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Task 2: Power Grid Technical Diagnosis

Final report

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Economic Consulting Associates Limited
41 Lonsdale Road, London NW6 6RA, UK
tel: +44 20 7604 4545, fax: +44 20 7604 4547
http:://www.eca-uk.com

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1 Introduction

This Task 2 report forms part of a series of 3 reports in an assignment examining the potential for wind power development in Bosnia and Herzegovina (BiH). Under this task, taking into account technical constraints and requirements for the connection of large-scale commercial wind power to the transmission network, the following aspects are covered:

- Based on the agreed scenarios of WPPs construction, we analyse the voltage profile in the BiH transmission network in order to determine in which parts of transmission network wind power plants reactive power generation control is required. Several characteristic operating regimes of the BiH power system are analysed: winter maximum, summer maximum and off-peak load. Power flow models of the the BiH power system contain the most probable wind power plants construction scenarios in BiH. Within these analyses the N–1 security criterion for all transmission network elements is checked and the Consultant examines whether transmission network reinforcements are needed in order to ensure secure evacuation of electricity produced by wind power plants.

- The Consultant investigates the secure operation of the power system in the situation of outages of the largest thermal power units in BiH for the highest penetration of wind power plants. This assessment includes the impact of faults of the largest thermal power units on reliability/stability of the national power networks in BiH as well as regional power networks.

- The Consultant defines and assesses the additional costs associated with increasing levels of wind energy, to cover the costs of extra reserve, reduced load factors on the thermal and/or hydro plant, modifications to network components and network reinforcements. Any limitations (regional or national) on the penetration of wind power are identified. The Consultant examines how, and by whom, these costs will be paid and makes proposals and recommendations for the treatment of additional costs. Reference to experience in different countries is included in support of the conclusions.

In accordance to the Terms of reference the further sections of the report cover the following:

- Section 2 gives an overview of the existing BiH power system.

- Section 3 describes the future power system of BiH, as planned in different reports and studies.

- Section 4 covers load flow, N-1 and voltage profile analysis for the existing and future power system, with and without new wind power plants.

- ❑ Section 5 considers situations of the largest power plant (unit) outages from a steady-state point of view.
- ❑ Section 6 describes identified transmission system bottlenecks and possible voltage problems due to integration of potential wind power plants.
- ❑ Section 7 looks at additional costs related to WPP integration in the BiH transmission system.

In section 8 we give a summary of the findings.

The Appendix shows load flow results for different scenarios of wind power plants construction and transmission network operational regimes (based on load level and production units engagement) relating to existing transmission system.

Before we go through detailed analyses, it is important to point out that these network calculations were done in order to identify network bottlenecks. In that sense verified power system model is used, along with WPP connection nodes and criteria given in the Task 1. But, neither NOS nor authors do not evaluate or prefer any of WPP projects. Accordingly, we don't analyze detailed WPP connection issues, but only expected overall WPP impact to network bottlenecks.

2 Existing power system overview

The Bosnia and Herzegovina electric power system was developed under the territorial framework of the former Yugoslavia, so it possesses some common characteristics with other ex-Yugoslavian countries like power production based on coal and hydro resources, strong interconnections with neighboring countries with large transmission capacities, large installed power in high voltage substations, but underdeveloped 110 kV network elsewhere.

This section summarises the most important technical characteristics of the BiH power system, especially with regard to transmission, from a perspective of wind power plants future integration. It gives an overview of production facilities presently operating within three domestic power production and supply companies (EP BiH, EP HZHB, ERS), historic data about electricity consumption and system load (maximum, minimum, winter, summer), and description of existing transmission system.

2.1 Production

Basic data on power plants within the BiH power system are shown in Table 1 and Table 2. There is a total of 3792 MW of installed capacity in the BiH power system, out of which 2005 MW (53%) is hydro power plants (HPP) and 1790 MW (47%) is thermal power plants (TPP). Of total installed capacity, 38 MW (1%) are connected to the distribution network, 925 MW (24%) are connected to 110 kV network, 1959 MW (52%) to 220 kV network, while 870 MW (23%) are connected to 400 kV network, as shown in Figure 1.

Figure 1 Installed capacity of power plants by voltage levels

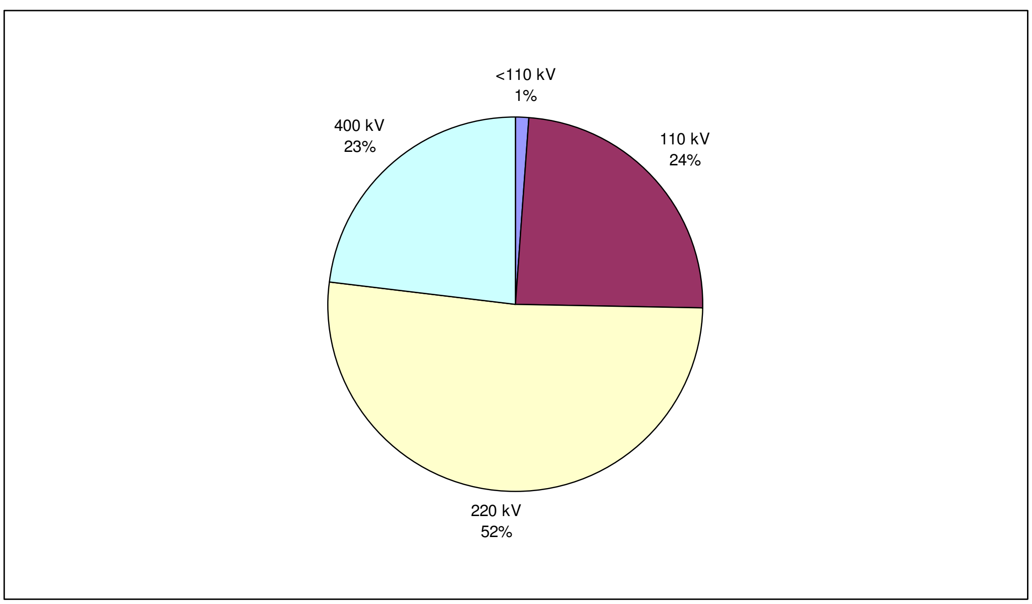


Table 1 Data on hydro power plants

River	HPP name	Installed power (MW)			Reactive power (M Var)		Connection voltage level (kv)
		No of units	Power	Total at transmission level	Q_{max}	Q_{min}	
Trebišnjica	Trebinje I	3	2x54+63	171	93	-60	220
	Trebinje II	1	8	8	-	-	<110
	Dubrovnik	1	108	108	52	-30	220
	Čapljina	2	220	440	252	-252	220
Neretva	Rama	2	80	160	78	-50	220
	Jablanica	6	30	180	126	-72	110
	Grabovica	2	57	114	56	-20	220
	Salakovac	3	70	210	99	-45	220
	Mostar	3	24	72	54	-24	110
	Mostarsko Blato	2	30	60	40	0	110
	Peć-Mlini	2	15,3	30,6	21	0	110
Vrbas	Jajce I	2	30	60	44	0	110
	Jajce II	3	10	30	16	0	<110
	Bočac	2	55	110	50	-20	110
Drina	Višegrad	3	105	315	150	-90	400

Hydro power plants are located along several rivers, Trebisnjica and Neretva rivers in the southern part, Vrbas river in the northern part, and Drina in the eastern part of the country.

Large accumulation basins are located near Jablanica and Rama HPPs. Useful storage of these power plants is 70 GWh on the river Neretva starting with HPP Jablanica and 303 GWh for HPP Rama.

HPP Capljina is a pumped-storage hydro power plant with a possibility to operate under several regimes: pumping water during off-peak hours, generating electricity during high-price hours, and compensating voltages in the network. It is used to provide tertiary power and frequency reserve in BiH and to the market..

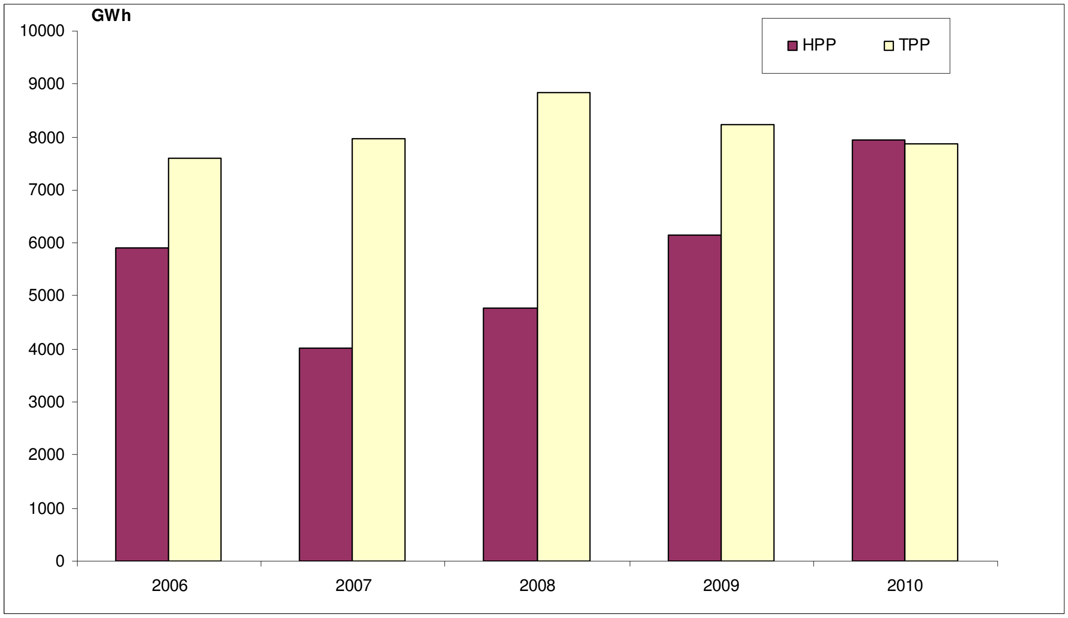
Table 2 Data on thermal power plants

TPP name	Maximum power at transmission level(MW)			Reactive power (Mvar)		Connection voltage level (kV)
	Unit	Power	Total	Q_{max}	Q_{min}	
TE Tuzla	G1	29	630	*	*	110
	G2	29		*	*	110
	G3	85		62	0	110
	G4	175		124	-40	220
	G5	180		124	-40	220
	G6	190		133	-45	220
TE Kakanj	G1	29	385	*	*	110
	G2	29		*	*	110
	G3	29		*	*	110
	G4	29		*	*	110
	G5	95		75	-25	110
	G6	85		83	-30	110
	G7	205		142	-54	220
TE Gacko	G1	255	255	175	-60	400
TE Ugljevik	G1	235,6	235,6	175	0	400

* not in operation

Thermal power plants in BiH use domestic coal (brown coal or lignite). Coal fired power plants are owned by EP BiH and ERS, while EP HZHB doesn't have any. In the Federation of BIH (FBIH) prices of coal for thermal power plants are controlled by the FBIH Government. By 2020 the following units will be decommissioned: Tuzla G3 (in 2013), Tuzla G4 (in 2019) and Kakanj G5 (in 2018). Kakanj G7 unit was rehabilitated in 2005. Tuzla G5 is undergoing rehabilitation; Tuzla G6 and Kakanj G6 are envisaged for rehabilitation. After rehabilitation, it is expected that the mentioned units will be decommissioned after 2020. Lifetime extension of the rehabilitated units is 15 years. Designed net power of TPP Ugljevik (owned by ERS) is 279 MW, but due to technical difficulties it can achieve only 250 MW as quoted. In order to reach the designed power the boiler should be reconstructed. Both TPP Gacko and TPP Ugljevik are envisaged to be revitalized which will extend their life and meet the environmental standards in terms of pollutant emissions (particles, sulfur, NO_x). The expected year of decommissioning of the revitalized units is beyond 2020.

Figure 2 Electricity production in BiH (2006-2010)



Source: DERK

The share of HPPs and TPPs in electricity production in the last five years is shown in Figure 2. Usually TPPs produce more, but 2010 was extremely favorable for hydro production (excellent hydrological conditions), so they produced more electricity during this year. A small amount of electricity (around 1%) is usually produced in industrial and smaller facilities.

Hydro production, as well as hydro unit engagement, is variable during a year, which causes different loading of the transmission network. Therefore, transmission planning studies should be performed comprising several scenarios of hydro production in BiH (dry hydrology, normal hydrology, wet hydrology). Typical engagement of hydro units depending on hydrological conditions is given in Table 3. Table 4 shows merit order of thermal units, based on marginal production costs. These data are used for load flow and other analyses.

It should be stressed that real engagement of production units in BiH has not been determined exactly based on merit order. Each power production company uses its units to cover tariff consumers' load (under a price regulated by the regulators), while possible surplus is sold on the marked based on bilateral contracts (usually using public tendering processes). Only a large consumer has an option to choose its own supplier and buy electricity in the market, but only the Aluminum factory in Mostar partially uses this right.

Table 3 Characteristic engagement of HPPs

Name	Maximum power (MW)	Typical engagement (MW)		
		Dry hydrology	*Normal hydrology*	*Wet hydrology*
Trebinje I	171	54	108	162
Trebinje II	8	2,4	4.8	7,2
Dubrovnik	108	55	63	94,5
Capljina	440	0	182	378
Rama	160	55	96	144
Jablanica	180	46,5	93	139,5
Grabovica	114	34,2	68.4	102,6
Salakovac	210	63	126	189
Mostar	72	22,5	45	67,5
Pec-Mlini	30,6	9	18	27
Mostarsko B	60	18	36	54
Jajce I	60	18	36	54
Jajce II	30	9	18	27
Bocac	110	33	66	99
Visegrad	315	94,5	189	283,5
TOTAL	**2068,6**	**514,1**	**1131,2**	**1801,8**

Table 4 Thermal units merit order

Order	Unit	Power (MW)
1	Kakanj - G7	205
2	Kakanj - G5	95
3	Gacko	255
4	Tuzla - G6	190
5	Tuzla - G4*	175
6	Kakanj - G6	85
7	Ugljevik	235,6
8	Tuzla - G5	180
9	Tuzla - G3*	85

* electricity and heat production (must run during winter season)

2.2 Consumption

Electricity consumption in BiH is around 11 TWh with system peak load around 2100 MW. Data on maximum and minimum loads within the BiH power system between 2001 and 2010 are given in Table 5 and Table 6, and illustrated in Figure 3. In the observed period, peak load was in a range of 1829 MW (2002) to 2173 MW (2010), with average annual growth of 1.83%. In the same period minimum system load was in a range of 633 MW to 870 MW, with average annual growth of 2.88%. Minimum load to maximum load ratio was between 0.34 and 0.41, or 0.38 in average.

Table 5 Maximum and minimum loads in the BiH power system, 2001-2005 (MW)

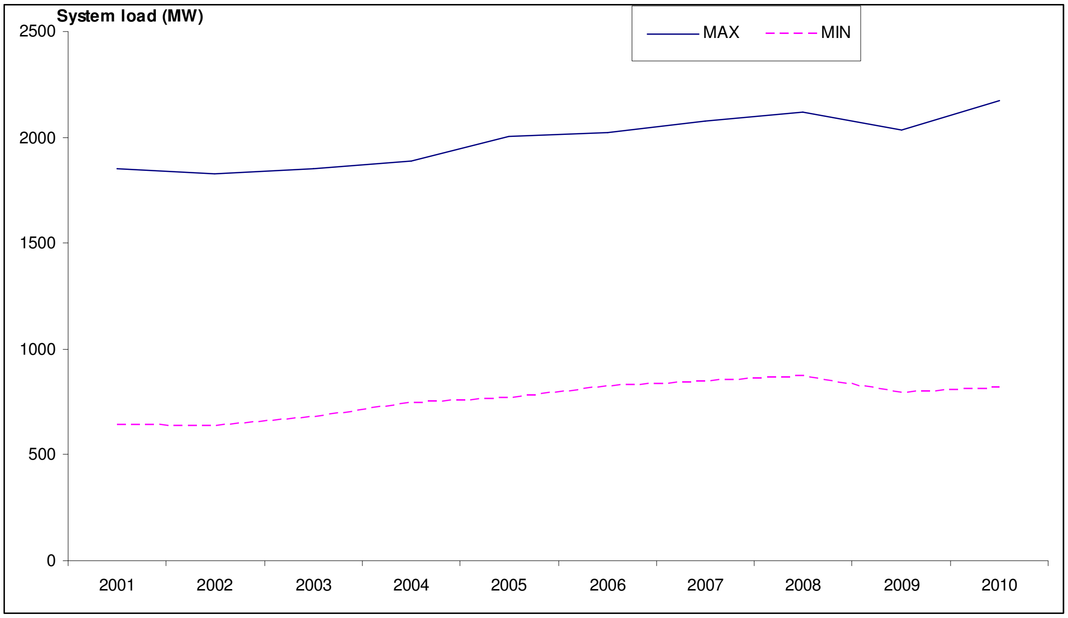
Month	2001		2002		2003		2004		2005	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
January	805	1693	864	1829	878	1854	908	1830	985	1861
February	847	1699	827	1605	980	1772	910	1741	1047	1946
March	728	1618	719	1555	799	1599	801	1670	874	1833
April	679	1487	694	1446	694	1541	787	1559	837	1589
May	656	1287	640	1218	676	1288	748	1368	784	1490
June	695	1262	633	1210	684	1288	746	1358	796	1448
July	705	1240	658	1201	686	1265	769	1360	796	1450
August	639	1266	663	1259	737	1280	778	1406	824	1492
September	691	1359	691	1449	723	1374	784	1489	768	1530
October	687	1475	737	1512	736	1604	796	1601	832	1657
November	806	1656	748	1593	812	1619	833	1773	931	1840
December	908	1853	838	1747	876	1781	930	1890	983	2005
Min/Max	**639**	**1853**	**633**	**1829**	**676**	**1854**	**746**	**1890**	**768**	**2005**

Table 6 Maximum and minimum loads in the BiH power system, 2006-2010 (MW)

Month	2006		2007		2008		2009		2010	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
January	1072	1955	981	1879	1046	2075	959	2033	934	1954
February	941	1863	944	1766	1017	1944	933	1892	983	1888
March	880	1780	912	1698	989	1860	896	1750	912	1885
April	850	1669	852	1669	870	1689	796	1573	893	1756
May	829	1516	856	1514	885	1618	802	1534	816	1631
June	827	1470	845	1480	896	1592	811	1485	851	1581
July	824	1455	861	1499	886	1569	806	1529	882	1611
August	843	1495	853	1550	939	1623	874	1588	890	1669
September	844	1572	853	1622	928	1816	824	1659	894	1721
October	867	1683	908	1790	963	1767	853	1769	953	1875
November	962	1822	976	1907	955	1927	940	1922	970	1888
December	997	2019	991	2078	1010	2117	945	2017	1021	2173
Min/Max	**824**	**2019**	**845**	**2078**	**870**	**2117**	**796**	**2033**	**816**	**2173**

Source: NOS BiH

Figure 3 Maximum and minimum system load in BiH (2001-2010)



Source: NOS BiH

Peak load is reached in winter months (December and January), probably as a result of use of electricity for heating, which leads to an assumption that system load significantly depends on outside temperature. Minimum load is achieved in spring and summer months (May through September). High increase rate of minimum system load and increasing peak to minimum ratio indicate the increased installation of air-conditioning equipment and higher consumption of electricity for cooling. Normalised (in relation to annual system peak load) maximum monthly loads in the BiH power system can be determined from Table 5 and Table 6. Maximum loads ranging from 80% to 100% of P_{max} are recorded in January, February, March, April, November and December while in other months of the year maximum monthly loads are below 80% of P_{max}.

Distribution of system load to individual substations 110/x kV (and 220/x kV for Aluminum factory in Mostar) is performed using historic contribution of substations in the moment of maximum load occurrence and in the moment of minimum load occurrence. The largest load centers in BiH are Sarajevo, Banja Luka, Tuzla, Zenica and Mostar.

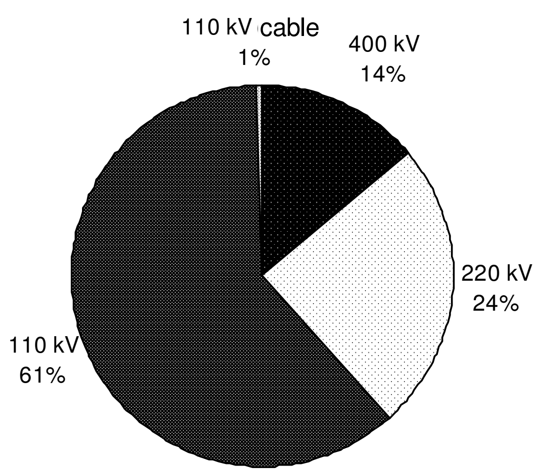
2.3 Transmission network

The BiH transmission network comprises overhead lines and cables of 400 kV, 220 kV and 110 kV voltage levels. The power system includes fifteen 400 kV lines with total length of 865 km, 42 lines of 220 kV with total length of 1525 km, more than 215 lines of 110 kV with total length of about 3888 km, and five 110 kV cables with total length of 31 km, as shown in Table 7[1]. Total length of all transmission lines within the The BiH power system is 6309 km. In terms of length, 400 kV lines are 14% of the total, 220 kV lines 24%, and 110 kV lines are 62%, as shown in Figure 4.

Table 7 Transmission lines in BIH electricity system

Rated Voltage	Number of lines	Number of interconnections	Length (km)
400 kV	15	4	867.1
220 kV	42	8	1,526.7
110 kV	215	19	3,836.5
110 kV (cable)	5	-	31.4
TOTAL	*277*	*31*	*6,261.9*

Figure 4 Shares of transmission lines in the BiH power system by voltage level



Lines of the highest voltage level in BiH were built in late 1970s and early 1980s, when the transmission network was developed in the frame of the former Yugoslavian system. The newest line is Ugljevik – Sremska Mitrovica, built in 2004. The 400 kV lines are designed with twin ACSR 490/65 mm² conductors and permanent allowable current in regular operation of 1920 A. The 400 kV line towers are made of steel, type Y. The 400 kV network in BIH is not looped in the state's territory but stretches from its north (Ugljevik, Tuzla), via central (Sarajevo) to south (Gacko, Trebinje) and southwest (Mostar). Radial 400 kV lines connect consumption and generation areas of Banja Luka (400 kV line Tuzla – Banja Luka) and HPP Višegrad (400 kV line Višegrad – Tuzla) with the main network. The line Sarajevo 20 – Buk Bijela was also built for 400 kV voltage but from the beginning it has operated only at 220 kV voltage up to HPP Piva in Montenegro. The line of the highest voltage

[1] http://www.derk.ba/ , State energy regulatory commission web site

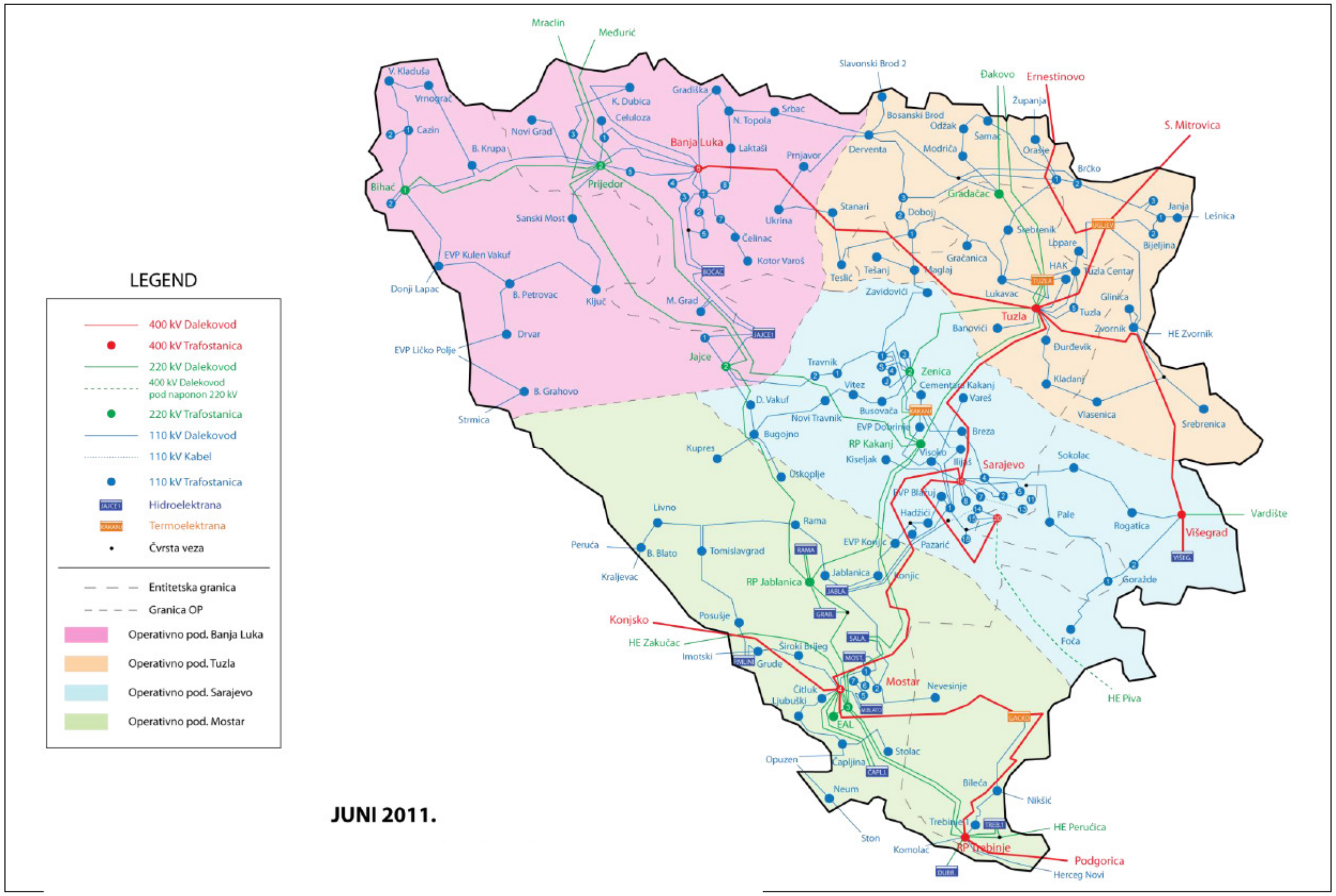
level connects the BiH power system with the neighboring systems of Croatia (400 kV line Ugljevik – Ernestinovo and 400 kV line Mostar – Konjsko), Serbia (400 kV line Ugljevik – Sremska Mitrovica) and Montenegro (400 kV line Trebinje – Podgorica). Good connections with the neighboring systems enable significant power export, import and transit through the transmission network, and make BIH one of the most important transit regions of Southeast Europe. The 400 kV network connects TPP Ugljevik in its north section, TPP Gacko in the south and HPP Višegrad in its east section. The connection of two large thermal power plants and one hydro power plant provide significant reactive power support on the highest voltage network.

The 220 kV network has an important role in the BiH power system. It holds connections of large thermal power plants and hydro power plants (TPP Tuzla, TPP Kakanj, HPP Salakovac, HPP Rama, HPP Grabovica, HPP Čapljina, HPP Trebinje). It was built in the 1960s and 1970s, and it used ACSR conductors of cross-section 360/57 mm^2, with maximum allowable current in normal operation in amount of 790 A. The pylons of 220 kV lines are made of steel. The looped 220 kV network was developed in north, central, south and northwest part of BiH and is connected to the neighboring systems: Croatia (220 kV line Tuzla – Đakovo, 220 kV line Gradačac – Đakovo, 220 kV line Prijedor – Međurić, 220 kV line Mraclin – Prijedor, 220 line kV Mostar – Zakučac), Montenegro (220 kV line Sarajevo 20 – HE Piva, 220 kV line Trebinje – Perućica) and Serbia (220 kV line Višegrad – Vardište). One generator of HPP Dubrovnik is directly connected to the BiH 220 kV network. In general, it can be concluded that the 220 kV network of BiH is well developed and looped, with the exception of radial feeding to the wider area of Bihać. This network supplies power to the largest consumer in BiH, Aluminij d.d. Mostar.

The 110 kV network covers the whole area of BiH, and has been developed since the 1950s until today. The 110 kV network includes steel pylons with ACSR conductors of 150/25 mm^2 and 240/40 mm^2 cross-section, of maximum allowable currents in regular operation of 470 A, and 645 A respectively. The 110 kV network also includes ACSR 95/15 mm^2, 120/20 mm^2, 120/70 mm^2, 210/35 mm^2, 360/57 mm^2, Copper 95 mm^2, Copper 120 mm^2, Copper 150 mm^2 and Aster 228 mm^2 conductors. The network is well looped and connected in the territory of BIH except for some transformer stations with radial feeding. Hydro power plants like HPP Mostar, HPP Peć-Mlini, HPP Mostarsko Blato, HPP Jablanica, HPP Jajce and HPP Bočac are connected to 110 kV network. Some of consumption areas are connected via 110 kV network to the neighboring systems of Croatia (110 kV line Orašje – Županja, 110 kV line EVP Kulen Vakuf – Donji Lapac, 110 kV line B. Grahovo – Strmica, 110 kV line Livno – Buško Blato, 110 kV line Imotski – Grude, 110 kV line Opuzen – Čapljina, 110 kV line Neum – Opuzen, 110 kV line Neum – Ston, 110 kV line Trebinje – Komolac), Montenegro (110 kV line Bileća – Nikšić, 110 kV line Trebinje – Herceg Novi) and Serbia (110 kV line Zvornik – HPP Zvornik, 110 kV line Bijeljina – Lešnica). 110 kV lines to Serbia are out of operation in normal conditions.

Figure 5 shows the transmission network in BiH.

Figure 5 Transmission system in BIH



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Statistical indicators on BiH transmission network availability in the period 2002 – 2006 show a satisfactory level of reliability, in accordance with highly developed networks of West European countries. The average unavailability of 400 kV lines in the studied period was 2.85%, of 220 kV lines, 1.33%, and of 110 kV lines, 0.64%. Forced unavailability was significantly lower than total unavailability and its average was about 0.14% by line at all voltage levels (0.145% in the 400 kV network, 0.137% in the 220 kV network, and 0.148% in the 110 kV network).

Within the power system of BiH, Table 8 shows that there are nine 400/x kV transformer stations, eight 220/x kV transformer stations and 127 110/x kV transformer stations[2]. There are seven 400/220 kV transformers with total installed power of 2800 MVA, seven 400/110 kV transformers with installed power of 2100 MVA, fourteen 220/110 kV transformers with total installed power of 2100 MVA, and 216 110/x kV transformers with total installed power of 5204 MVA (Table 9). Individual power of installed transformers are 400 MVA (400/220 kV), 300 MVA (400/110 kV), 150 MVA (220/110 kV), 63 MVA, 40 MVA, 31.5 MVA, 20 MVA, 10 MVA (110/x kV). Manufacturers of the largest energy transformers are Končar, Hyundai, Elektroputere, Elin, Italtrafo, Pauwels and Elta. Transformers are mainly designed as three-winding transformers, where tertiary is not used for power transmission.

Table 8 Transformer stations of 400/x kV, 220/x kV i 110/x kV within the BiH power system

Voltage levels	Number of SS
SS 400/x kV	9
SS 220/x kV	8
SS 110/x kV	127
SS 35/x kV *	5
TOTAL	*144+5*

* property of Elektroprijenos BiH
Source: DERK

[2] http://www.derk.ba/, State energy regulatory commission web site

Table 9 Number of transformers and installed power of transformation in the BiH power system

Transformer ratio	No. of transformers	Installed power (MVA)
SS 400/220 kV	7	2,800
SS 400/110 kV	7	2,100
SS 220/110 kV	14	2,100
SS 110/x kV	216	5,204
SS MV/MV kV *	24	137
TOTAL	*252*	*12,341*

* property of Elektroprijenos BiH

Source: DERK

All 400/x kV and 220/x kV transformers are designed as tap-changers, where regulation on 400/220 kV transformers can be conducted only in non-voltage condition, 220/110 kV transformers can be regulated under load, and some 400/110 kV transformers have a regulation possibility either in non-voltage or under load condition. The position of tap-changers are on the primary side, in range of ±1x5% (400/220 kV), ±2x2.5% (400/110 kV), and ±12x1.25% (220/110 kV).

Statistics on transformer availability in the period 2002 – 2006 show satisfactory reliability level, in the range of 1.8% to 4.3% on average. 400/110 kV transformers have somewhat higher level of unavailability, primarily because of high unavailability of transformers in Banja Luka and Sarajevo in 2005.

The BiH power system contains appropriate protecting, metering and telecommunication equipment. In most transformer stations active and reactive power is metered. However, their synchronized readings are not known; only maximum non-synchronized values are registered. The national dispatching center in NOS BiH has been recently modernized and equipped with the modern SCADA/EMS system. All transformer stations are included in the remote control system. The telecommunication network is developed over the whole electricity system.

Voltage and reactive power regulation in the BiH electricity system is carried out by means of generators and transformers. The generator connection to all three transmission voltage levels provides a satisfactory voltage profile. The pumped storage HPP Capljina is used in the compensation operational regime for the purpose of fine adjustments and regulation of voltage conditions. There are no modern compensation devices in the network.

BiH is a significant electricity exporter. In almost all months in the observed period from 2001 to 2009 BIH had a positive balance. At the annual level the balance was positive on the export side by 1 to 2 TWh.

Because of its position and transmission network structure BiH provides significant support to its neighbors and enable market activities in this part of Europe. NOS BiH calculates Net Transfer Capacity values on the basis of technical rules and recommendations of ENTSO-E. Transmission capacities are allocated at annual, monthly and daily levels.

Cross-border capacities in Serbia → BiH direction and BiH → Croatia direction are well used, which points to limited possibilities of expanding exchanges in these directions.

Loading of 400 kV and 220 kV transmission network of BiH, after its integration in and synchronization with ENTSO-E synchronic zones I and II (in 2004), was not a limiting factor in realization of power balance aimed at meeting its own needs and required import and export of electricity. In the past period, congestions in the BiH transmission network were not recorded in BiH even in cases where some of the lines were out of operation. In regular situations the load of 220 kV lines is below 50% of their transmission capacities (300 MVA), while the loads of the 400 kV lines do not exceed 30% of transmission capacities (1300 MVA).

Some interconnection lines were congested when trading is concerned, either selling of surpluses or import of electricity for meeting domestic demand and transits. However, this is due to congestions in the neighboring systems. Critical borders are those with Croatia and Serbia, i.e., the directions Serbia → BiH and BiH → Croatia. It should be noted that bottlenecks in cross-border transmission appear mostly because of methodology of setting NTC values or because of bottlenecks in the neighboring systems.

Concerning the transmission system topology the following points should be stressed[3]:

- At present level of development of the BiH transmission network operational safety is not satisfactory within the 110 kV network in the region of Herzegovina and 110 kV network of the areas Banja Luka, Sarajevo and Tuzla.
- From the point of view of voltage conditions, 110 kV network topology is not satisfactory in the region of Herzegovina (Čitluk, Čapljina, Ljubuški and Stolac area).
- Within the present BIH transmission network configuration there are about 20 110/x kV transformer stations with radial feeding from the 110 kV network side, so it is necessary to ensure two feeding direction of all 110/x kV transformer stations.
- Within the present BIH transmission network configuration there are several T connections which reduce reliability and safety of supply to customers so it is necessary to eliminate these shortcomings.

[3] Energy Sector Study in BiH, Energy Institute Hrvoje Pozar, Soluziona, Economy Institute Banja Luka, Mining Institute Tuzla, 2008

- In the shortest period it is necessary to undertake repair of war damage (110 kV network in Herzegovina, Sarajevo, etc.), finalize 110 kV lines presently under construction or under preparation for construction (Kotor Varoš – Ukrina, Ugljevik – Brčko 2, Nevesinje – Gacko, etc.) and undertake rehabilitation of lines and SS (especially in Tuzla, Banja Luka and Hercegovina region areas).

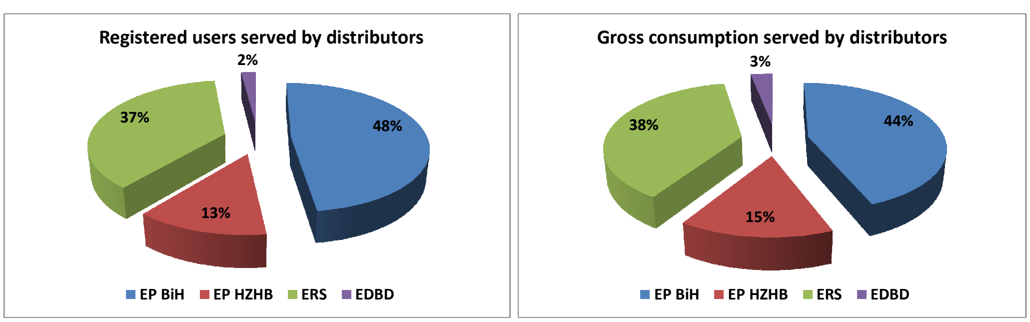
Current operation efficiency of Elektroprijenos BiH is not satisfactory, mainly due to organizational and political issues. The transmission system suffers from this condition, so proper functioning of the company, without political and any other influences beside technical ones, should be assured in the shortest period. This is of utmost importance, not only from the wind power plants grid connection perspective, but for the sake of all electricity consumers and producers in BiH.

2.4 Distribution and supply

The distribution network is a part of the electric energy system, which transfers electricity from the transmission network or embedded generators to customers connected to the distribution network. In the electricity system of BiH the electricity distribution activity is performed by eight distribution system operators: Elektroprivreda Bosne i Hercegovine (EP BiH), Elektroprivreda Hrvatske zajednice Herceg Bosne (EP HZHB), Elektrodistribucija Distrikta Brčko (EDBD) and five users of electricity distribution licence owned by Elektroprivreda Republike Srpske (ERS): Elektrokrajina, Elektro Doboj, Elektro Bijeljina, Elektrodistribucija Pale and Elektrohercegovina.

In BiH, there are about 1,331,000 registered electricity users. EP BIH serves 48%, EP HZHB 13%, ERS 37% and EDBD 2%. Total gross consumption (including loss) of electricity at the level of BIH distribution amounts to around 4 GWh, with the following shares of individual distribution system operators: EP BIH 44%, EP HZHB 15%, ERS 38% and EDBD 3%. Figure 6 shows percentage of electricity served by distributors.

Figure 6 Electricity served by distributors



In BiH, there are 127 SS 110/MV owned by Elektroprijenos BIH, through which the customers on 35 kV, 10(20) kV and low voltage are served, and 7 industrial TS 110/MV owned by 110 kV users. Distribution system operators own (fully or partially) 179 SS 35/MV and over 2,000 km of 35 kV lines. The share of direct 110/MV transformation, or electricity distribution without 35 kV network mediation and 35/10(20) kV transformation, is the highest in EP HZHB. However, from the local perspective, direct transformation prevails in the distribution area of Elektrokrajina (ERS) and the distribution area of Sarajevo (EP BIH), and is largely present in the distribution areas of South and Center (EP HZHB) and the distribution area of Bihać (EPBIH). The 35 kV network is highly developed in the distribution area of Tuzla (EPBIH) and Elektro Doboj (ERS).

Out of total 2,071 km of 35 kV lines, there are 160 km of cable, out of which 33% are paper insulated lines (IPZO 13 and similar), a 36% are XLP insulated (XHP 48 and similar). In the overhead network, 3/4 of lines are built on steel towers, and this corresponds to the fact that almost 80% of lines have 95 mm^2 or larger sections. The 35 kV network in the area of EP BIH is of particularly good quality.

In the 35/MV transformer stations over 70% of installations are of traditional design (air insulated), over ¾ are minimum-oil circuit breakers, electromechanical protection exist in 50% of stations of EP BIH and 70% of ERS stations (in average 60% at BiH level), respective shares of digital protections are 28%, 12% (24%), share of 20 kV installation is 25% in EP BIH, 8% in ERS, or 16% at BiH level, and implementation of remote control system is wide spread in 110/MV transformer stations, while in 35/MV stations it is used only exceptionally, except in Elektro Doboj (ERS), where it is in general application.

The overhead 10(20) kV network is built on wooden poles, the share of which is approximately 45%, over 60% in EP HZHB and 67% in EP BIH, and up to 75% in ERS, which gives an average of 70% in BiH. The share of steel towers is negligible and does not exceed 5% at the level of individual distribution network operators. A vast part of conductors are of 25 mm^2 to 50 mm^2 section. Other conductors do not exceed 7%. The share of conductors with sections below 50 mm^2 is 70% in ERS, 64% in EPBIH, 44% in EPHZHB and 40% in EDBD, which gives an average of 63% at BiH level. Less than 20% of the overhead network in BIH level operates at 20 kV, but there are vast differences: the entire network of EPHZHB and EDBD operates at 10 kV, while the share of network operating at 20 kV is about 5% in EPBIH (parts of ED Bihać and ED Zenica) and as much as 30% in ERS (a large part of Elektrokrajina and a very small part of Elektrodistribucija Pale).

The 10(20) kV cables which may be used at the 20 kV voltage level figure from 35% in ERS and EDBD to over 70% in EP BIH, or about 60% at the level of BiH (taking into account also the 10 kV IPO). 10% of the cable network of EP BIH (ED Bihać, ED Zenica, ED Sarajevo) and 25% of the cable network of ERS (Elektrokrajina, Elektrodistribucija Pale) operate at 20 kV.

The share of cable transformer stations in the total number of MV/LV transformer stations is 37% in EP BIH, 28% in EP HZHB, 18% in ERS, 28% in EDBD, or around 27% at the BiH level. The remainder is made of mostly pylon-mounted substations (approximately 65%). In the structure of pylon-mounted substations, steel towers and concrete pylons prevail: 60% and 35% in EPBIH, 75% and 20% in ERS. In EPBIH, 4% of transformation operates at the 20 kV voltage level and 24% in ERS, which makes an average of approximately 12% at the BiH level. The remaining transformation operates at 10 kV, and the share of installed switchable transformers 10(20)/0.4 kV is 28% in EPBIH and 5% in ERS, or 12% at the BiH level.

The low voltage network consists of the underground cable network (5%) and the overhead network. The latter consists of insulated (33%) and non-insulated (62%) parts. A relatively high share of the overhead network designed in self-supporting cable bundles points to a conclusion that a significant part of the low voltage network is renovated. Nevertheless, almost 30% of the network is made of lines with very small sections (Al/Fe 25 mm^2 or below). Over ¾ of the overhead network rests on wooden poles, 18% on concrete pylons and 7% still rests on roofs or other supporters. One of the main indicators for network analysis and planning is the average length of the low voltage network by the MV/LV transformer station. In this regard there are significant differences between individual distribution network operators. The average length of the low voltage network by the MV/LV transformer stations is 2.7 km in EP HZHB, 3.0 km in EP BIH, 3.7 km in EDBD and as much as 3.9 in ERS, while the average for BIH is 3.4 km.

2.5 Summary of existing power system

Generation

- Sufficient generation capacity to meet domestic demand
- Sufficient export quantity
- Generation by HPPs and TPPs, with similar share of production depending on annual hydrological conditions
- Large plans to expand generation portfolio by all three production and power supply companies but very slow realisation of their plans
- Needs for thermal power plants modernisation in the next few years.

Consumption

- Domestic demand forecast to increase
- Moderate growth of system peak in last ten years.

Transmission network

- Extensive transmission network with good connection to neighouring countries
- Congestions occur due to restrictions from neighbouring countries rather than in the BiH network
- Needs to reinforce mainly 110 kV network
- Missing 110 kV lines in the area with extensive plans for WPPs construction.

Distribution and supply

- Generally good distribution network
- Needs for further improvement in the future
- Low electricity price, influenced by the Government.

Market

- Developed legislative, Grid code, Market rules
- Barriers in connection and construction application
- Bilateral contracts between three power production and supply companies, each company is responsible to cover consumption in defined political areas.

3 Future power system overview

All three power production companies in BiH have ambitious plans to revitalize existing power production facilities and to build new ones. List of all planned production facilities in BiH is given within NOS BiH Indicative production plans[4].

By constructing new power plants, power production companies plan to cover increased electricity consumption in the future, and to sell electricity at the market. The region of Southeast Europe is generally short of electricity, and additional benefit could be made by selling electricity to the large Italian market once the HVDC cable is constructed between Montenegro and Italy.

Attempts were made by Elektroprenos BiH and international Consortium in 2008[5]. Within NOS BiH and Elektroprijenos BiH an agreement has been made to use SECI models for planning purposes. The same models will be used in this study, representing expected transmission system situation in BiH for the 2015 and 2020 time frame.

3.1 Production

Between 2011 and 2020, according to the Indicative power production development plan, significant new production capacities are planned by power production companies and other investors:

- ❑ 1941 MW in new HPPs (only 72 MW is included in the electricity balance made by NOS BiH as shown in Table 10, 108 MW are not included in the balance but they have appropriate government approval, 1761 MW are not included in the balance and are without government approval).

- ❑ 2240 MW in new TPPs (1050 MW is included in the electricity balance made by NOS BiH as shown in Table 11, 240 MW are not included into the balance but they have appropriate government approval, 950 MW are not included into balance and do not have government approval).

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[4] Indicative power production development plan 2011-2020, NOS BiH, July 2010

[5] Energy Sector Study in BiH, Energy Institute Hrvoje Pozar, Soluziona, Economy Institute Banja Luka, Mining Institute Tuzla, 2008

Table 10 New HPPs included in the electricity balance

HPP	Installed power (MW)	Expected year of commissioning
Sutjeska	19,15	2013
Ulog	34,4	2015
Dub i Ustiprača	17,1	2014
Vranduk	19,6	2015
Total	**90,25**	

Source: NOS BiH

Table 11 New TPPs included in the electricity balance

TPP	Installed power (MW)	Expected year of commissioning
Stanari	300	2014
Tuzla, unit 7	450	2017
Kakanj, unit 8	300	2018
Total	**1,050**	

Source: NOS BiH

- 3016 MW in new WPPs (0 MW is included in the electricity balance made by NOS BiH, 2069 MW are not included into balance but they have appropriate government approval, 947 MW are not included into balance and without government approval).

- A total of 7206.5 MW in new power plants is planned (1121,9 MW is included in the electricity balance made by NOS BiH, 2416.8 MW are not included into the balance but they have appropriate government approval, 3667.8 MW are not included into balance and without government approval).

It is obvious that not all planned new power plants will be constructed because their installed capacity is several times higher than present system needs. The electricity market in Southeast Europe that could accept such production has not been developed to a sufficiently advanced stage, so investments in production facilities still face large risk.

Production that is included in the electricity balance would allow BiH to keep its relatively small exporter role in the SEE market. If all production facilities with governmental approvals are constructed, BiH could become a significant SEE exporting country.

Concerning new WPPs projects, there are 47 projects included in the Indicative power production development plan. Among them, 27 projects have some administrative documents already prepared, but only one project (WPP Mesihovina) is at the advanced stage of preparation with approved financial construction (KfW bank).

The majority of planned WPPs are located in the southern and western parts of BiH.

3.2 Consumption

NOS BiH prediction of system peak load at the transmission level[6] is given in Table 12, Figure 7 and Figure 8. It is expected that peak load will rise with an average load growth rate of 2.4 % in the time period from 2011 to 2020, rising from 2130 MW in 2011 up to 2637 MW in 2020 (absolute difference is 507 MW).

Planned base load of large consumers connected at the transmission level (220 kV or 110 kV)[7]. All of them plan to keep the same load level as today, except Aluminum factory in Mostar that predicts moderate rise of load in one scenario (from 230 MW to 234 MW), and extremely large rise up to 468 MW in high scenario.

Electricity consumption at the transmission level should rise from 11.4 TWh in 2010 up to 15 TWh (according to expected GDP growth), or 13.7 GWh (according to the Indicative production plan for time period 2007 – 2016), or 16.8 TWh (according to the Energy Sector Study in BiH, high scenario). Predictions say that electricity consumption at the transmission level will be between 13 TWh and 17 TWh in 2020.

[6] Indicative power production development plan 2011-2020, NOS BiH, July 2010

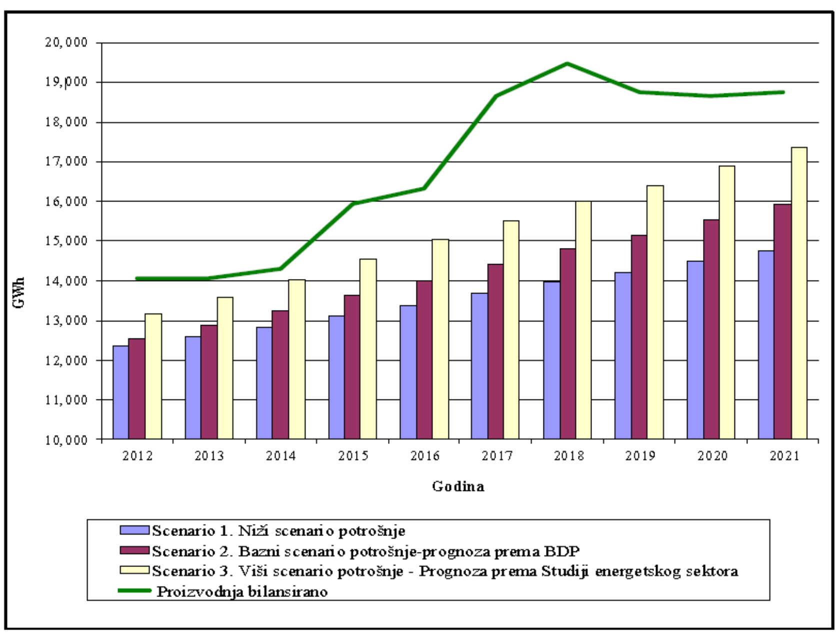
[7] Ibid.

Table 12 Prediction of system peak load up to 2020

Year	P_{max} (MW)
2001	1853
2002	1829
2003	1854
2004	1890
2005	2005
2006	2019
2007	2078
2008	2117
2009	2033
2010	2173
forecast	
2011	*2130*
2012	*2260*
2013	*2305*
2014	*2351*
2015	*2398*
2016	*2446*
2017	*2495*
2018	*2545*
2019	*2596*
2020	*2648*

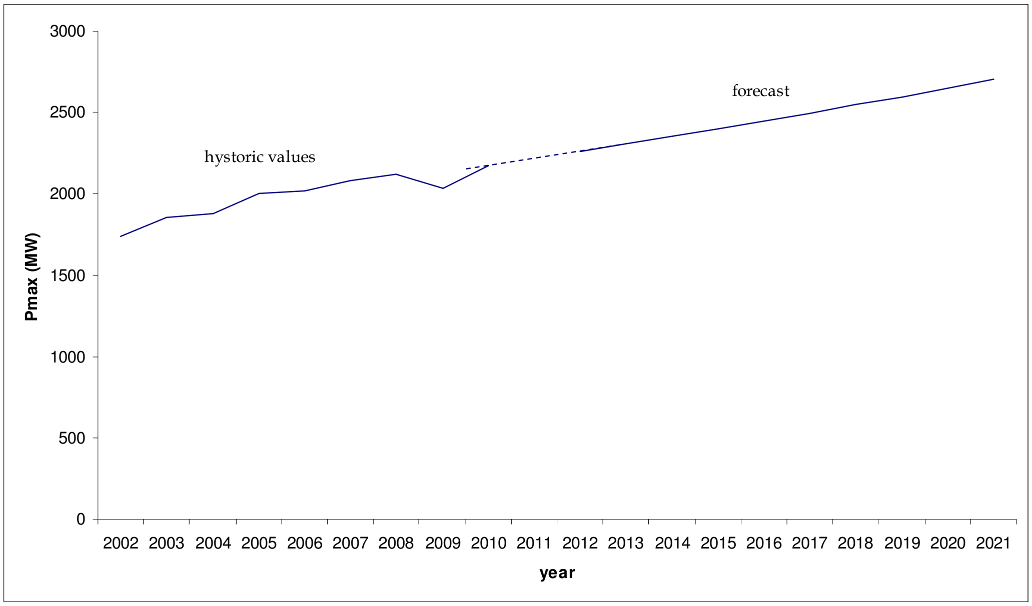
Source: NOS BiH

Figure 7 Future consumption in BiH



Source: NOS BiH

Figure 8 Predicted peak load in BiH



Source: NOS BiH

3.3 Transmission network

At the beginning of this section it was mentioned that the official mid term and/or long term development plan of the BiH transmission system has not been defined. Other problems related to this are:

- large and not realistic number of new production facilities planned for construction by different investors,
- large and not realistic plans of power production and supply companies of new substations 110/x kV construction,

In this sub-section, planned network topology included in the SECI models of BiH will be described. The same models are used latter for load flow and N-1 security analyses comprising different scenarios of WPP integration.

BiH high-voltage transmission network topology in 2015 is shown in Figure 9. The 400 kV network stays the same as today, except for a new 400 kV switchyard for new TPP Stanari is going to be connected to the 400 kV line Tuzla – Banja Luka. In the 220 kV network new lines 2x220 kV Posusje – Rama will be connected, by 220 kV lines Mostar – Zakucac and Rama – Jablanica. Existing 220 kV line Jajce – Jablanica will be introduced to the 220 kV switchyard of HPP Rama.

Figure 9 400 kV and 220 kV network topology in 2015 (SECI model of BiH)

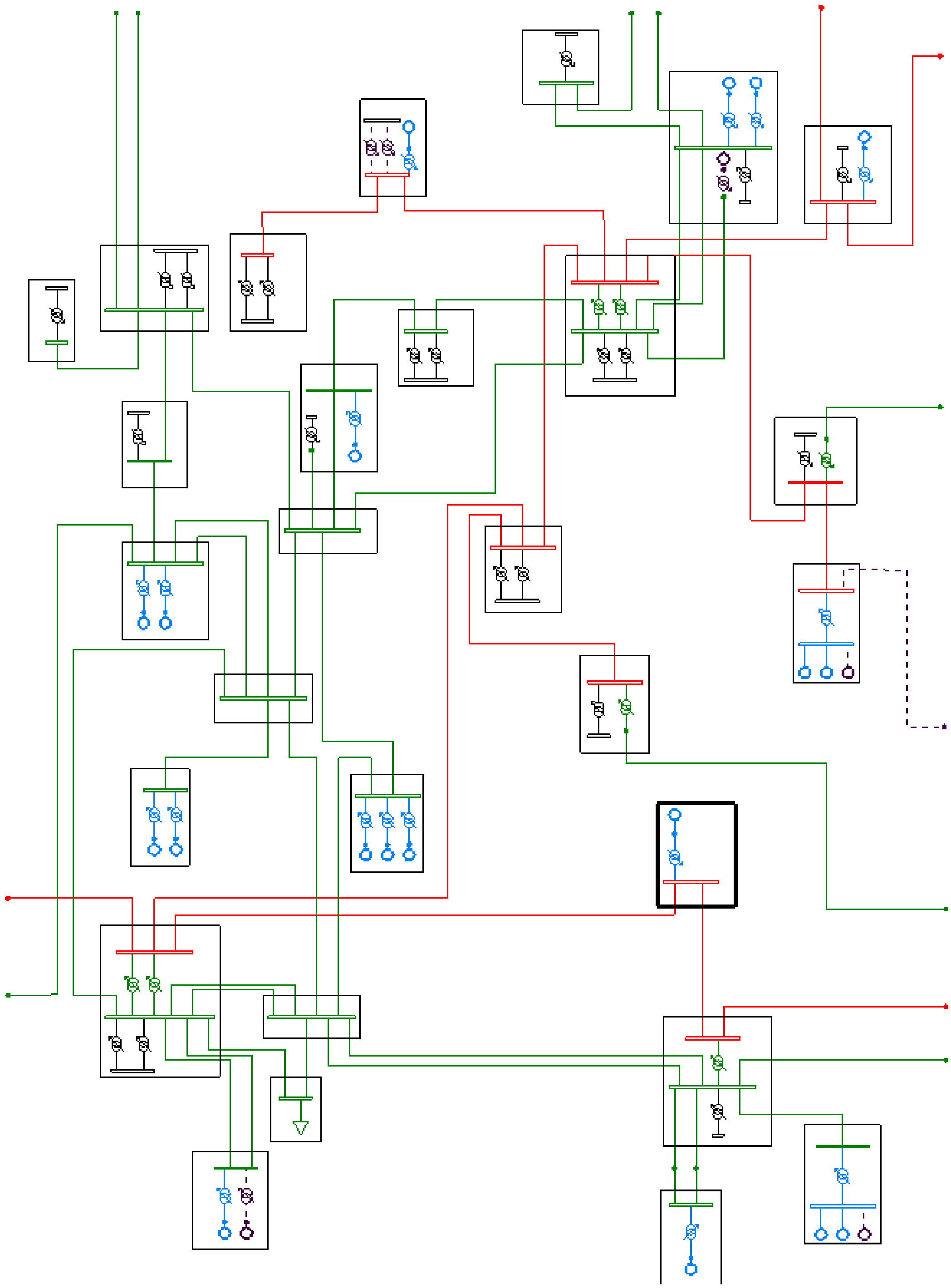
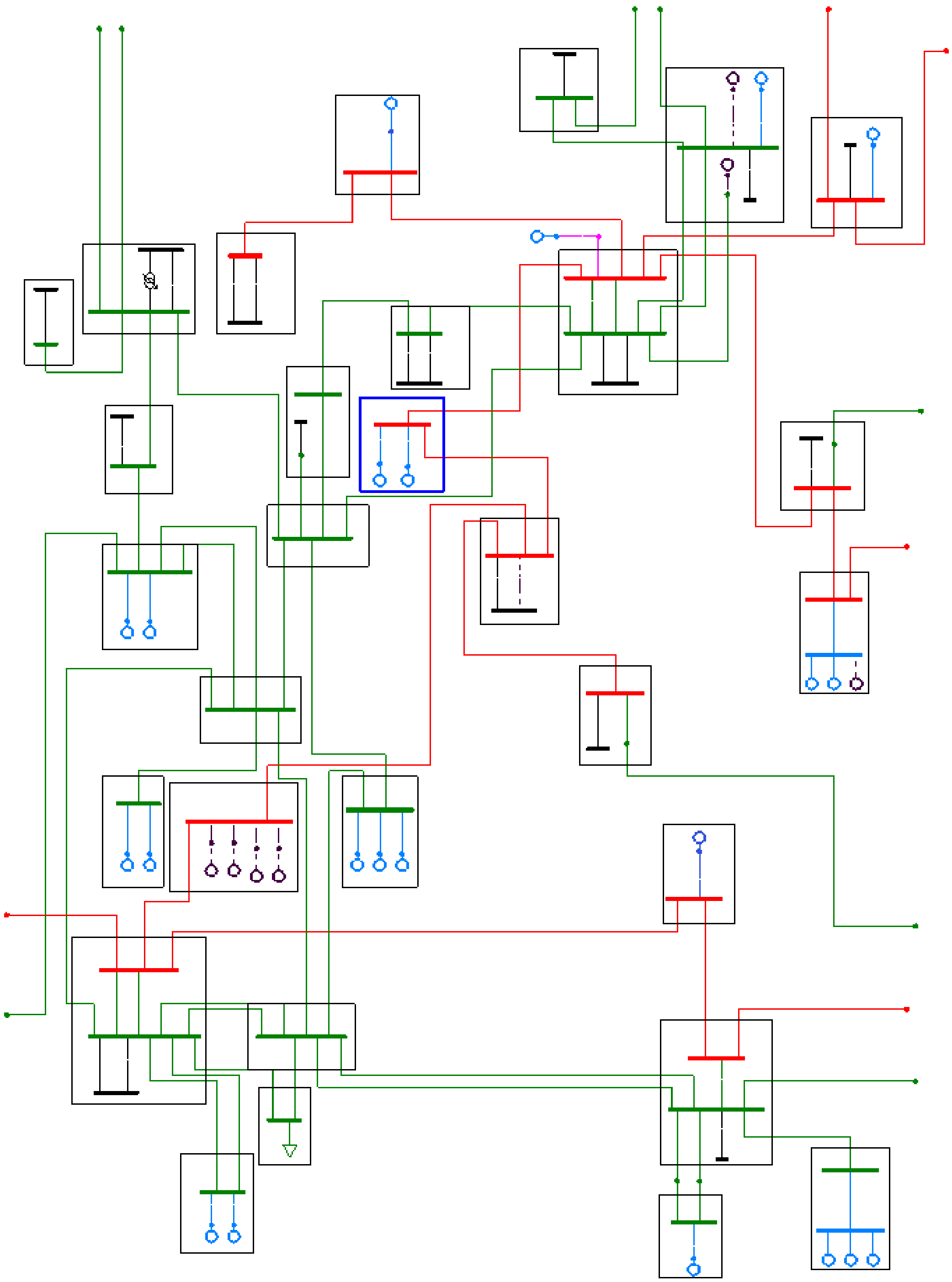


Figure 10 400 kV and 220 kV network topology in 2020 (SECI model of BiH)



No new transformers 400/220 kV, 400/110 kV or 220/110 kV are included in the model for 2015 compared with the present situation.

Two WPPs are connected in the 2015 model to the 110 kV network (WPP Kamena and WPP Mesihovina). There are no other new power plants connected to the 110 kV network in the observed time frame. Some new 110 kV lines are included in the model such as Nevesinje – Gacko, Bileca – Stolac, Ugljevik – Brcko, Kotor Varos – Ukrina, Bugojno – Kupres, Tomislavgrad – Kupres etc.

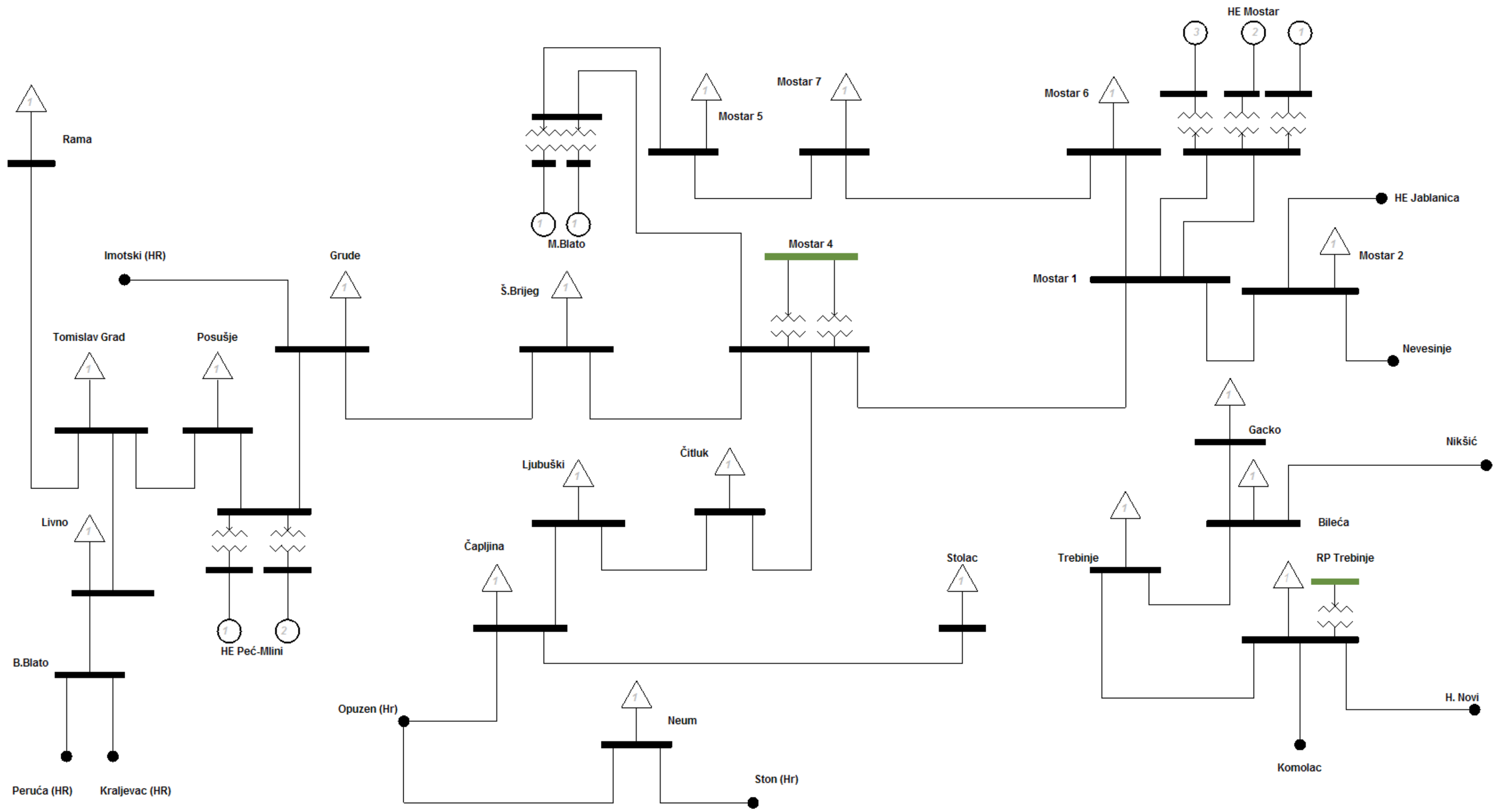
The BiH high-voltage transmission network topology in 2020 is shown in Figure 10. New 400 kV switchyard Kakanj is going to be introduced to the 400 kV line Sarajevo – Tuzla due to predicted TPP Kakanj unit 8 construction. Tuzla unit 7 is going to be connected to the 400 kV network (existing switchyard Tuzla). New interconnection 400 kV line from Visegrad to Pljevlja in Montenegro is included. There are no changes in the 220 kV network comparing it with 2015 topology. New 220/110 kV transformer in SS Gradacac is added at the model. One new WPP Merdzan Glava is connected at the 110 kV network in 2020.

From the new WPPs grid connection perspective it is very important how the 110 kV network will be developed in the vicinity of new WPPs. Most of them are located in the southern and southwestern parts of the country. Present topology of the 110 kV network in this part of the country is given in Figure 11. One may notice weak characteristics of existing 110 kV network topology in this area:

- some substations have radial feeding in 110 kV network (Rama, Gacko, Stolac)
- 110 kV network of wider Mostar area is not connected with 110 kV network of Trebinje area (missing 110 kV lines Nevesinje – Gacko and Bileca – Stolac[8])
- weak connection of Siroki Brijeg, Grude, Posusje and Tomislavgrad with Croatia and SS Mostar 4 (lines with small cross-sections)
- weak connection of Citluk, Capljina, Ljubuski and Stolac area with Croatia and SS Mostar 4 (some lines have small cross-section like Capljina – Opuzen)
- weak connection (cross-section) of 110 kV line RP Trebinje – TS Trebinje 1 (conductors are made of Al/Mg 95/55, 346 A, at the route end), and one 220/110 kV transformer in the RP Trebinje which doesn't provide sufficient support to this region.
- low transmission capacities of 110 kV lines used for connection of Trebinje area with Montenegro (Trebinje – Herceg Novi and Bileca – Niksic) and Croatia (Trebinje – Komolac).

[8] Presently in operation under 35 kV voltage.

Figure 11 110 kV Existing network topology at the area where majority of new WPPs are going to be constrENTSO-Ed



4 Load flow and voltage profile analysis

This section contains analyses of load flow and voltage profiles in the BiH transmission network for different scenarios, which are differentiated by time frames, levels of demand, hydro power plants engagement and wind power plants that could be constructed.

The analyses undertaken in this section help to determine the need for wind turbine participation in voltage/reactive power control and to identify bottlenecks in the transmission network resulting from wind power integration. Several typical operating regimes of the BiH power system are analysed: winter peak load, summer maximum load and off-peak load. Load flow models of the BiH power system are based on the five WPP construction scenarios outlined in the previous sections of this report. The scenarios of 1300 MW of WPPs was not analyzed from load flow perspective, as previously agreed with NOS BiH. For each scenario, the N–1 security criterion for all transmission network elements is checked and transmission network bottlenecks are identified. Secure operation of the power system in a situation of the largest thermal power unit outage (TPP Ugljevik today, TPP Stanari in the near future) for the highest penetration of wind power plants is also estimated but results are shown in the next section.

4.1 Input data, assumptions and scenarios

The analyses are done for each of the scenarios with the following assumptions:

- Time frame:
  - existing transmission network configuration (referred to 2011);
  - planned transmission network configuration (2015 and 2020).
- Load level and operation regime:
  - peak load situation (winter maximum load);
  - summer maximum load;
  - off-peak load situation (summer or spring minimum load).
- WPP construction scenarios:
  - scenario A: 150 MW in WPPs
  - scenario B: 300 MW in WPPs
  - scenario C: 600 MW in WPPs
  - scenario D1: 900 MW in WPPs, concentrated
  - scenario D2: 900 MW in WPPs, wide distribution.

- HPPs engagement:
  - Normal hydrological situation;
  - Wet hydrological situation;
  - Dry hydrological situation.

Figure 12 Scenarios for load flow and voltage profile analysis in 2011

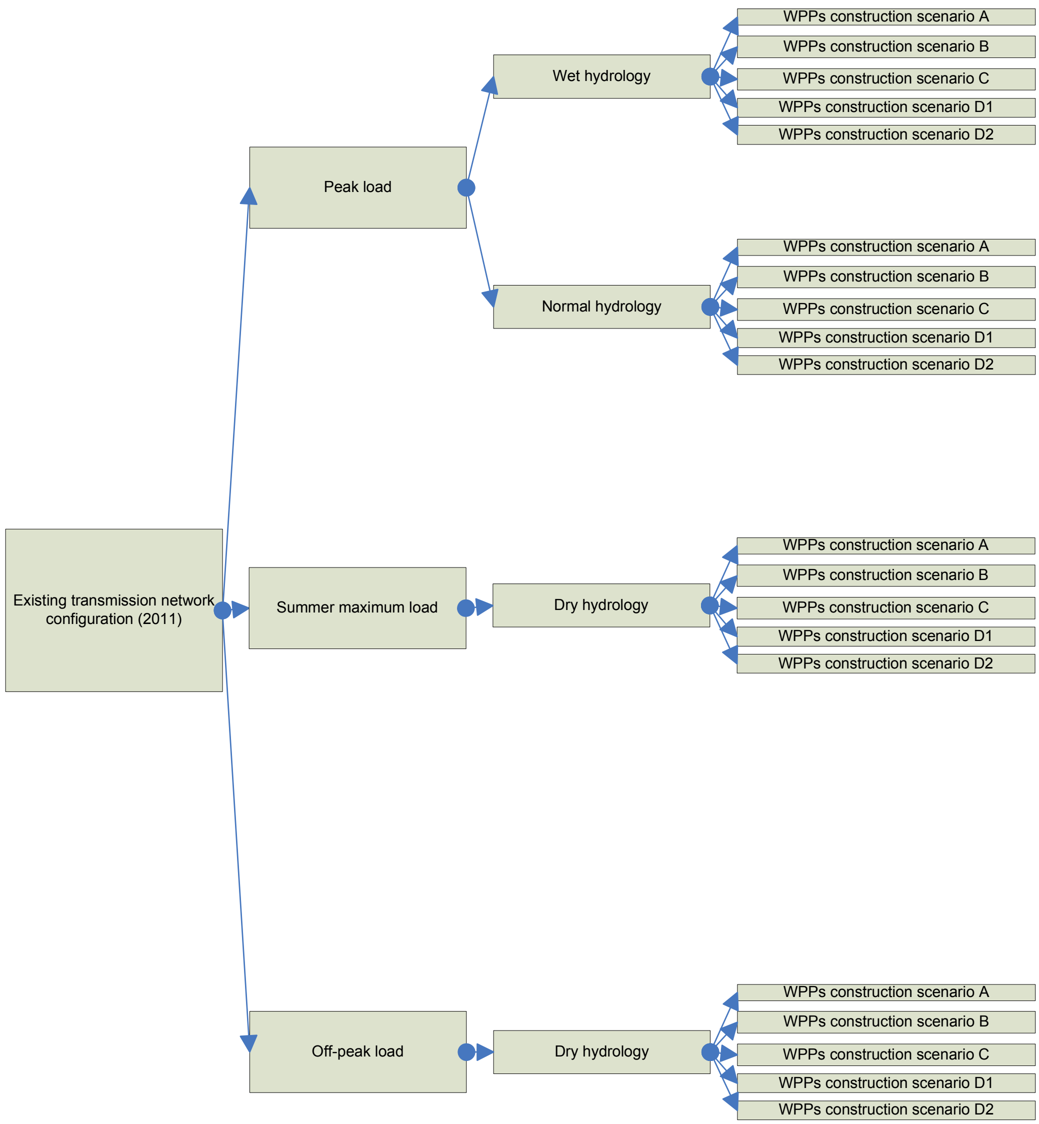
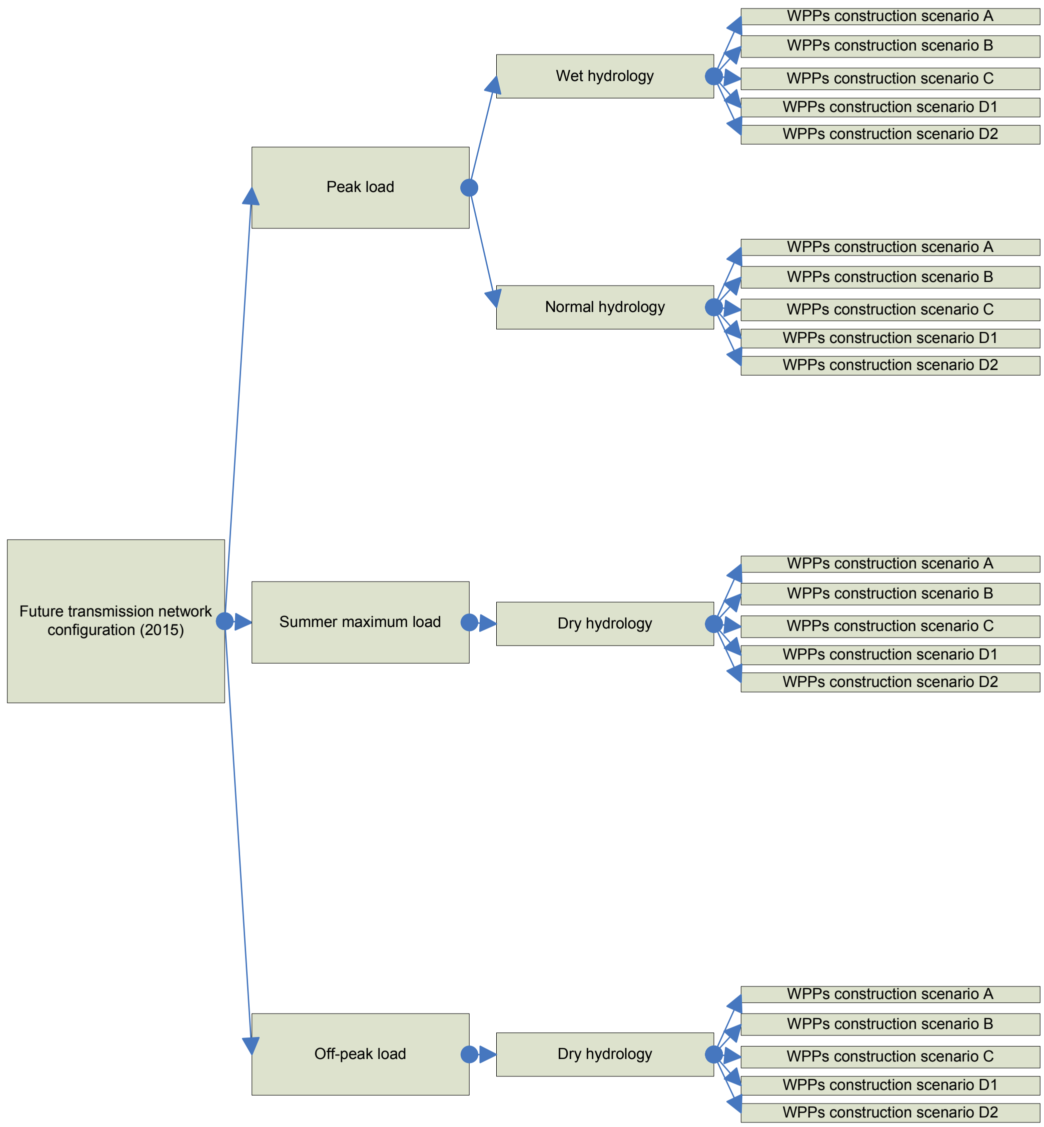


Figure 13 Scenarios for load flow and voltage profile analysis in 2015

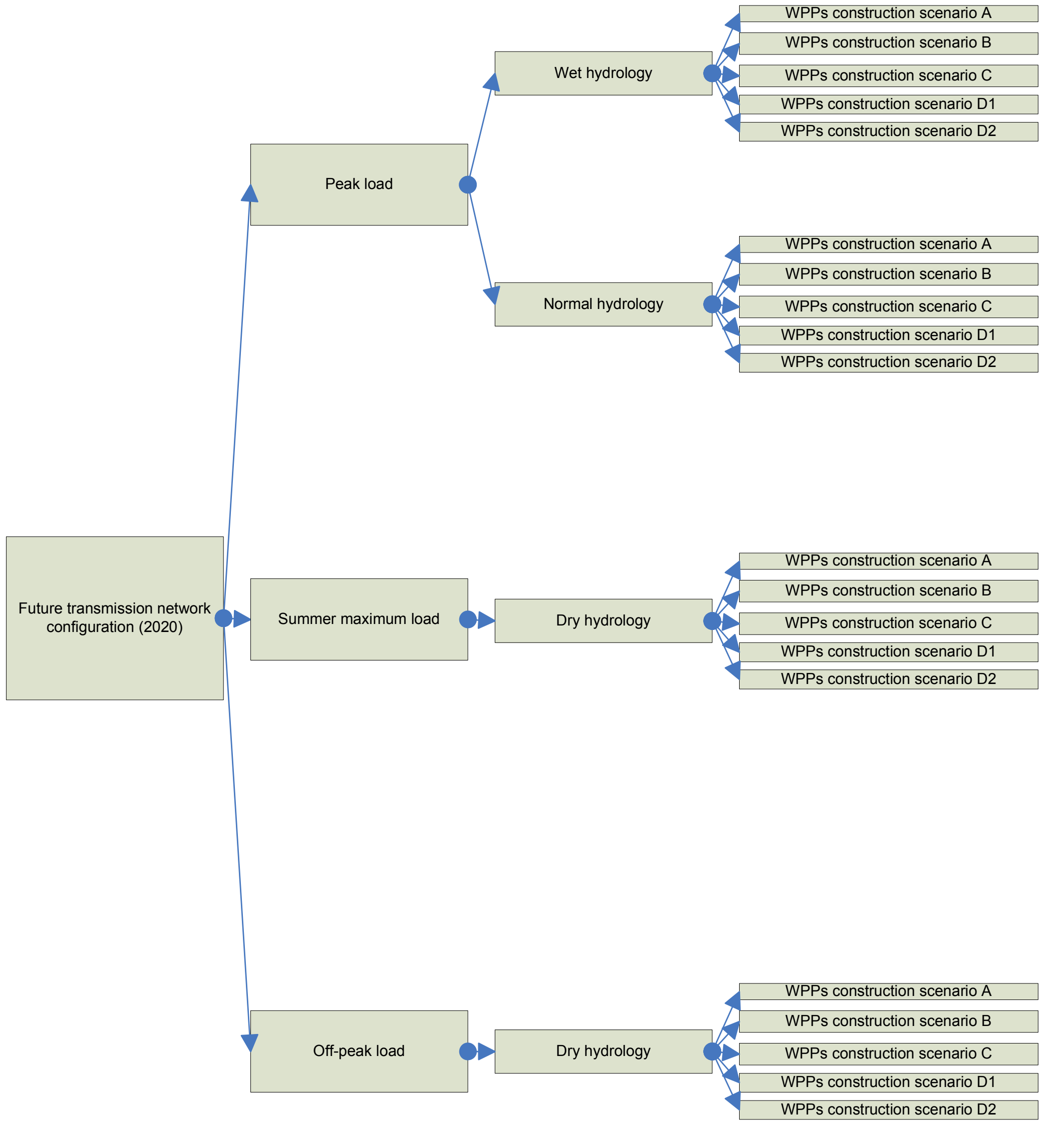


A representation of the analysed scenarios is provided in Figure 12 - Figure 14. Overall 60 scenarios have been simulated. They can be split into existing transmission network scenarios (2011) and future transmission network scenarios (2015 and 2020):

- 20 scenarios have been analysed for the ***existing transmission network configuration*** situation in 2011. The scenarios are based on a load level, hydrological situation and possible WPP construction.

- 40 scenarios have been analysed for ***future transmission network configuration*** (situation in 2015 and 2020). Scenarios are based on a load level, hydrological situation and possible WPP construction.

Figure 14 Scenarios for load flow and voltage profile analysis in 2020



The scenarios of WPP construction are:

(i) Scenario A with 150 MW in WPPs,

(ii) Scenario A1 with 200 MW in WPPs,

(iii) Scenario B with 300 MW in WPPs,

(iv) Scenario C with an additional 300 MW of wind capacity included, comparing with the previous scenario (total of 600 MW).

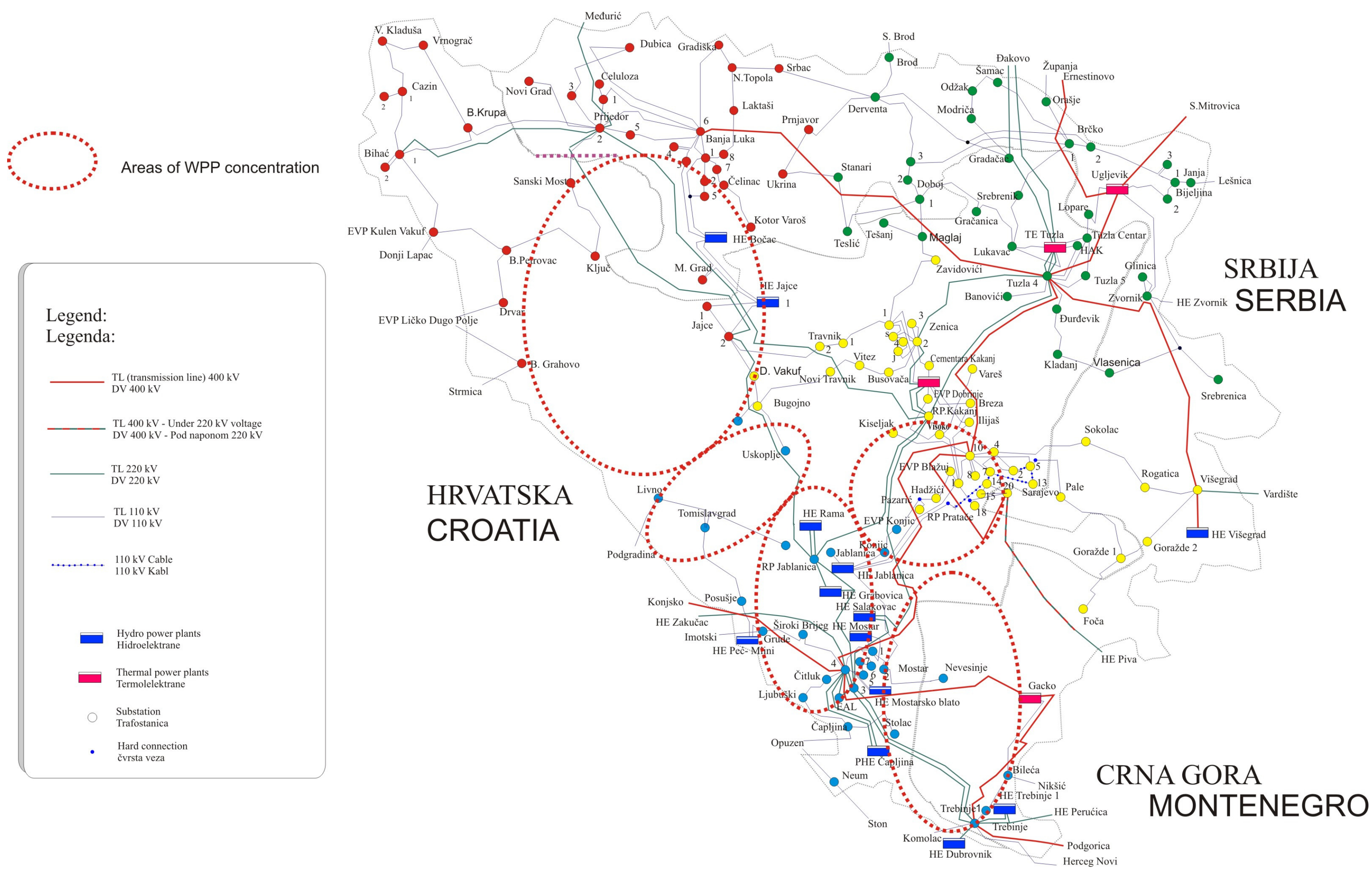
(iv) Scenario D1 with an additional 300 MW of wind capacity included, comparing with the previous scenario (total of 900 MW), but with concentrated locations of WPP.

(v) Scenario D2 with an additional 300 MW of wind capacity included, comparing with the previous scenario (total of 900 MW), but with wide distribution of WPP locations.

It is initially assumed that all WPPs are connected at the 110 kV voltage level. New wind farms (especially those with large installed power) could also be connected to the 220 kV or 400 kV grids, but according to their predicted installed capacities (between 18 MW and 145 MW) and 220 kV or 400 kV connection costs this option is considered as not realistic. Connection to the grid at 220 kV, and especially at 400 kV, would result with high connection costs thus probably make whole project economically not feasible.

It is important to note that the objective of the analyses is to assess the overall impact of WPP on the grid and not to identify individual WPPs connection solutions. Grid connections of individual wind power plants were taken from individual studies and Technical connection solution studies (ETRP) where applicable.

Figure 15 Planned wind farms locations in the existing BiH power system



As the BiH transmission network is characterised by provisional connection condition of some 110 kV lines due to war damages, weak 110 kV connection of some substations and low transmission capacities of some 110 kV lines (like 110 kV lines Mostar 4 – S. Brijeg, S. Brijeg – Grude, Grude – Imotski etc.), significant problems with WPP integration may be expected under the present configuration of the transmission system. The 110 kV transmission infrastructure has not even been developed in some parts of the country where WPP projects may be developed (such as the area around Glamoc, Nevesinje, Poklecani etc.).

4.2 Models

On the basis of the input data described in the previous sections the BiH power system models for 2011, 2015 and 2020 were developed in PSS/E format (Power System Simulator for Engineers, Siemens PTI). The model includes the 400 kV, 220 kV and 110 kV network of BiH with loads modelled at the 110 kV nodes, and power plants modelled as the generation units and related unit step-up transformers.

The model also includes the 400 kV, 220 kV, 150 kV and 110 kV networks of the surrounding countries: Montenegro, Serbia, Croatia, Albania, Slovenia, Austria, Hungary, Romania, Bulgaria, Macedonia, Greece, Italy as well as remaining part of the ENTSO-E.

It is initially assumed that all branches are in operation and there is no branch that is switched off due to forced outage or maintenance activities. Within the N-1 analysis individual losses of all branches in the power system of BiH are observed. Results however are only presented for critical events that lead to unsatisfactory system conditions (over-loadings, unacceptable voltage profile). Loss of radial feeders (SS Stolac, SS Pazaric, SS Cazin 2, SS Nevesinje in 2011 etc.) is not presented in the results since it does not depend on WPP construction. The loss of TPP Ugljevik in 2011 and TPP Stanari in 2015 and 2020 is also observed, assuming that a lack of power will be covered by additional import from neighbouring power systems (Croatia, Serbia, Montenegro), or increased engagement of the hydro power plants within the power system of BiH (see next section).

WPPs were modelled using a simple representation of an equivalent synchronous generator with a power factor of 1 at a transmission node connection point. If the voltage situation is found unacceptable during the analysis, a possible contribution of wind power plants in Q/U control is observed (power factor is then 0.95 or 0.90 at the mid-voltage side of internal substations x/110 kV).

WPPs are engaged in the models with 90% of their installed power, since this value is estimated as the highest possible synchronous engagement of a group of wind farms. Operation conditions which are analyzed represent a situation with extremely favourable wind conditions. It should be stressed that usually wind will be less favourable for electricity production and the network will be less exposed and loaded due to wind power plants engagement.

Table 13 WPP engagement in the models (MW)

	Scenario A 150 MW	Scenario B 300 MW	Scenario C 600 MW	Scenario D1 900 MW	Scenario D2 900 MW
TOTAL	**142.2**	**316.8**	**573.3**	**855**	**810.9**

Reactive power engagement of existing and future generators (except those representing wind farms) is determined during calculations based on predefined generator voltage (usually 1 per unit) and permitted range of reactive power engagement (Q_{min} – Q_{max}) defined by individual operational diagrams of generators. If high or low voltages are achieved at a model, change of generators voltage is permitted within ±5% U_n range. Tap changers on transformers included into the models are initially in the zero position (rated U_{n1}/U_{n2} ratio).

Load flows in the Appendix figures are presented in MW (active power) and Mvar (reactive power), with the sign plus (+) if power flows from a node, and the sign minus (-) if power flows to a node. Swing node for the load flow calculations (with predefined voltage of 1 pu and voltage angle of 0 degrees) is chosen to be far away from the analysed network. A generator's reactive power production is calculated within a permitted range for each generator in order to achieve generator rated or predefined voltage if possible. Tap changers are in the mid positions unless otherwise noted. Line loadings are shown with respect to their current ratings (thermal current or protection settings), not with respect to their power flows (MW or MVA). The Appendix figures present only the BiH transmission system. Even though other power systems are included in the analysis they are not presented in the Appendix figures.

Basic load flow results for the base case models in 2011, 2015 and 2020, representing situations without any wind power plants, are shown in Table 14.

Table 14 Basic load flow results for base case models without WPPs

Year	Base case	Domestic production (MW)	Load (MW)	Losses (MW)	Import/Export (MW)*
2011	Peak load	2327	2130	42	155
	Summer maximum load	1667	1636	31	0
	Off-peak load	818	800	18	0
2015	Peak load**	2948	2398	50	500
	Summer maximum load	2297	1854	43	400
	Off-peak load	1228	900	28	300
2020	Peak load**	3515	2648	117	750
	Summer maximum load	2520	2045	75	400
	Off-peak load	1362	995	67	300

* sign + for export from BiH, sign – for import in BiH
** according to the new version of Indicative production development plan 2012 - 2021

In situations with wind power plants included into the models, thermal and hydro power plants engagement stays the same but exports from BiH are increased due to new wind production. That's a way to achieve maximum expected transmission network loading for analyzed time frames, which will be a base for suggested network reinforcements and transmission investments due to wind power plants integration in the following sections.

4.3 Analysis based on existing transmission system

4.3.1 Load flow, voltage profile and N-1 analysis without WPPs

The load flow and voltage profile of the high-voltage transmission system of BiH (400 kV and 220 kV, 110 kV around Mostar) for existing network topology are given in the Appendix representing peak load (Figure 24 - Figure 29), summer maximum load (Figure 30 - Figure 32) and off-peak load conditions (Figure 33 - Figure 35). New wind power plants are not included in the model but will be explored in the next section where the results can be compared with the ones presented in this section.

Peak load scenario

During peak load conditions and HPPs engagement due to normal hydrological situation there are no branches of the network which are loaded by more than 81% of their maximum permitted loading. 400 kV lines are loaded below 23% of permitted value (Ugljevik – S. Mitrovica), while 220 kV lines are loaded below 38% of permitted limit (Tuzla – Gradacac). The most loaded line in the 110 kV network (comparing it with permitted limit) is Mostar 4 – Siroki Brijeg (81% I_{max}).

The voltage profile is satisfactory, with voltages between 403 kV and 410 kV in the 400 kV network, between 226 kV and 237 kV in the 220 kV network and between 111 kV and 120 kV in the 110 kV network.

N-1 criterion is not satisfied in the analysed situation due to the 110 kV network overloading and voltage violations in Banja Luka and Hercegovina region (Table 15). Critical events are outages of one 110 kV line between SS Banja Luka 1 and SS Banja Luka 6, and outages of lines Mostar 4 – Citluk or Citluk – Ljubuski. 110 kV lines which are at risk include Mostar 4 – Siroki Brijeg, Capljina – Opuzen and Banja Luka 1 – Banja Luka 6 (circuit 1). Voltage could be unacceptably low at 110 kV nodes Citluk, Ljubuski, Capljina and Stolac.

Table 15 Bottlenecks during peak load no WPPs (existing system, normal hydrology)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	104
OHL 110 kV Mostar 4 – Citluk	OHL 110 kV Capljina – Opuzen	113
	OHL 110 kV Mostar 4 – S.Brijeg	108
OHL 110 kV Citluk – Ljubuski	OHL 110 kV Mostar 4 – S.Brijeg	100
Critical outage	**Node**	**Voltage violations (kV)**
OHL 110 kV Mostar 4 – Citluk	Capljina	95,7
	Ljubuski	93,5
	Citluk	92,4
	Stolac	95,7

During peak load and wet hydrological situation 220 kV and 110 kV networks are generally more loaded, due to connection of most HPPs to these voltage levels. The most loaded line in the 220 kV network is Zenica – Kakanj (50% I_{max}), while the most loaded line in 110 kV network is Mostar 4 – Siroki Brijeg (85% I_{max}).

The N-1 criterion is not satisfied in the analysed situation due to the 110 kV network overloading and voltage violations in Hercegovina region (Table 16). There is one more critical event, loss of 400 kV line between SS Mostar 4 and Konjsko in Croatia that may cause 110 kV line Mostar 4 – Siroki Brijeg overloading because of its low transmission capacity.

Critical 110 kV line Mostar 4 – Siroki Brijeg is planned for WPP Velika Vlajina (32 MW) grid connection, and it is located on the very important path in the 110 kV network where the majority of wind farms will be located. Details on this line are given in the following sections.

Table 16 Bottlenecks during peak load no WPPs (existing system, wet hydrology)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 400 kV Mostar 4 - Konjsko	OHL 110 kV Mostar 4 – S.Brijeg	102
OHL 110 kV Mostar 4 – Citluk	OHL 110 kV Capljina – Opuzen	113
	OHL 110 kV Mostar 4 – S.Brijeg	112
OHL 110 kV Citluk – Ljubuski	OHL 110 kV Mostar 4 – S.Brijeg	105
Critical outage	**Node**	**Voltage violations (kV)**
OHL 110 kV Mostar 4 – Citluk	Capljina	95,7
	Ljubuski	93,5
	Citluk	92,4
	Stolac	95,7

Summer maximum load scenario

During summer maximum load there are no branches loaded by more than 64% of their maximum permitted loading. 400 kV lines are loaded below 24% of the permitted values (Ugljevik – S.Mitrovica), while 220 kV lines are loaded below 49% of permitted limits (TPP Tuzla – Tuzla). The most loaded line in the 110 kV network (comparing it with permitted limit) is Mostar 4 – S.Brijeg (64% I_{max}).

The voltage profile is satisfactory, with voltages between 403 kV and 411 kV in the 400 kV network, between 228 kV and 235 kV in the 220 kV network and between 114 kV and 120 kV in the 110 kV network.

N-1 criterion is satisfied in the analysed situation. 110 kV lines Banja Luka 1 – Banja Luka 6 (1) and Mostar 4 – S. Brijeg are highly loaded (81% and 84% I_{max} respectively) during critical events (loss of 110 kV line Banja Luka 1 – Banja Luka 6 (1) and Mostar 4 – Citluk).

Off-peak load scenario

During off-peak load there are no branches loaded by more than 43% of their maximum permitted loading. 400 kV lines are loaded below 24% of permitted values (Ugljevik – S.Mitrovica), while 220 kV lines are loaded below 43% of the permitted limits (Kakanj 5 – SS Kakanj). The most loaded line in the 110 kV network is Trebinje – Herceg Novi (43% I_{max}).

The voltage levels are close to the upper limits, exceeding them in SS Banja Luka 6 (421 kV), SS Tuzla 6 (244 kV), SS Zenica 2 (244 kV) and several 110 kV switchyards in the North-western part (area around Prijedor). Voltage values in the 110 kV network may be additionally decreased by usage of automatic regulation on 220/110 kV transformers. Voltages in the 220 kV network could be improved by hydro and thermal generators which are in operation during low load conditions, and by proper positioning of tap changers on transformers 400/220 kV (possible only in the out-of-operation condition). Voltages in the 400 kV network are a real problem, because they could be controlled only slightly by generators connected to that voltage level (TPP Gacko, TPP Ugljevik and HPP Visegrad) which could be out-of operation during low load conditions.

The system operator in BiH doesn't have efficient sources to control voltages in the 400 kV network and voltages may rise above permitted 420 kV in some network nodes (like Banja Luka, Ugljevik, Mostar 4 etc.). High voltages may cause deconstruction or deterioration of nework equipment connected to this voltage level, especially insulators and circuit-breakers. Nevertheless, future wind power plants will not be able to make an influence on voltages in the 400 kV network since they will be connected to the 110 kV voltage level.

The N-1 criterion is almost satisfied in the analysed situation. The only problem could be caused by loss of radial 220 kV line Prijedor 2 – Bihać when voltage may rise high in the Bihać and Prijedor area.

Table 17 Bottlenecks during off-peak load no WPPs (existing system)

Critical outage	Node	Voltage violations (kV)
OHL 220 kV Prijedor 2 – Bihać	Bihać 110 kV	121,7
	Prijedor 2 110 kV	121,6
	other nodes 110 kV around Prijedor and Bihać	121 - 122

Existing network and no WPP conclusions

The BiH power system is mainly at risk in its north and southwestern parts because of low transmission capacities of some lines like Banja Luka 1 – Banja Luka 6 (1), Mostar 4 – Siroki Brijeg and Capljina – Opuzen. Voltage problems are detected in the 400 kV network during off-peak load condition when voltages may rise above upper limits, spreading disturbance over 220 kV and 110 kV networks, and in the 110 kV network around Capljina during peak load condition following an outage of the Mostar 4 – Citluk line.

- The Banja Luka 1 – Banja Luka 6 (1) line which is 12.7 km long, with conductors cross-section ACSR 150 mm², thermal limit 470 A (90 MVA), is jeopardized following a loss of the parallel line during peak load conditions;
- The Mostar 4 – Siroki Brijeg line which is 16.8 km long, with conductors cross-section ACSR 240 mm² and Copper 95 mm², thermal limit 380 A (72 MVA), concrete towers, is jeopardized following a loss of 400 kV line Mostar 4 – Konjsko or 110 kV line Mostar 4 – Citluk or 110 kV line Citluk – Ljubuski, during peak load conditions;

- The Capljina – Opuzen line between BiH and Croatia which is 21.9 km long (11.9 km in BiH), with conductors cross-section ACSR 150 mm² and ACSR 120 mm², thermal limit 385 A (73 MVA), is jeopardized following a loss of 110 kV line Mostar 4 – Citluk during peak load conditions;

- Loss of 110 kV line Mostar 4 – Citluk during peak load condition causes low voltages (below 99 kV) in the SS Citluk, SS Capljina, SS Ljubuski and SS Stolac. Improvement is expected soon when 110 kV line Ljubuski – Vrgorac (Croatia) will be put in operation under rated voltage (today in operation under 35 kV, construction of SS 110/35 kV Vrgorac underway).

- High voltages may appear in the 400 kV network during off-peak load situation, especially at SS 400/110 kV Banja Luka 6.

- Voltages in the 220 kV and 110 kV networks around substations 220/110 kV Prijedor 2 and Bihać may rise above permitted upper values following an outage of 220 kV line between these two substations during off-peak load condition.

For future WPPs connection the most important bottleneck today is Mostar 4 – Siroki Brijeg line. There are no WPPs planned for construction around Banja Luka, while those located around Capljina and Stolac may only improve operational security of the network because they would decrease loading of Mostar 4 – Citluk line.

Before we go through detailed analyses, it is important to point out that these network calculations were done in order to identify network bottlenecks. In that sense verified power system model is used, along with WPP connection nodes and criteria given in the Task 1. But, neither NOS nor authors do not evaluate or prefer any of WPP projects. Accordingly, we don't analyze detailed WPP connection issues, but only expected overall WPP impact to network bottlenecks.

4.3.2 WPPs construction in scenario A

In scenario A, wind power plants in Regions 2, 3 and 4 (WPP Mesihovina 44 MW, WPP V.Vlajina 32 MW, WPP Ivan Sedlo 40 MW and WPP Kamena 42 MW) were added to the model used and described in the previous section. Power exports of BiH were increased for the production of WPPs, which means that the engagement of TPPs and HPPs within the BiH power system remains the same.

The load flow and voltage profile of the high-voltage transmission system of BiH (400 kV and 220 kV, 110 kV around Mostar) for existing network topology, with new WPPs referring to scenario A of their construction, are given in the Appendix representing peak load (Figure 36 - Figure 41), summer maximum load (Figure 42 - Figure 44) and off-peak load conditions (Figure 45 - Figure 47).

Peak load scenario

WPPs in scenario A will not change load flow and voltage situation in the 400 kV network and 220 kV significantly. Production of WPP Mesihovina is consumed mostly at Tomislavgrad, WPP V.Vlajina at Siroki Brijeg, WPP Kamena at Mostar 2 and WPP Ivan Sedlo at Hadzici. 110 kV lines are loaded below 64% (normal hydrology) and 75% (wet hydrology) of their transmission capacities and voltage situation is acceptable during peak load, no matter of hydrological situation and HPPs engagement. There is no need for Q/U contribution of wind turbines in this scenario.

Results of the N-1 analysis are given in Table 18 and Table 19. New critical events are now marked in red; blue represents critical situations that are now relieved.

Table 18 Bottlenecks during peak load, WPPs in scenario A (existing system, normal hydrology)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	103
OHL 110 kV Mostar 4 – Citluk	OHL 110 kV Capljina – Opuzen	113
	OHL 110 kV Mostar 4 – Vlajina - S. Brijeg	63 / 98
OHL 110 kV Citluk – Ljubuski	OHL 110 kV Mostar 4 – Vlajina - S. Brijeg	55 / 90
Critical outage	**Node**	**Voltage violations (kV)**
OHL 110 kV Mostar 4 – Citluk	Capljina	95.7
	Ljubuski	93.5
	Citluk	92.4
	Stolac	95.7

Table 19 Bottlenecks during peak load, WPPs in scenario A (existing system, wet hydrology)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 400 kV Mostar 4 - Konjsko	OHL 110 kV Mostar 4 – Vlajina - S. Brijeg	57 / 93
OHL 110 kV Mostar 4 – Citluk	OHL 110 kV Capljina – Opuzen	113
	OHL 110 kV Mostar 4 – Vlajina - S. Brijeg	67 / 103
	OHL 110 kV Mostar 4 – Vlajina - S. Brijeg	67
OHL 110 kV Citluk – Ljubuski	OHL 110 kV Mostar 4 – Vlajina - S. Brijeg	60 / 95
Critical outage	**Node**	**Voltage violations (kV)**
OHL 110 kV Mostar 4 – Citluk	Capljina	95.7
	Ljubuski	93.5
	Citluk	92.4
	Stolac	95.7

There is only one critical contingency in the network, partially related to WPP integration. Connection of WPP Mesihovina and WPP V.Vlajina and their high engagement will relieve critical line section Mostar 4 – V.Vlajina so this line section doesn't appear as critical any more. Connection of WPP V. Vlajina will cause additional load of the 110 kV line V.Vlajina – S.Brijeg (part of existing line Mostar 4 – S.Brijeg). Section from WPP V.Vlajina to SS S.Brijeg is highly loaded or overloaded (up to 98% I_{max} during normal hydrological situation and up to 103% during wet hydrological situation) following an outage of 110 kV line Mostar 4 – Citluk or Citluk – Ljubuski. 110 kV line Mostar 1 – Mostar 6 could be loaded up to 84% I_{max} (normal hydrology) and 95% I_{max} (wet hydrology) when 110 kV line Mostar 1 – Mostar 4 goes out of operation. Voltage problems are still present in the wider Capljina area.

Summer maximum load scenario

During summer maximum load newly connected wind farms do not cause any new problem in the 110 kV network, and voltages are kept within permitted range.

N-1 criterion is still satisfied, so network may accept all wind production in this scenario and operate in a safe way.

Off-peak load scenario

The same is valid for the off-peak situation. WPPs will not increase voltages in connection nodes significantly, pushing them above permitted upper limit. Still, the tap changer at transformers 220/110 kV in the Mostar substation has to be positioned to keep the desired voltage level in the 110 kV network. In mid position (ratio 220/115 kV) voltages would rise above 121 kV.

Existing network and WPP in scenario A conclusions

Construction and connection to the 110 kV grid of WPP Mesihovina, WPP Velika Vlajina, WPP Kamena and WPP Ivan Sedlo proves to be feasible if 110 kV line Mostar 4 – S.Brijeg is revitalised. The line section from WPP Velika Vlajina to S.Brijeg could be overloaded due to WPP V.Vlajina high engagement, and the line section from Mostar 4 to WPP Velika Vlajina could be overloaded during WPP V.Vlajina low engagement. The 110 kV line from Mostar 4 to Siroki Brijeg needs replacement (sections with copper conductors and concrete towers), equipped with conductors ACSR 240/40 mm^2 and steel towers, regardless of whether wind power plants are constructed.

In the other parts of network, no critical branches were detected.

4.3.3 WPPs construction in scenario A1

This scenario comprises a construction of one WPP with installed power 50 MW located in the wide area of Trebinje. Connection of this WPP is planned using new 110 kV line Nevesinje – Gacko that is going to be constructed in the near future. Influence of wind power plants integration in this scenario is analyzed later concerning future transmission system.

4.3.4 WPPs construction in scenario B

In scenario B new WPPs with installed power of 150 MW (total 300 MW) and located in the Regions 1, 2 and 3, were added to the model used and described in the previous section. Power exports from BiH were increased for the production of wind power plants, which means that the engagement of thermal and hydro power plants within the BiH power system remains the same.

All new wind farms are located in the vicinity of SS Tomislavgrad, presently connected to SS Livno with one line, SS Posusje and SS Rama (radial connection of SS Rama, this line is planned to be introduced to the 110 kV switchyard at WPP Poklecani).

The load flow and voltage profile of the high-voltage transmission system of BiH (400 kV and 220 kV, 110 kV around Mostar) for existing network topology, with new wind power plants referring to scenario B of their construction, are given in the Appendix representing peak load (Figure 48 - Figure 53), summer maximum load (Figure 54 - Figure 56) and off-peak load conditions (Figure 57 - Figure 59).

Peak load scenario

Loading of the 400 kV and 220 kV networks will remain almost unchanged but transformers 220/110 kV in the SS Mostar 4 will be relieved. Power will go from 220 kV to 400 kV network in SS Mostar 4, also from 110 kV to 220 kV network through Mostar 4 under wet hydrological situation. Connection of WPP Poklecani, WPP Gradina and WPP Borova Glava will cause high loading of some 110 kV lines like Livno – Busko Blato (up to 74% I_{max}), Livno – Borova Glava (up to 83% I_{max}) and HPP Pec Mlini – Posusje (up to 75% I_{max}) under full network topology.

Production of WPP Poklecani will go in the direction of Posusje, making other 110 kV lines (to Rama and Tomislavgrad) unloaded. A significant part of WPP production will go in the direction of Croatia using lines from Busko Blato to Peruca and Kraljevac.

The voltage situation is acceptable, voltage profile is close to the upper limit but voltages could be decreased using tap changers in Mostar 4 220/110 kV transformers.

The N-1 criterion is not satisfied because there are many 110 kV lines in the area of S. Brijeg, Posusje, Tomislavgrad and Livno which are at risk of being severely overloaded (Table 20, Table 21). It is clear that existing network topology doesn’t allow connection of wind power plants in this scenario without significant network investments.

Summer maximum load scenario

110 kV network in western Herzegovina is highly loaded during summer maximum load also. Voltage situation is acceptable, with voltages within permitted limits at all three transmission voltage levels (400 kV, 220 kV, 110 kV).

Outage of one line in the 110 kV network of Hercegovina will bring risk to other lines which will become overloaded and the power system will probably break down in this part of the country (Table 22).

Off-peak load scenario

Due to unfavourable voltage conditions tap changer at transformers 220/110 kV in the Mostar substation has to be positioned to keep the desired voltage level in the 110 kV network. N-1 criterion is not satisfied, and even under full network topology the 110 kV line Mostar 4 – V.Vlajina is overloaded (Table 23).

Table 20 Bottlenecks during peak load, WPPs in scenario B (existing system, normal hydrology)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	102
OHL 110 kV Mostar 4 – Citluk	OHL 110 kV Capljina – Opuzen	113
	OHL 110 kV Mostar 4 – V. Vlajina	46
OHL 110 kV Citluk – Ljubuski	OHL 110 kV Mostar 4 – V. Vlajina	49
OHL 110 kV Grude – Imotski	OHL 110 kV Mostar 4 – V. Vlajina	103
OHL 110 kV B.Blato – Livno	OHL 110 kV Grude – Imotski	125
	OHL 110 kV Mostar 4 – V. Vlajina	127
	OHL 110 kV S.Brijeg – Grude	114
	OHL 110 kV Pec Mlini – Grude	143
	OHL 110 kV Pec Mlini – Posusje	141
OHL 110 kV Mostar 4 – V. Vlajina	OHL 110 kV Grude – Imotski	105
OHL 110 kV Pec Mlini – Grude	OHL 110 kV B.Blato – Kraljevac	101
	OHL 110 kV B.Blato – Livno	148
	OHL 110 kV Livno – B.Glava	157
	OHL 110 kV Tomislavgrad – B.Glava	121
OHL 110 kV Pec Mlini – Posusje	OHL 110 kV B.Blato – Livno	142
	OHL 110 kV Livno – B.Glava	151
	OHL 110 kV Tomislavgrad – B.Glava	114
OHL 110 kV Livno – B.Glava	OHL 110 kV Grude – Imotski	132
	OHL 110 kV Mostar 4 – V. Vlajina	135
	OHL 110 kV S.Brijeg – Grude	122
	OHL 110 kV S.Brijeg – V.Vlajina	105
	OHL 110 kV Pec Mlini – Grude	152
	OHL 110 kV Pec Mlini – Posusje	150
OHL 110 kV Tomislavgrad – B.Glava	OHL 110 kV Grude – Imotski	103
	OHL 110 kV Mostar 4 – V. Vlajina	101
	OHL 110 kV Pec Mlini – Grude	116
	OHL 110 kV Pec Mlini – Posusje	110
Critical outage	**Node**	**Voltage violations (kV)**
OHL 110 kV Mostar 4 – Citluk	Capljina	95.7
	Ljubuski	93.5
	Citluk	92.4
	Stolac	95.7

Table 21 Bottlenecks during peak load, WPPs in scenario B (existing system, wet hydrology)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV Mostar 4 – Citluk	OHL 110 kV Capljina – Opuzen	113
	OHL 110 kV Mostar 4 – V. Vlajina	42
OHL 110 kV Citluk – Ljubuski	OHL 110 kV Mostar 4 – V. Vlajina	44
OHL 110 kV Grude – Imotski	OHL 110 kV Mostar 4 – V. Vlajina	106
OHL 110 kV B.Blato – Livno	OHL 110 kV Grude – Imotski	139
	OHL 110 kV Mostar 4 – V. Vlajina	127
	OHL 110 kV S.Brijeg – Grude	114
	OHL 110 kV Pec Mlini – Grude	151
	OHL 110 kV Pec Mlini – Posusje	141
OHL 110 kV Mostar 4 – V. Vlajina	OHL 110 kV Grude – Imotski	112
OHL 110 kV Pec Mlini – Grude	OHL 110 kV B.Blato – Kraljevac	106
	OHL 110 kV B.Blato – Livno	158
	OHL 110 kV Livno – B.Glava	167
	OHL 110 kV Tomislavgrad – B.Glava	130
OHL 110 kV Pec Mlini – Posusje	OHL 110 kV B.Blato – Livno	143
	OHL 110 kV Livno – B.Glava	151
	OHL 110 kV Tomislavgrad – B.Glava	115
OHL 110 kV Livno – B.Glava	OHL 110 kV Grude – Imotski	146
	OHL 110 kV Mostar 4 – V. Vlajina	135
	OHL 110 kV S.Brijeg – Grude	122
	OHL 110 kV S.Brijeg – V.Vlajina	105
	OHL 110 kV Pec Mlini – Grude	160
	OHL 110 kV Pec Mlini – Posusje	150
OHL 110 kV Tomislavgrad – B.Glava	OHL 110 kV Grude – Imotski	117
	OHL 110 kV Mostar 4 – V. Vlajina	100
	OHL 110 kV Pec Mlini – Grude	124
	OHL 110 kV Pec Mlini – Posusje	111
Critical outage	**Node**	**Voltage violations (kV)**
OHL 110 kV Mostar 4 – Citluk	Capljina	95.7
	Ljubuski	93.5
	Citluk	92.4
	Stolac	95.7

Table 22 Bottlenecks during summer maximum load, WPPs in scenario B (existing system)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV Grude – Imotski	OHL 110 kV Mostar 4 – V. Vlajina	115
OHL 110 kV B.Blato – Livno	OHL 110 kV Grude – Imotski	121
	OHL 110 kV Mostar 4 – V. Vlajina	145
	OHL 110 kV S.Brijeg – Grude	127
	OHL 110 kV Pec Mlini – Grude	147
	OHL 110 kV Pec Mlini – Posusje	149
OHL 110 kV Mostar 4 – V. Vlajina	OHL 110 kV Grude – Imotski	111
OHL 110 kV Pec Mlini – Grude	OHL 110 kV B.Blato – Kraljevac	102
	OHL 110 kV B.Blato – Livno	150
	OHL 110 kV Livno – B.Glava	156
	OHL 110 kV Tomislavgrad – B.Glava	120
OHL 110 kV Pec Mlini – Posusje	OHL 110 kV B.Blato – Kraljevac	101
	OHL 110 kV B.Blato – Livno	148
	OHL 110 kV Livno – B.Glava	155
	OHL 110 kV Tomislavgrad – B.Glava	118
OHL 110 kV Livno – B.Glava	OHL 110 kV Grude – Imotski	126
	OHL 110 kV Mostar 4 – V. Vlajina	151
	OHL 110 kV S.Brijeg – Grude	133
	OHL 110 kV S.Brijeg – V.Vlajina	120
	OHL 110 kV Pec Mlini – Grude	153
	OHL 110 kV Pec Mlini – Posusje	156
OHL 110 kV Tomislavgrad – B.Glava	OHL 110 kV Mostar 4 – V. Vlajina	116
	OHL 110 kV Pec Mlini – Grude	115
	OHL 110 kV Pec Mlini – Posusje	115

Table 23 Bottlenecks during off-peak load, WPPs in scenario B (existing system)

Critical outage	Overloaded branch	Loading (% of permitted loading)
-	OHL 110 kV Mostar 4 – V. Vlajina	101
OHL 110 kV Grude – Imotski	OHL 110 kV S.Brijeg – V. Vlajina	101
	OHL 110 kV S.Brijeg – Grude	107
OHL 110 kV B.Blato – Livno	OHL 110 kV Grude – Imotski	117
	OHL 110 kV S.Brijeg – Grude	145
	OHL 110 kV S.Brijeg – V. Vlajina	141
	OHL 110 kV Pec Mlini – Grude	151
	OHL 110 kV Pec Mlini – Posusje	158
OHL 110 kV Mostar 4 – V. Vlajina	OHL 110 kV Grude – Imotski	122
OHL 110 kV Pec Mlini – Grude	OHL 110 kV B.Blato – Kraljevac	108
	OHL 110 kV B.Blato – Livno	155
	OHL 110 kV Livno – B.Glava	158
	OHL 110 kV Tomislavgrad – B.Glava	122
OHL 110 kV Pec Mlini – Posusje	OHL 110 kV B.Blato – Kraljevac	108
	OHL 110 kV B.Blato – Livno	156
	OHL 110 kV Livno – B.Glava	158
	OHL 110 kV Tomislavgrad – B.Glava	122
OHL 110 kV Livno – B.Glava	OHL 110 kV Grude – Imotski	119
	OHL 110 kV S.Brijeg – Grude	148
	OHL 110 kV S.Brijeg – V.Vlajina	143
	OHL 110 kV Pec Mlini – Grude	153
	OHL 110 kV Pec Mlini – Posusje	161
OHL 110 kV Tomislavgrad – B.Glava	OHL 110 kV S.Brijeg – Grude	110
	OHL 110 kV S.Brijeg – V.Vlajina	105
	OHL 110 kV Pec Mlini – Grude	114
	OHL 110 kV Pec Mlini – Posusje	120
Critical outage	**Node**	**Voltage violations (kV)**
OHL 220 kV Prijedor 2 – Bihać	Bihać 220 kV	268
	Bihać 110 kV	121.7
	Prijedor 2 110 kV	121.6
	other nodes 110 kV around Prijedor and Bihać	121 - 122

Existing network and WPP in scenario B conclusions

Construction and connection to the 110 kV grid of WPPs in Regions 1, 2 and 3 is not possible without significant investments in the 110 kV network. There are several highly loaded lines in the area of Mostar, S. Brijeg, Posusje, Tomislavgrad and Livno which could be overloaded in different operating conditions.

Voltage profile is still satisfying without Q/U contribution from wind farms.

4.3.5 WPPs construction in scenario C, D1 and D2

Due to large network overloading in scenario B it is clear that the existing transmission system is not designed to integrate WPPs in the range of 600 MW or 900 MW, no matter how they were distributed. Due to that, load flow calculations for these scenarios were not performed at existing network topology. The future transmission system is analyzed in the next section, including WPPs referred to in these three scenarios.

4.4 Analysis based on future transmission system

4.4.1 Load flow, voltage profile and N-1 analysis without WPPs

The future transmission system in BiH includes some important investments in 110 kV network of particular interest for new WPP connection such as:

- OHL 110 kV Rama – Uskoplje,
- OHL 110 kV Rama – Jablanica,
- OHL 110 kV Mostar 4 – V.Vlajina – S.Brijeg (revitalization and transmission capacity increase),
- OHL 110 kV Tomislavgrad – Kupres.

New 110 kV paths are planned to be made in order to allow transmission of power/energy from WPPs to Jablanica, Kupres, Bugojno and other consumption centres in central Bosnia and Herzegovina (Jajce, Travnik, Zenica). Some critical 110 kV lines in the existing network topology will be relieved after that.

Peak load scenario 2015

During peak load condition in 2015 and HPPs engagement due to normal hydrological situation, there are no overloaded branches in the 400 kV, 220 kV and 110 kV networks. The voltage profile is satisfactory with voltages within permitted range.

The N-1 criterion is not satisfied in the analysed situation due to the 110 kV network overloading in Banja Luka, Gradacac, Kakanj area and Mostar (Table 24). The only critical contingency in the area of WPP connection is an outage of the 110 kV line Mostar 4 – Mostar 5 that could cause overloading of the 110 kV line between SS

Mostar 1 and SS Mostar 6. Critical situations with respect to voltage range were not detected.

Table 24 Bottlenecks during peak load no WPPs (2015 system, normal hydrology)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	122
TR 400/110 kV Ugljevik	TR 220/110 kV Gradacac	105
OHL 110 kV Kakanj 5 – Cementara	OHL 110 kV Kakanj 5 – Zenica 1	105
OHL 110 kV Mostar 4 – Mostar 5	OHL 110 kV Mostar 1 – Mostar 6	100

During peak load and wet hydrological situation there are no overloaded branches in the network under full topology. Voltage profile is satisfactory. N-1 criterion is not satisfied in the analysed situation due to the 110 kV network overloading in Banja Luka, Kakanj area and Mostar (Table 25).

Table 25 Bottlenecks during peak load no WPPs (2015 system, wet hydrology)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	115
OHL 110 kV Kakanj 5 – Cementara	OHL 110 kV Kakanj 5 – Zenica 1	101
OHL 110 kV Mostar 4 – Citluk	OHL 110 kV Mostar 9 – Capljina	100

Summer maximum load scenario 2015

During summer maximum load there are no branches loaded by more than 100% of their maximum permitted loading.

The voltage profile is satisfactory, with voltages between permitted ranges.

The N-1 criterion is not satisfied in the analysed situation. The 110 kV lines Banja Luka 1 – Banja Luka 6 (1) and the 220/110 kV transformer at Gradacac are at risk of being overloaded. An outage of the 400/110 kV transformer in the Ugljevik TPP may cause an unacceptable voltage situation in Bijeljina (Table 26), if 110 kV line Janja – Lešnica is out of operation.

Table 26 Bottlenecks during summer maximum load no WPPs (2015 system)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	110
TR 400/110 kV Ugljevik	TR 220/110 kV Gradacac	105
Critical outage	**Node**	**Voltage violations (kV)**
TR 400/110 kV Ugljevik	Bijeljina 1	99
	Bijeljina 3	99
	Bijeljina 4	98

Off-peak load scenario 2015

During off-peak load there are no branches overloaded under full topology. Voltages are close to the upper limits, exceeding them in SS Banja Luka 6 (421 kV), SS Tuzla 6 (425 kV, 244 kV), SS Sarajevo 10 (422 kV), SS Sarajevo 20 (421 kV), SS Visegrad (425 kV), SS Zenica 2 (243 kV) and several 110 kV switchyards in different parts of the country. Voltage levels in the 110 kV network may be additionally decreased by usage of automatic regulation on 220/110 kV transformers, but voltages will then go higher in the 220 kV network. Connection of wind power plants in analyzed situation may cause further increase of voltages in the 110 kV network.

The N-1 criterion is satisfied in the analysed situation.

Peak load scenario 2020

During peak load condition in 2020 and HPPs engagement due to normal hydrological situation there are no overloaded branches in the 400 kV, 220 kV and 110 kV networks. The voltage profile is satisfactory with voltages within permitted range.

N-1 criterion is not satisfied in the analysed situation due to the 110 kV network overloading in Banja Luka, Bijeljina, Brcko and Tuzla area, all of them far away from new wind power plants connection nodes (Table 27).

110 kV line Mostar 1 – Mostar 6 is not jeopardized any more because revitalization and transmission capacity increase of this line has been planned between 2015 and 2020 (according to the SECI models).

Table 27 Bottlenecks during peak load no WPPs (2020 system, normal hydrology)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	112
OHL 110 kV B.Luka 1 – B.Luka 6 (1)	OHL 110 kV B.Luka 1 – B.Luka 6 (2)	108
TR 400/110 kV Ugljevik	TR 220/110 kV Tuzla	103
OHL 110 kV Bijeljina 1 – Bijeljina 2	OHL 110 kV Ugljevik – Brcko 2	129
OHL 110 kV Bijeljina 1 – Bijeljina 3	OHL 110 kV Ugljevik – Brcko 2	101
OHL 110 kV Ugljevik – Bijeljina 2	OHL 110 kV Ugljevik – Brcko 2	129
TR 400/110 kV Banja Luka 6 (1)	TR 400/110 kV Banja Luka 6 (2)	130
TR 400/110 kV Banja Luka 6 (1)	TR 400/110 kV Banja Luka 6 (2)	131
OHL 110 kV Ugljevik – Brcko 2	OHL 110 kV Bijeljina 1 – Bijeljina 2	102
	OHL 110 kV Ugljevik – Bijeljina 2	103
Critical outage	**Node**	**Voltage violations (kV)**
OHL 110 kV Bijeljina 1 – Bijeljina 2	Bijeljina 1	95.4
	Bijeljina 3	95.9
	Bijeljina 4 (Janja)	95.0
OHL 110 kV Ugljevik – Bijeljina 2	Bijeljina 1	95.3
	Bijeljina 2	95.3
	Bijeljina 3	95.8
	Bijeljina 4 (Janja)	95.0
OHL 110 kV Banja Luka 1 – B.Luka 7	Celinac	98.5
	Banja Luka 7	98.2
OHL 220 kV Prijedor 2 – Bihać	Bihać 220 kV	196
OHL 400 kV B.Luka – Stanari	Gradiska	98.8
	Laktasi	98.5
	Laktasi 2	98.3
	Celinac	99.0
	K.Varos	98.9
	Topola	98.6
	B.Luka 8	99.0
	B.Luka 6	96.7

During peak load and wet hydrological situation there are no overloaded branches in the network. Voltage profile is satisfactory. N-1 criterion is not satisfied in the analysed situation (Table 28).

Table 28 Bottlenecks during peak load no WPPs (2020 system, wet hydrology)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	110
OHL 110 kV B.Luka 1 – B.Luka 6 (1)	OHL 110 kV B.Luka 1 – B.Luka 6 (2)	106
TR 400/110 kV Ugljevik	OHL 110 kV Zvornik – Bistrica	117
OHL 110 kV Bijeljina 1 – Bijeljina 2	OHL 110 kV Ugljevik – Brcko 2	136
OHL 110 kV Bijeljina 1 – Bijeljina 3	OHL 110 kV Ugljevik – Brcko 2	107
OHL 110 kV Ugljevik – Bijeljina 2	OHL 110 kV Ugljevik – Brcko 2	136
TR 400/110 kV Banja Luka 6 (1)	TR 400/110 kV Banja Luka 6 (2)	123
TR 400/110 kV Banja Luka 6 (1)	TR 400/110 kV Banja Luka 6 (2)	123
OHL 400 kV B.Luka 6 – Stanari	OHL 110 kV Ugljevik – Brcko 2	103
OHL 110 kV Ugljevik – Brcko 2	OHL 110 kV Bijeljina 1 – Bijeljina 2	107
	OHL 110 kV Ugljevik – Bijeljina 2	107
Critical outage	**Node**	**Voltage violations (kV)**
OHL 110 kV Bijeljina 1 – Bijeljina 2	Bijeljina 1	92,7
	Bijeljina 3	93,3
	Bijeljina 4 (Janja)	92,4
OHL 110 kV Ugljevik – Bijeljina 2	Bijeljina 1	92,6
	Bijeljina 2	92,6
	Bijeljina 3	93,2
	Bijeljina 4 (Janja)	92,3
OHL 110 kV Banja Luka 1 – B.Luka 7	Kotor Varos	96,9
	Celinac	96,0
	Banja Luka 7	95,8
TR 400/110 kV Ugljevik	Bijeljina 1	98,1
	Bijeljina 3	98,0
	Bijeljina 4 (Janja)	97,9
	Orasje	98,9
OHL 110 kV Celinac – B.Luka 7	Celinac	98,8
OHL 220 kV Prijedor 2 – Bihać	Bihać 220 kV	194,9
OHL 400 kV B.Luka – Stanari	Many nodes 110 kV	96,8 – 99

Summer maximum load scenario 2020

During summer maximum load there are no branches loaded by more than 100% of their maximum permitted loading.

The voltage profile is satisfactory, with voltages between permitted ranges.

N-1 criterion is not satisfied in the analysed situation (Table 29). At risk are 110 kV lines in Banja Luka and Brcko area, with a possible unacceptable voltage situation in Bijeljina.

Table 29 Bottlenecks during summer maximum load no WPPs (2020 system)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	109
OHL 110 kV B.Luka 1 – B.Luka 6 (1)	OHL 110 kV B.Luka 1 – B.Luka 6 (2)	109
OHL 110 kV Bijeljina 1 – Bijeljina 2	OHL 110 kV Ugljevik – Brcko 2	101
OHL 110 kV Ugljevik – Bijeljina 2	OHL 110 kV Ugljevik – Brcko 2	101
Critical outage	**Node**	**Voltage violations (kV)**
OHL 110 kV Bijeljina 1 – Bijeljina 2	Bijeljina 4 (Janja)	98.9
OHL 110 kV Ugljevik – Bijeljina 2	Bijeljina 4 (Janja)	98.8

Off-peak load scenario 2020

During off-peak load there are no branches overloaded. The voltage levels are close to the upper limits, but not exceeding them in any network node.

The N-1 criterion is satisfied in the analysed situation.

Future network and no WPP conclusions

The planned transmission network of BiH in 2015 and 2020 could suffer mainly in its northern and northeastern parts around Banja Luka, Bijeljina and Brcko. In the area where the majority of wind farms are analyzed there are no larger problem with transmission capacities, except for 110 kV line Mostar 1 – Mostar 6, planned for revitalization between 2015 and 2020.

- The Mostar 1 – Mostar 6 line which is 4.3 km long, with conductors cross-section ACSR 240 mm^2 and ACSR 150 mm^2, constructed on concrete and steel towers, thermal limit 470 A (90 MVA), is jeopardized in 2015 following a loss of the Mostar 4 – Mostar 5 line during peak load and normal hydrological situation.

For future WPP connections and their integration into the power system, other possible contingencies in the BiH transmission network will not be influential (Banja

Luka, Kakanj, Bijeljina and Brcko areas, not predicted for any wind power plant connection).

4.4.2 WPPs construction in scenario A

In scenario A new WPPs in Regions 2, 3 and 4 were added to the model for 2015 and 2020. Power exports of BiH were increased for the production of WPPs, which means that the engagement of TPPs and HPPs within the BiH power system remains the same.

Peak load scenarios 2015 and 2020

Under peak load in 2015 and normal hydrological situation or wet hydrological situation there are no overloaded branches in the transmission network. Voltage situation is acceptable during peak load, regardless of the hydrological situation and HPPs engagement. There is no need for Q/U contribution from wind turbines in this scenario.

Results of the N-1 analysis are given in Table 30 and Table 31. New critical events are now marked in red.

There is only one critical event due to WPPs connection in scenario A of their construction. An outage of the 110 kV line Mostar 4 – Mostar 5 could cause overloading of the 110 kV line from Mostar 1 to Mostar 6 that was critical during peak load and normal hydrological situation without any WPP connected.

It is obvious that Mostar 1 – Mostar 6 line will have to be revitalized sooner than it was planned (during time period 2015 – 2020). The most influential WPP for this line is WPP Kamena, predicted to be connected to SS Mostar 2 and SS Nevesinje, so line revitalization will probably have to be performed in line with WPP Kamena construction.

Table 30 Bottlenecks during peak load, WPPs in scenario A (2015 system, normal hydrology)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	119
TR 400/110 kV Ugljevik	TR 220/110 kV Gradacac	104
OHL 110 kV Kakanj 5 – Cementara	OHL 110 kV Kakanj 5 – Zenica 1	106
OHL 110 kV Mostar 4 – Mostar 5	OHL 110 kV Mostar 1 – Mostar 6	100

Table 31 Bottlenecks during peak load, WPPs in scenario A (2015 system, wet hydrology)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	113
OHL 110 kV Kakanj 5 – Cementara	OHL 110 kV Kakanj 5 – Zenica 1	103
OHL 110 kV Mostar 4 – Citluk	OHL 110 kV Mostar 9 – Capljina	104
OHL 110 kV Mostar 4 – Mostar 5	OHL 110 kV Mostar 1 – Mostar 6	105

Analyzing peak load in 2020 and normal hydrological situation or wet hydrological situation there are no overloaded branches in the transmission network if all lines and transformers were in operation. Voltage situation is within permitted limits, so there is still no need for Q/U contribution from wind turbines.

Results of the N-1 analysis show that there are no new critical contingences beside those that were detected for the no wind power plants scenarios (in northern and northeastern parts of the country).

Summer maximum load scenarios 2015 and 2020

During summer maximum load in 2015 there are no overloaded branches in the network and voltage profile is satisfactory. The same is valid for summer maximum load scenario in 2020 with wind power plants in scenario A.

The N-1 criterion is not satisfied in the analysed situation (Table 32) and there is one new critical contingency; an outage of the 400 kV line Trebinje – Podgorica could overload the 110 kV line Trebinje – Herceg Novi. In the base case model this line was loaded slightly below permitted limit during the same contingency. New wind power plants connected to the 110 kV network around Mostar don't contribute significantly to this problem, but due to decreased load flow from 400 kV network to 220 kV network and from 220 kV to 110 kV network they cause slight increase of power flow in the 400 kV network, which could cause a risk for Trebinje – Herceg Novi 110 kV line when 400 kV line Trebinje – Podgorica goes out of operation.

In 2020 there are no additional problems with WPP integration in scenario A. 110 kV line Trebinje – Herceg Novi is planned to be put permanently out of operation, once the Montenegrin 110 kV network around Herceg Novi and Tivat is developed under the HVDC cable project.

Table 32 Bottlenecks during summer maximum load, WPPs in scenario A (2015 system)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	108
TR 400/110 kV Ugljevik	TR 220/110 kV Gradacac	104
OHL 400 kV Podgorica – Trebinje	OHL 110 kV Trebinje – H.Novi	101
Critical outage	**Node**	**Voltage violations (kV)**
TR 400/110 kV Ugljevik	Bijeljina 1	99
	Bijeljina 3	99
	Bijeljina 4	98

Off-peak load scenarios 2015 and 2020

During off-peak load in 2015 and 2020 there are no branches overloaded under full network topology.

Voltages are close to the upper limits, exceeding them in 2015 in some 400 kV, 220 kV and 110 kV network nodes, but not exceeding them in any network node in 2020. Voltage problems in 110 kV network could be solved by tap changers on 220/110 kV transformers. The contribution of wind farms, connected to the 110 kV grid, in Q/U control is not necessary because they are not able to improve the voltage situation in the 220 kV and 400 kV networks.

The N-1 criterion is satisfied in the analysed situations.

4.4.3 WPP construction in scenario A1

Construction of new 110 kV line Nevesinje – Gacko will be finished by 2015, and construction of one wind power plant with installed capacity of 50 MW situated in the wide area of Trebinje will be feasible. Load flow analysis using 2015 and 2020 models show that the transmission system will not be jeopardized due to this WPP connection, so new transmission investments are not necessary. Critical contingences stay the same as described in the previous section.

4.4.4 WPP construction in scenario B

In scenario B new WPPs in Regions 1, 2 and 3 were added to the models for 2015 and 2020. Power exports of BiH were increased for the production of WPPs, which means that the engagement of TPPs and HPPs within the BiH power system remains the same.

Peak load scenarios 2015 and 2020

Under peak load in 2015 and normal hydrological situation or wet hydrological situation there are no overloaded branches in the transmission network and voltage situation is acceptable during peak load, regardless of the hydrological situation and HPPs engagement. There is no need for Q/U contribution from wind turbines in this scenario.

Results of the N-1 analysis are given in Table 33 and Table 34. New critical events are marked in red, while blue represents critical contingences in the base case which are not critical any more.

110 kV line from Mostar 1 to Mostar 6 is at the limit following an outage of Mostar 1 – Mostar 4 line, beside an outage of Mostar 4 – Mostar 5 line that was previously detected.

110 kV line Kakanj 5 – Zenica 1 that was critical during the base case is now slightly relieved, but still highly loaded and at risk of being overloaded.

Table 33 Bottlenecks during peak load, WPPs in scenario B (2015 system, normal hydrology)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	116
TR 400/110 kV Ugljevik	TR 220/110 kV Gradacac	103
OHL 110 kV Kakanj 5 – Cementara	OHL 110 kV Kakanj 5 – Zenica 1	100
OHL 110 kV Mostar 4 – Mostar 5	OHL 110 kV Mostar 1 – Mostar 6	100

Table 34 Bottlenecks during peak load, WPPs in scenario B (2015 system, wet hydrology)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	110
OHL 110 kV Kakanj 5 – Cementara	OHL 110 kV Kakanj 5 – Zenica 1	97
OHL 110 kV Mostar 4 – Citluk	OHL 110 kV Mostar 9 – Capljina	102
OHL 110 kV Mostar 4 – Mostar 5	OHL 110 kV Mostar 1 – Mostar 6	100
OHL 110 kV Mostar 1 – Mostar 4	OHL 110 kV Mostar 1 – Mostar 6	100

Analyzing peak load in 2020 and normal hydrological situation or wet hydrological situation there are no overloaded branches in the transmission network if all lines and transformers were in operation. Voltage situation is within permitted limits, so there is still no need for Q/U contribution of wind turbines.

Results of the N-1 analysis show that there are no new critical contingences beside the ones detected at the base case scenarios and located in the northern and northeastern parts of the country.

Summer maximum load scenarios 2015 and 2020

During summer maximum load in 2015 and 2020 there are no overloaded branches under complete network topology, and voltage profile is satisfactory.

The N-1 criterion is not satisfied in the analysed situation (Table 35). 110 kV line Trebinje – Herceg Novi is now slightly more overloaded when the 400 kV line Trebinje – Podgorica goes out of operation comparing the same situation in scenario B. This is due to increased load flow in the 400 kV network. In 2020 there are no additional problems with wind power plant integration in scenario B.

The 110 kV line from HPP Pec-Mlini to SS Grude is now jeopardized in 2015 following a loss of the 110 kV line Livno – Busko Blato or Livno – WPP Borova Glava. This problem occurs because large production of WPP Mesihovina, WPP Borova Glava, WPP Gradina and WPP Poklecani is directed to Grude substation and further to Imotski in Croatia. This problem is not visible in 2020 because operation of 110 kV line Rama – Jablanica under rated voltage (today this line is in operation under 35 kV; one additional line bay 110 kV in the SS Jablanica has to be constructed) is planned by then. This line gives one more transit path to transmit production of previously mentioned wind power plants and because of that the critical line from HPP Pec-Mlini to SS Grude is relieved. In 2020, under the same contingency (for example outage of the 110 kV line Livno – WPP Borova Glava) the 110 kV line Pec Mlini – Grude is loaded to 79% of its maximum thermal limit.

Table 35 Bottlenecks during summer maximum load, WPPs in scenario B (2015 system)

Critical outage	Overloaded branch	Loading (% of permitted loading)
OHL 110 kV B.Luka 1 – B.Luka 6 (2)	OHL 110 kV B.Luka 1 – B.Luka 6 (1)	104
TR 400/110 kV Ugljevik	TR 220/110 kV Gradacac	103
OHL 110 kV Livno – B.Blato	OHL 110 kV Pec Mlini – Grude	100
OHL 110 kV Livno – WPP B.Glava	OHL 110 kV Pec Mlini – Grude	105
OHL 400 kV Podgorica – Trebinje	OHL 110 kV Trebinje – H.Novi	105
Critical outage	**Node**	**Voltage violations (kV)**
TR 400/110 kV Ugljevik	Bijeljina 1	99
	Bijeljina 3	99
	Bijeljina 4	98

Off-peak load scenarios 2015 and 2020

During off-peak load in 2015 and 2020 there are no branches overloaded under full network topology.

Voltages are close to the upper limits, exceeding them in 2015 in some 400 kV, 220 kV and 110 kV network nodes, but not exceeding them in any network node in 2020. Voltages in 2015 are too high (between 121 kV and 123 kV) in Herzegovina area due to WPPs connection in this part of the country, but using voltage regulation at 220/110 kV transformers in the SS Mostar 4 voltages could be decreased below maximum permitted value. That's the reason why any Q/U contribution of wind farms is still not necessary. The N-1 criterion is satisfied in the analysed situations.

4.4.5 WPPs construction in scenario C

In scenario C new WPPs in Regions 2 and 3 were added to the models for 2015 and 2020. Power exports of BiH were increased for the production of WPPs, which means that the engagement of TPPs and HPPs within the BiH power system remains the same.

In this scenario the two largest WPPs are going to be connected to the 110 kV network. Both of them are situated in the vicinity of Tomislavgrad that is an area already filled with wind farms (WPP Mesihovina in scenario A, WPP Poklecani, WPP Gradina and WPP Borova Glava in scenario B). Grid connection of WPP Pakline is assumed through the new switchyard connecting existing 110 kV lines Tomislavgrad – Rama and Livno – Tomislavgrad. 110 kV line Livno – Rama was recently connected to the SS Tomislavgrad, and in this scenario construction of a new 110 kV switchyard at the location where this line is disconnected and connected to the double circuit line to Tomislavgrad is assumed. This is because of large installed capacity of WPP Pakline that needs to be connected to the grid with at least three 110 kV lines. This assumption makes grid connection of WPP Pakline with three 110 kV lines , one double circuit line to SS Tomislavgrad, one single circuit line to WPP Borova Glava and one single circuit line to WPP Poklecani or WPP Ljubusa (SS x/110 kV for WPP Ljubusa grid connection will be connected with 110 kV lines Poklecani – Tomislavgrad and Poklecani – Rama).

Peak load scenarios 2015 and 2020

During peak load in 2015 and normal hydrological situation under full network topology there are several overloaded lines in the 110 kV network. They are:

- Grude – Imotski 124% I_{max}
- Grude – Pec Mlini 149% I_{max}
- Posusje – Pec Mlini 141% I_{max}

In the analyzed scenario voltage profile is within permitted range.

There are many different outages which lead to unacceptable situation within the network. Jeopardized 110 kV lines are mostly located around SS Livno, SS Bugojno and SS Kupres, except those which are under risk without any outage in the network. In some situations, like outage of Grude – Pec Mlini or Posusje – Pec Mlini lines, convergent load flow solution can not be found, which is a sign of voltage collapse in the network.

It is obvious that without significant network investments wind power plants in the scenario C could not be integrated into the power system in 2015.

Operation of the 110 kV line Rama – Jablanica under rated voltage in 2015 is not helpful for N-1 criterion fulfilment.

During peak load in 2015 and wet hydrological situation under full network topology the following lines are overloaded in the 110 kV network:

- Grude – Imotski 130% I_{max}
- Grude – Pec Mlini 146% I_{max}
- Posusje – Pec Mlini 131% I_{max}
- Livno – Borova Glava 100% I_{max}

In the analyzed scenario voltage profile is within permitted range.

N-1 criterion is not fulfilled, with many critical contingencies which cause overloading of many 110 kV lines in the wide area of Mostar, Bugojno and Tomislavgrad. Risk of voltage collapse is also present.

Voltage control provided by WPPs Ljubusa and Pakline, assuming that both WPPs could operate under power factor 0.95, would remove a risk of voltage collapse in the network, but several lines are still overloaded under full network topology (Grude – Imotski, Grude – Pec Mlini and Posusje – Pec Mlini) and the others are at risk following outages of other 110 kV lines in the area of western Herzegovina.

In 2020 during peak load and normal hydrology three critical 110 kV lines, Grude – Imotski, Grude – Pec Mlini and Posusje – Pec Mlini, are overloaded under full network topology, and all other 110 kV lines in the area are still at risk under the N-1 criterion. This meant that transmission network reinforcements planned for 2015 – 2020 are not suitable to integrate WPPs in scenario C. Voltage collapse risk also exists if WPP Ljubusa and WPP Pakline were not able to participate in Q/U control.

In 2020 during peak load and wet hydrology three critical lines are overloaded under full network topology.

Summer maximum load scenarios 2015 and 2020

During summer maximum load in 2015 the 110 kV network is not able to integrate WPPs in scenario C, due to overloading of previously discussed critical 110 kV lines under full network topology, and many situations of N-1 criterion dissatisfaction. There is also risk of voltage collapse in the network, especially if WPP Ljubusa and

WPP Paklene were constructed without any reactive power production/consumption ability (power factor equal to 1).

The same is valid for summer maximum load scenario in 2020. A certain number of 110 kV lines are at risk of being overloaded under full network topology (110 kV lines around SS Livno, HPP Pec Mlini, SS Grude and SS Posusje).

Off-peak load scenarios 2015 and 2020

The 110 kV network around HPP Pec Mlini, Bugojno, Grude and Posusje is overloaded in 2015 under full network topology even during off-peak situation. Voltage profile is satisfactory.

The N-1 criterion is not fulfilled, there are many critical contingencies in the network and risk of voltage collapse is also present.

The situation is not going to be improved in 2020 during off-peak load situation.

4.4.6 WPPs construction in scenario D1 and D2

In scenario D1 that represents concentrated distribution of 900 MW of installed power in new WPPs mostly located in Regions 1, 2 and 3 were added to the models for 2015 and 2020. Power exports of BiH were increased for the production of WPPs, which means that the engagement of thermal and hydro power plants within the BiH power system remains the same.

Without any load flow and security analysis one may conclude that this scenario is not feasible from transmission network capacities point of view. 110 kV network in the western Herzegovina was not able to accept 600 MW of wind farms due to 110 kV lines overloading even under full network topology in 2015 and 2020. In this scenario large new WPPs Kupres and Glamoc – Slovinj, located in the vicinity of Kupres and Livno, would cause additional network overloading, especially at critical areas around SS Livno and SS Bugojno.

In scenario D2 that represents wide distribution of 900 MW of installed power in new WPPs situated in all five analyzed regions were added to the models for 2015 and 2020.

The network will not be able to accept these wind farms also, because some of them are located around critical 110 kV substations and lines.

Peak load scenarios 2015 and 2020

For scenario D1, during peak load in 2015 and normal hydrological situation under full network topology the following 110 kV lines are overloaded[9]:

[9] Convergent solution can not be found because of voltage collapse in the network under full network topology. WPP Glamoc – Slovinj has to be constrENTSO-Ed with Q/U control ability to avoid low voltages (power factor must be at least 0,95 in 2015 and 0,90 in 2020).

- Grude – Imotski 159% I_{max}
- Bugojno – D.Vakuf 158% I_{max}
- Bugojno – Kupres 153% I_{max}
- D.Vakuf – Jajce 2 149% I_{max}
- Busko Blato – Livno 131% I_{max}
- Grude – Pec Mlini 188% I_{max}
- Posusje – Pec Mlini 179% I_{max}

There are many different outages which lead to unacceptable situation within the network and there is still a risk of voltage collapse. 110 kV network in Herzegovina area and in central Bosnia (Bugojno, Travnik, Jajce area) is at risk, and disturbance could be spread far away to Zenica and Busovaca area.

It is obvious that without significant network investments wind power plants in the scenario D1 could not be integrated into the power system in 2015 and 2020.

If we observe hydro engagement during wet hydrological conditions the situation is not going to be particularly changed.

For scenario D1, in 2020 during peak load and normal hydrology several 110 kV lines will be overloaded under full network topology:

- Grude – Imotski 130% I_{max}
- Bugojno – D.Vakuf 112% I_{max}
- Bugojno – Kupres 165% I_{max}
- D.Vakuf – Jajce 2 109% I_{max}
- Busko Blato – Livno 135% I_{max}
- Grude – Pec Mlini 122% I_{max}
- Posusje – Pec Mlini 115% I_{max}
- Livno – Borova Glava 110% I_{max}

All other 110 kV lines in the areas of western Herzegovina and central Bosnia are at risk under the N-1 criterion.

Construction of widely distributed wind power plants with total installed capacity of 900 MW (scenario D2) will not be beneficial from a transmission capacities point of view. The following 110 kV lines are overloaded under full network topology during peak load and normal hydrological situation in 2015:

- Grude – Imotski 147% I_{max}
- Bugojno – D.Vakuf 111% I_{max}
- D.Vakuf – Jajce 2 105% I_{max}
- Busko Blato – Orlovaca 111% I_{max}
- Grude – Pec Mlini 160% I_{max}
- Posusje – Pec Mlini 151% I_{max}
- Mostar 1 – Mostar 6 109% I_{max}

There are still many critical contingences in the 110 kV network which would breach the N-1 criterion.

In 2020 the situation is not going to be improved concerning WPP integration in scenario D2. The following 110 kV lines are overloaded under full network topology during peak load and normal hydrological situation in 2020:

- Grude – Imotski 127% I_{max}
- Busko Blato – Orlovaca 119% I_{max}
- Grude – Pec Mlini 110% I_{max}
- Posusje – Pec Mlini 103% I_{max}
- Livno – Borova Glava 107% I_{max}
- Tomislavgrad – Kupres 104% I_{max}

Summer maximum load scenarios 2015 and 2020

WPPs in scenario D1 could not operate during summer maximum load in 2015 and 2020 because of severe overloading in the 110 kV network. Critical lines are the same as previously detected.

WPPs in scenario D2 could not operate either during summer maximum load in 2015 and 2020 because of severe overloading in the 110 kV network.

Off-peak load scenarios 2015 and 2020

WPPs in both scenarios D1 and D2 could not operate during off-peak load in 2015 and 2020 because of severe overloading in the 110 kV network.

4.5 Summary of findings

The majority of WPPs are planned to be located in Herzegovina area in the southwestern part of the country. Existing transmission network topology in this area is characterized by the following:

- one main feeding point, substation 400/220/110 kV Mostar 4 (2x400 MVA+2x150 MVA),
- connection at 400 kV level to Sarajevo and Trebinje area in BiH and Dalmatia region in Croatia,
- well developed 220 kV network, with many hydro power plants located within and around the area,
- several mid-sized hydro power plants connected at the 110 kV network (Pec Mlini, Mostarsko Blato, Mostar),
- undeveloped 110 kV network, not well-meshed within observed area, radial connection of some substations, low transmission capacities of some 110 kV lines.

Poorly developed 110 kV network in the most important area for WPPs grid connection will restrict their construction and grid connection until significant network reinforcements are conducted.

With minor investment in the 110 kV line Mostar 4 – Siroki Brijeg revitalization and transmission capacity increase (line should be equipped with conductors ACSR 240 mm^2 in full length) the existing network will allow integration of WPPs in scenario A, with total installed capacity of 150 MW.

Other scenarios of WPPs construction (300 MW, 600 MW, 900 MW) are not feasible under existing network topology.

Critical branches with respect to WPP integration in scenario A and scenario B are shown in Figure 16. All of them are operated under 110 kV voltage level. Other scenarios of WPP integration (600 MW and 900 MW) are not feasible under existing network topology, mainly because of missing infrastructure.

Some important investments in the transmission network are planned in the future in the most important area of western Herzegovina area (also in areas of eastern Herzegovina and central Bosnia) concerning WPP integration:

- OHL 110 kV Mostar 4 – V.Vlajina – Siroki Brijeg (revitalization and transmission capacity increase) by 2015,
- connection of SS Rama to SS Uskoplje by 2015,
- connection of SS Tomislavgrad to SS Kupres by 2015,

- operation of 110 kV line Jablanica – Rama under 110 kV voltage level by 2020,
- OHL 110 kV Mostar 1 – Mostar 6 (revitalization and transmission capacity increase) by 2020.

Planned network reinforcements which are included in the SECI model of BiH for 2015 will not allow further integration of WPPs above scenario A1 (200 MW). Furthermore, even for this scenario of WPP integration one more 110 kV line has to be revitalized by 2015 (Mostar 1 – Mostar 6).

Integration of WPPs in scenario B, with total installed capacity of 300 MW, will not be possible in 2015 due to bottlenecks related to the 110 kV lines Pec Mlini – Grude and Pec Mlini – Posusje. Operation of 110 kV line Rama – Jablanica planned in 2020 allows integration of WPPs in scenario B with 300 MW.

Integration of WPPs in scenario C, with total installed capacity of 600 MW, will not be possible due to network bottlenecks under full network topology and due to N-1 security criterion dissatisfaction for many critical outages in the 110 kV network.

Integration of WPPs in scenario D1 or D2 would cause severe network overloading even under full network topology. Areas around Bugojno, Livno, Kupres, Tomislavgrad, Posusje and Grude are particularly jeopardized, but distrurbances could be spread all the way to the Zanica and Busovaca areas.

Critical branches with respect to WPP integration in scenario A, B and scenario C are shown in Figure 17. For scenarios D1 and D2 almost all branches in the 110 kV network of the wider area between Zenica, Mostar, Livno and Jajce are critical.

In scenario A and B of WPP integration there is no risk of unacceptable voltage situations in the network if WPPs were not equipped to provide Q/U control reserve (power factor equal to 1). Risk of voltage collapse begins with scenario C of WPP integration, so large WPPs like WPP Ljubusa and WPP Pakline in this scenario, or WPP Glamoc – Slovinj and WPP Kupres in scenario D1, should be design to provide certain range of Q/U control (power factor should be between 0,90 and 0,95).

Figure 16 Critical branches at existing 110 kV network topology, in the area where new WPPs are going to be constructed

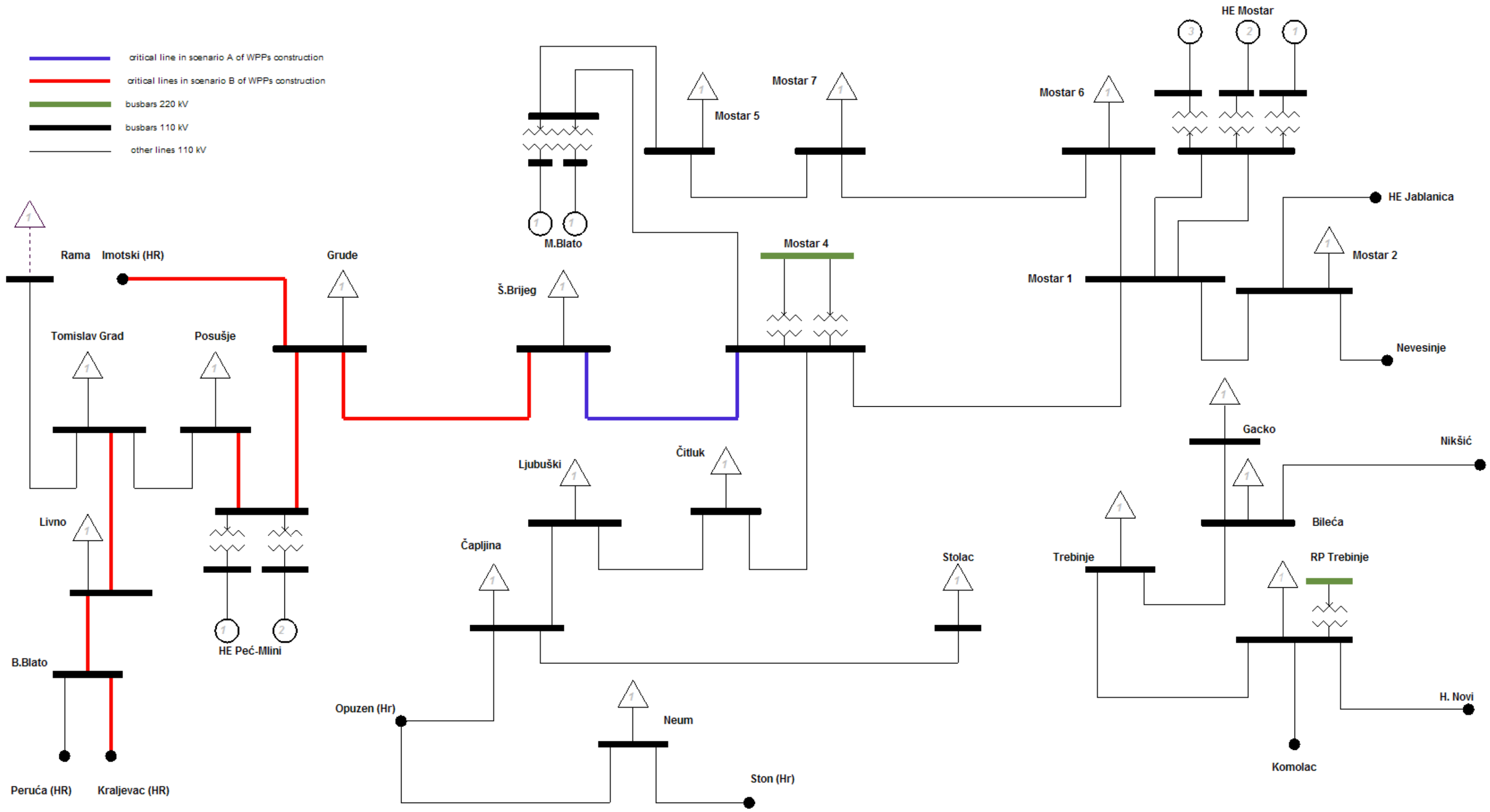
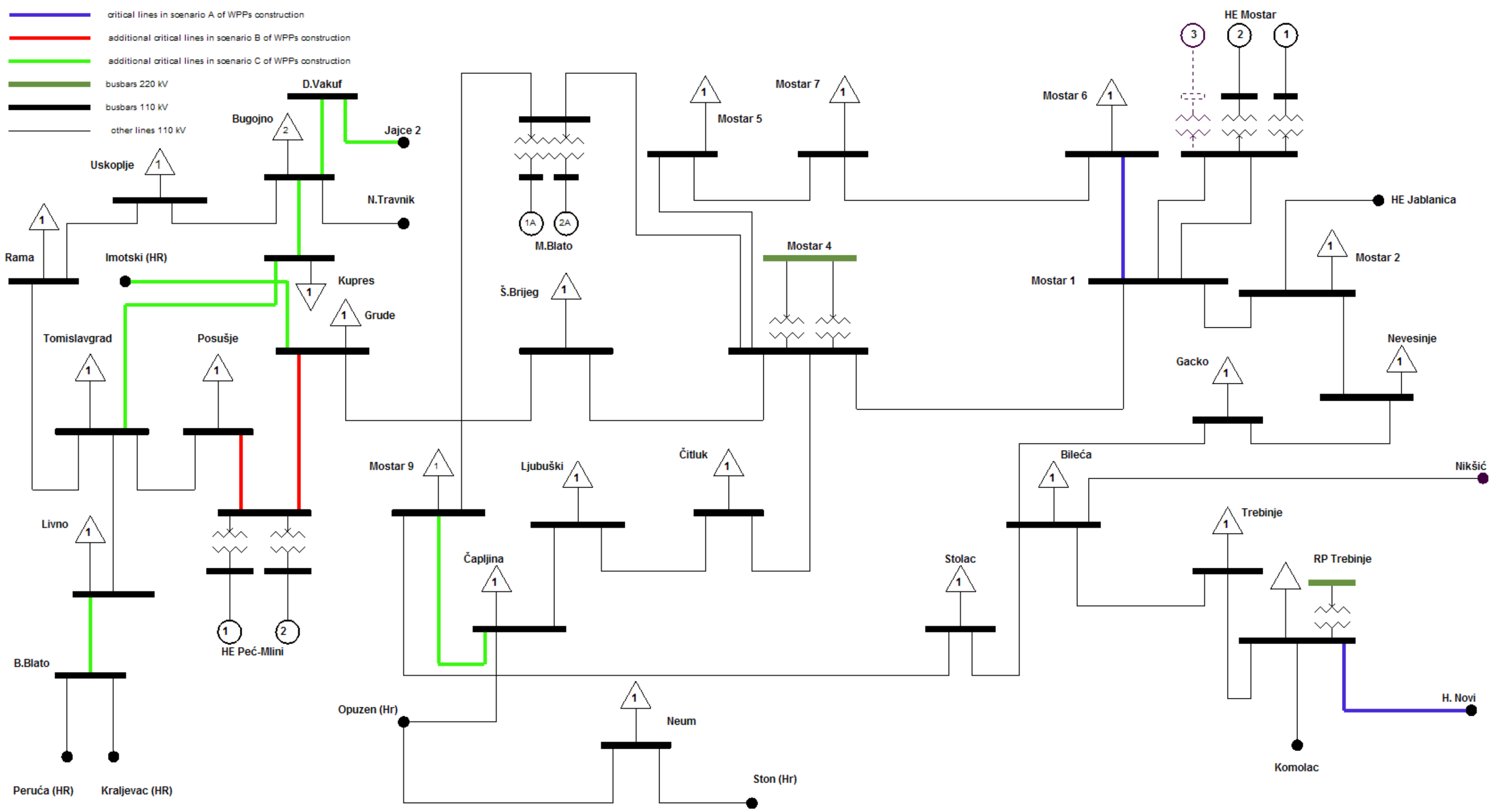


Figure 17 Critical branches at future 110 kV network topology, in the area where new WPPs are going to be constructed (2015)



5 Secure operation of the system with outages of the largest plant

This section assesses secure system operation for the various wind penetration scenarios in the situation where output is lost from the largest thermal plant. In the BiH power system the largest production unit today is the one in TPP Ugljevik with 279 MW of installed capacity. In the future, it is expected that TPP Stanari will be built with the largest unit of 330 MW.

Steady state analyses were performed related to loss of TPP Ugljevik in the model of 2011, and related to loss of TPP Stanari in the models of 2015 and 2020. Both units are, or are going to be, connected at the 400 kV level, while WPPs connection will be realized at the 110 kV network. This is important because mainly larger production units, connected to the 400 kV and 220 kV networks, will increase their production following a loss of the largest unit, causing additional load of 400 kV network and 220 kV, which is favourable from a WPP production point of view.

Within several seconds following a loss of the largest unit primary reserve in all power plants in BiH and surrounding countries will be activated, increasing production of all power plants which are able to provide that service (operating below their installed capacity). This was simulated in the models by increasing production of all units which were operating below installed capacity in BiH, Croatia, Serbia and Montenegro.

Secondary power and frequency control keeps the control area's balance in normal operating conditions, and contributes to restoring balance in case of a sudden unbalance due to an incident. In case of a sudden large unbalance or a sustained demand variation, tertiary control reserve is required to restore the secondary control reserves. Secondary control should be provided by several hydro power plants (HPPs) within the BiH power system[10]. These HPPs are HPP Visegrad, HPP Jablanica, HPP Rama, HPP Bocac and HPP Trebinje. Secondary reserve within the BiH power system is determined according to maximum monthly load and it has a range between 43 MW and 59 MW[11]. Future expectation is that necessary secondary control reserve will rise up to 73 MW in 2020[12] (without considerations about necessary secondary control reserve increase because of WPP integration). Activation of secondary control reserves was simulated in the models by increasing production of all units nominated for this ancillary service and decreasing production of all units in BiH, Croatia, Serbia and Montenegro which provided primary reserve.

Loss of the largest TPP unit has to be eventually covered by the activation of tertiary P/f control reserve. According to the ENTSO-E Operational Handbook, tertiary

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[10] Regulation about ancillary services tariffs, DERK, 2010

[11] Ina real situation nominated hydro power plants mostly don't provide needed value of secondary reserve so there is a constant lack of control abilities.

[12] Indicative power production development plan 2011-2020, NOS BiH, July 2010

control is any automatic or manual change in the working points of generators mainly by re-scheduling, in order to restore an adequate secondary control reserve at the right time. The power which can be connected (automatically or) manually under tertiary control, in order to provide an adequate secondary control reserve, is known as the tertiary control reserve. This reserve must be used in such a way that it will contribute to the restoration of the secondary control range when required. The restoration of an adequate secondary control range may take, for example, up to 15 minutes, whereas tertiary control for the optimisation of the network and generating system will not necessarily be complete after this time. If the loss of the largest generating unit is not already covered by the requisite secondary control reserve, additional tertiary control reserve (15 minute reserve) is required to offset the shortfall within a short time.

Each control area must have access to sufficient tertiary reserve to follow up secondary control within a short period of time after an incident. An adequate control reserve must be available at all times to cover the loss of a generating unit. If the loss of the largest generating unit is not already covered by the requisite secondary control reserve, a tertiary control reserve will be required to offset the shortfall. Each TSO must immediately activate tertiary reserve if insufficient free secondary control reserve is available in order to free up secondary control reserves again. Tertiary reserve is activated by either updating the total exchanges schedule of the control area/block (the control program) or by changing the generation schedules within the control area/block.

According to regulation by DERK (SERC)[13], tertiary control has to be provided by HPP Capljina, HPP Grabovica, HPP Salakovac, HPP Visegrad, HPP Bocac and HPP Trebinje. Necessary tertiary control reserve is 250 MW today and up to 300 MW after 2015[14].

In BiH, tertiary reserve is manually controlled and so far there is no programme for making it automatic. Furthermore, it may be activated a limited number of times per month. Due to these facts it is not realistic to include tertiary reserve capacities in WPP balancing on a continuous basis. In other words, WPP fluctuations are to be covered by the automatic secondary regulation mechanism only. In some emergency cases (extremely dry hydrology, multiple outages, power transit interruptions etc.) or interregional imbalances, dispatchers are to support secondary regulation with manual tertiary reserve.

Activation of tertiary control reserve was stimulated in the models by increasing production mainly in HPP Capljina and HPP Jablanica, because they are closest to a majority of planned WPPs.

Analyses were performed for scenarios A, A1 and B of WPP integration which are feasible (scenario A and A1) or may be feasible after adequate network reinforcements (scenario B). Outage of the largest production unit for scenarios C, D1

[13] Regulation about ancillary services tariffs, DERK, 2010

[14] Indicative power production development plan 2011-2020, NOS BiH, July 2010. In reality there is a lack of the needed tertiary reserve.

and D2 was not analyzed because there are so many network overloads even under full network topology that influence of primary, secondary and tertiary reserve activation could only make things even less feasible.

Outage of TPP Ugljevik in the model for 2011 during peak load situation and normal hydrological conditions will not cause additional network overloading for both scenarios of WPP integration (A and B). Moreover, if TPP Ugljevik is permanently out of operation, the N-1 criterion will not be additionally ruined. The same is valid for TPP Stanari outages in the models for 2015 and 2020.

Based on steady state analysis one may conclude that outages of the largest production unit in the BiH power system will not cause additional network overloading with or without WPPs integrated within the power system. This is due to usually low loading of 400 kV and 220 kV network, well-developed 400 kV and 220 kV network, large interconnection capacities and appropriate design of grid connection for existing power plants within the BiH power system (it allows maximum production of each power plant to be transmitted even if one connection line/transformer is out of operation).

6 Identified transmission system bottlenecks and voltage problems due to wind power plants integration

The majority of WPPs in BiH is planned to be located in the southwestern part of the country. Present transmission network topology, especially concerning the 110 kV voltage level, is not favorable to connect these WPPs.

Load flow and N-1 security analyses, explained in Section 4, determined weak parts of the network and indentified critical network bottlenecks due to WPP integration.

Eventual voltage problems and requests for WPPs to participate in Q/U control were also analyzed and identified.

Existing network configuration allows connection of WPPs in scenario A with total installed capacity 150 MW. Only minor network reinforcement will be necessary to connect all four planned WPPs in this scenario (WPP Mesihovina, WPP Kamena, WPP Ivan Sedlo and WPP Velika Vlajina). This reinforcement is related to WPP Velika Vlajina grid connection. Existing 110 kV line Mostar 4 – Siroki Brijeg, made partially by conductors Copper 95 mm^2 on concrete towers, will have to be revitalized and made of conductors ACSR 240 mm^2 on steel towers across the total line route.

With no additional network reinforcements (with existing 110 kV line Mostar 4 – Siroki Brijeg) connection of WPP Mesihovina, WPP Kamena and WPP Ivan Sedlo is feasible, which means that network is ready to integrate around 126 MW of WPPs without any additional investment except those for their grid connection (mid voltage internal network between wind turbines and internal substations x/110 kV at the location of a wind farm).

The critical line for scenario A of WPP integration is presented in Figure 18. For future network configuration one more 110 kV line appears to be critical: the 110 kV line Mostar 1 – Mostar 6.

To integrate WPPs in scenario A1 (200 MW) it is necessary to construct the 110 kV line Nevesinje – Gacko.

To integrate WPPs in scenario B with total installed power of 300 MW necessary prerequisite is development of 110 kV network around WPP Poklecani (OHL 2x110 kV Poklecani – Posusje and OHL 2x110 kV Poklecani – Tomislavgrad/Rama). Bottlenecks in the transmission system were detected related to 110 kV lines:

- Mostar 4 – Siroki Brijeg,
- Siroki Brijeg – Grude,
- Grude – Imotski,
- HPP Pec Mlini – Grude,

- HPP Pec Mlini – Posusje,
- Tomislavgrad – (WPP Borova Glava) – Livno,
- Livno – Busko Blato.

In the future, related to planned transmission network configuration that includes important new 110 kV lines Tomislavgrad – Kupres, Bugojno – Kupres, Rama – Uskoplje and Jablanica – Rama, for scenario B of WPP integration only two lines are critical in 2015 when the 110 kV line Rama – Jablanica has still not been planned to be functional under 110 kV voltage:

- HPP Pec Mlini – Grude, and
- HPP Pec Mlini – Posusje.

Critical lines for scenario B of WPP integration are presented in Figure 19. Thin light blue lines represent planned transmission lines in 2015 and 2020, necessary even to consider WPP integration in this area of BiH.

Scenarios C, D1 and D2 are not feasible from a transmission network capacities point of view, even if we observe planned network configuration in 2015 and 2020, because some 110 kV lines are overloaded under full network topology. Further problems could be expected relating to almost all lines in Western Herzegovina and around Bugojno and Kupres for scenario C, and problems could be spread all the way to Travnik, Zenica and Busovaca for scenario D1 and D2.

In order to integrate WPPs in high installed power scenarios it is necessary to construct new 220/110 kV substations and/or 400/110 kV substations at certain locations to transmit wind power plants production to higher voltage levels grid.

Critical lines for scenario C and D (D1 and D2) of WPP integration are presented in Figure 20 and Figure 21.

In scenarios C and D large WPP projects are planned to be implemented, such as WPP Ljubusa, WPP Pakline, WPP Glamoc-Slovinj and WPP Kupres. It is strongly recommended that these WPPs have to be designed to provide Q/U control service, in a range of power factor between 0.90 and 0.95. This is necessary in order to avoid voltage collapse in the system.

Other WPPs, especially smaller ones (approximately up to 50 MW) generally don't have to be designed to provide Q/U control service, if tap changing on 220/110 kV transformers is automatically operated.

Figure 18 Network bottleneck for scenario A of wind power plants integration

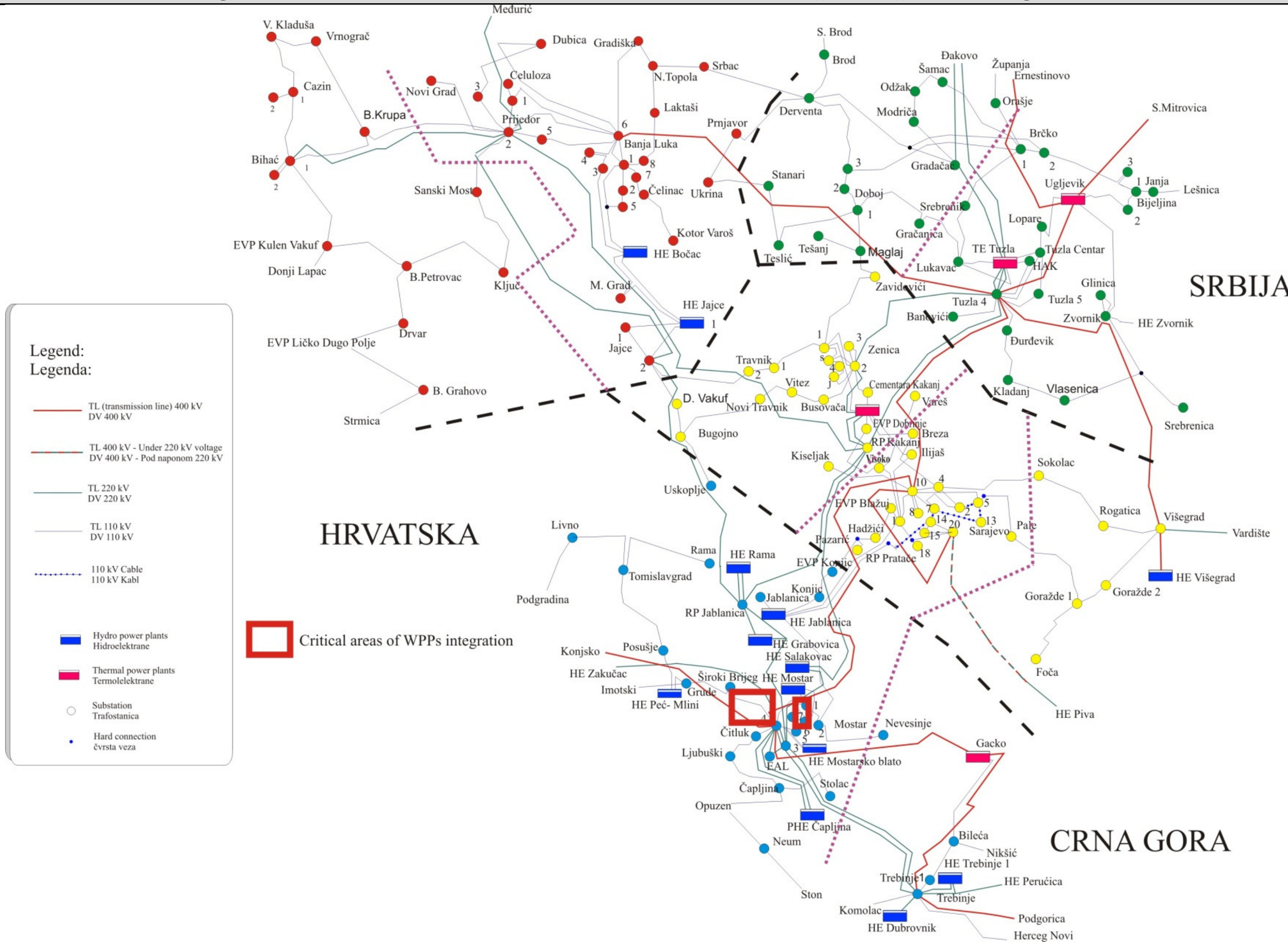


Figure 19 Network bottleneck for scenario B of wind power plants integration

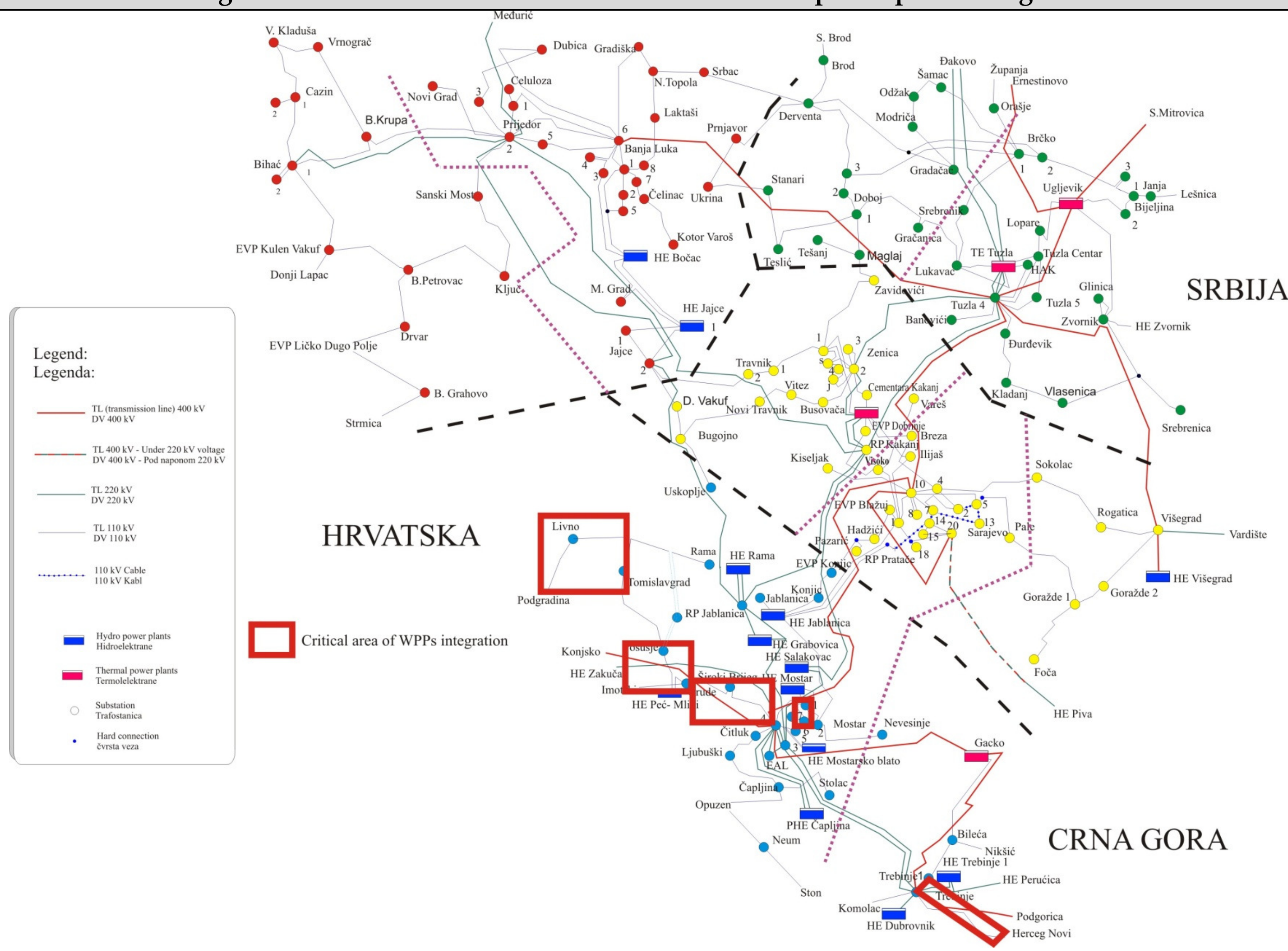


Figure 20 Network bottleneck for scenario C of wind power plants integration

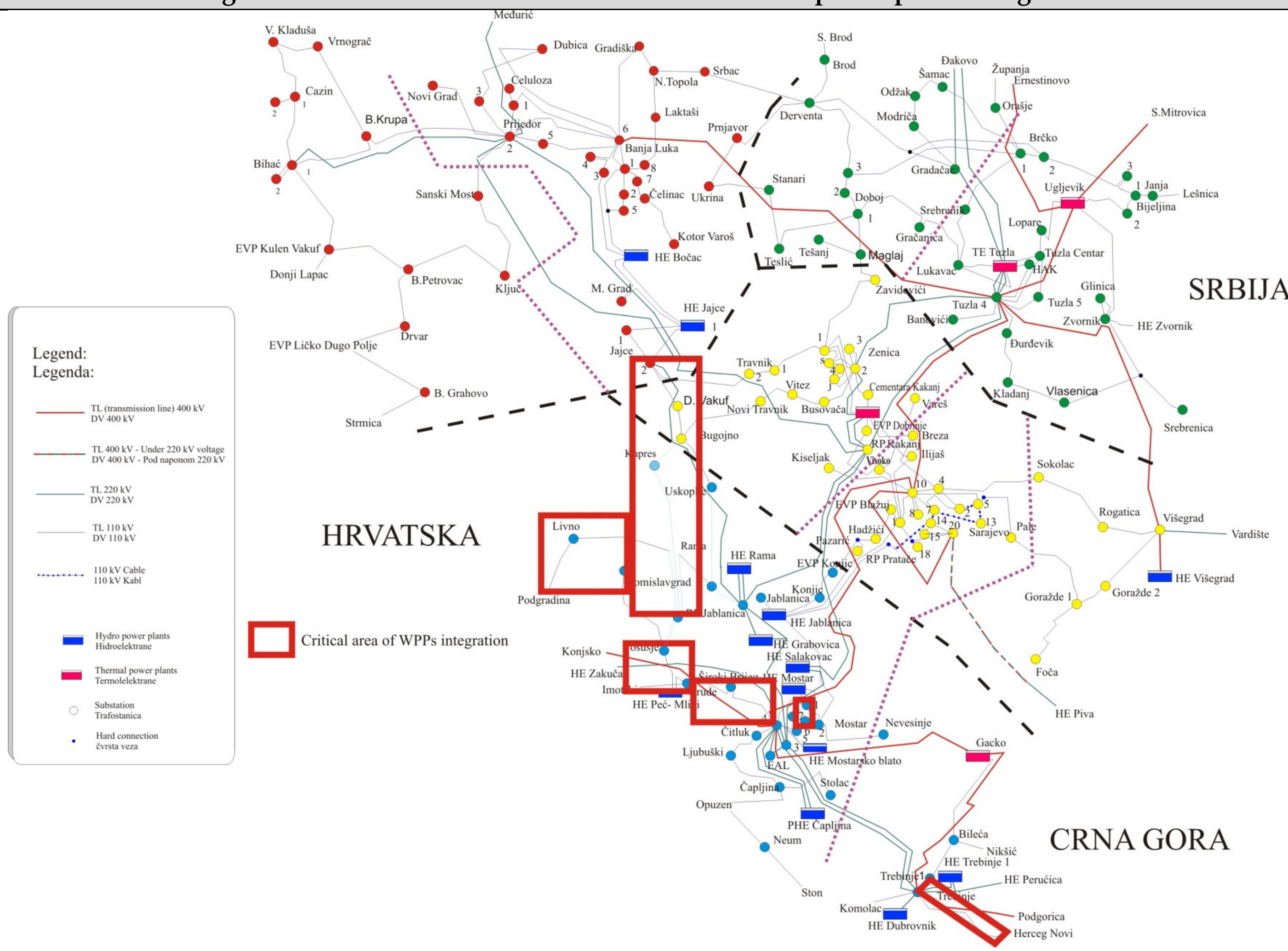
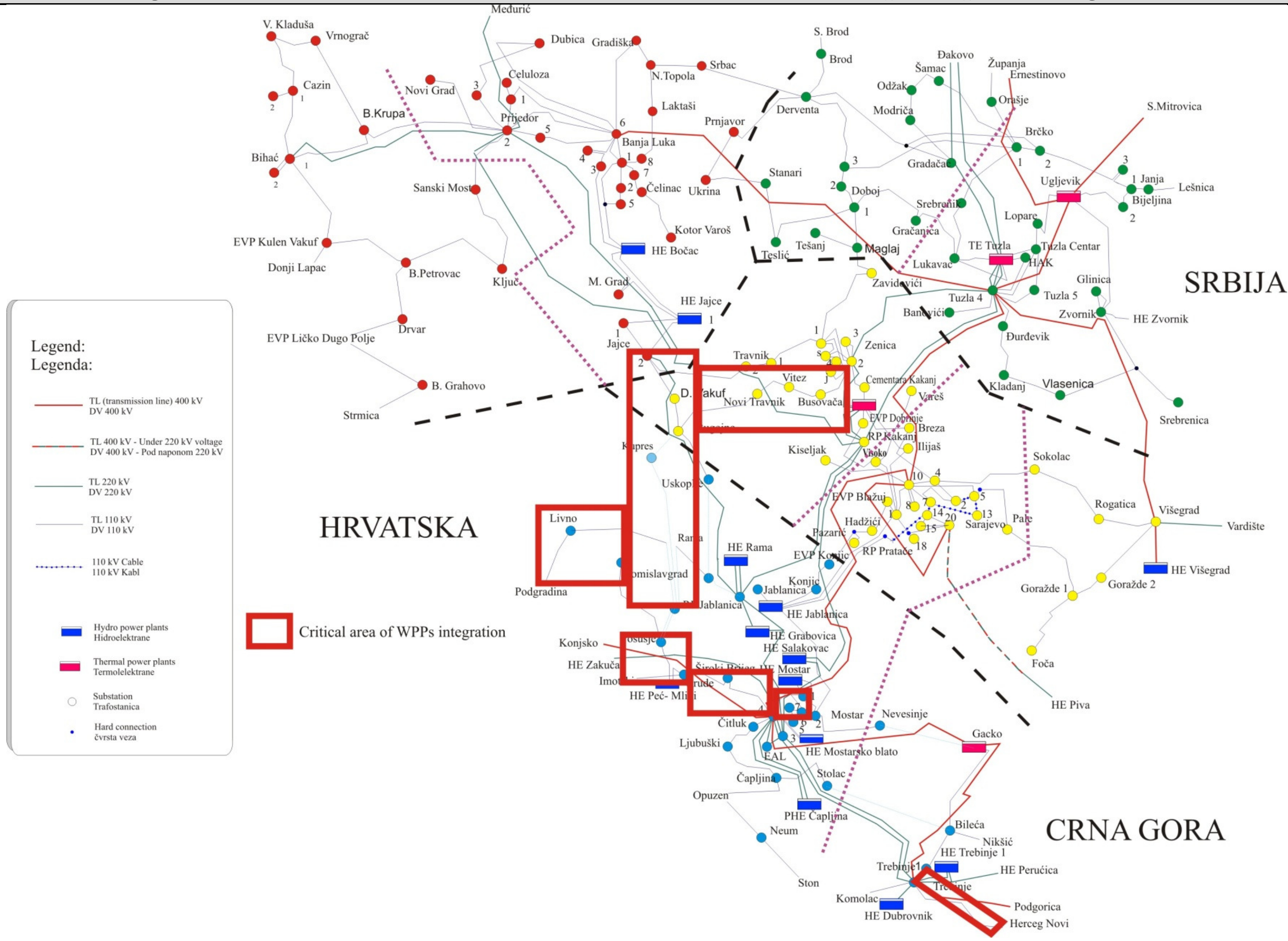


Figure 21 Network bottleneck for scenario D (D1 and D2) of wind power plants integration



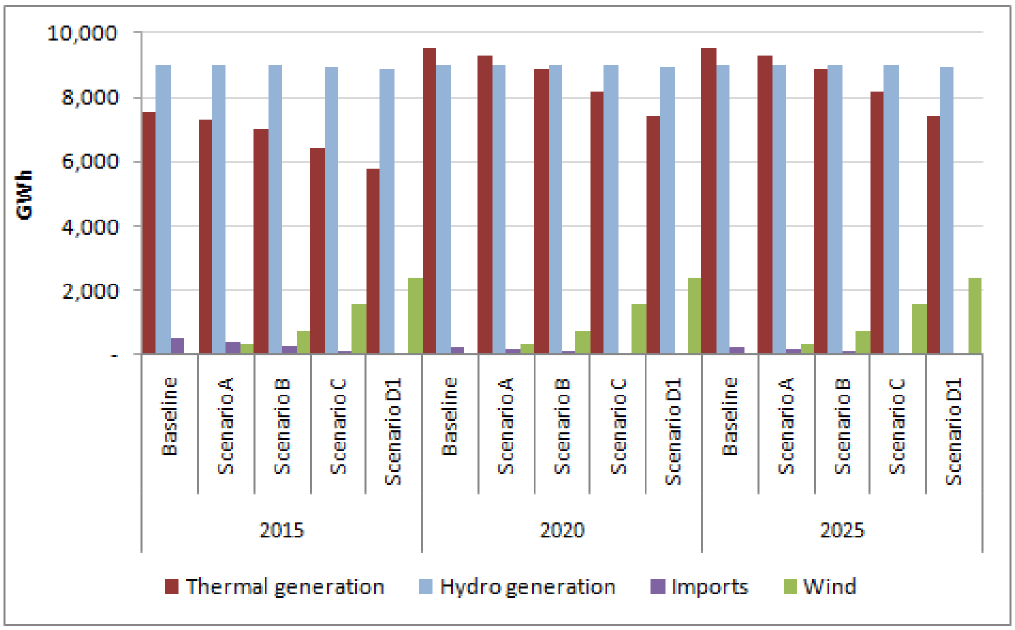
7 Costs of WPP integration

Impact of wind integration on conventional generation

As wind capacity increases its main impact is to displace thermal sources and imports, as shown in Figure 22 (see Report 3 section 4.1 for more details of this analysis). Thermal generation currently provides the largest share of generation in BiH and tends to be the marginal generation source. This means that the introduction of new baseload generation (wind) has the greatest impact on thermal, which is pushed out of the dispatch order. Thermal generation sees a reduction in revenues in all wind scenarios.

Hydro output, which is able to sell any surplus energy into the export market, remains stable in all wind scenarios.

Figure 22 Impact of wind on GWh from conventional sources



The impact on consumers, summarised in Table 36, is an increase in net cost in all cases except the later years under wind Scenario A. The additional cost reflects the higher cost of supporting wind generation through the feed-in tariff. However, the net cost of wind as a percent of the total cost of generation in each scenario is less than 1% in Scenario A and rises to just over 5% in Scenario C. The highest it gets as a proportion of generation cost is 8% when there are 900MW of wind added (Scenario D1).

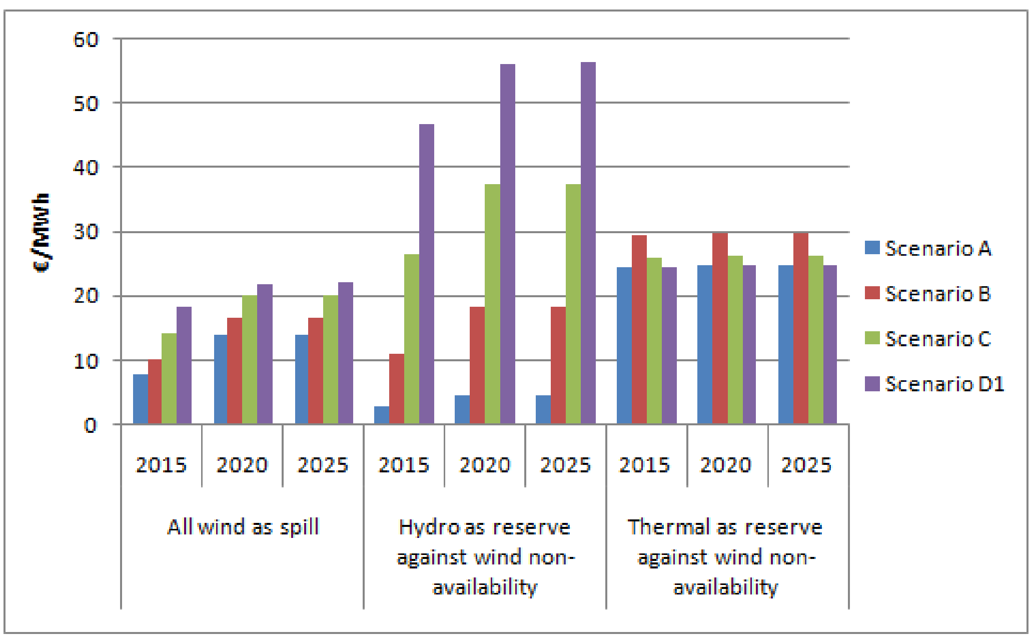
Table 36 Summary of net cost to the consumer of wind additions

	2015	2020	2025
	Net cost to consumers, € million		
Scenario A	-7.3	+3.5	+4.4
Scenario B	-20.8	-13.8	-11.8
Scenario C	-43.4	-47.0	-44.0
Scenarios D1, D2	-69.6	-78.1	-74.7
	Net cost as % of total cost to consumers		
Scenario A	0.9%		
Scenario B	2.5%	1.5%	1.3%
Scenario C	5.2%	4.9%	4.6%
Scenarios D1, D2	8.0%	7.9%	7.5%

Impact of wind integration on reserve costs

With the introduction of wind to a power system two forms of additional reserve need to be considered: reserve against wind failing to deliver when scheduled to do so, but equally important is a need for downward flexibility on other generating units when wind delivers unscheduled energy onto the system. Different approaches can be taken to valuing reserve for wind. In the analysis here three approaches were used and in all cases the cost of providing reserve for wind is high. Figure 23 summarises the cost per MWh of the three methodologies.

Figure 23 Comparison of reserve provision methodologies



The analysis assumes that there is no short term forecasting of wind output and this results in a conservative view on the required reserve. It is possible, following the experience in Western Europe, that considerable savings could be made through the introduction of techniques to forecast wind availability a few hours ahead.

8 Summary, conclusions, and key recommendations

Existing characteristics of BiH transmission system with respect to WPP integration

The present situation of the transmission system in the area where the majority of future WPPs will be located is not favorable for their integration. The problem is caused by under-developed 110 kV networks around Mostar, Grude, Posusje and Tomislavgrad. Some important 110 kV lines and paths like Mostar 4 – Siroki Brijeg – Grude – Imotski have low transmission capacities caused by line sections equipped with Copper 95 mm^2 conductors placed on concrete towers.

Presently, there is only one connection of the 110 kV network with higher voltage levels (220 kV and 400 kV) of the most important area for WPP integration (western Herzegovina region), realized in SS 400/220/110 kV Mostar 4. This is particularly important if large WPPs installed capacity is going to be connected to the 110 kV network, because this network will not be able to transmit their production with adequate security and reliability.

The 400 kV and 220 kV networks in BiH are well-designed, with large transmission capacities, and these voltage levels will not cause barriers for WPPa integration.

Future transmission system of BiH

There is no official long-term transmission development plan in BiH.

Important 110 kV lines, which were planned in some studies or attempts to define transmission development plan, with respect to WPP integration, are:

- OHL 110 kV Tomislavgrad – Kupres,
- OHL 110 kV Rama – Uskoplje, and
- OHL 110 kV Rama – Jablanica.

These lines assure two new electricity paths from the Tomislavgrad area towards the Bugojno area transmitting WPP production and relieving existing 110 kV paths from Tomislavgrad via Livno to Croatia, and from Grude to Croatia.

These three lines are necessary and almost a prerequisite if more significant installed capacity of WPPs (150 MW and above) is going to be constructed in BiH (particularly within the area of western Herzegovina where the majority of wind projects are under development).

Transmission bottlenecks due to wind power plants integration – existing network

The most important transmission bottlenecks related to WPP integration are as follows (in order of priority and importance):

- OHL 110 kV Mostar 4 – Siroki Brijeg,

- OHL 110 kV Pec Mlini – Grude,
- OHL 110 kV Pec Mlini – Posusje,
- OHL 110 kV Siroki Brijeg – Grude,
- OHL 110 kV Imotski – Grude,
- OHL 110 kV Tomislavgrad – Livno,
- OHL 110 kV Busko Blato – Livno.

Transmission bottlenecks due to wind power plants integration – future network

The most important transmission bottlenecks for future transmission network configuration, related to WPP integration are as follows (in order of priority and importance):

- OHL 110 kV Mostar 1 – Mostar 6,
- OHL 110 kV Pec Mlini – Grude,
- OHL 110 kV Pec Mlini – Posusje,
- OHL 110 kV Imotski – Grude,
- OHL 110 kV Tomislavgrad – Livno,
- OHL 110 kV Busko Blato – Livno,
- OHL 110 kV Bugojno – D.Vakuf,
- OHL 110 kV Bugojno – Kupres,
- OHL 110 kV D.Vakuf – Jajce 2,
- OHL 110 kV Tomislavgrad – Kupres,
- OHL 110 kV Bugojno – Novi Travnik,
- OHL 110 kV Zenica 2 – Busovaca,
- OHL 110 kV Busovaca – Vitez,
- OHL 110 kV Novi Travnik – Vitez.

Voltage problems due to wind power plants integration

Voltage problems in the 110 kV network could be expected in scenarios of WPP integration with installed capacity of 600 MW and above.

Large WPPs like WPP Glamoc-Slovinj, WPP Kupres, WPP Pakline and WPP Ljubusa should be designed with Q/U control ability (power factor should be 0,90 or 0,95) in order to avoid a risk of voltage collapse.

Smaller WPPs (approximately up to 50 MW) could be designed with power factor equal to 1, without automatic regulation on x/110 kV transformers.

WPPs installed capacity limit due to transmission network capacities (existing network)

The existing network configuration allows integration of approximately 126 MW of WPPs (WPP Mesihovina, WPP Kamena and WPP Ivan Sedlo) without any network reinforcement.

With minor investment in the 110 kV line Mostar 4 – Siroki Brijeg revitalization it is possible to integrate WPPs with installed capacity of 150 MW (additionally WPP Velika Vlajina).

WPPs installed capacity limit due to transmission network capacities (future network)

The future planned transmission network configuration allows integration of 200 MW of WPPs in 2015 (WPP Mesihovina, WPP Kamena, WPP Ivan Sedlo, WPP Velika Vlajina and WPP located the wide Trebinje area) without any additional network reinforcement, and another 150 MW (WPP Poklecani, WPP Gradina, WPP Borova Glava), or 300 MW in total, in 2020 when line Rama – Jablanica is planned to be put in operation at the 110 kV level.

Additional costs due to wind power plants integration

Impact of wind integration on conventional generation

As wind capacity increases its main impact is to displace thermal sources and imports. Thermal generation currently provides the largest share of generation in BiH and tends to be the marginal generation source. This means that the introduction of new baseload generation (wind) has the greatest impact on thermal, which is pushed out of the dispatch order. Thermal generation sees a reduction in revenues in all wind scenarios.

Hydro output, which is able to sell any surplus energy into the export market, remains stable in all wind scenarios.

The impact on consumers is an increase in net cost in all cases except the later years under wind Scenario A. The additional cost reflects the higher cost of supporting wind generation through the feed-in tariff. However, the net cost of wind as a percent of the total cost of generation in each scenario is less than 1% in Scenario A and rises to just over 5% in Scenario C. The highest it gets as a proportion of generation cost is 8% when there are 900MW of wind added (Scenario D1).

Impact of wind integration on reserve costs

With the introduction of wind to a power system two forms of additional reserve need to be considered: reserve against wind failing to deliver when scheduled to do so, but equally important is a need for downward flexibility on other generating units when wind delivers unscheduled energy onto the system. Different approaches can be taken to valuing reserve for wind. In the analysis here three approaches were used and in all cases the cost of providing reserve for wind is high.

The analysis assumes that there is no short term forecasting of wind output and this results in a conservative view on the required reserve. It is possible, following the experience in Western Europe, that considerable savings could be made through the introduction of techniques to forecast wind availability a few hours ahead.

Bibliography

1. ***Energy Sector Study in BiH***, Energy Institute Hrvoje Pozar, Soluziona, Economy Institute Banja Luka, Mining Institute Tuzla, 2008

2. http://www.derk.ba/, State energy regulatory commission web site

3. http://www.nosBiH.ba/, Independent system operator of BiH web site

4. Indicative power production development plan 2011-2020, NOS BiH, July 2010

5. Indicative power production development plan 2012-2021, NOS BiH, June 2011

6. Integral study of JP "Elektroprivreda" HZ HB development, Institute for electric power and energy sector, 2007

7. Draft Energy development strategy of Republic of Srpska, 2010

8. Regulation about ancillary services tariffs, DERK, 2010

Appendix

Load flow results

The following Figures summarise the load flow results and have been referred to in the main report.

Figures represent the 400 kV and 220 kV networks, as well as the 110 kV network of the wider Mostar area where the majority of WPP projects will be built. The rest of the BiH 110 kV network is not represented, since no new WPPs are planned to be connected there.

Results are shown for existing network topology.

Figure 24 Load flow during peak load no WPPs (existing system, 400 kV network, normal hydrology)

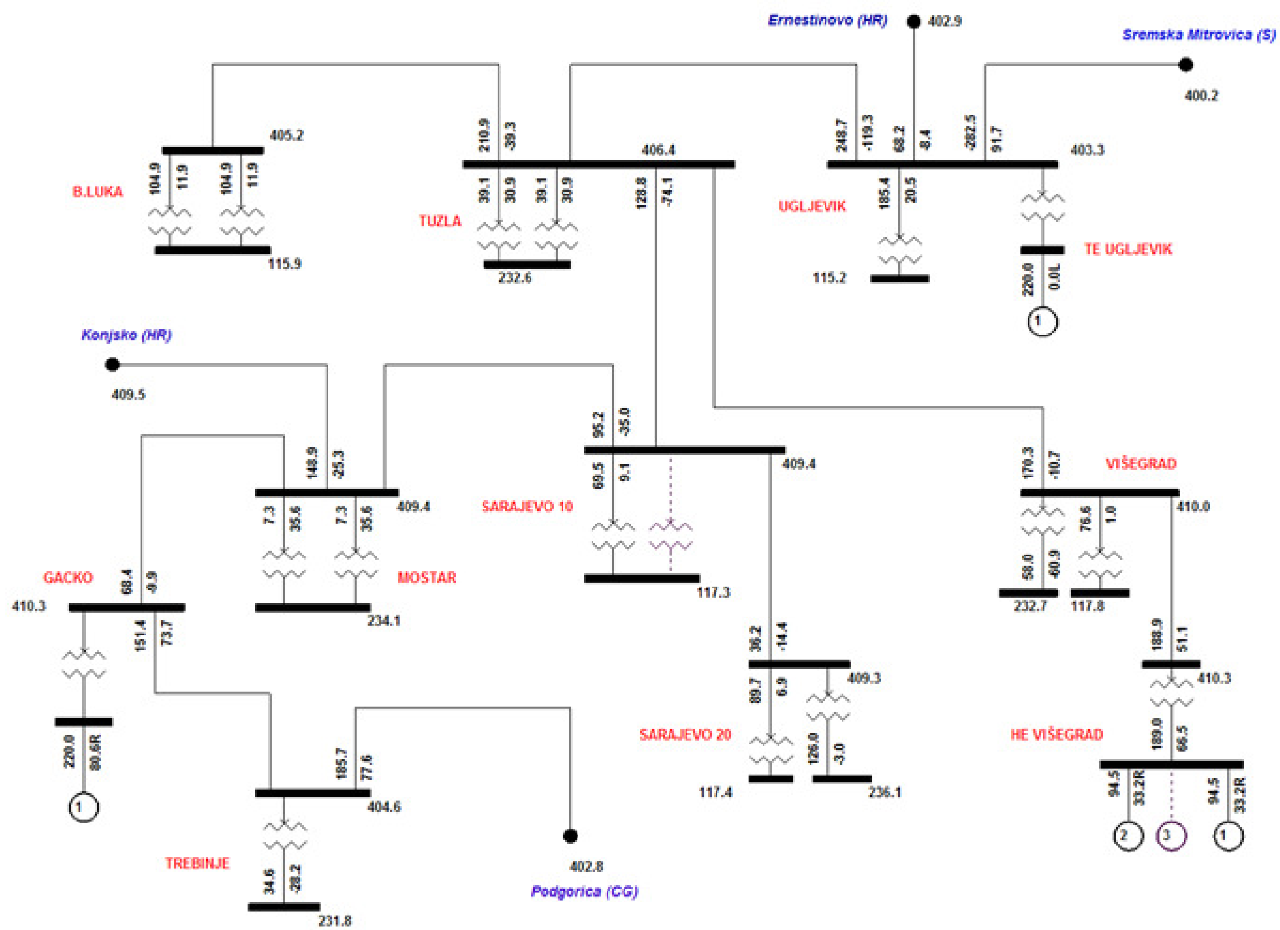


Figure 25 Load flow during peak load no WPPs (existing system, 220 kV network, normal hydrology)

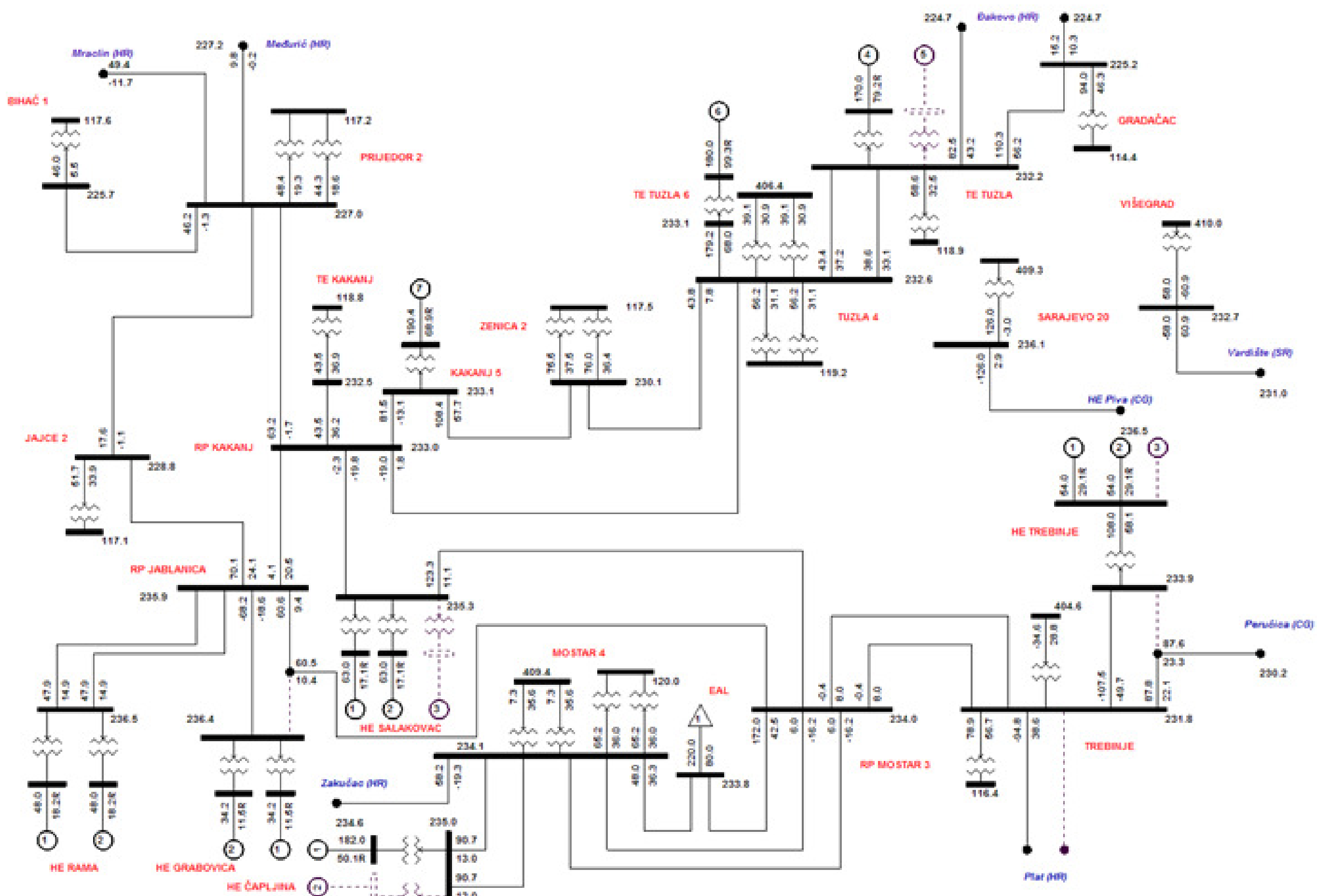


Figure 26 Load flow during peak load no WPPs (existing system, 110 kV network of wider Mostar area, normal hydrology)

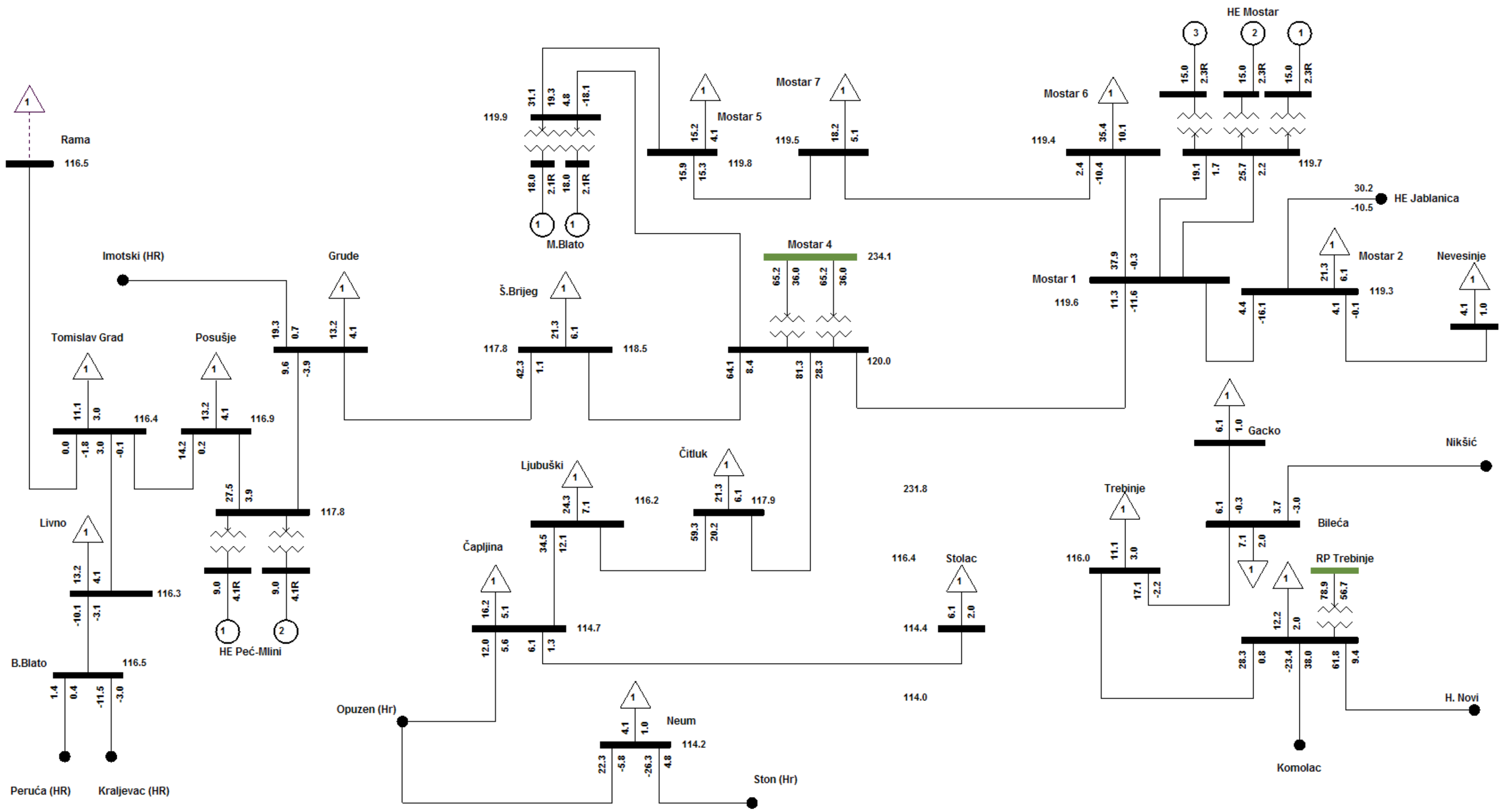


Figure 27 Load flow during peak load no WPPs (existing system, 400 kV network, wet hydrology)

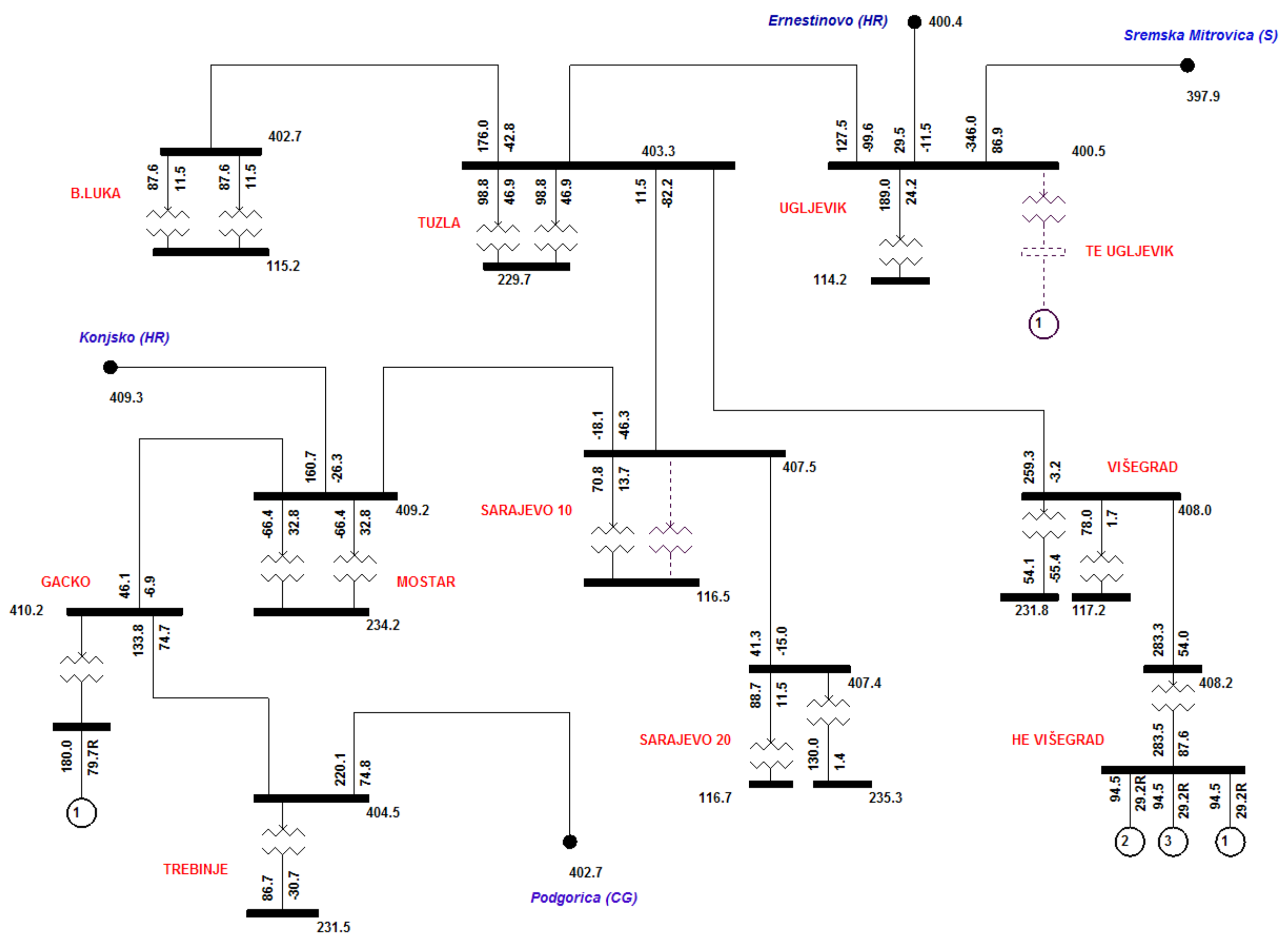


Figure 28 Load flow during peak load no WPPs (existing system, 220 kV network, wet hydrology)

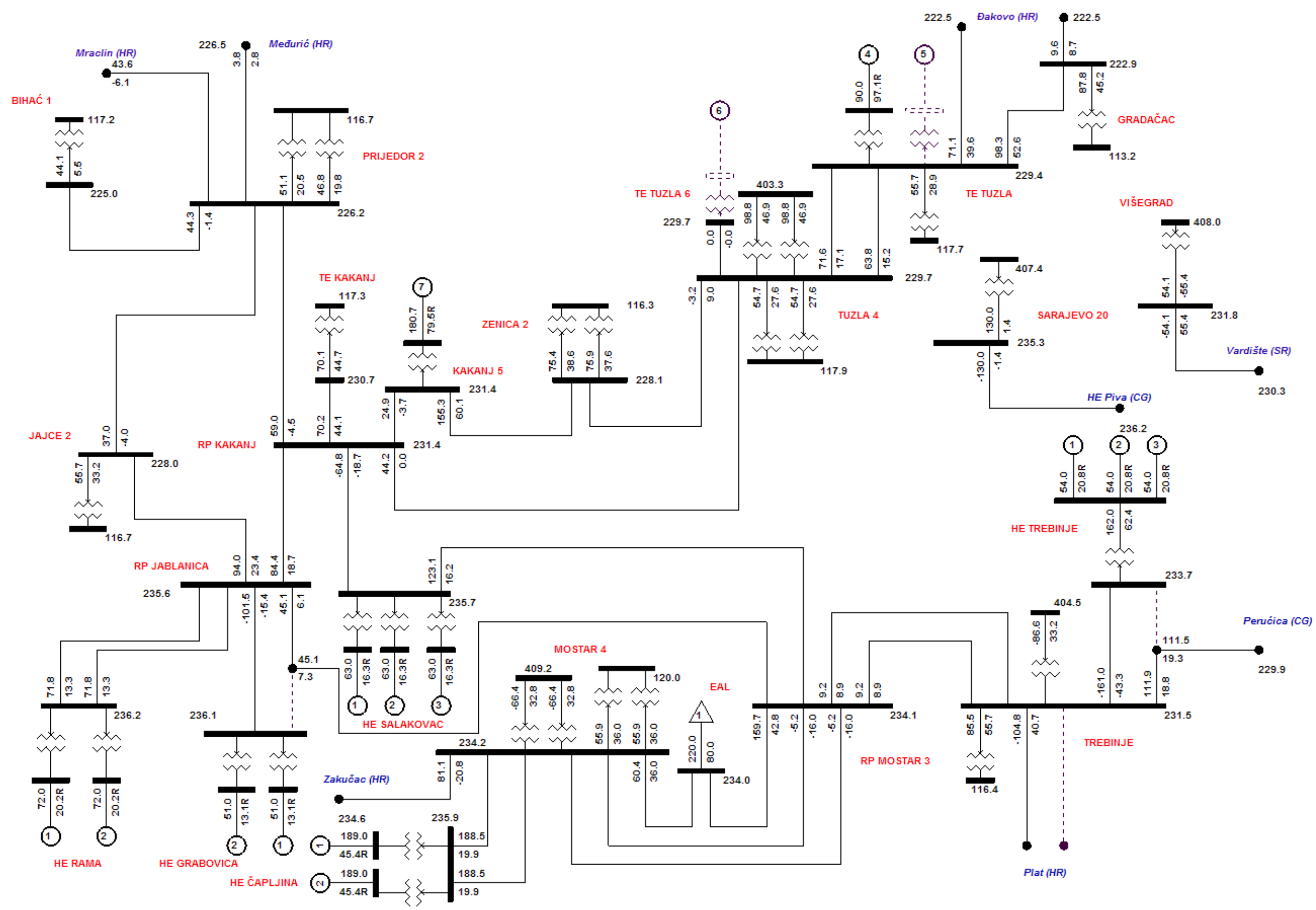


Figure 29 Load flow during peak load no WPPs (existing system, 110 kV network of wider Mostar area, wet hydrology)

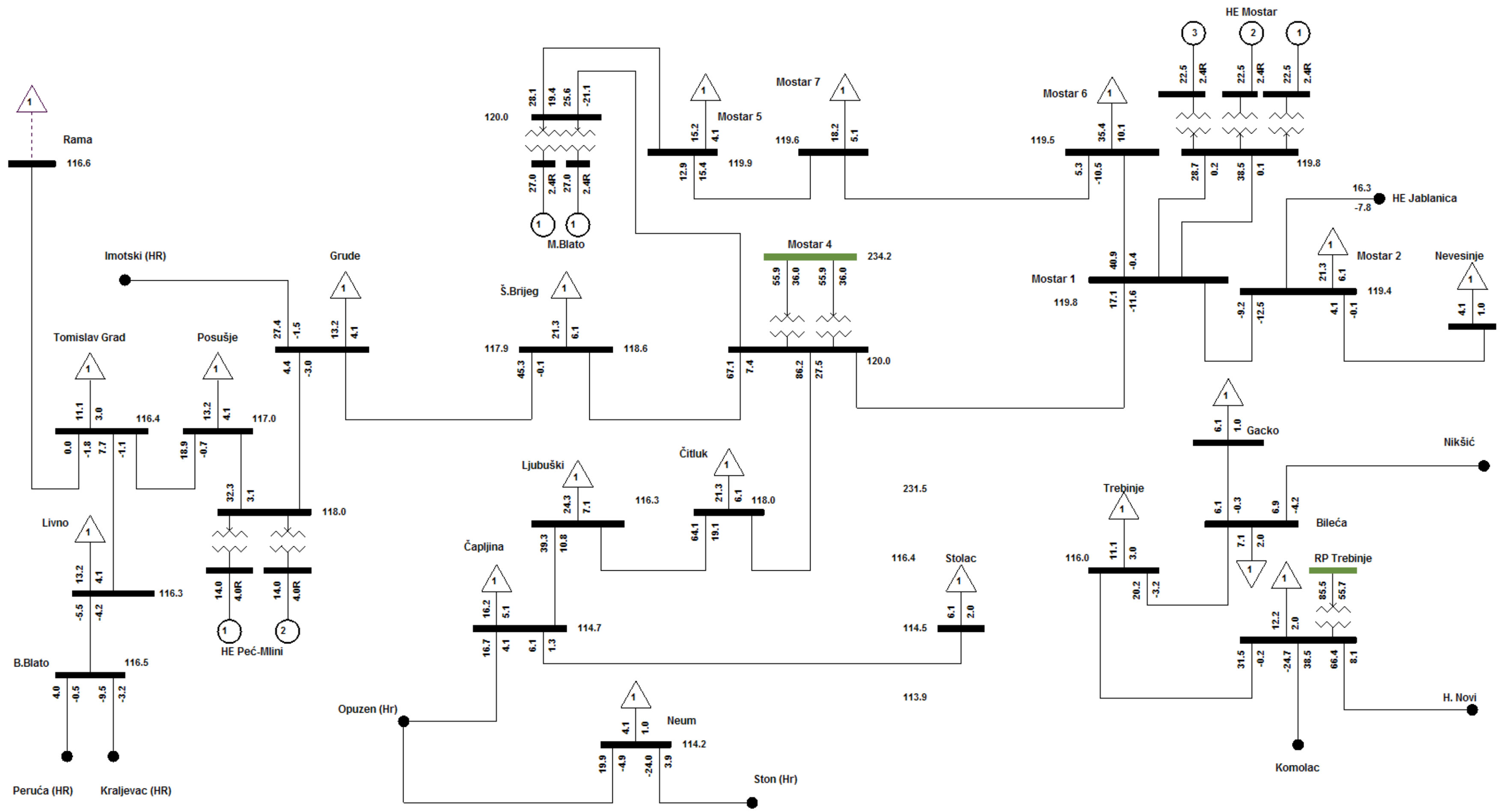


Figure 30 Load flow during summer maximum load no WPPs (existing system, 400 kV network)

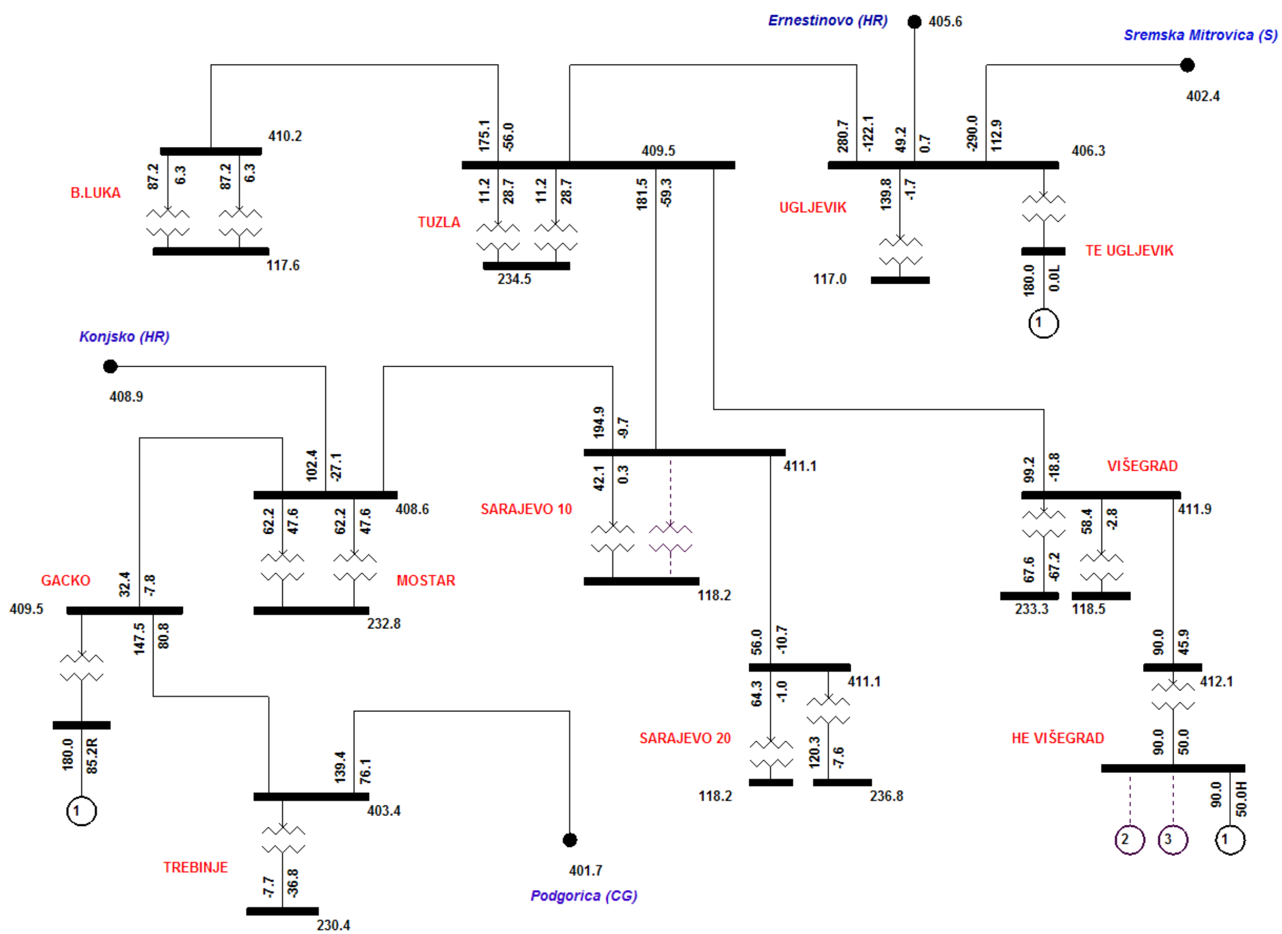


Figure 31 Load flow during summer maximum load no WPPs (existing system, 220 kV network)

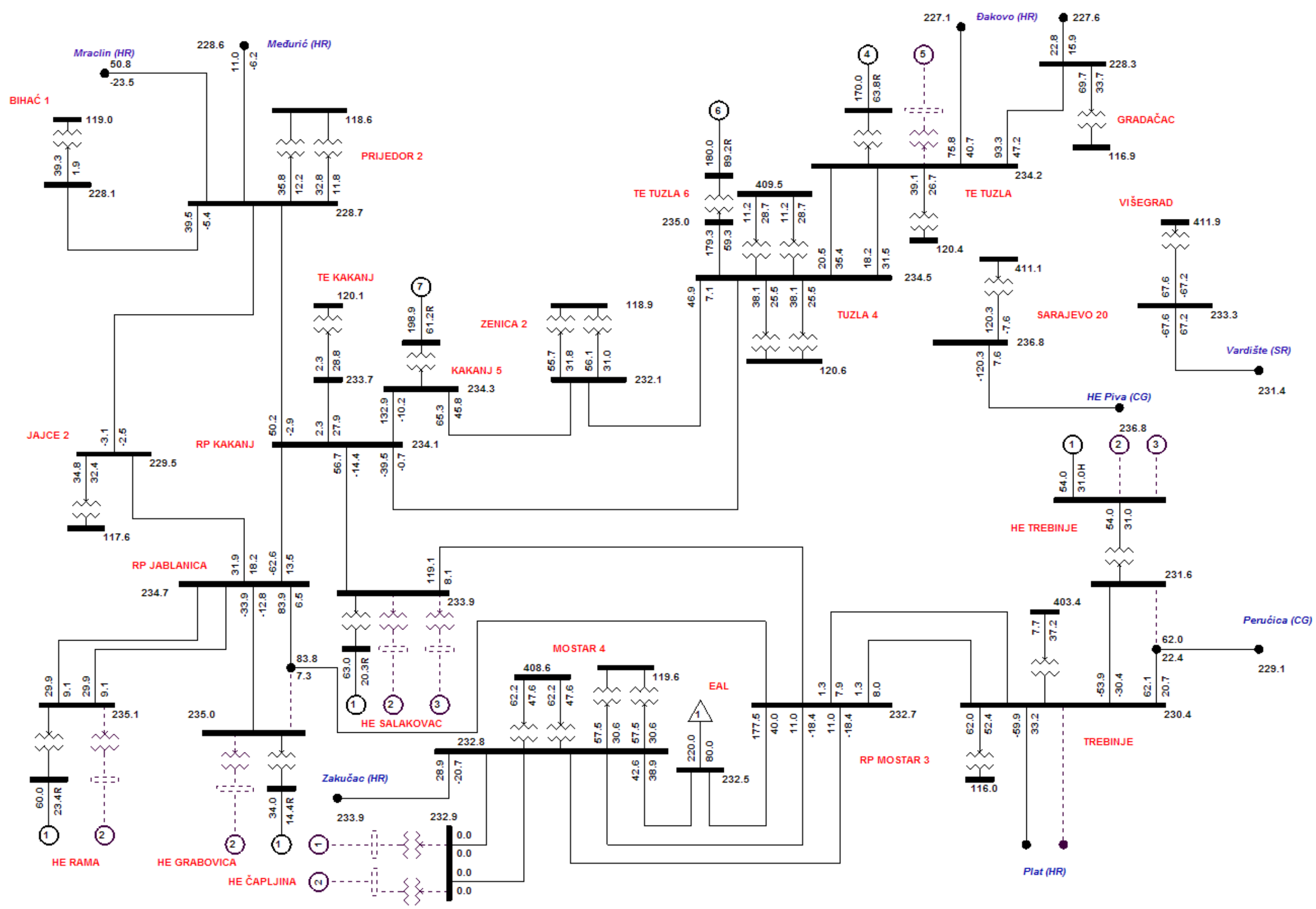


Figure 32 Load flow during summer maximum load no WPPs (existing system, 110 kV network of wider Mostar area)

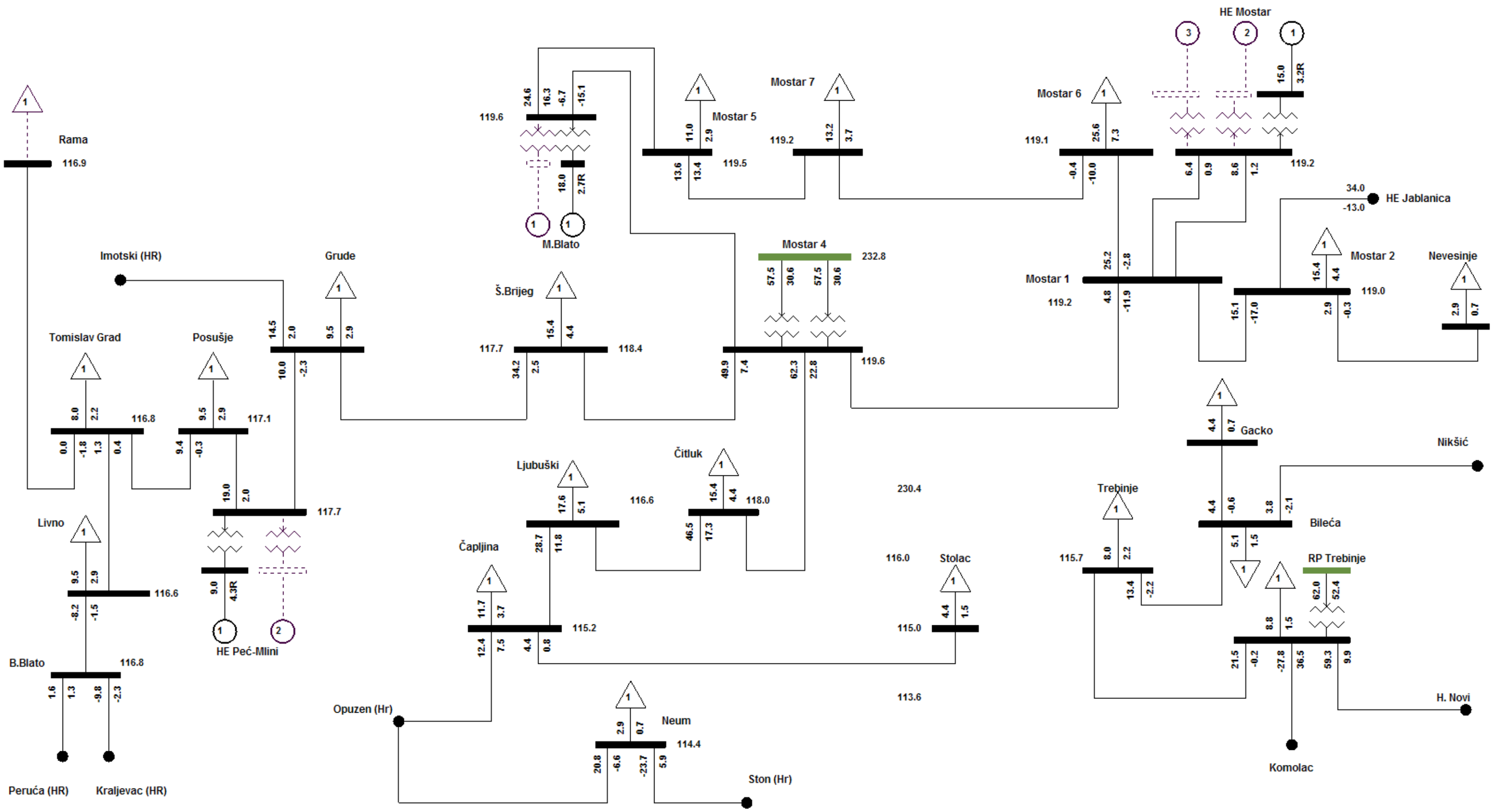


Figure 33 Load flow during off-peak load no WPPs (existing system, 400 kV network)

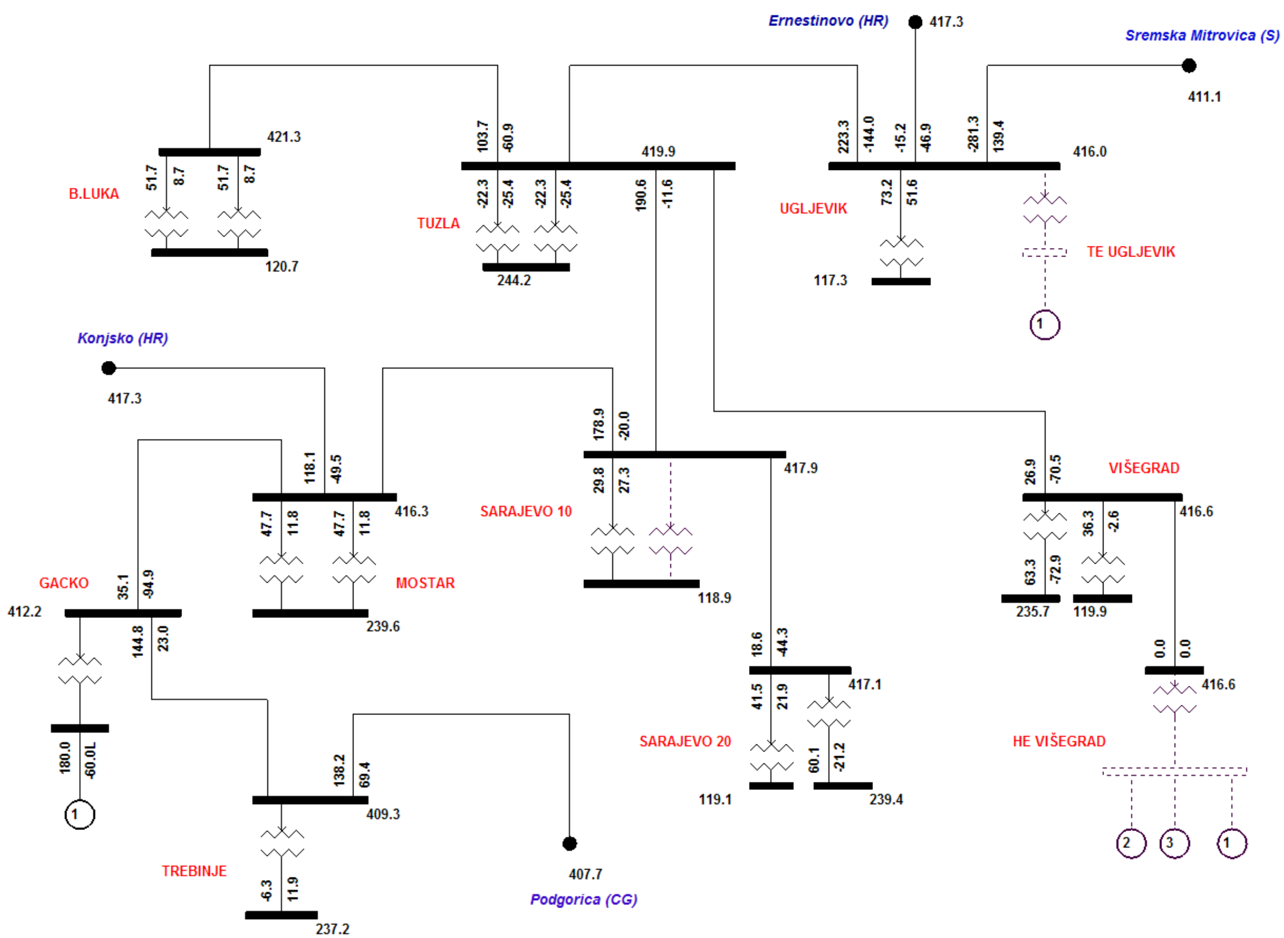


Figure 34 Load flow during off-peak load no WPPs (existing system, 220 kV network)

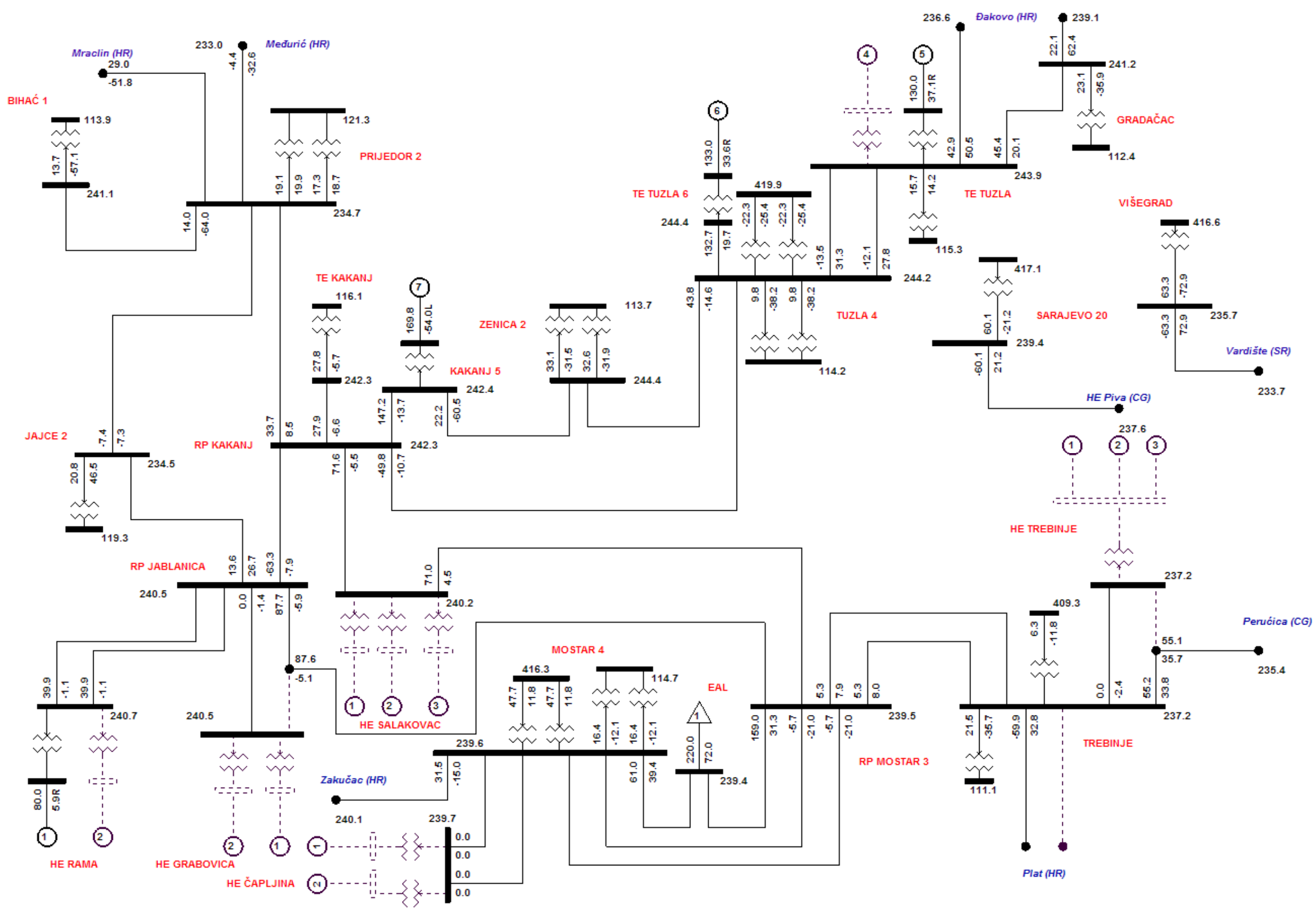


Figure 35 Load flow during off-peak load no WPPs (existing system, 110 kV network of wider Mostar area)

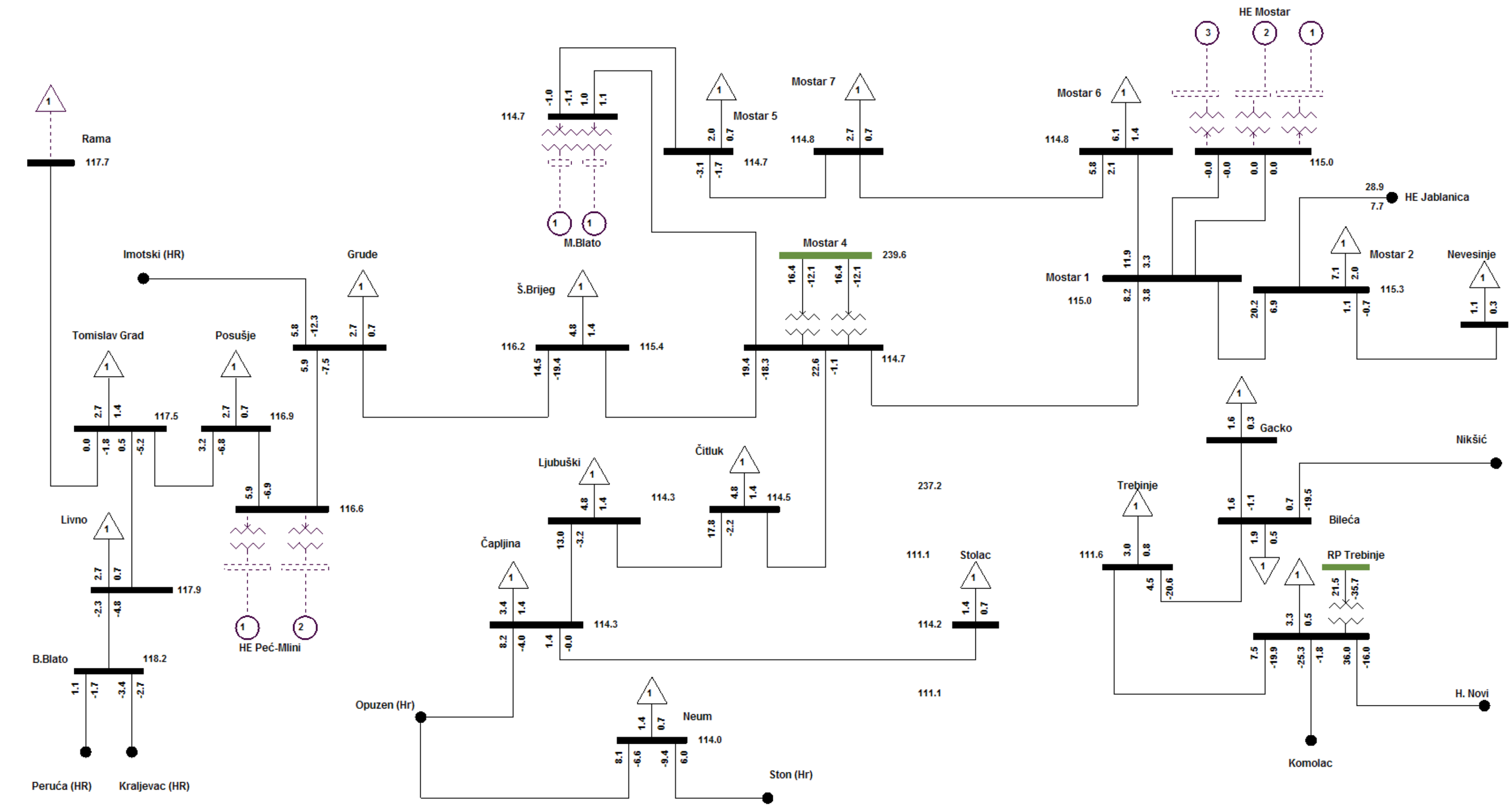


Figure 36 Load flow during peak load, WPPs scenario A (existing system, 400 kV network, normal hydrology)

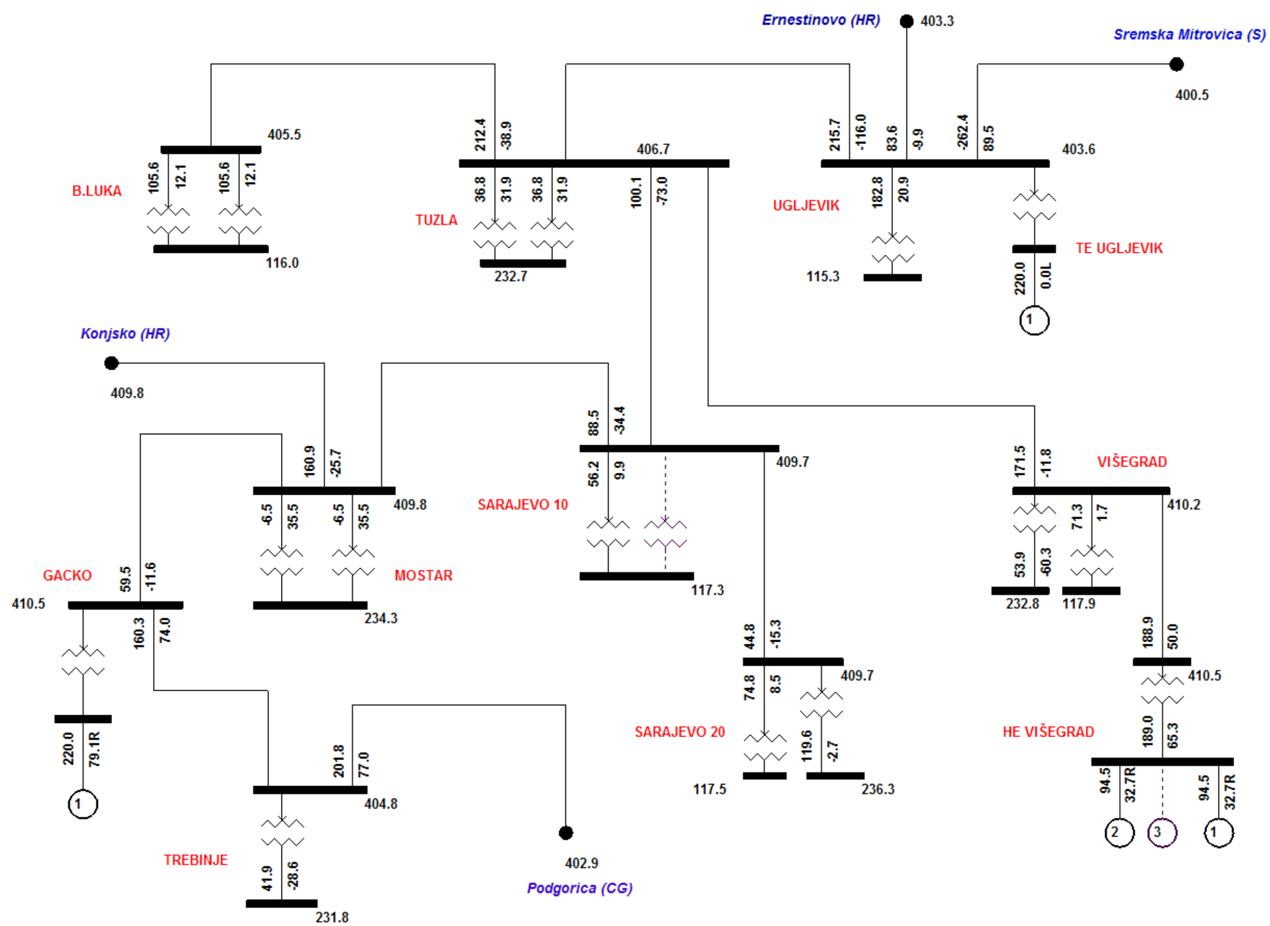


Figure 37 Load flow during peak load, WPPs scenario A (existing system, 220 kV network, normal hydrology)

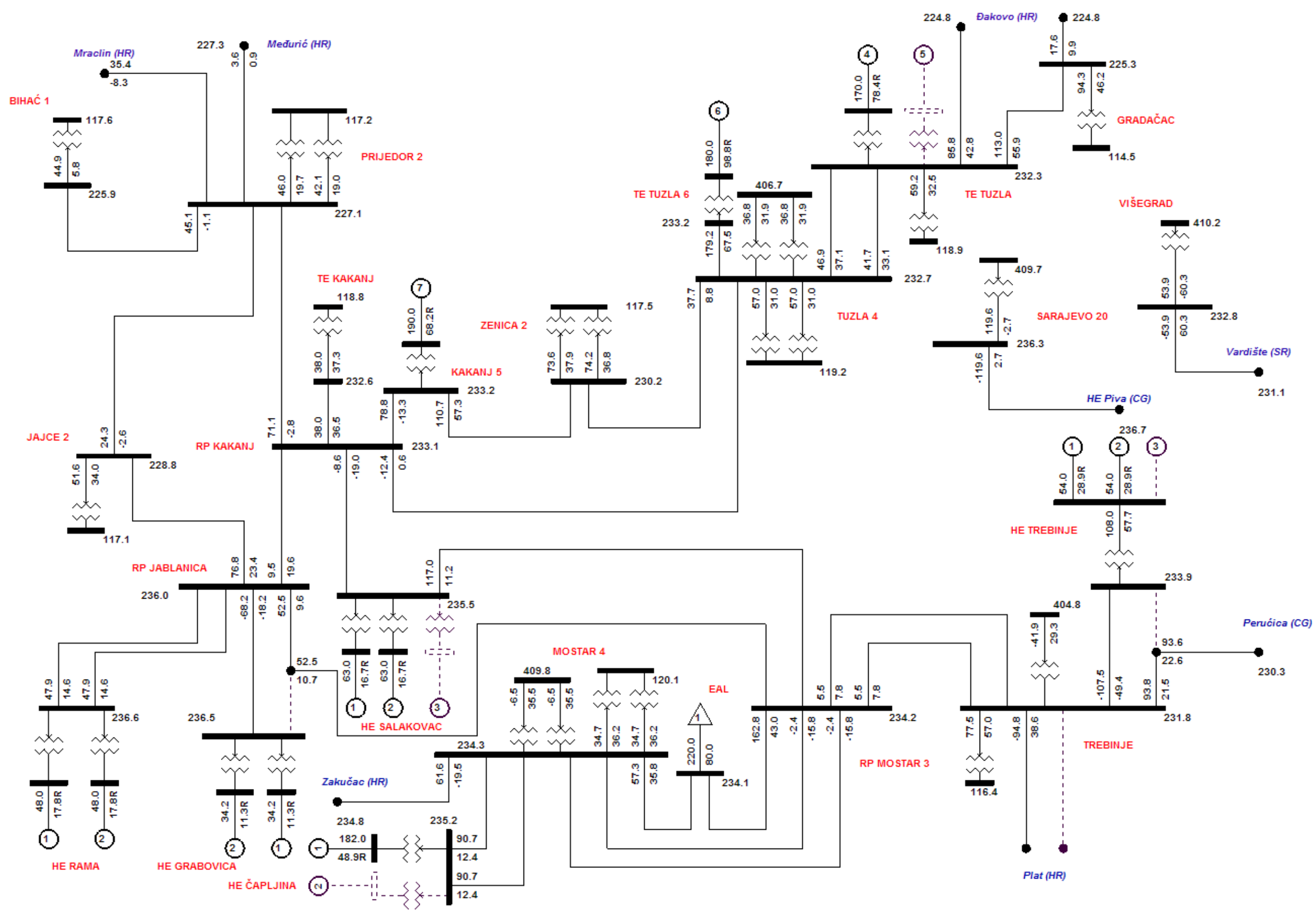


Figure 38 Load flow during peak load, WPPs scenario A (existing system, 110 kV network of wider Mostar area, normal hydrology)

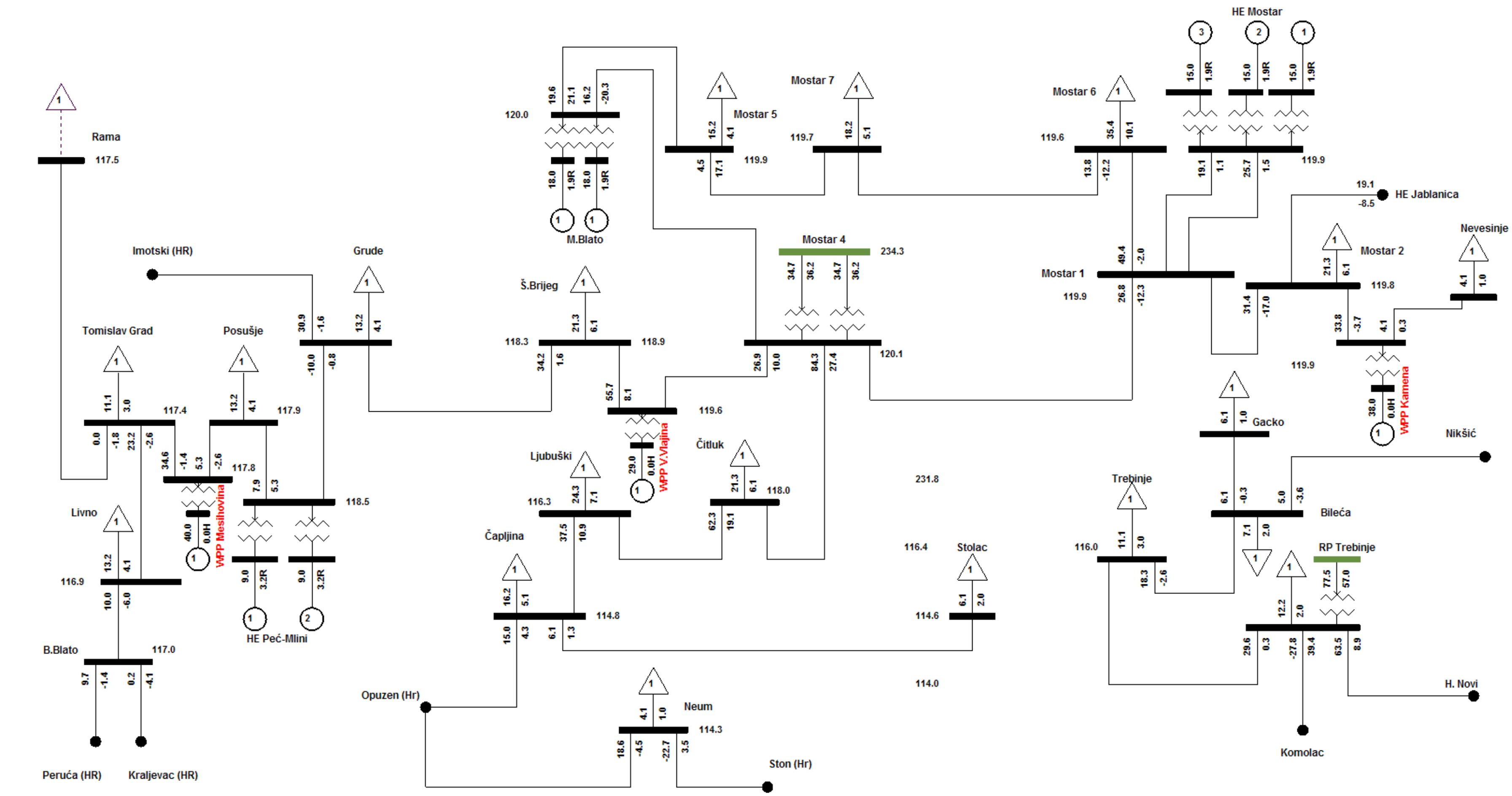


Figure 39 Load flow during peak load, WPPs scenario A (existing system, 400 kV network, wet hydrology)

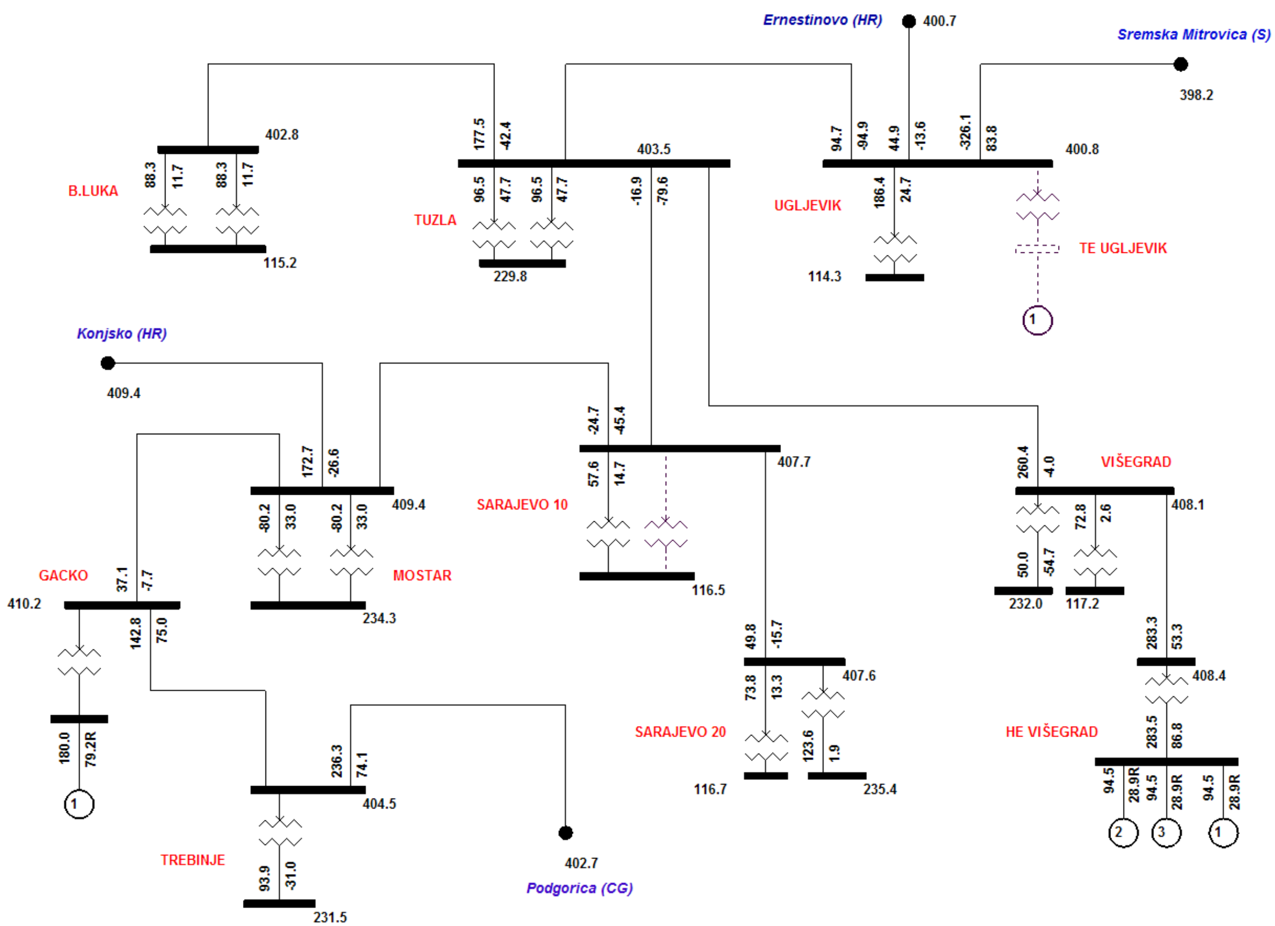


Figure 40 Load flow during peak load, WPPs scenario A (existing system, 220 kV network, wet hydrology)

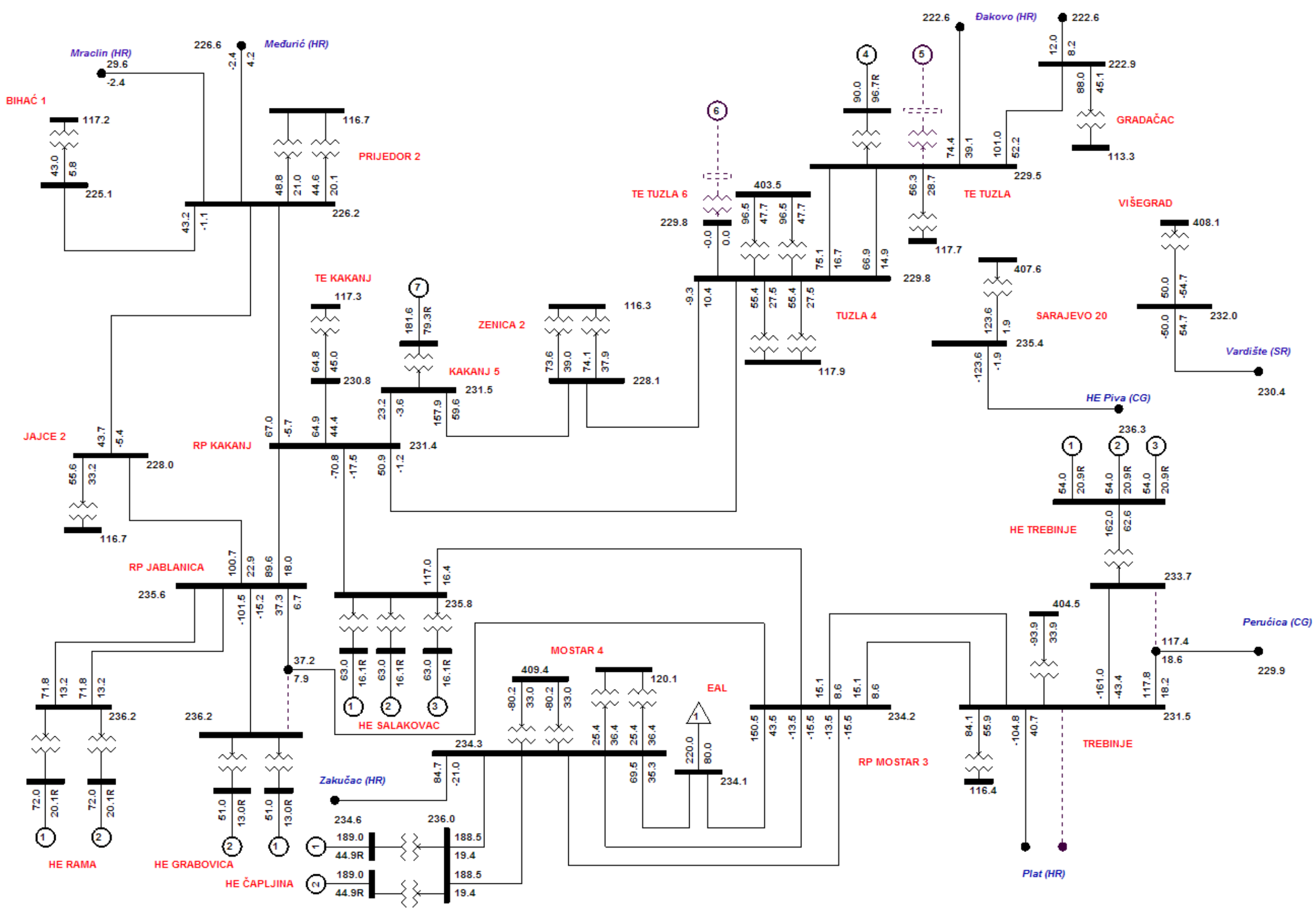


Figure 41 Load flow during peak load, WPPs scenario A (existing system, 110 kV network of wider Mostar area, wet hydrology)

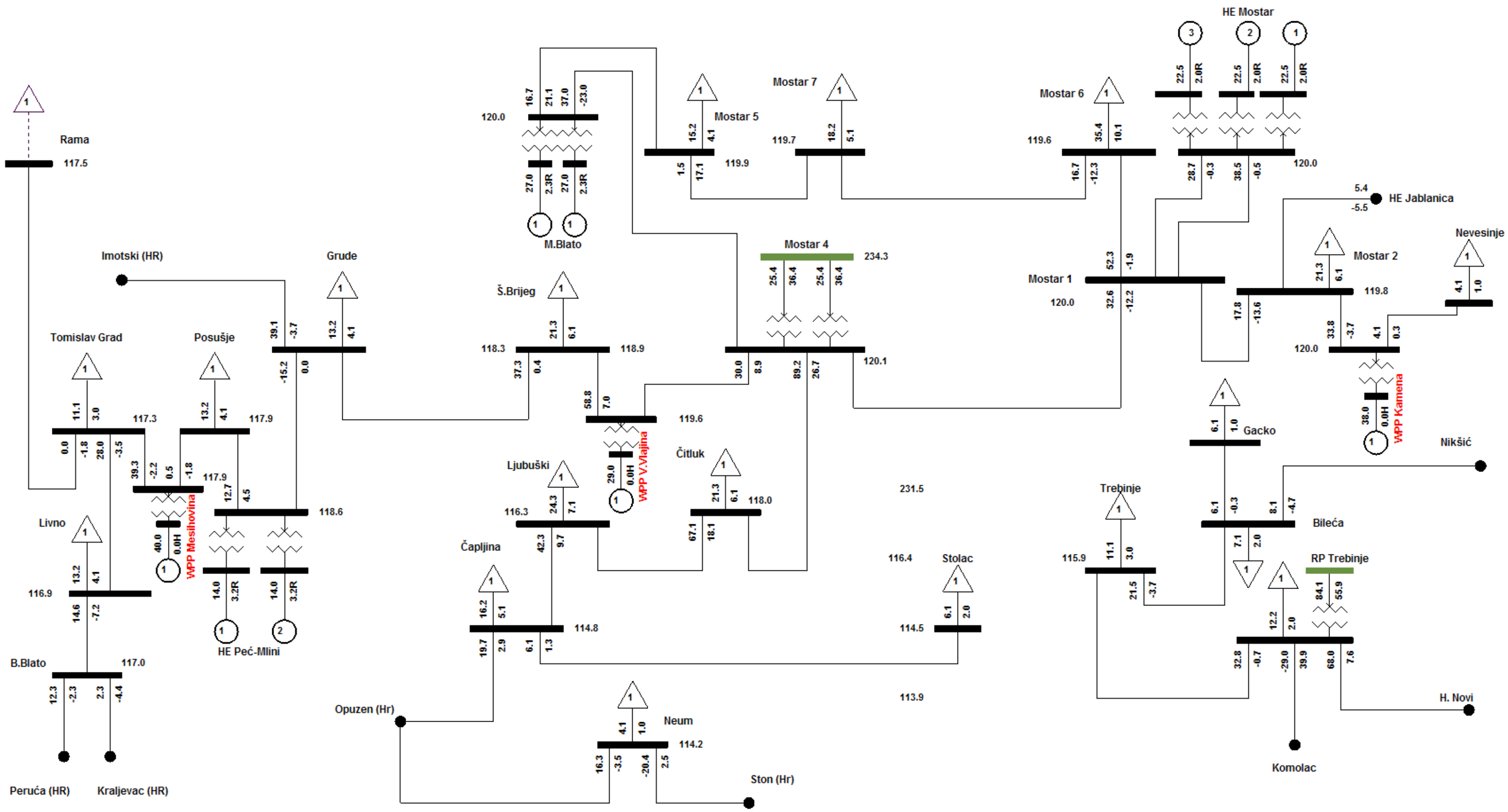


Figure 42 Load flow during summer maximum load, WPPs scenario A (existing system, 400 kV network)

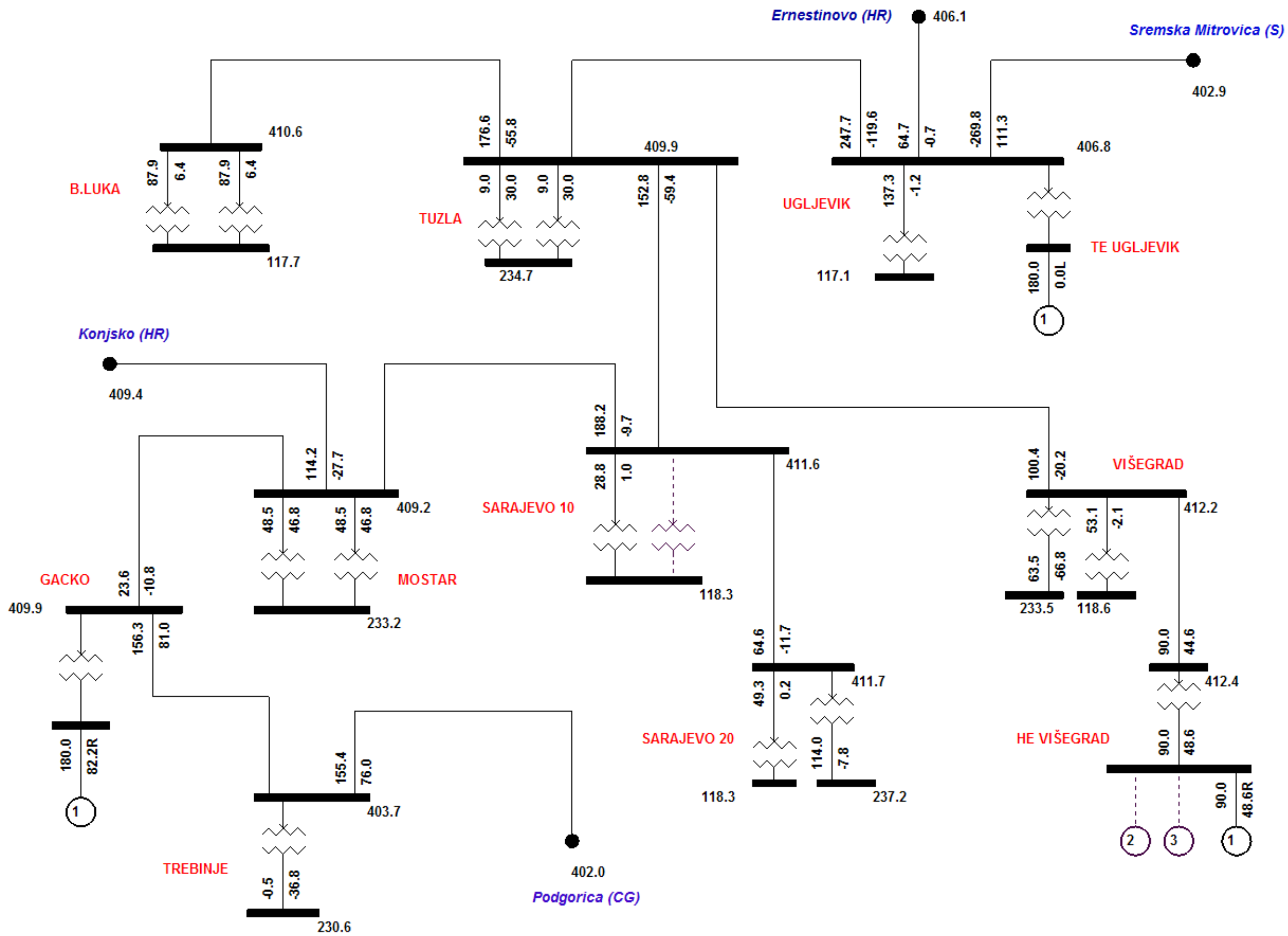


Figure 43 Load flow during summer maximum load, WPPs scenario A (existing system, 220 kV network)

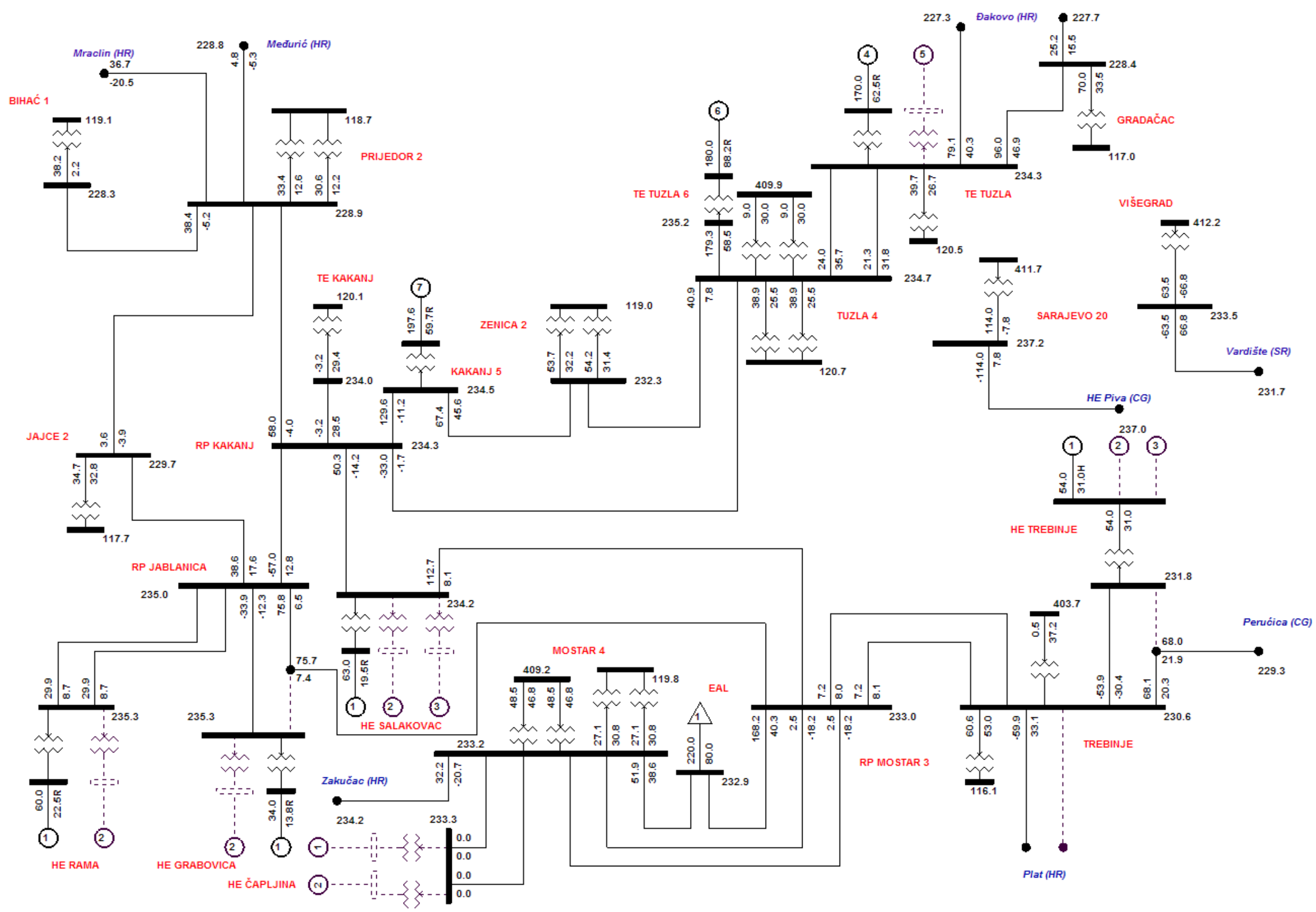


Figure 44 Load flow during summer maximum load, WPPs scenario A (existing system, 110 kV network of wider Mostar area)

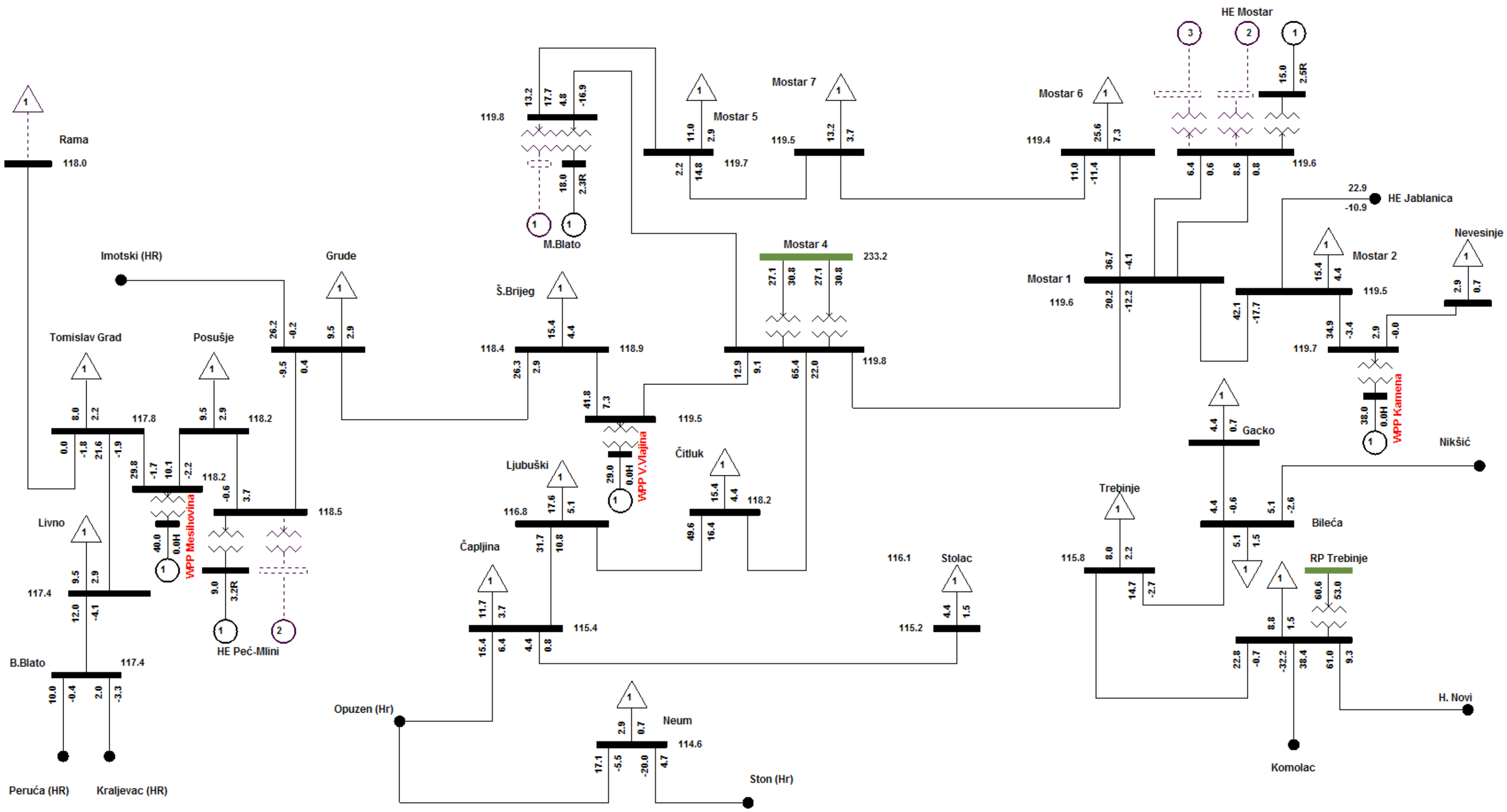


Figure 45 Load flow during off-peak load, WPPs scenario A (existing system, 400 kV network)

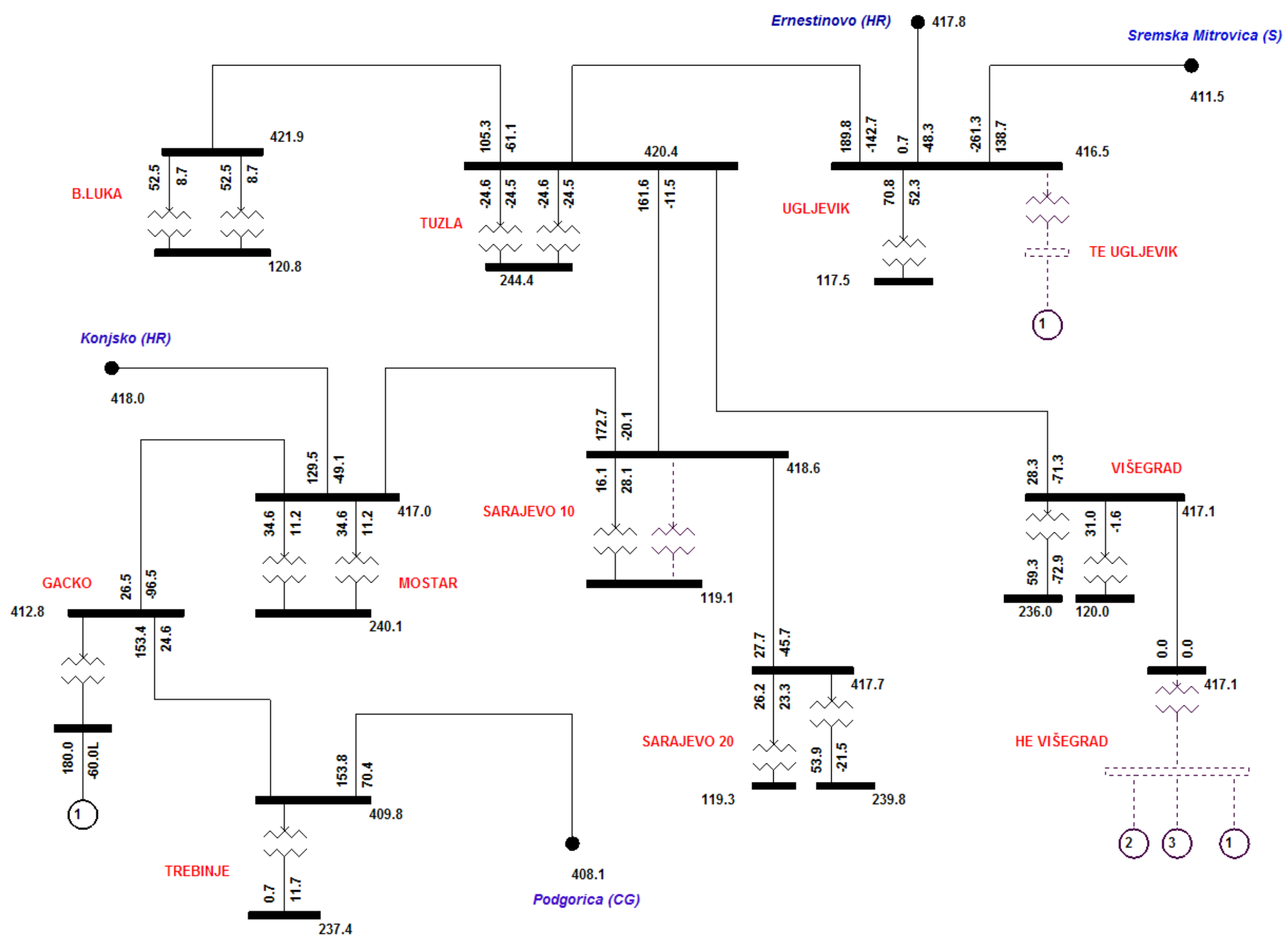


Figure 46 Load flow during off-peak load, WPPs scenario A (existing system, 220 kV network)

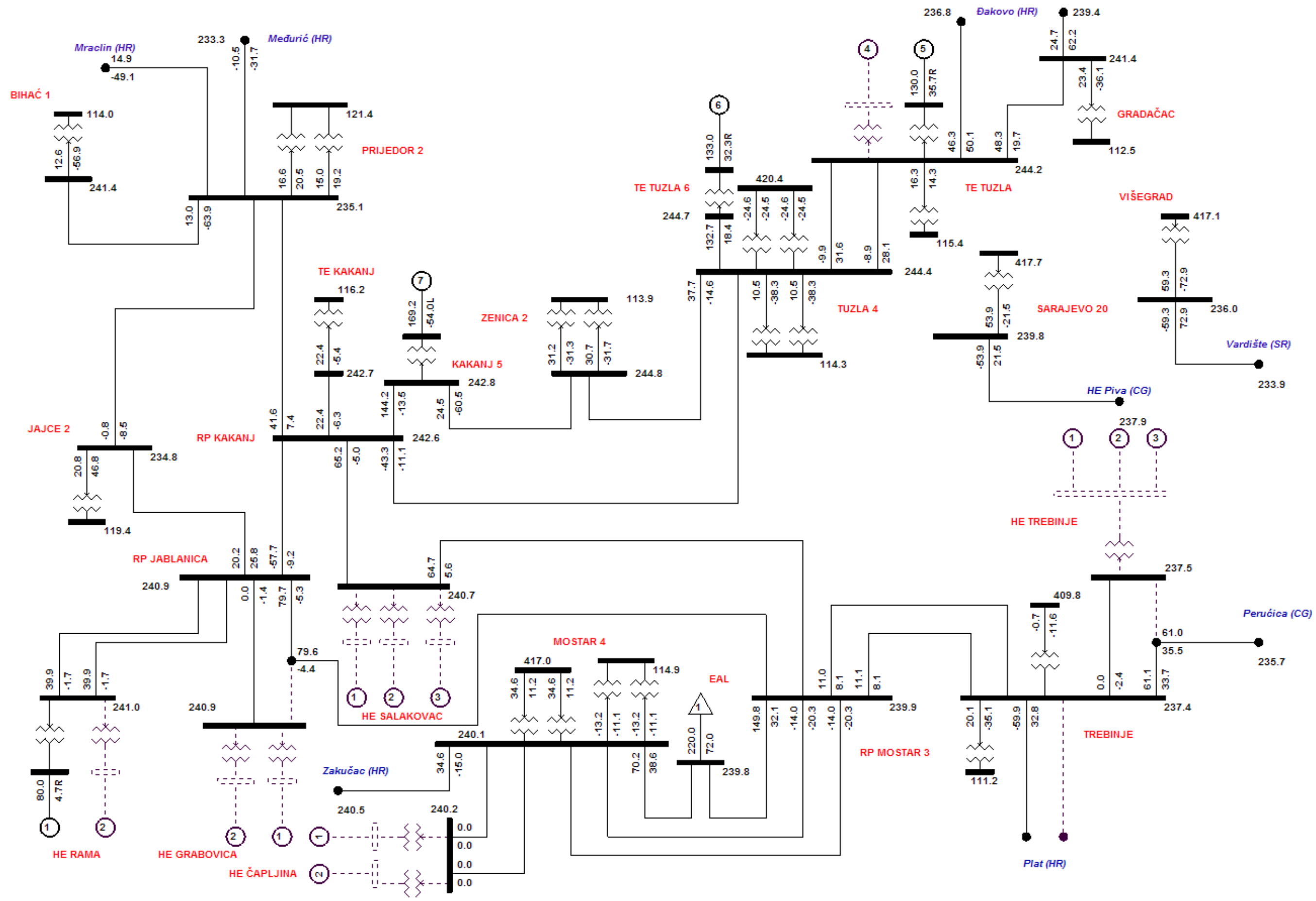


Figure 47 Load flow during off-peak load, WPPs scenario A (existing system, 110 kV network of wider Mostar area)

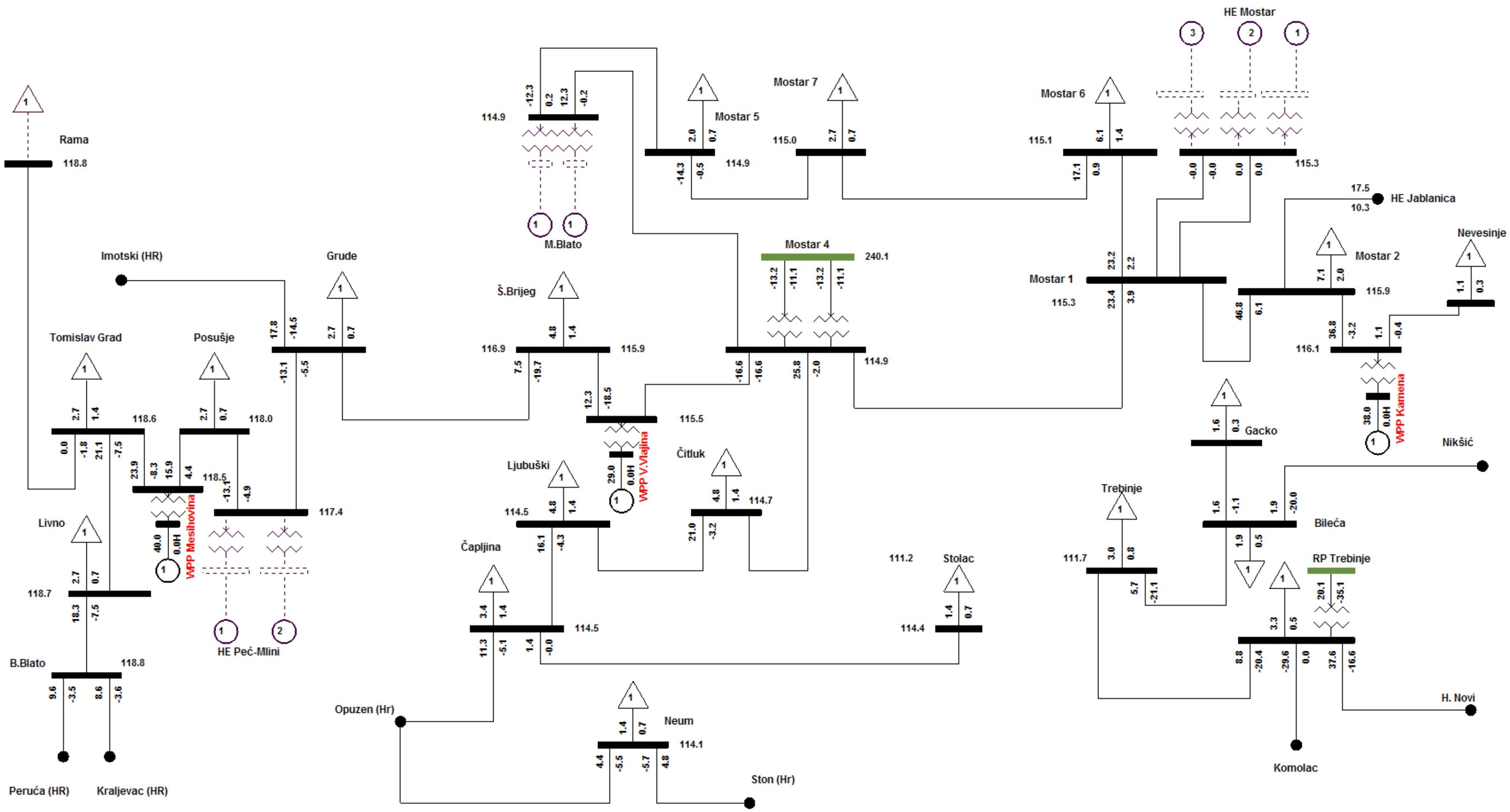


Figure 48 Load flow during peak load, WPPs scenario B (existing system, 400 kV network, normal hydrology)

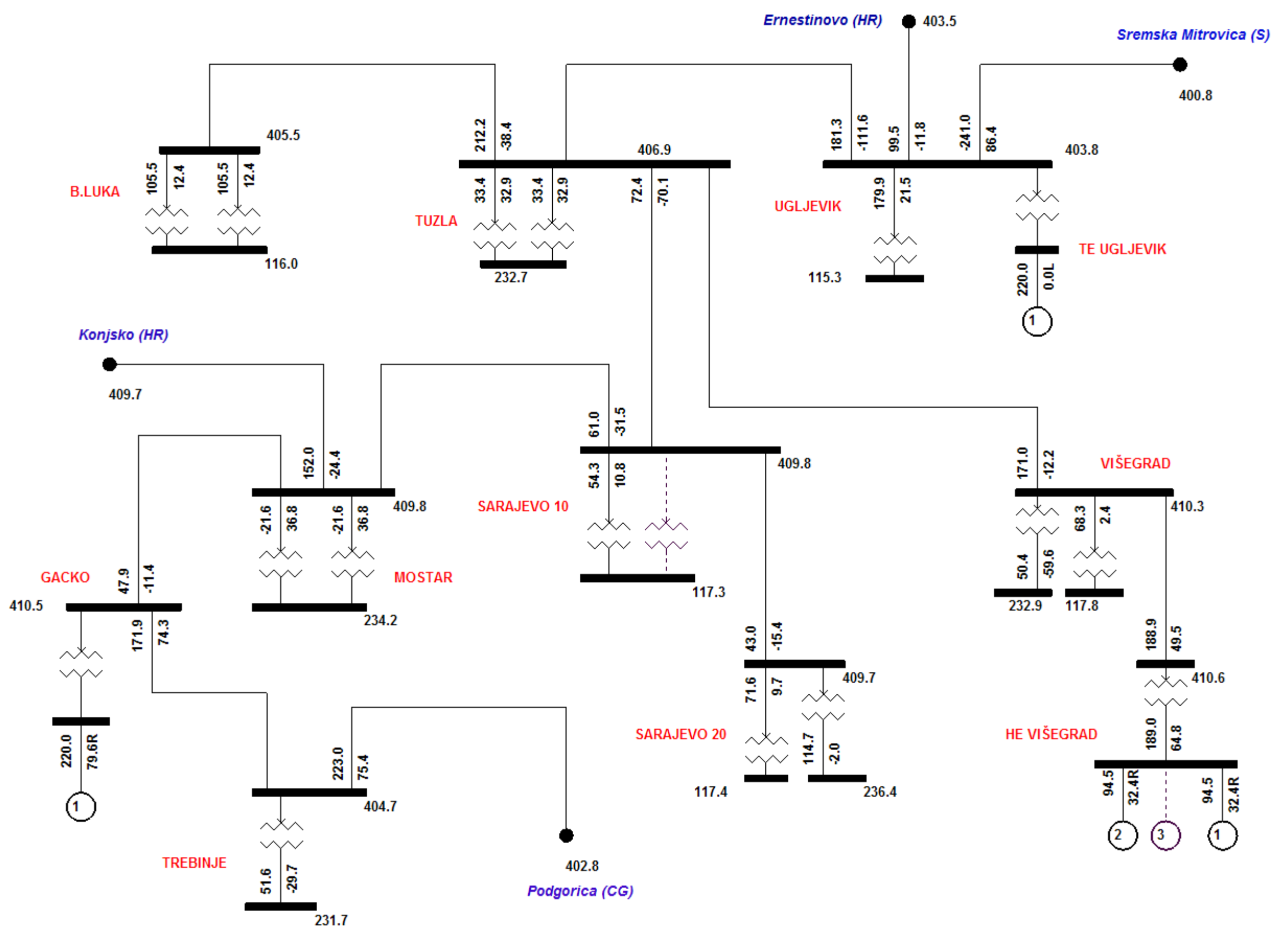


Figure 49 Load flow during peak load, WPPs scenario B (existing system, 220 kV network, normal hydrology)

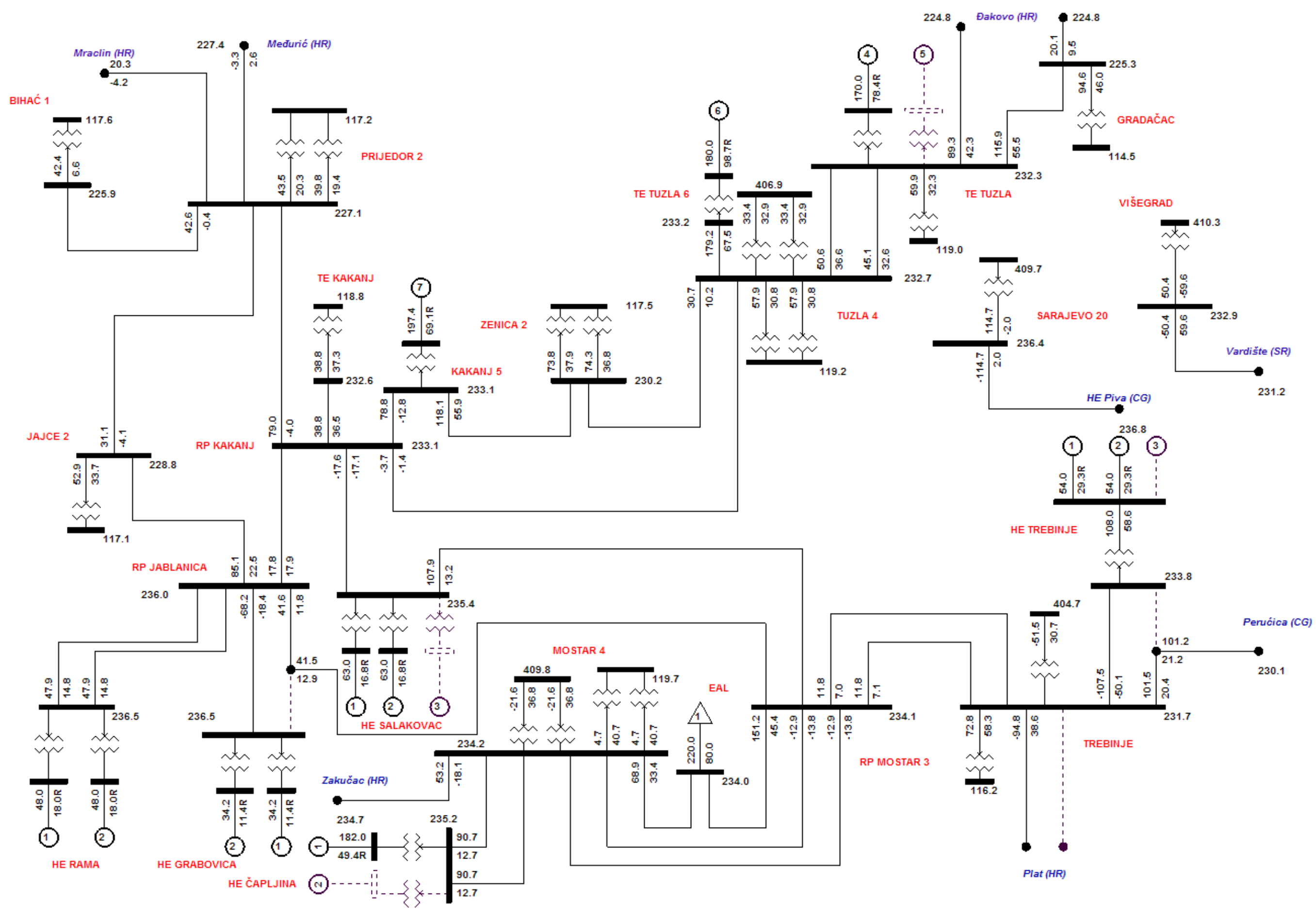


Figure 50 Load flow during peak load, WPPs scenario B (existing system, 110 kV network of wider Mostar area, normal hydrology)

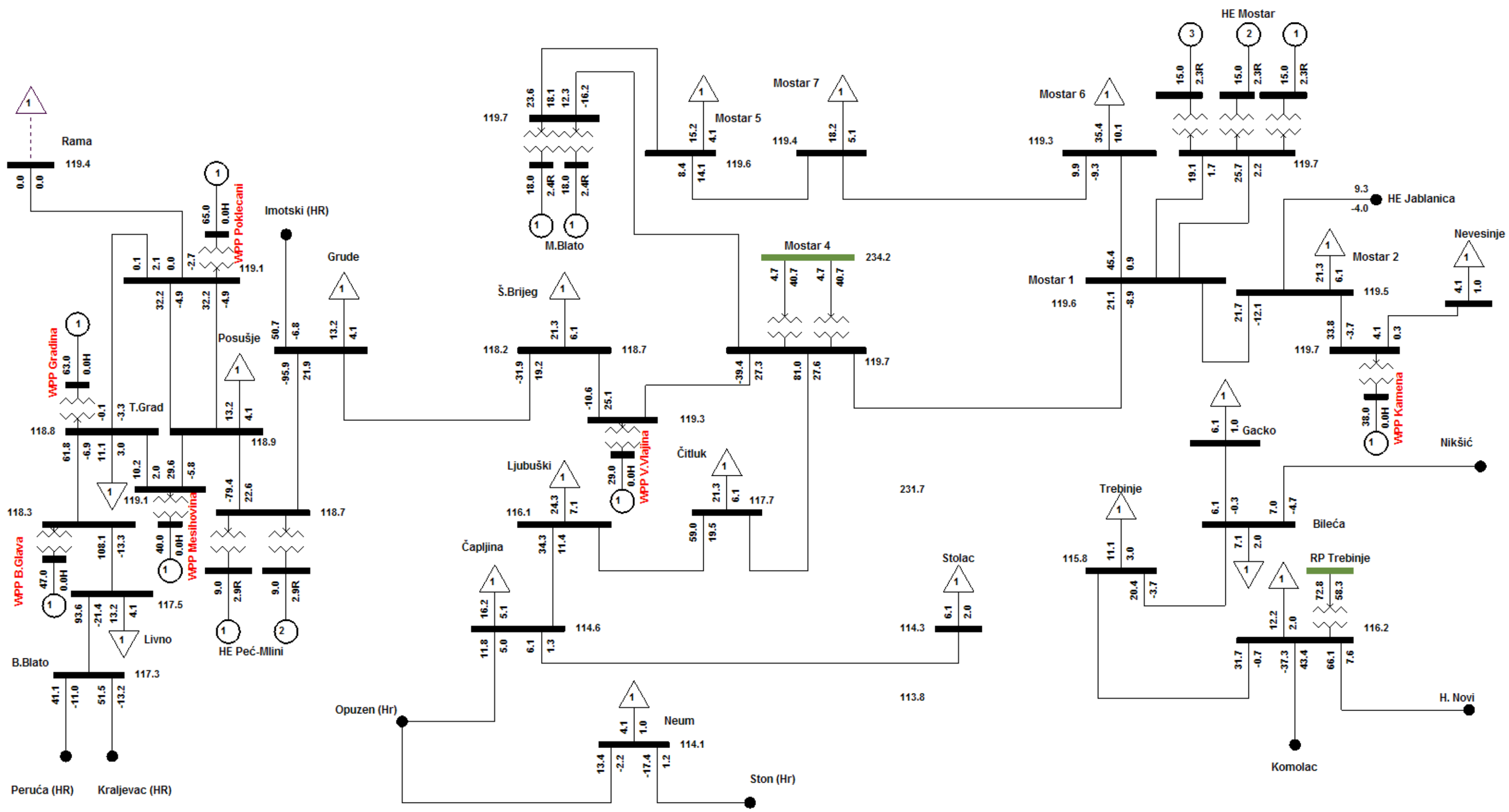
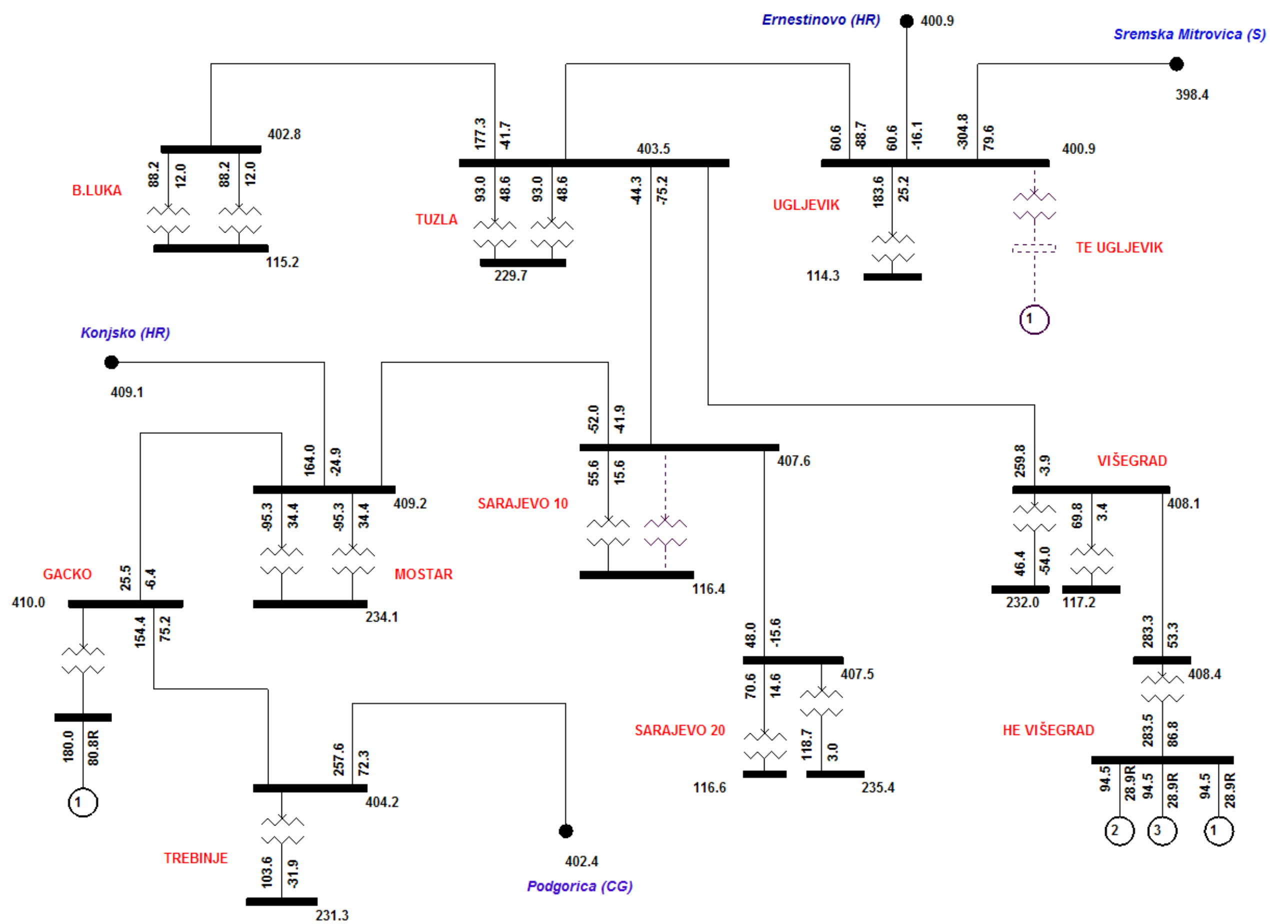


Figure 51 Load flow during peak load, WPPs scenario B (existing system, 400 kV network, wet hydrology)



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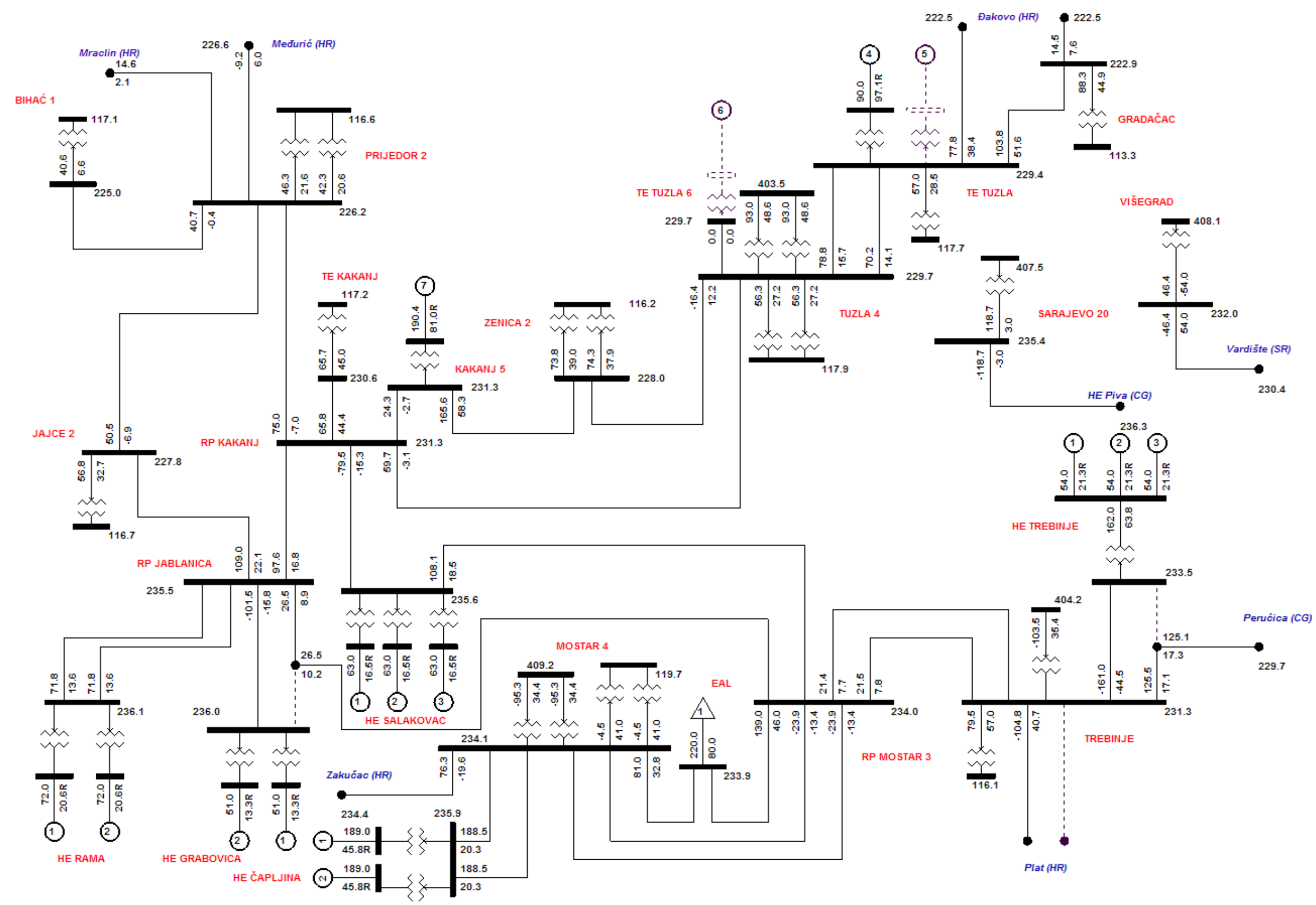


Figure 53 Load flow during peak load, WPPs scenario B (existing system, 110 kV network of wider Mostar area, wet hydrology)

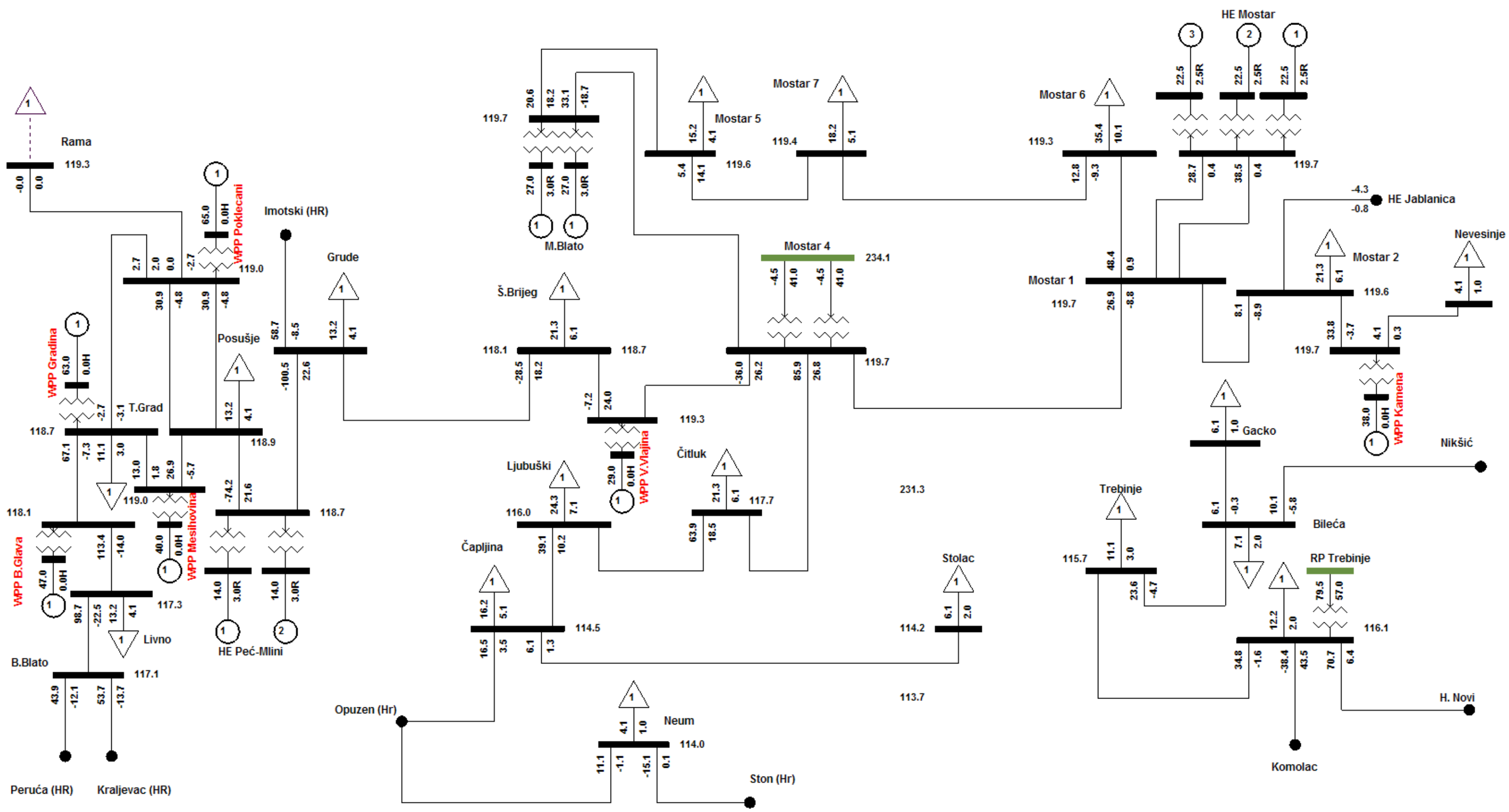


Figure 54 Load flow during summer maximum load, WPPs scenario B (existing system, 400 kV network)

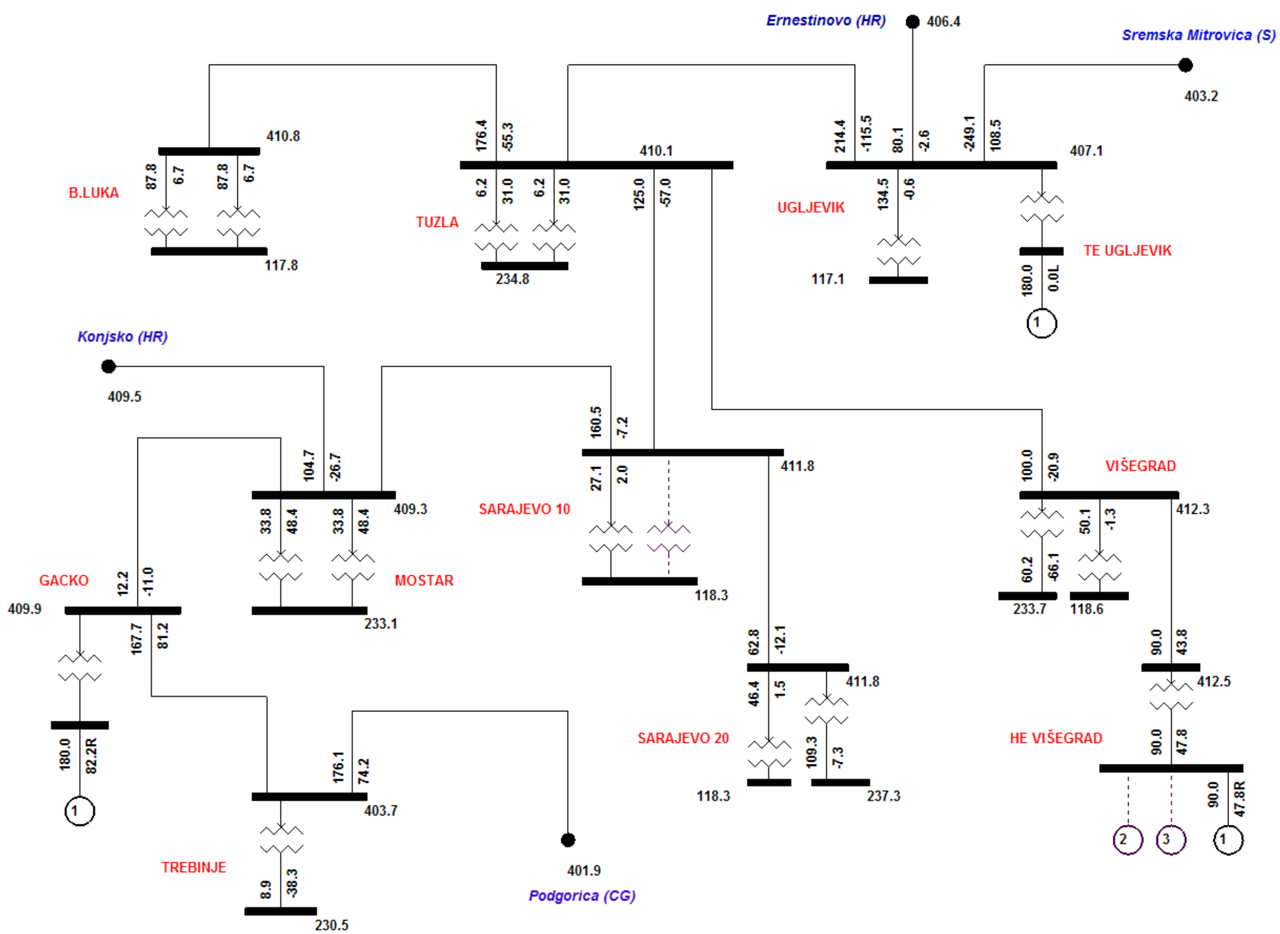


Figure 55 Load flow during summer maximum load, WPPs scenario B (existing system, 220 kV network)

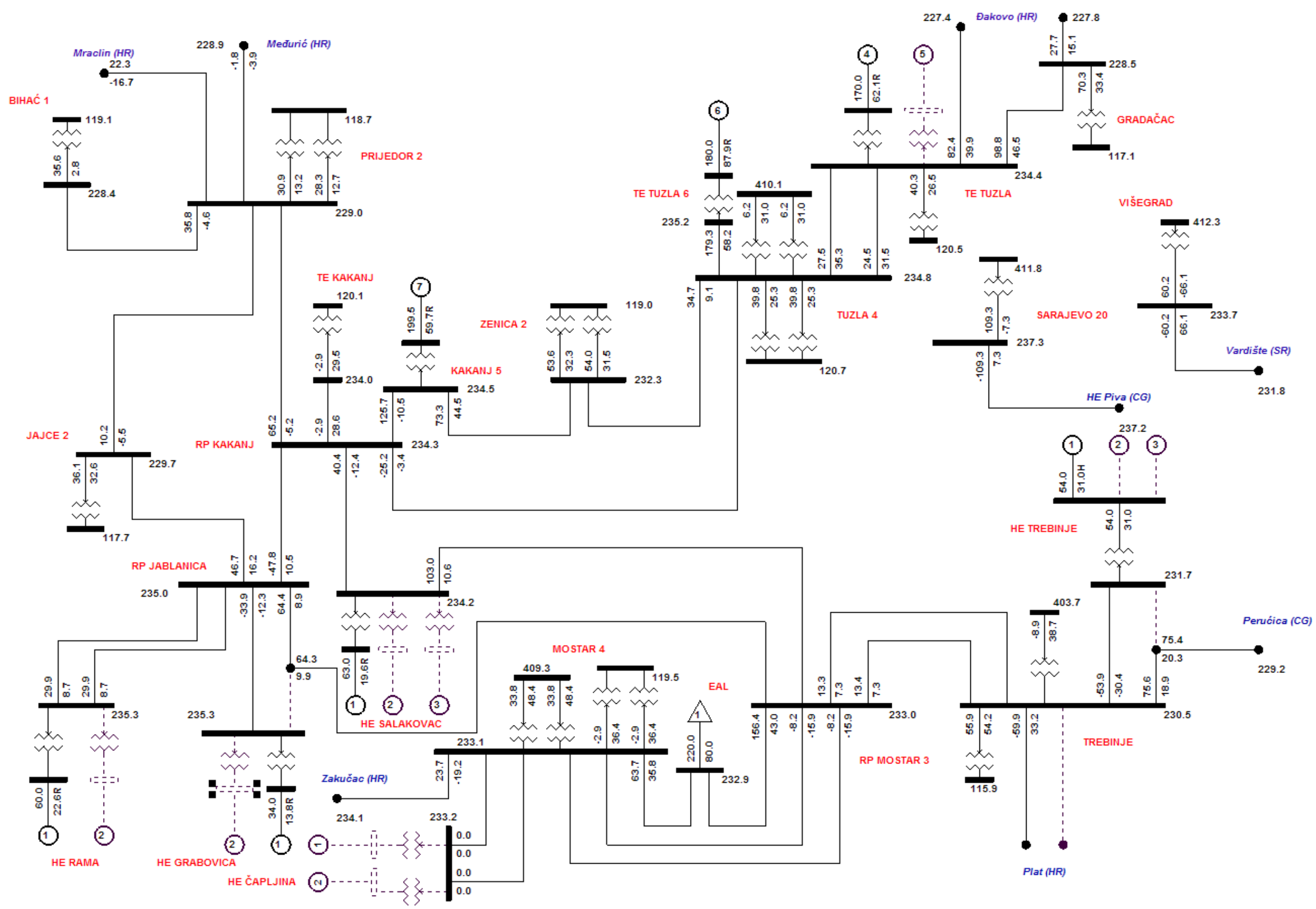


Figure 56 Load flow during summer maximum load, WPPs scenario B (existing system, 110 kV network of wider Mostar area)

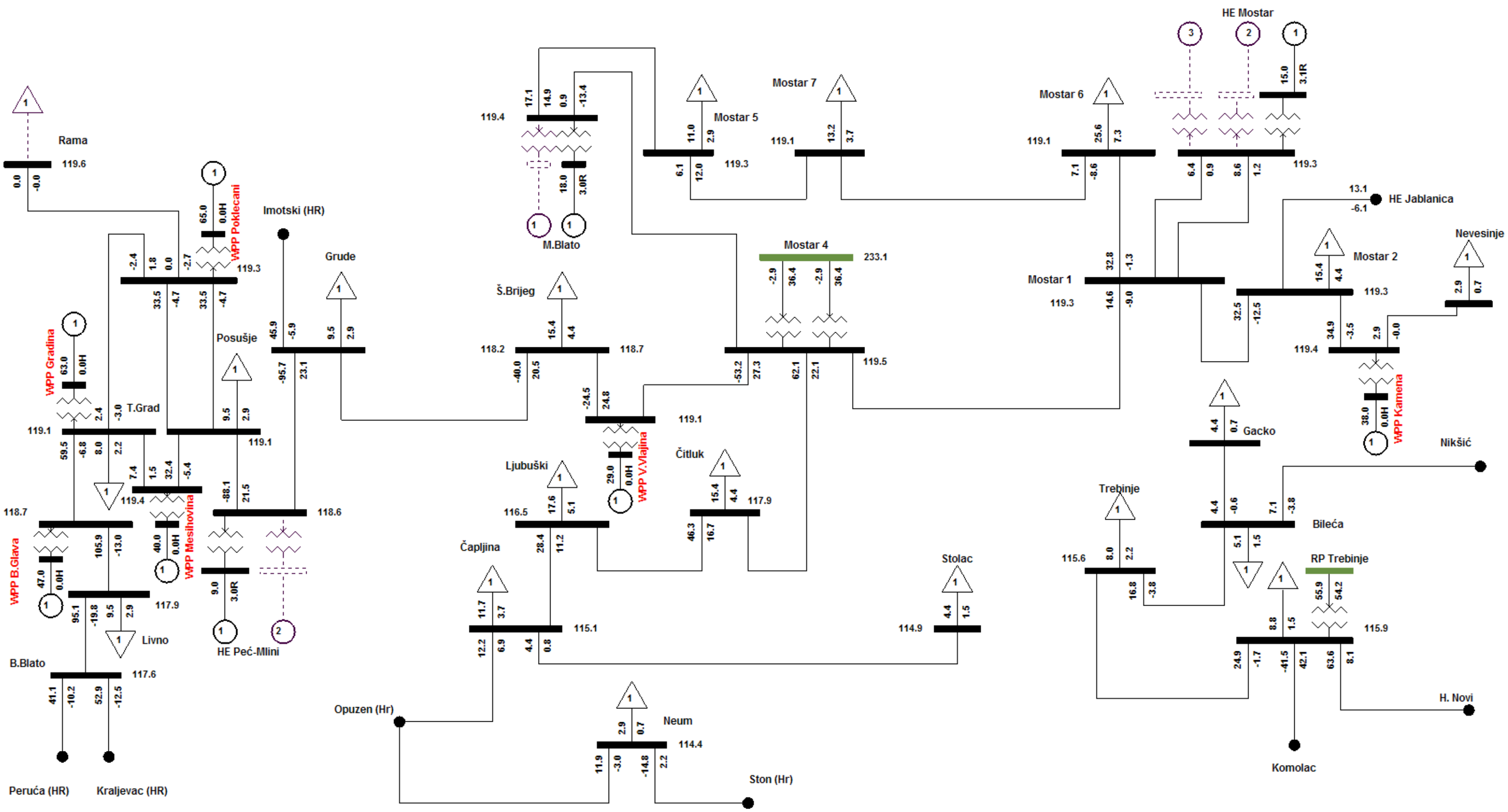
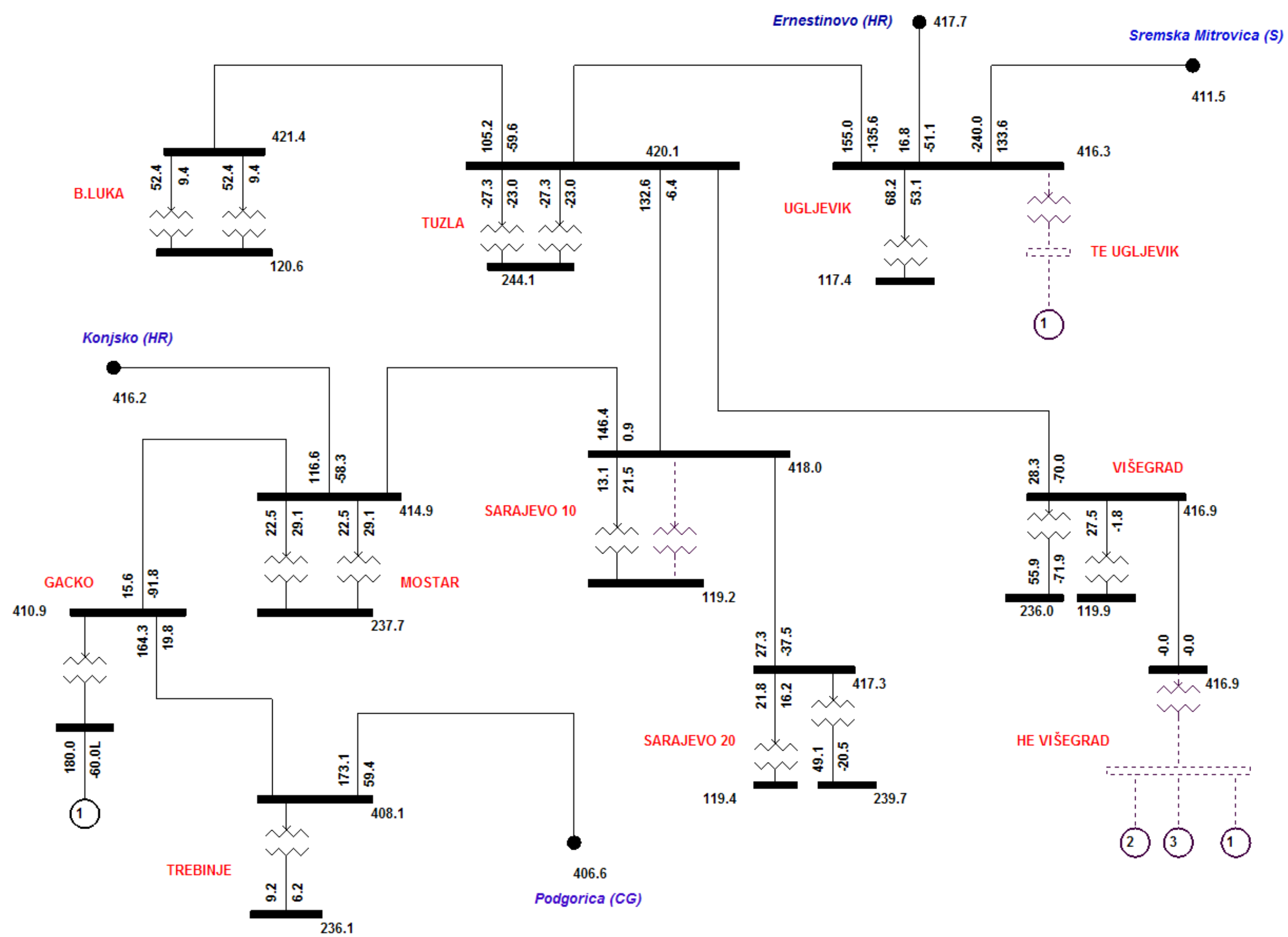


Figure 57 Load flow during off-peak load, WPPs scenario B (existing system, 400 kV network)



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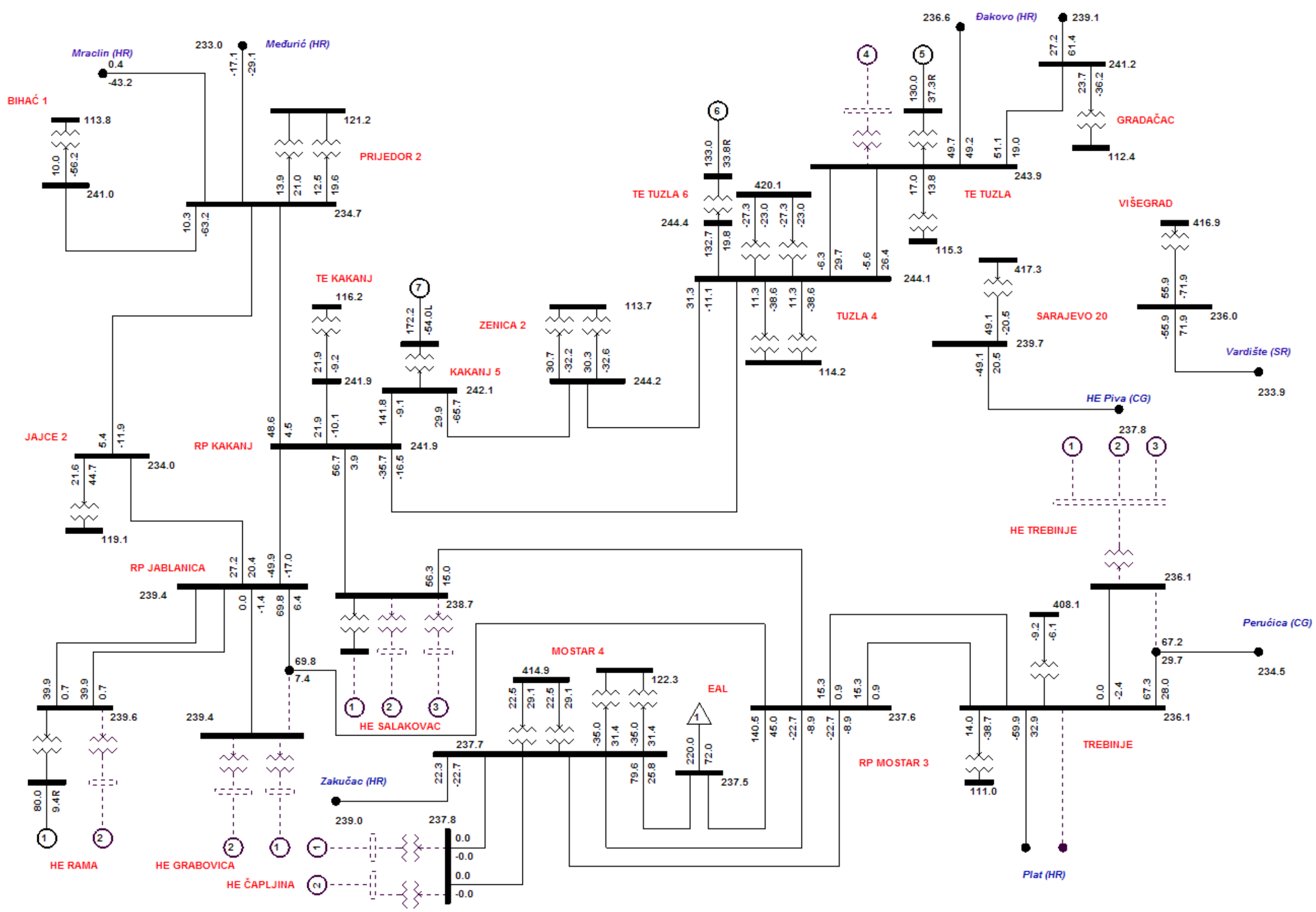

Figure 59 Load flow during off-peak load, WPPs scenario B (existing system, 110 kV network of wider Mostar area)