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VOLTAGE CONDITIONS ANALYSIS ON THE TRANSMISSION NETWORK OF THE ELECTRIC POWER SYSTEM OF BOSNIA AND HERZEGOVINA

ANALIZA NAPONSKIH PRILIKA NA PRENOSNOJ MREŽI ELEKTROENERGETSKOG SISTEMA BOSNE I HERCEGOVINE

Senad Hadžić[1], Husnija Ferizović[1]

Abstract: Hourly measured high voltage values in power network 400 kV, 220 kV and 110 kV are presented in this document. Higher values of voltage in relation to nominal voltages, maximum voltages and their time duration have been identified in observed time period. Maximum voltage values are compared with duration of higher voltages for available time period of measuring from 2014 to 2016. This document presents the results for power flow analysis, charging of reactive power and voltage conditions on transmission lines. A review of the operational state of the power system in Bosnia and Herzegovina is given in specific maximum and minimum consumption regime. In addition, a comparison of voltage values being calculated and measured was made.

Keywords: transmission network, overvoltage, quality of electricity, power flows

Sažetak: U radu su pokazane izmjerene satne vrijednosti napona u 2016. godini, u karakterističnim tačkama 400 kV, 220 kV i 110 kV mreže. Izvršena je identifikacija povišenih napona u odnosu na referentne napone, maksimalne vrijednosti i njihova dužina trajanja u razmatranom periodu mjerenja. Data je uporedba maksimalnih vrijednosti napona i trajanja povišenih napona za raspoloživi period mjerenja od 2014. do 2016. godine. U radu se prezentiraju rezultati proračuna tokova snaga, punjenja dalekovoda i naponskih prilika, daje se osvrt na pogonsko stanje sistema za karakteristični maksimalni i minimalni režim elektroenergetskog sistema Bosne i Hercegovine, kao i uporedba izračunatih i izmjerenih vrijednosti napona.

Ključne riječi: prenosni sistem, povišeni naponi, kvalitet električne energije, tokovi snage

INTRODUCTION

The transmission system of Bosnia and Herzegovina (BiH) is characterised by the specific structure of the power lines of 400 kV and 220 kV, which are mostly in under load condition, and it can be said that after the starting of operation of 400 kV grids there were some problems related to overvoltage. After the reconnection of the electric power system (EES) of BiH in October 2004 into the single electric power system UCTE (Union for the Coordination of Transmission of Electricity), which is presently ENTSO-E (European Network of Transmission System Operators for Electricity), there were some events of disallowed overvoltage, especially during low loaded regimes (spring, autumn, weekends, night hours). Standard IEC 60038 defines and specifies the values of rated voltages of the grid and of the highest voltages of equipment [1]. This Standard does not provide the highest and the lowest voltages of the transmission networks i.e. it does not list the allowed voltage variations. In managing the EES the voltage limits are respected i.e. allowed voltage variations as provided by the Grid Code are respected [2]. The Grid Code defines that the highest allowed voltages for the transmission system of 110 kV, 220 kV and 400 kV are 123 kV, 245 kV and 420 kV, respectively. It is particularly important to stress that voltages above the allowed limits, lasting for few hours or even days, have a bad impact on insulation level of equipment thus shortening its lifetime which is specifically important in terms of the power transformers.

This paper presents the results of voltage measurements recorded in hourly intervals in the period of one year. For a number of years now, the transformer stations of 220 kV and 400 kV have been recording the information on voltage, and they have recorded the highest number of hours with overvoltage thus confirming the continuous appearance of disallowed voltages. The stress is on the 400 kV grids which is mostly low loaded, below natural load of lines and, for the most part of the year, 400 kV power lines in the EES BiH generate significant amount of reactive power. The same goes for 220 kV and 110 kV

[1]Independent System Operator in BiH, BiH
s.hadzic@nosbih.ba
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power lines; mostly low loaded, below natural load of lines, which additionally generates reactive power and raise voltages above the allowed limits set forth by the Grid Code. The data shows that over the years there is a longer duration of exceeded voltage causing the danger of the insulation break, which can further result with outages of the system elements endangering the safety and supply of the electricity buyers. Therefore, it is necessary to identify values and duration of overvoltage, to analyse what causes them, to make calculations of power flows and power lines charging, to indicate the measures taken and to propose new measures to lower overvoltage in the transmission system.

1. OVERVOLTAGE IN EES BIH

The data on voltage values in significant connection nodes of 400 kV and 220 kV grids of the electric power system in BiH are taken via SCADA/EMS system (Supervisory Control and Data Acquisition/Energy Management System) at the system operator for BiH by overtaking the data from the remote stations. These data have been continuously gathered from the year 2010 [3], [4] and [5] in a way that an appropriate archive of voltage values was made for every year; the same voltage archive was made for a time period from 1st January to 31st December 2016 (8760 hours). In the respected period, an analysis of hourly voltage values in the transformer station buses (SS) listed in Table I was made.

Unlike the previous years, when at the SS 400/220/110 kV Mostar 4 recorded the largest number of operating hours in higher voltages conditions in the voltage levels of 400 kV and 220 kV, in 2016 the longest duration of overvoltage at both 400 kV and 220 kV voltage levels was recorded in the SS 400/220/110 kV Trebinje. The given list presents the number of operating hours in 2014, 2015 and 2016, the respective stations at voltages above the allowed limits as defined by the Grid Code for 400, 220 and 110 kV voltage levels. It also presents the percentage of overvoltage duration in the analysed years. The table also shows the maximum voltage (Um) defined by the Grid Code and the maximum values of recorded voltage (Umm) in 2014, 2015 and 2016.

It can be said that from 2010 there has been a continuous increase in duration of overvoltage at 400 kV and 220 kV voltage levels, but unfortunately the year 2016 has the record not only in terms of the duration of disallowed voltages, but also in terms of maximum recorded voltage values at the 400 kV and 220 kV levels. Voltages on 220 kV side of the SSs, whose primary voltage is not 220 kV, in previous years mostly remained within the allowed limits, because the successful voltage control was achieved by changing the position of a tap changer of the transformer on load. However, in 2016, due to very long duration of disallowed voltages on the primary side (400 kV) and on the 220 kV voltage level there were long durations of high voltages especially in SS Trebinje and SS Mostar, which amounted to 37% of the operational time of the year with overvoltage.

The table shows that at the 110 kV voltage levels the respective SSs were operating in disallowed voltage levels for small number of hours in the given year, and the maximum recorded voltages were only somewhat higher than the allowed border value of 123 kV which is defined by the Grid Code.

From the given SSs, the SS Trebinje 400 kV has recorded the highest voltage at 451.41kV. It was recorded on Monday, 13 June 2016, at 4:00 in the morning, and it presents the historical maximum of disallowed voltage value, from within the records taken from 2010. The main reason for this high voltage on that day was a disconnection of a big consumer (around 70 MW) of Aluminium Plant Podgorica (KAP) from the transmission system. In addition, this SS recorded the total maximum duration of disallowed high voltages, at the 400kV voltage level it was 94% and at the 220 kV voltage level it was 37%. One of the reasons for this long duration of overvoltage in SS Trebinje is a low load of PL (power line) 400 kV Trebinje – Podgorica – Tirana – Elbasan. The diagrams in Figure 1 and Figure 2 serve for illustration. The diagram in Figure 1 presents the voltage change at 400 kV in SS Trebinje during 2016, it provides all hourly values in the respective period of one year and daily voltage profiles and periods of overvoltage can be seen there. The only period of the year when the voltage was within the nominal values was July and the first half of August 2016 which corresponds to the longest period of work of air conditioners in that region. Figure 2 shows that overvoltage in SS Trebinje at 400 kV voltage level lasted for 8293 hours.

In the last couple of years, the longest duration of disallowed voltage at 400 kV voltage level was recorded at the SS Mostar. Figure 3 shows the duration of overvoltage at the SS Mostar for the time period from 2010 to 2016. Various durations of the SS's working under overvoltage conditions can be noted. One of the main reasons for occurrence of this long-lasting overvoltage is the influence of reactive power flows from Croatia, through 400 and 220 kV interconnection power lines. The maximum voltage value at 400 kV and 220 kV voltage levels was also recorded in the morning hours on 13 June 2016.

Table I: Number of operating hours of SS at the voltage level higher than the maximum allowed

	Substations	Voltage level (kV)	Um (kV)	Number of hours when it U>Um	Number of hours in % when it U>Um	Umm (kV)
2014	Banja Luka 6	400	420	4686	54%	431,02
		110	123	77	1%	124,71
	Tuzla 4	400	420	4076	47%	435,21
		220	245	199	2%	249,34
		110	123	0	0%	120,08
	Prijedor 2	220	245	1256	14%	250,64
		110	123	220	3%	125,48
	Mostar 4	400	420	7262	83%	441,58
		220	245	2296	26%	252,9
		110	123	0	0%	122,37
	Sarajevo 10	400	420	5720	65%	437,4
		110	123	152	2%	124,81
	Trebinje	400	420	6113	70%	441,54
		220	245	1138	13%	252,16
		110	123	22	0%	125,55
2015	Banja Luka 6	400	420	1242	18%	430,94
		110	123	83	0%	123,88
	Tuzla 4	400	420	2508	29%	431,25
		220	245	116	1%	246,8
		110	123	0	0%	120,47
	Prijedor 2	220	245	1258	14%	251,36
		110	123	272	3%	125,6
	Mostar 4	400	420	6367	73%	441,42
		220	245	1952	22%	253,59
		110	123	4	0%	123,55
	Sarajevo 10	400	420	3318	38%	433,62
		110	123	30	0%	124,12
	Trebinje	400	420	6319	72%	443,56
		220	245	1066	12%	253,49
		110	123	5	0%	123,75
2016	Banja Luka 6	400	420	1838	21%	431,53
		110	123	0	0%	122,56
	Tuzla 4	400	420	4591	52%	435,23
		220	245	550	6%	248,53
		110	123	0	0%	119,37
	Prijedor 2	220	245	2268	26%	252,21
		110	123	27	0%	123,72
	Mostar 4	400	420	7838	89%	446,43
		220	245	3249	37%	255,57
		110	123	30	0%	124,28
	Sarajevo 10	400	420	5675	65%	436,36
		110	123	79	1%	124,32
	Trebinje	400	420	8293	94%	451,41
		220	245	3276	37%	254,44
		110	123	3	0%	123,44

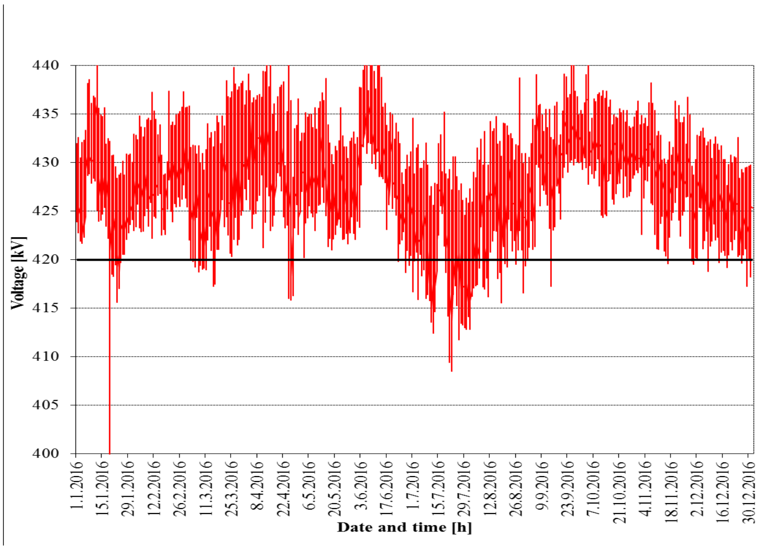

Figure 1: Diagram of 400 kV voltage change at SS Trebinje during 2016

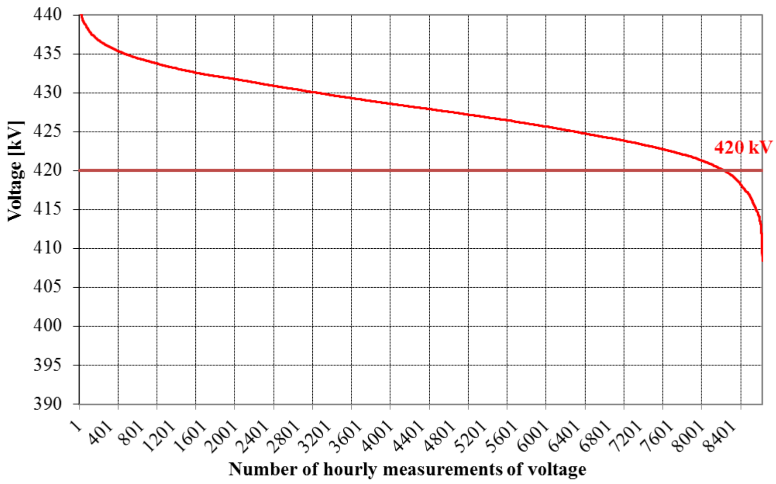

Figure 2: Diagram of duration of 400 kV voltage at SS Trebinje during 2016

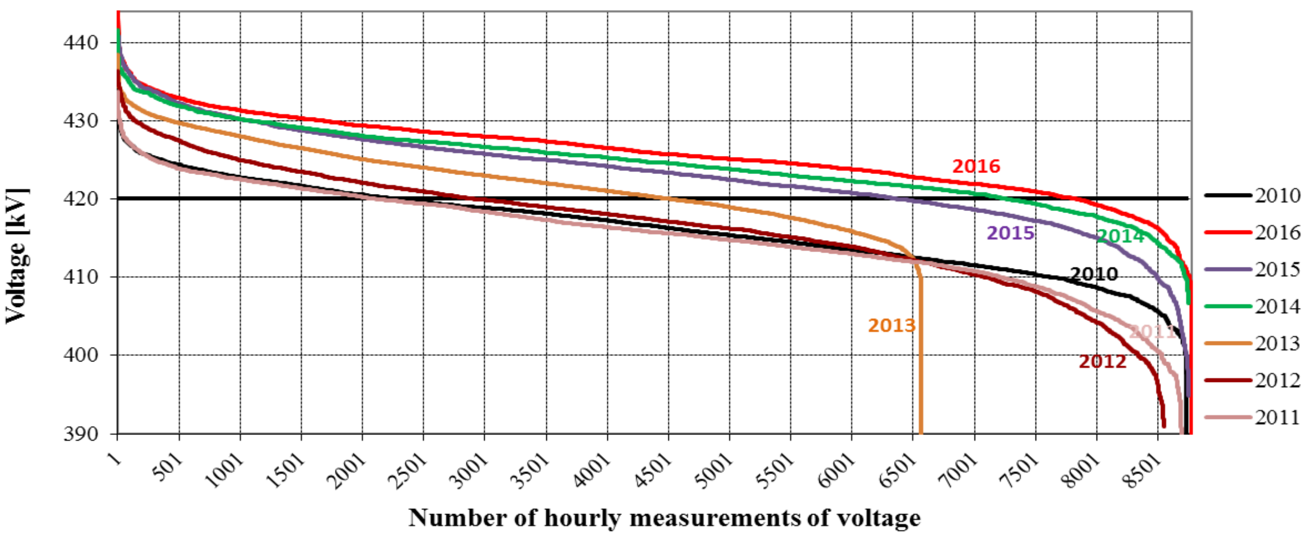

Figure 3: Diagrams of duration of 400 kV voltage at SS Mostar 4 from 2010 to 2016

Average hourly reactive power in 2016 in the 400 kV interconnection power lines with Croatia, Montenegro and Serbia is presented in Figure 4. It indicates that the greatest and constant injection of reactive power between 50 and 100 MVAr during the entire year was at the PL 400 kV Mostar 4 – Konjsko, and almost equal injection from 0 to 50 MVAr at the PL 400 kV Trebinje – Podgorica and PL 400 kV Ugljevik – Ernestinovo.

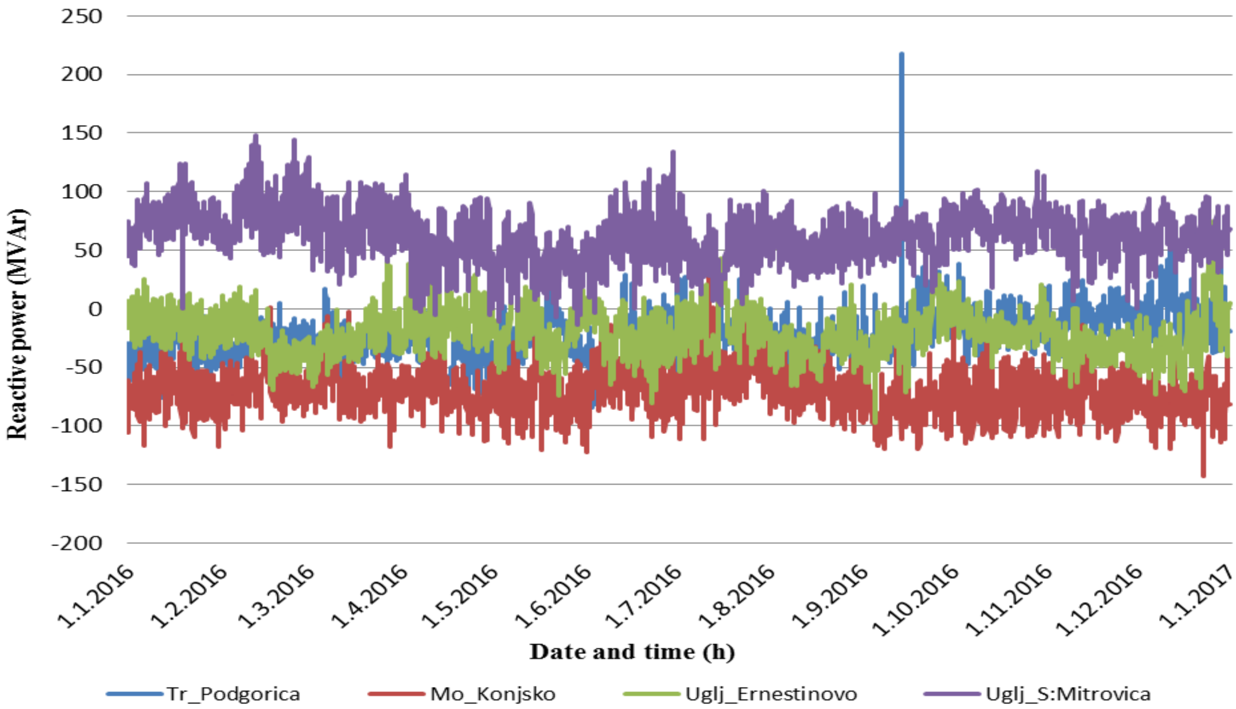

Figure 4: Diagram of the change of average hourly reactive power at 400 kV interconnection transmission lines in 2016

2. DISCONNECTION OF POWER LINES AS A MEASURE FOR LOWERING OVERVOLTAGE

Measures used to reduce the overvoltage in the electric power system of BiH are: a change of generation, i.e. overtaking the reactive power from generators, voltage control by changing the position of a tap changer on the transformer and a change of the operating state, i.e. disconnection of 220 kV and 400 kV power lines with the purpose of voltage reduction.

The greatest importance for maintaining the allowed voltage profile in 400 kV transmission system lies on the thermal power plants (TPP) Gacko and Ugljevik and to hydro power plant (HPP) Višegrad, if operational at the critical period. The most important power plant in BiH for 220 kV and 400 kV voltage control, is the pumped-storage power plant (PSPP) Čapljina of 2x240 MVA installed capacity. PSPP Čapljina, depending on the situation in the EES, can be in a compensation regime where it can be in over or under excitation state of 150-160 MVAr per a machine. However, it is not used for this purpose [6].

Thermal power plants rarely lower injection of reactive power in the transmission system and almost never go in under excitation state upon a request made by a system operator which in this way tries to shorten the duration of overvoltage at least partially.

By changing the ratio, i.e. the tap changer of the transformer, it is attempted to keep the wanted voltage at the low voltage side of the transformer. This process is mostly done automatically or by a remote control on the transformers 400/115 kV, 220/115 kV and 110/x kV, which have the capacity of voltage control under load. In this way, the voltage at 110 kV is successfully kept within the allowed limit which is shown from 2010 in [7].

As the last protection measure of the transmission equipment against continuously higher voltages, disconnection of appropriate power lines, primarily of 400 kV should be used, and this is regularly done by the system operator in BiH in coordination with neighbouring transmission system operators.

This measure is undertaken at those power lines that significantly contribute to reactive power generation due to insufficient network load and this measure is most often undertaken. At the same time this measure is constraining, because one must take into consideration the safety system of the EES BiH during the disconnection. In 2016, the most disconnected power lines were 220 kV Prijedor 2 – Mraclin and 220 kV Prijedor 2 – SS Kakanj, and among 400 kV power lines the most disconnected were Mostar 4 - Sarajevo 10, while the previously frequently disconnected power line 400 kV SS Tuzla – Banja Luka 6 has no longer been disconnected because of the entrance of TPP Stanari. Mostar 4 – Konjsko has also not been disconnected and its disconnection used to serve for the most efficient voltage reductions. There were 54 disconnections of 220 kV and 400 kV power lines with the purpose to lower higher voltages in 2016.

3. ANALYSIS OF THE OPERATIONAL CONDITIONS IN THE TRANSMISSION SYSTEM OF EES BIH

With the purpose of reviewing the voltage conditions in the transmission system of EES BiH during 2016, calculations were made of power flows and voltage conditions in specific regimes: maximum load regime registered on the 18th hour on 31st December 2016 and minimum load regime registered on the 4th hour on 23rd May 2016. The results of the calculations for the transmission system of 400 kV and 220 kV, which were made in a program package PSS/E (Power System Simulator Siemens Energy, Inc., Power Technologies International) [8], are shown in Figure 5 and Figure 6, in the appendix. Modelling of EES for the respective regimes was done on the basis of daily reports of Independent System Operator in BiH (NOSBiH) for the 31st December 2016 and 23rd May 2016, and the load per connection nodes 220/x and 110/x kV was done on the basis of recorded load measurements in specific regimes of EES BiH during the year 2016. Model of EES of neighbouring countries were formed on the basis of DACF (Day Ahead Contingency Forecast) models for characteristic regimes. The presented results suggest:

● Maximum load regime
- the most loaded is PL 400 kV Ugljevik – Tuzla, 22,1% loaded in relation to allowed circuit load,
- the most loaded is PL 220 kV Tuzla 6 – TPP Tuzla, 54% loaded,
- the most loaded is PL 110 kV Trebinje – H.Novi, 86,7% loaded,
- all voltages in the connection nodes are within the technically allowed limits,
- contribution to capacity power/injection from the transmission system is 899,5 MVAr.

● Minimum load regime
- the most loaded is PL 400 kV Mostar 4 - Konjsko, 21,7% loaded in relation to allowed circuit load,
- the most loaded is PL 220 kV Kakanj 5 – RP Kakanj, 37,5% loaded,
- the most loaded is PL 110 kV Trebinje – Komolac, 59,4% loaded,
- all voltages on the 400 kV and the majority of the 220 kV nodes are elevated above the technically allowed limits,
- contribution to capacity power/injection from the tramission system is 986,2 MVAr.

The presented calculation results indicate that the transmission system of the EES BiH is low loaded, below natural load of lines, resulting with huge contribution of charging reactive power and with higher voltages.

4. CONCLUSION

Historically maximum values of higher voltages and their longest duration on both voltage level of 400 kV (from 1838 to 8293 hours annually) and of 220 kV (from 550 hours to 3276 hours annually) were recorded in the transmission system of Bosnia and Herzegovina in 2016. The period under consideration was from the year 2010 to 2016 in specific transformer stations. Any voltage increase above the allowed limits has the accelerating aging effect on the insulation equipment and it affects the quality of electricity.

By observing the voltage diagram, it was determined that increase in voltage above the allowed limits does not occur only in night hours, during holidays and weekends that is in low load regimes, but during the entire year. The main causes of the problems are low loaded 400 kV power lines which generate high amounts of reactive power. Another problem is the reception of reactive power during the entire year in the interconnection power lines of 400 kV and 220 kV from Croatia and adverse effect from the EES of Montenegro upon entering into operation PL 400 kV Podgorica – Tirana/Elbasan. The duration of higher voltages and their increasing values over the years can be expected in the future, which depends on the planned operations on the system elements, new generation and consumer facilities in the system and in neighbouring systems.

When observing the single voltage levels it is seen that the most vulnerable connection nodes are those in 400 kV grid followed by the connection nodes of 220 kV grid. It is important to underline the positive influence of the transformer 400/231 kV, 400/115 kV and 220/115 kV regardless the fact whether those are regulating transformers or transformers that have on load control switch. The transformers basically prevent spreading of voltage disturbance into the lower voltage networks.

The measures for lowering higher voltages in the EES of BiH proved to be insufficient. The system should be improved by installing appropriate devices therein, i.e. by constructing compensation facilities connected to 400 kV or 110 kV network or by changing the Market rules and the procedures as to procure ancillary service to control voltage and reactive power by which the producers, mostly those connected to 400 kV network, would be stimulated for the work in under excitation.

A well-known software package PSS/E was used for analysis of higher voltages in a stationary state. The presented calculation results of power flows, power lines charging and voltage conditions for the respective regimes showed a good match with recorded voltage and power flow values.

ANNEX

The annex contains Figure 5 and Figure 6 presenting calculation results of power flows and voltage conditions in specific maximum and minimum operating regimes of the EES BiH.

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BIOGRAPHY

Senad Hadžić was born in 1965 in Višegrad. He graduated from the Faculty of Electrical Engineering in Sarajevo in 1993, where he also obtained his master's degree in 2012. He is employed at the NOS BiH as a System and Market Development Engineer. From 2007 to 2015, he performed the duties of the Head of the Real Time Operation Department. In addition to operation control of the power system through SCADA / EMS, he performed the tasks of operational planning, calculation and electricity exchange. Previously, he worked at the JP EP BiH on the same tasks; wholesale electricity and calculations of losses in the transmission and distribution network.

Husnija Ferizović was born in 1958 in Drvar. He graduated from the Faculty of Electrical Engineering in Sarajevo in 1982, where he also obtained his master's degree in 2003. He is employed at the NOS BiH in Sarajevo in the Strategic Planning Department. He works on analyzing the operation of the EES in stationary and dynamic conditions, coordinating the settings of protection, using modern PowerSymulator for Engineering, Siemens Power Technologies International, ASPEN (Advanced Systems for Power Engineering, Inc.). Previously, he worked in JP EP BiH, on the tasks of analyzing and planning the development of the EES.

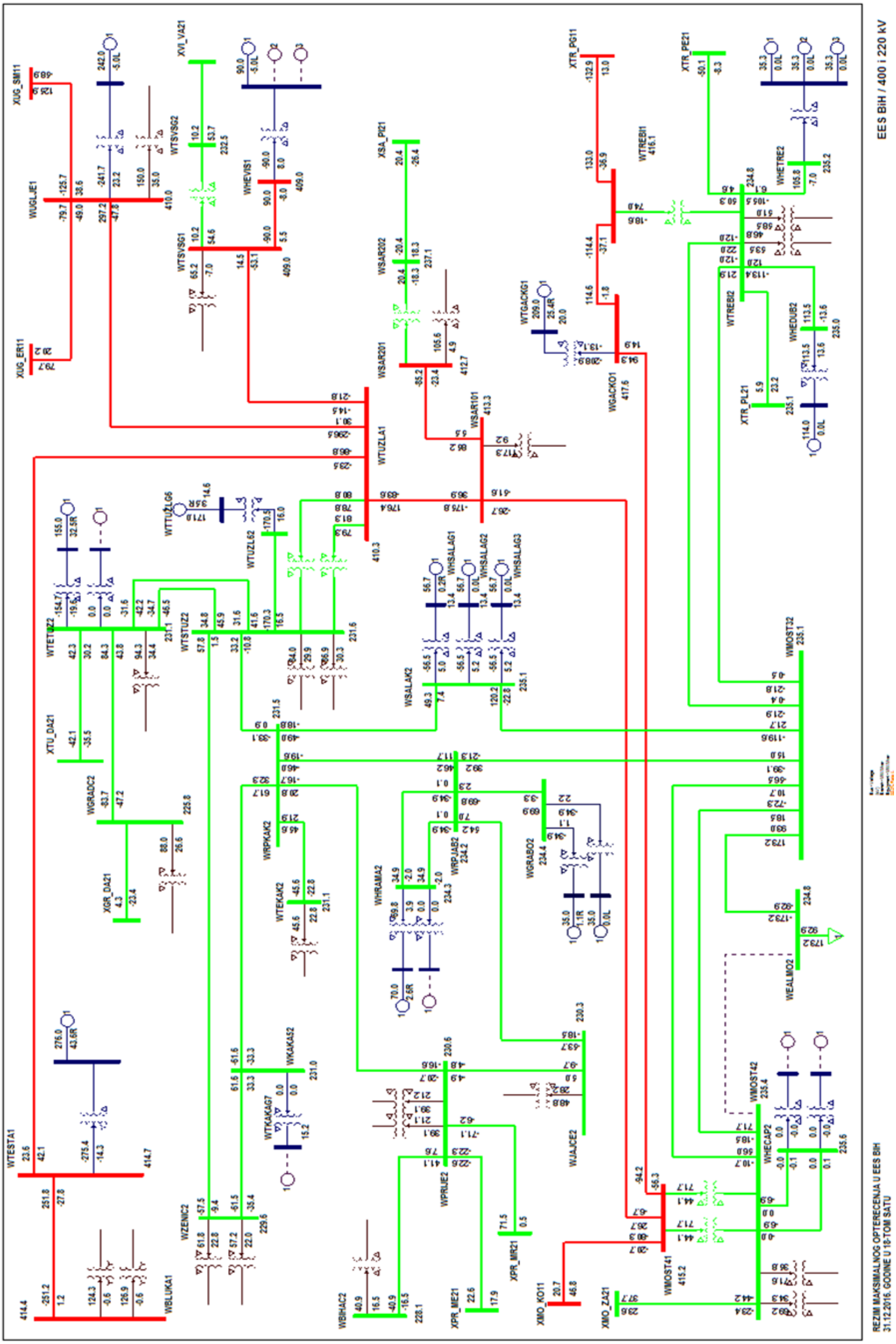

Figure 5: Results of the calculation of power flows and voltage conditions for the maximum operating regime of EES BiH

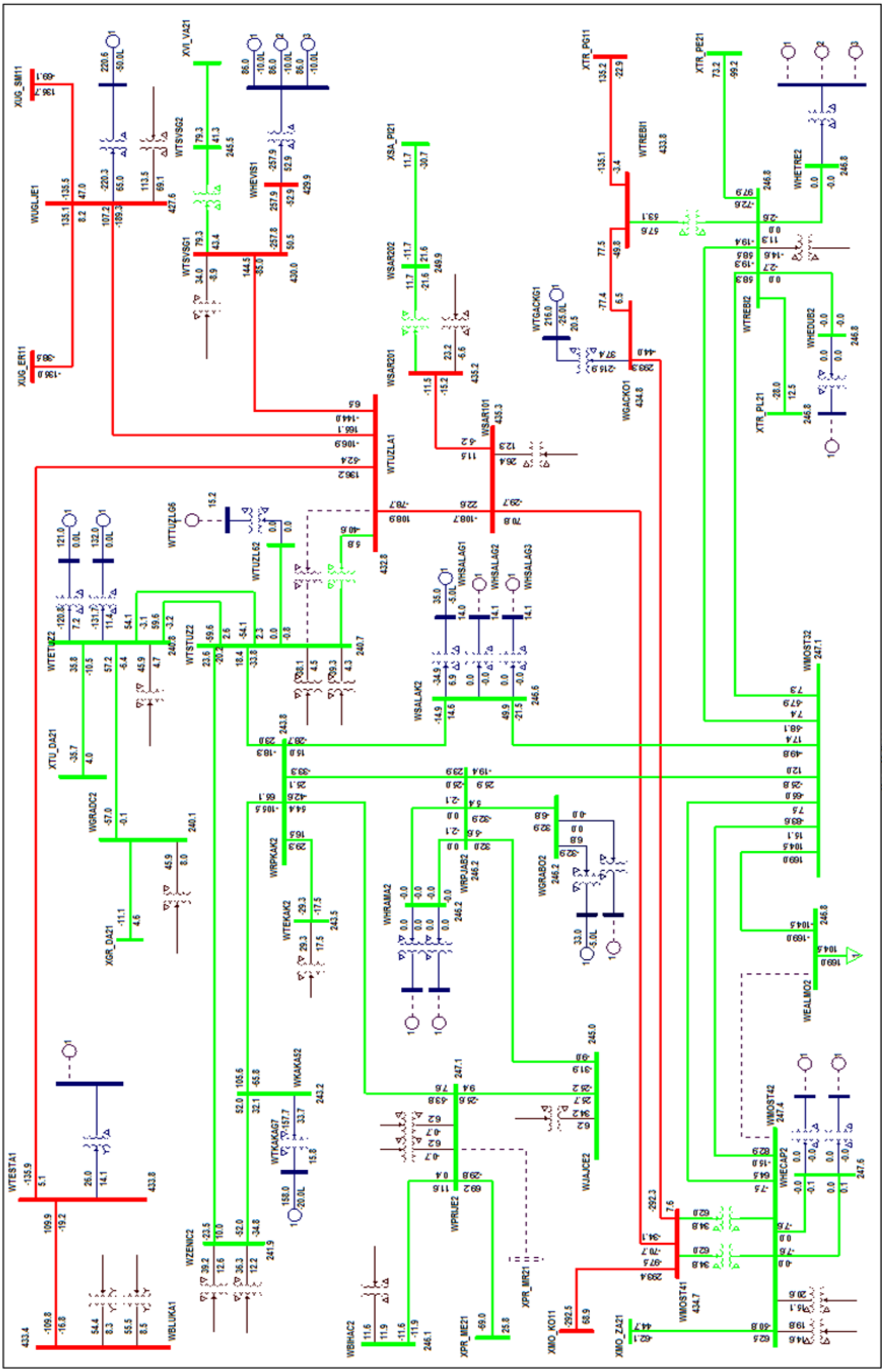

Figure 6: Results of calculation of power flows and voltage conditions for the minimum operating regime of EES BiH