage step changes are caused by switching the TR tap.

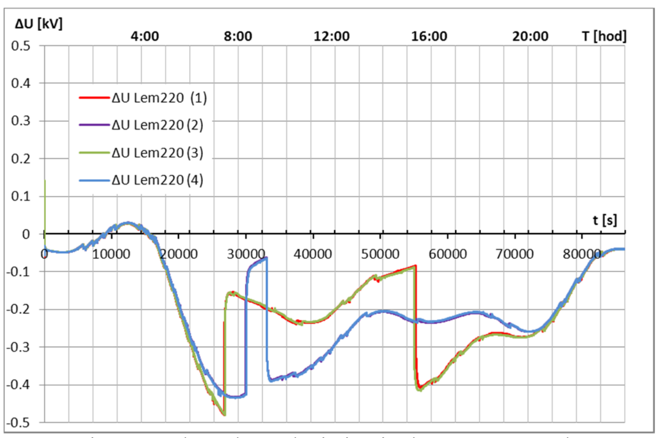

Fig. 11. The voltage deviation in the Leme220 node

The effect of PPP on the voltage in PS SR is thus due to primary voltage regulation minimal. The voltage change occurs at lower voltage levels of DS, which can, however, be compensated by a change in the reactive power supply of the sources working to the DS, eventually by a change in the TR

VVN / 110 branch, or alternatively. The voltage change due to PPP is directly in the node where the PPP output is less than 0.5 kV. Depending on the node, any change in voltage is changed by changing the excitation of a nearby reactive power source or by changing the TR branch at a nearby substation. The effect of PPP on the voltage variation in the node where the power is output depends directly on the size of the installed PPP power. However, it is significantly diversified in the distribution system.

As mentioned above, the voltage deviation caused by the delivery of active power from the PPP is compensated by a change in the generator excitation - the primary voltage regulation. In the PS SR model, RDP is activated at the EMO and EBO power plants. The process of supplying the Q block of TG31 in the EBO power plant is shown in Fig. 12

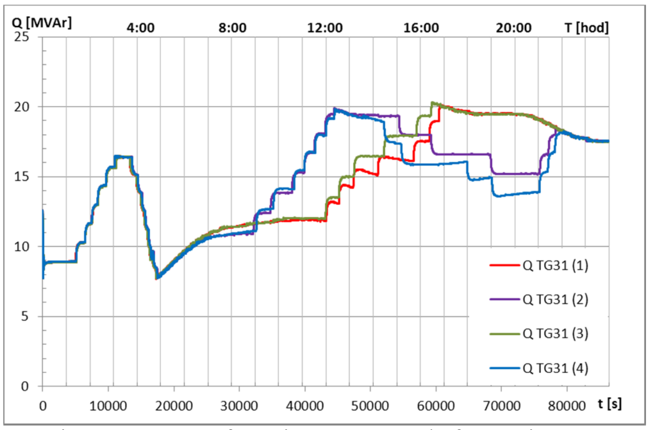

Fig. 12. Course of reactive power supply from unit TG31

The voltage waveform in the other PS pilot nodes at the 220 kV voltage level and the reactive power supply of the units operating to the PS for the above cases are shown in Fig. 13 to 16.

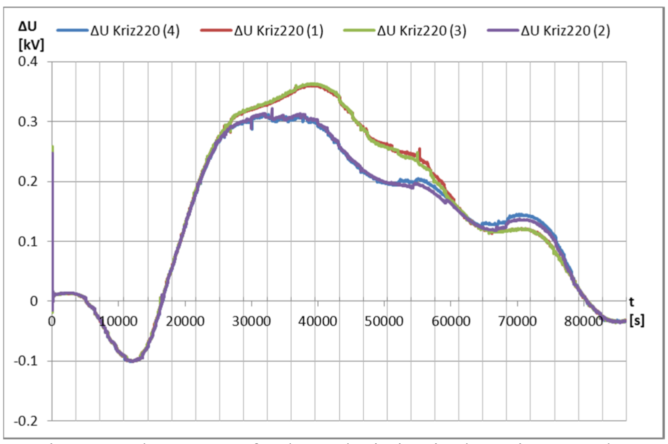

Fig. 13. The course of voltage deviation in the Kriz220 node

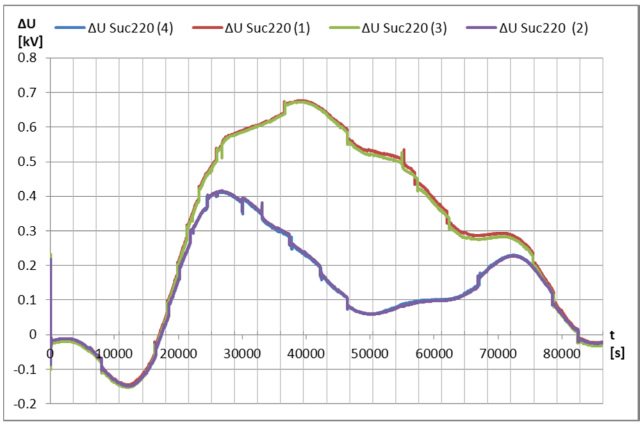

Fig. 14. The course of voltage deviation in the Suc220 node

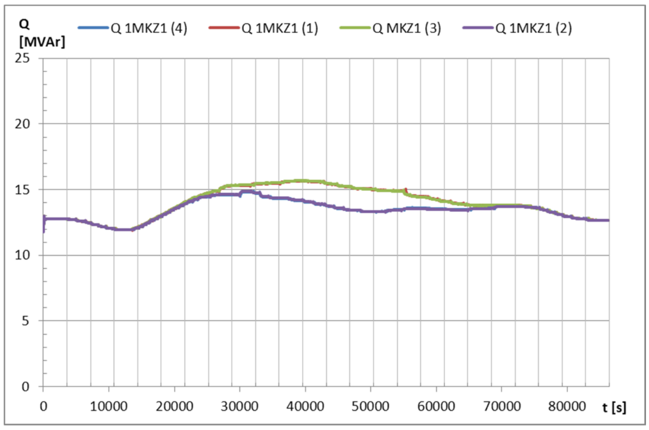

Fig. 15. Course of delivery Q from source 1MKZ1

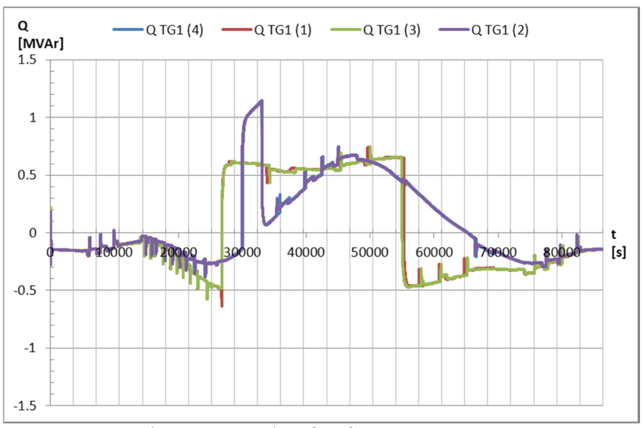

Fig. 16. Supply of Q from source TG1

IV. Analysis of Results

The mathematical model of PS SR created in the MODES program is in the described topology and deployment of resources suitable for modelling the activities of PPP. The sources in the RO SR led directly to the transmission system are modelled individually by individual power plant units. The blocks that work into the DS are modelled by two equivalent blocks, one representing hydroelectric power stations that have their specific parameters and dynamic properties compared to thermal. The second equivalent block represents other thermal power plants working into the system (except for the ENO, which is modelled as a separate source).

The task of dynamics modelling was to analyse the impact of PPP on long-term resp. medium-term dynamic behaviour of the interconnected system, special sources working to the MA SR

In the first step, the normal operation of the system is analysed throughout the day, considering day load diagram. The aim was to compare the current day for different weather conditions. First of all, it is a comparison of the clear (prediction of production from PPP is relatively accurate and the dispatching can ensure sufficient secondary regulation reserve) and the cloudy day, when the change of supply from PPP is relatively fast and hard to predict. The latter case occurs under specific conditions in the system when passing the hilly cloud over the territory with a high density of installed power in PPP.

The remote voltage regulation (DRN) is investigated on the PS model at the PS nodes. In this case, it can be said that the influence of PPP on PS pilot nodes is small to negligible under the set conditions of PPP impact. The voltage change occurs in the distribution system nodes. There are several ways to regulate the voltage in the node to which the PPP power is applied. Firstly, it is the regulation of Q by PPP itself. In the case of pilot nodes, this is the regulation of the proximity of the near-block excitation, possibly by changing the TR transmission under load. In the real system, all PPP are led to the DS, therefore it is difficult to accurately determine the effect of PPP on the node voltage when modelling the PS SR.

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REFERENCES

[1] KAREL MÁSLO: Dynamické modely pro dispečerské tréningové simulátory Poděbrady 2008 - 13. Ročník

[2] A. KASEMBE, K. MÁSLO: Regulace Napětí v Elektrizační Soustavě (ES) ELEN 2000

[3] P. Hocko,M. Kolcun “Modelovanie diaľkovej regulácie napätia v programe MODES” In: Electric Power Engineering 2011 : proceedings of the 12th international scientific conference : May 17-19 2011, Kouty nad Desnou, Czech Republic. - Ostrava : VŠB-TU, 2011 P. 1-4. - ISBN 978-80-248-2393-5

[4] Ročenka SEPS a.s. Dokument dostupný on-line: http://sepsas.SK/seps/DispSkladacka2012.asp?kod=559

[5] R. Šmidovič, J. Rusnák, “The possibilities of optimal voltage control for pilot node in Lemešany”. In: Zborník z konferencie ELEKTRO 2006, 2 s. 23. – 24. máj 2006, Žilina, SR

[6] Annual report SEPS a.s. on-line: http://sepsas.SK/seps/DispSkladacka2012.asp?kod=559

[7] Z. Čonka, M. Kolcun: Impact of TCSC on the Transient Stability In:Acta Electrotechnica et Informatica. Roč. 13, č. 2 (2013), s. 50-54. ISSN 1335-8243 Available on internet :www.versita.com/aei.

[8] Ministry of Economy of Slovak Republic: Návrh Energetickejpolitiky Slovenskej republiky, May 2014 Online: cit.[19. feb. 2015] http://www.rokovania.sk/File.aspx/ViewDocumentHtml/Mater-Dokum-165253?prefixFile=m_

[9] R. Cimbala, J. Kiraly, M. German-Sobek, S.Bucko, J. Kurimsky, J. Dzmura,”Polarization Phenomena in Magnetic Liquids”,.In: Chemicke listy Volume: 109 Issue: 2 Pages: 117-124

[10] B. Dolník, J. Kurimský, “Contribution to earth fault current compensation in middle voltage distribution networks”. PRZEGLD ELEKTROTECHNICZNY (Electrical Review), ISSN 0033-2097, R. 87 NR 2/2011

[11] J. Zbojovský, M. Pavlík, “Calculating the shielding effectiveness of materials based on the simulation of electromagnetic field “ In: Elektroenergetika 2017. - Košice : TU, 2017 S. 369-372. - ISBN 978-80-553-3195-9

[12] D. Medved, M. Klesc, „Modeling of electrical off-grid network in the simscape power systems“, In: Elektroenergetika 2017. Košice: TU, 2017, pp. 465-470. ISBN 978-80-553-3195-9.

[13] D. Medved, L. Misencik, M. Kolcun, J. Zbojovsky, M. Pavlik, „Measuring of magnetic field around power lines“, In: Elektroenergetika 2015. Košice: TU, 2015, pp. 144-147. ISBN 978-80-553-2187-5.

[14] A. Mikkelsen, A. Kertmen, K. Khobaib, M. Rajňák, J. Kurimskỳ, Z. Rozynek, Assembly of 1D granular structures from sulfonated polystyrene microparticles, Materials. 10 (2017). https://doi.org/10.3390/ma10101212.

[15] Herchl, F. et al.: Dielectric properties of magnetic liquids in high electric fields. In: Acta Physica Polonica A. Vol. 113, no. 1 (2008), p. 569-573, ISSN 0587-4246

[16] I. Kolcunova, M. Pavlik, L. Lison,“Assessment of long thermal ageing on the oil-paper insulation,“ Advances in Electrical and Electronic Engineering, 14(5), 506-511. doi:10.15598/aeee.v14i5.1836

[17] J. Dzmura, J. Petras, J. Balogh, J. Kurimsky, R. Cimbala, I. Kolcunova, B. Dolnik, M. Kolcun, "Separation of solid particles from flowing,gases by AC high voltage," in JOURNAL OF ELECTROSTATICS, vol. 88, ELSEVIER SCIENCE BV, 2017, pp. 158-164, ISSN: 0304-3886

[18] J. Pálfi, M. Tompa, P. Holcsik,“ Analysis of the Efficiency of the Recloser Function of LV Smart Switchboards” In: ACTA Polytechnica Hungarica, Vol. 14, No.2. 2017, ISSN: 1785-8860

[19] K. Máslo, M. Pistora: Dlouhodobá Dynamika Soustavy s Rozptýlenou Výrobou Včetně OZE Tábor 9. a 10.11.2010 Konference ČK CIRED 2010 K. Máslo, M. Pistora - Sekce č. 4 / 4 © ČK CIRED 2010

[20] J. Zbojovský, L. Kruželák, M. Pavlík, “Impedance Spectroscopy of Liquid Insulating Materials In: Proceedings IEEE International Conference AND Workshop in Óbuda on Electrical and Power Engineering. - New York (USA) : Institute of Electrical and Electronics Engineers s. 249-253 [USB-key]. - ISBN 978-1-7281-1153-7

[21] Z. Čonka, M. Kolcun: Impact of TCSC on the Transient Stability In:Acta Electrotechnica et Informatica. Roč. 13, č. 2 (2013), s. 50-54. ISSN 1335-8243 Available on internet :www.versita.com/aei.

[22] P. Holcsik, L. Pokorádi, J. Pálfi, „ Determination of customer number by matrix operations in case of network failure“ In: Hadmérnok, Vol. 13, N o. 3, 2018, ISSN 1788-1929