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IMPACT OF THE SEPARATION OF THE CONTINENTAL EUROPE POWER SYSTEM ON JANUARY 8, 2021 ON THE WORK OF THE BOSNIA AND HERZEGOVINA POWER SYSTEM

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Abstract: After the separation of the Continental Europe power system on 8th January 2021 in two synchronous zones, the electric power system of BiH (EPS BiH) shows a significant increase in frequency and voltages and oscillations of active and reactive power. The paper discusses the operation of protective devices in the BiH power system when the system was operating at high frequencies and voltages and had oscillations of active and reactive power. As a consequence of this behaviour in the EPS BiH there was activation of distance protections (DP) in substation (SS) 220/110 kV Prijedor 2 and overhead transmission lines (OHL) 220 kV Prijedor 2 - Međurić and OHL 220 kV Prijedor 2 – Sisak were disconnected. This was followed by activation of generator protections (reverse power protection and under-excitation protection) and outages of generator units in Hydro Power Plant (HPP) Salakovac, Thermal Power Plant (TPP) Kakanj, HPP Mostar, HPP Bočac, HPP Peć Mlini and HPP Jajce 2.

Keywords: voltage, frequency, power, interconnection, oscillations, disturbance

INTRODUCTION

Disturbance that caused the separation of ENTSO-E (European Network of Transmission System Operators) interconnection in two synchronous zones occurred on SS 400/110 kV Ernestinovo, in close proximity to EPS BiH, and had significant impact on EPS BiH operations. This SS is equipped with double busbar system, joined with a busbar coupler and at the moment preceding the disturbance there was relatively large-scale power flow running through this busbar coupler coming from two overhead lines (OHL 400 kV Ernestinovo - Ugljevik, OHL 400 kV Ernestinovo - Sremska Mitrovica) towards a single (same) busbar system. The topology in SS Ernestovo always follows the rule that both transformers 400/110 kV (TR1 and TR2) are not connected to the same busbar system. This is also applied to interconnective OHL 400 kV between Ernestinovo and Pech (number 1 and number 2). This rule is respected so that the substation topology in SS Ernestinovo would not change too often and in order to avoid further reduction of the transmission assets lifetime. The topology was not changed when the line Ernestinovo (HR) – Pech (HU) 2 was taken out of operation on 5th January 2021. Chronology of events on 8th January 2021 is as follows [1]:

- Initial event happened at 14:04:26 h when a circuit-breaker in a busbar coupler in SS 400/110 kV Ernestinovo (HR) was tripped by overcurrent protection.
- As a result of the overcurrent protection trip, 400 kV busbars in SS Ernestinovo were separated, and power flows were separated into north-western and south-eastern power flows:
  - OHL 400 kV Ernestinovo - Zerjavinec (HR), OHL 400 kV Ernestinovo - Pech 1 (HU) and TR1 400/110 kV remained connected to one busbar,
  - OHL 400 kV Ernestinovo - Ugljevik (BA), OHL 400 kV Ernestinovo - Sremska Mitrovica (RS) and TR 2 400/110 kV remained connected to the other busbar.
- Initial disconnection of the busbar coupler circuit breaker in SS Ernestinovo, in the beginning, resulted with re-direction of power flow through transformers 400/110 kV, 300 MVA, which were then also tripped. This caused redirection of power flow to neighbouring transmission lines, causing further:
  - disconnection of OHL 400 kV Subotica - Novi Sad (RS) at 14:04:48.9 h due to overload protection trip,
  - further disconnection of lines due to distance protections trip and separation of the ENTSO-E interconnection in two synchronous zones at 14:05:08.6 h, shown in Figure 1.
- The result is separation of the system in two synchronous zones
  - North-West zone with a deficit of power (around -5.8 GW)
  - South-East zone with a surplus of power (around +5.8 GW).

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Figure 1: Geographic location of main disconnected elements in the transmission network

1. BEHAVIOUR OF EPS BIH AFTER THE DISTURBANCE

The operating condition of the EPS BiH transmission network had been analysed right before and during the incident. Total production EPS BiH at the 14th hour of the system's operation (in period from 13 to 14 hours) was 3029 MW, consumption was 1639 MW and export in neighbouring power systems was 1305 MW, as shown in Figure 2. Figure 3 presents results of calculations of power flows and voltage conditions on 400 and 220 kV network EPS BiH [2] for the system's operational state on 8th January 2021, at the 14th hour of work (in period from 13 to 14 hours), just before the event. Power flows and voltage conditions were almost identical to flows and voltages measured on SCADA (Supervisory Control and Data Acquisition) system at NOSBiH, which confirmed "validity" of the model.

Values of frequency EPS BiH, voltage, and active power flow on OHL 400 kV Mostar 4 - Konjsko was taken from the system archive WAMS (Wide Area Monitoring System) at NOSBiH, according to the record from PMU (Phasor Measurement Unit) device at SS 400/220/110 kV Mostar 4. Figure 4 graphically presents active power change in the period between 14:00 h – 16:00 h (minute resolution), as recorded by the PMU device in SS Mostar 4, and Figure 5 presents frequency change between 14:04:40 h - 14:05:40 h (resolution 100 ms).

As data in Figure 6 suggest, frequency of EPS BiH just before the disturbance occurred had been within the standard frequency range or slightly above (50 Hz ± 50 mHz, for the Continental Europe synchronous area) in steady state, for normal operational mode (normal working conditions). At the time of the disturbance in the ENTSO-E interconnection, at 14:04:25.9 h, frequency of the EPS BiH was 50.0295 Hz and this was followed by significant increase in frequency in the EPS BiH and in the entire southeast synchronous zone. The highest value of frequency in the EPS BiH was registered at 14:04:58.0 h, when frequency was 50.61748 Hz. The activation of frequency containment reserve (FCR) and the disconnection of generation units in the EPS BiH and in the southeast synchronous zone resulted with stabilization of frequency at 50.2 Hz with minor oscillations [3]. The data presented from the PMU device in SS 400/220/110 kV Mostar 4 suggested that there were large oscillations of power and voltage in the EPS BiH. Voltage oscillates in the range of 375,652 kV to 452,798 kV and active power in the range of + 680 MW to - 300 MW [4]. With the EPS BiH working under the stated conditions, with frequency larger than normal and oscillations of power and voltage, it primarily happened that DP were activated at SS 220/110 kV Prijedor 2, on OHL 220 kV Prijedor 2 - Međurić and OHL 220 kV Prijedor 2 – Sisak, which in their third zone sent order to breakers for three-pole disconnection in OHL bays 220 kV Međurić and Sisak. After that, the generator protections tripped (reverse power protection, under excitation protection) and outages the following generator units: G1, G2, and G3 in HPP Salakovac; G6 and G7 in TPP Kakanj; G1, G2,

PTI INTERACTIVE POWER SYSTEM SIMULATOR--PSS(R)E WED, MAR 17 2021 14:32
EES BIH, 08.01.2021. AREA TOTALS
14 SAT RADA EES BIH IN MW/MVAR

	FROM	------AT AREA BUSES-------			TO					-NET INTERCHANGE-	
X-- AREA --X	GENE- RATION	FROM IND GENERATN	TO IND MOTORS	TO LOAD	TO BUS SHUNT	GNE BUS DEVICES	TO LINE SHUNT	FROM CHARGING	TO LOSSES	TO TIE LINES	TO TIES + LOADS
13	3028.9	0.0	0.0	1639.1	0.0	0.0	13.6	0.0	70.9	1305.3	1305.3
BA	462.4	0.0	0.0	308.6	0.0	0.0	136.4	912.3	722.2	207.5	207.5
COLUMN TOTALS	3028.9	0.0	0.0	1639.1	0.0	0.0	13.6	0.0	70.9	1305.3	1305.3
	462.4	0.0	0.0	308.6	0.0	0.0	136.4	912.3	722.2	207.5	207.5

Figure 2: Power balance of the electric power system of BiH, 8th January 2021, 14th hour of work

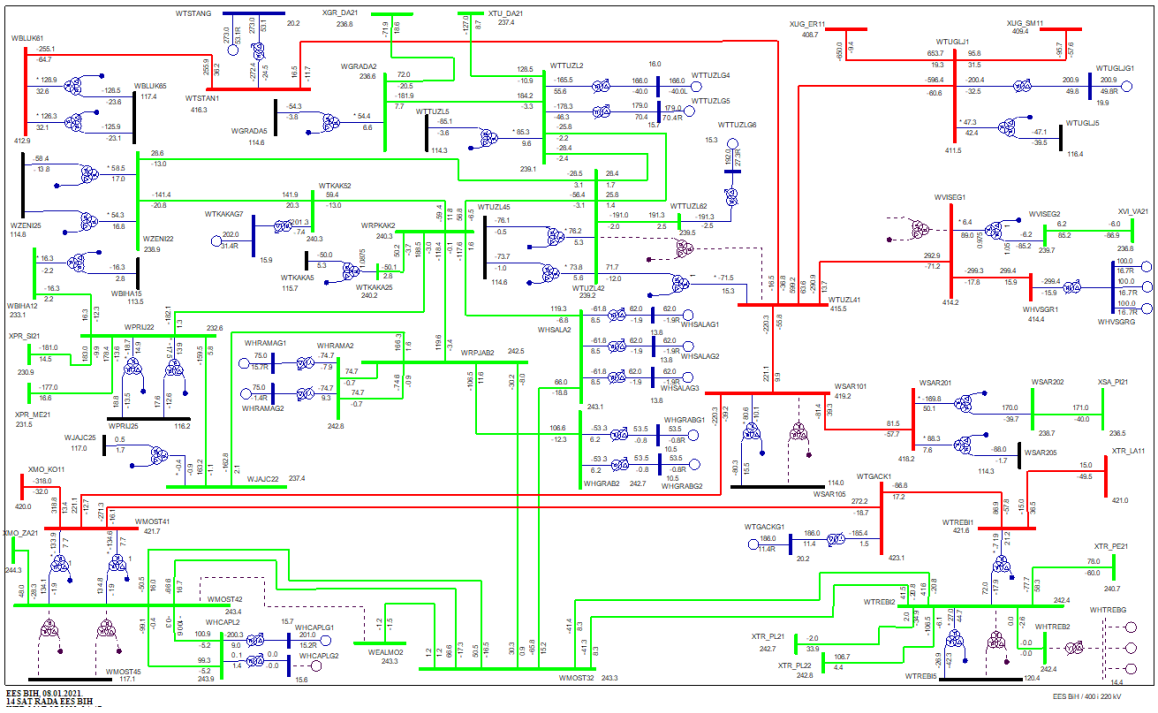


Figure 3: 400 and 220 kV Transmission network of BiH power system on 8th January 2021, at the 14th hour of work

and G3 in HPP Mostar; G1 in HPP Bočac; G1, and G2 in HPP Peć Mlini; G1, G2, and G3 in HPP Jajce 2. After a quick analysis of events in coordination with neighbouring system operators NOSBiH initiated activities in the synchronous zone of Southeast Europe as to create adequate conditions for resynchronization with the synchronous zone of the remaining part of the Europe, as soon as possible. To obtain the conditions for resynchronization, the production of electricity in the EPS BiH was additionally reduced. Upon NOSBiH request, the following units came out of operation: G1 in HPP Rama; G1 in HPP Čapljina; G2 in HPP Grabovica; G3 in HPP Višegrad [4].



Figure 4: Change P on D 400 kV Mostar 4 - Konjsko in period 14:00 h - 16:00 h (minute resolution)

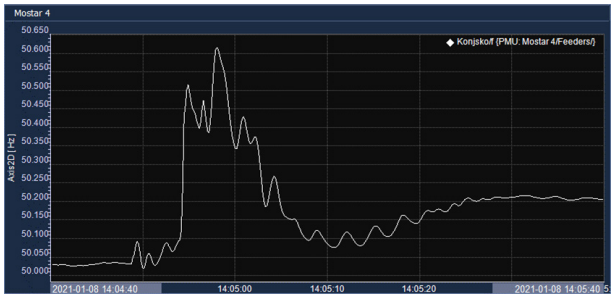


Figure 5: Change f on DV 400 kV Mostar 4 - Konjsko in period 14:04:40 h - 14:05:40 h (resolution 100 ms)

Date	Local Time	IT-Brindisi.f	HR-Ern	BA-Mostar 4.f	SI-Diva	BA-Mostar 4.u.mag	BA-Mostar 4.u.ang
Date [CEST]	Time [CEST]	-		-		-	
1/8/2021	14:00:17.1	50.061001		50.05990601		423.5748404	6.496589646
1/8/2021	14:00:17.2	50.061001		50.06106949		423.5456599	6.529253169
1/8/2021	14:00:17.3	50.061001		50.0599823		423.4733358	6.45109857
1/8/2021	14:00:17.4	50.060001		50.06039047		423.450655	6.472420093
1/8/2021	14:00:17.5	50.060001		50.06087112		423.4334043	6.475431111
1/8/2021	14:04:25.8	50.029999		50.02891541		422.9349615	6.627231295
1/8/2021	14:04:25.9	50.028999		50.02952194		422.9744044	6.612928261
1/8/2021	14:04:26.0	50.028999		50.04343796		424.1949297	7.668850066
1/8/2021	14:04:26.1	50.028		50.05522156		423.8005888	7.954652426
1/8/2021	14:04:26.2	50.027		50.06197357		422.7809823	8.203620696
1/8/2021	14:04:54.0	50.028999		50.0960083		379.2648528	31.21658274
1/8/2021	14:04:54.1	50.028999		50.11299133		376.5166373	32.70217936
1/8/2021	14:04:54.2	50.028999		50.14788055		375.6515999	35.03358879
1/8/2021	14:04:54.3	50.026001		50.24362946		432.7263354	18.00687626
1/8/2021	14:04:54.4	50.023998		50.35939789		429.412157	34.16745041
1/8/2021	14:04:54.5	50.021		50.44903564		444.6069955	56.54362205
1/8/2021	14:04:54.6	50.015999		50.4589386		448.9288078	179.2962106
1/8/2021	14:04:54.7	50.009998		50.49942398		452.7977451	-145.8510772
1/8/2021	14:04:54.8	50.004002		50.5041275		445.7887482	-141.7472776
1/8/2021	14:04:54.9	49.993		50.51534653		440.4645703	-140.5239603
1/8/2021	14:04:55.0	49.987		50.49802399		432.4870791	-163.5743195

1/8/2021	14:04:57.6	49.889999	50.53231049	434.3738297	-142.9855355
1/8/2021	14:04:57.7	49.889999	50.5722847	433.9300308	-152.0015756
1/8/2021	14:04:57.8	49.889999	50.59828568	433.0683804	-160.8686011
1/8/2021	14:04:57.9	49.891998	50.61325836	432.0029653	-166.4370201
1/8/2021	14:04:58.0	49.894001	50.61748123	430.9308888	-169.3629018
1/8/2021	14:04:58.1	49.897999	50.61300659	430.0846902	-170.0041077
1/8/2021	14:04:58.2	49.902	50.60604477	429.638334	-168.9222351
1/8/2021	14:04:58.3	49.907001	50.59512711	429.3941672	-166.1263362
1/8/2021	14:04:58.4	49.911999	50.58618546	429.2368605	-162.0562418
1/8/2021	14:08:16.6	49.846001	50.23285675	444.0832481	-97.23045128
1/8/2021	14:08:16.7	49.846001	50.23276901	443.9222383	-97.8284181
1/8/2021	14:08:16.8	49.846001	50.23205948	443.7406237	-98.61289707
1/8/2021	14:08:16.9	49.846001	50.23103333	443.6163528	-99.15206536
1/8/2021	14:08:17.0	49.846001	50.23007202	443.6848654	-99.15479409
1/8/2021	14:08:17.1	49.846001	50.22993088	443.8311468	-98.63634068
1/8/2021	15:07:31.4	49.969002	49.93758392	435.9913654	-149.5275768
1/8/2021	15:07:31.5	49.969002	49.93707657	436.1049421	-149.039296
1/8/2021	15:07:31.6	49.969002	49.93941498	436.2002266	-148.1884453
1/8/2021	15:07:31.7	49.969002	49.94396973	436.2489316	-147.1769936
1/8/2021	15:07:31.8	49.970001	49.94928741	436.3223941	-146.3561368
1/8/2021	15:07:31.9	49.970001	49.95426178	436.4272855	-146.0232581

Figure 6: Synchro phasors U and f at PMU Mostar 4

2. CHRONOLOGY OF WORK OF PROTECTION DEVICES IN EES BIH

The analysis of the considered operating events was done on the basis of records from protective devices and SCADA systems in SS 220/110 kV Prijedor 2, records from protective devices and SCADA systems in generation facilities of power utilities in BiH and data from SCADA and WAMS systems of NOSBiH [4].

2.1. SS 220/110 kV Prijedor 2

According to the records of local SCADA system in SS Prijedor 2, the switch-off times of 220 kV OHL Prijedor 2 - Međurić and 220 kV OHL Prijedor 2 - Sisak in 220 kV OHL bays Međurić and Sisak were:

- OHL 220 kV Prijedor 2 - Međurić, 14:04:54.080 h (CB open state),
- OHL 220 kV Prijedor 2 - Sisak, 14:04:54:138 h (CB open state).

This state of switches (contacts open) was registered on control device REC 561, which was connected to SCADA system in SS Prijedor 2 using fiber optics. Internal device time clock is synchronized with the time of the GPS (Global Positioning System) clock. At SS 220/110 kV Prijedor 2 and OHL 220 kV Prijedor 2 - Međurić and OHL 220 kV Prijedor 2 - Sisak the protection system is "redundant" with two main distance protections REL 521 (main 1) and REL 316*4 (main 2), vendor ABB. In the considered case of the disturbance, both transmission lines were switched off by the main protection 2, by the trip of DP REL 316*4 in the third zone. These devices were not connected to local SCADA system in SS Prijedor 2 due to LON communication card malfunction on DP REL 316*4. Therefore the trip signals were not registered on SCADA system and the time on REL316*4 protections was not synchronized. The disturbance record (oscillographic recording of the event in COMTRADE format) from the 220 kV Međurić OHL bay is only one available. The recording of the disturbance shows that voltages, shown in Figure 7, and the currents, shown in Figure 8, are symmetrical in all three phases, and the protection did not register a short circuit on the OHL [5]. After the above-described disturbance in the ENTSO-E interconnection at 14:04:25.9 h in Ernestinovo substation, there was redistribution of power flows and switching off OHLs, shown in Figure 1. We can see from the DP REL316*4 record that the power on the 220 kV OHL Prijedor 2 - Međurić, shown in Figure 9, in the time interval of 350 ms before the shutdown signal until the shutdown, was in the range S = 488.47-473.76 MVA, line voltage U = 133.10-121.06 kV, and current I = 2.13-2.26 kA. The consequence of this operating state was that the operating impedance vector "Zpog" changed from 36.27∟9.8° Ω to 31.11∟13.6° Ω, shown in Figure 10, entered the third zone of DP REL316*4. After the appropriate time delay of the third zone, DP gives an order to turn off the switch in the OHL bay 220 kV Međurić [5], [6].

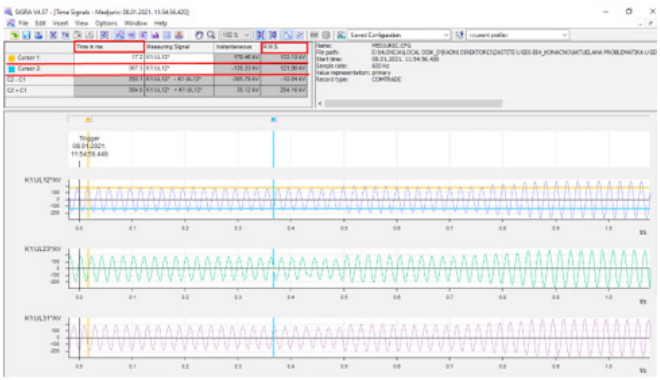


Figure 7: Voltage on DV 220 kV Prijedor 2 – Međurić

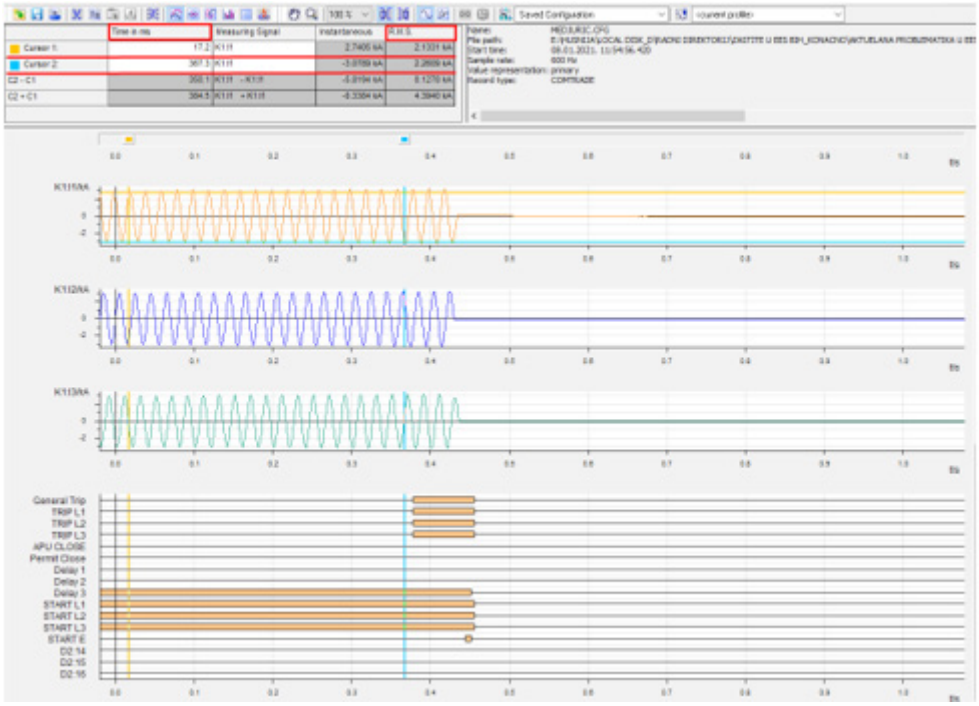


Figure 8: Current on DV 220 kV Prijedor 2 – Međurić

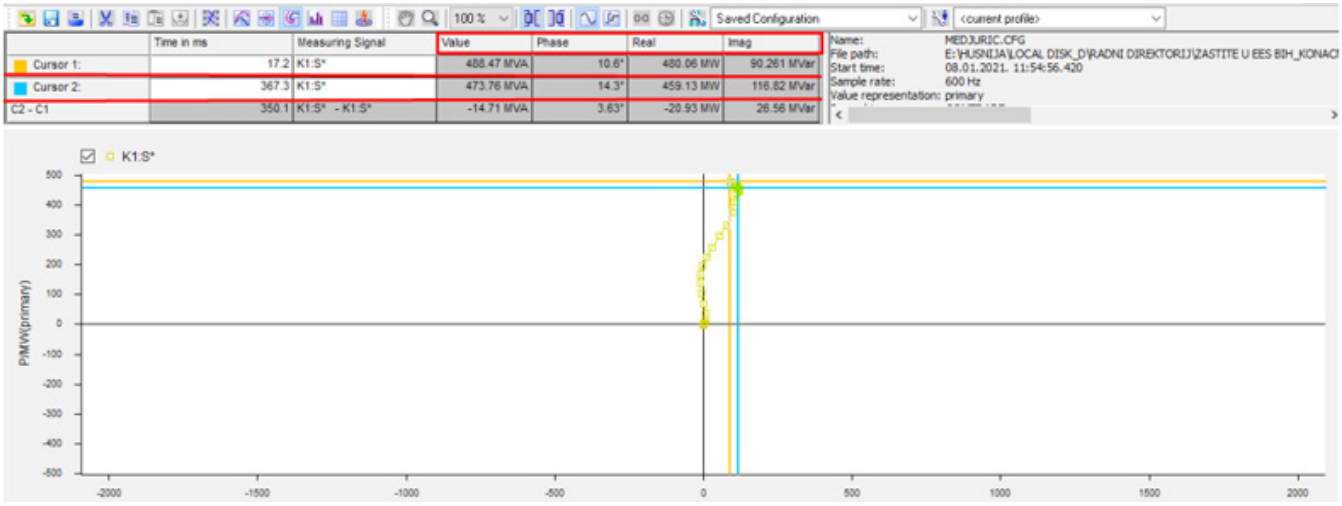


Figure 9: Power on OHL 220 kV Prijedor 2 – Međuric

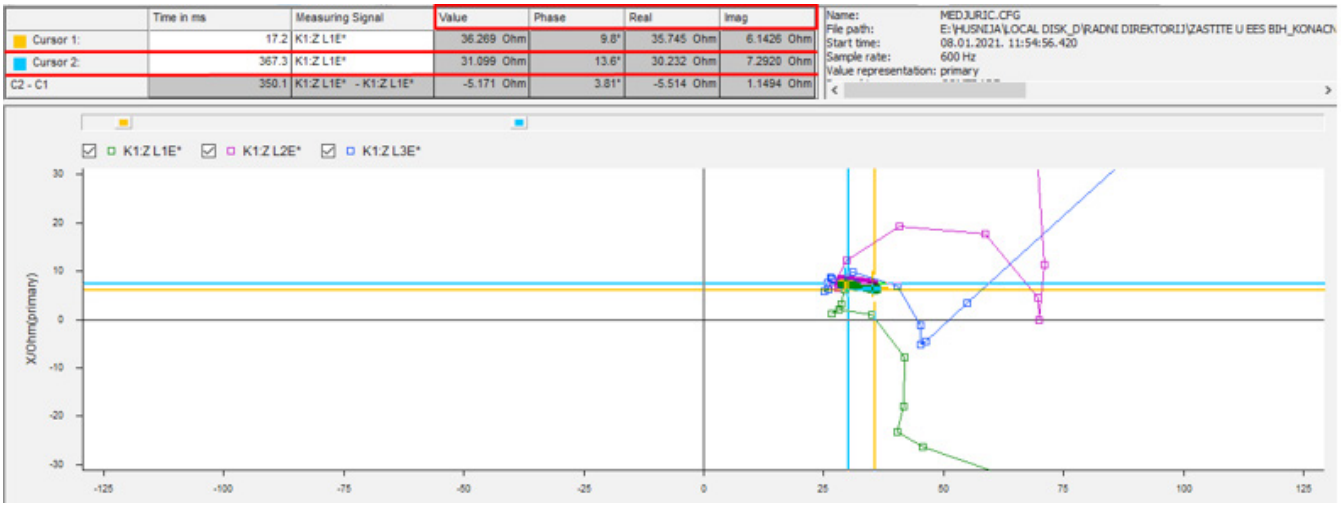


Figure 10: Vector of operational impedance Zpog on DV 220 kV Prijedor 2 – Međurić

2.2. HPP Salakovac

After the initial event in SS Ernestinovo, apart from the increase in frequency there were also oscillations of voltage, active and reactive power in the BiH power system. In normal operational regime generators in HPP Salakovac usually work in an inductive regime (over-excitation) and give reactive power to the network. We can see from the record generator protection trip record of hydro aggregate No. 3, as shown in Figure 11, that there was an oscillation of generator's reactive power. At 14:04:54.093 h the generator gives 43.23 MVAr of reactive power to the network and after 542 ms the generator switches to the capacitive regime of operation (under-excitation), and withdraws -0.496 MVAr from the network. At 14:04:55.454 h, shown in Figure 12, this reactive power withdrawal is -13.51 MVAr, and after 500 ms the reactive power withdrawal is -14.33 MVAr. Generator protection 7UM 85 of the hydro aggregate No. 3 is activated and the sequence of events according to the Trip Log, shown in Figure 13, is: at 14:04:04:55 the protection detects a fault, there is a pick-up of under-excitation protection of generators, and this protection with a time delay of 500 ms gives an order to trip the circuit breaker. At 14:04:55.954 h the protection gives an order to trip the circuit breaker and at 14:04:55.984 h the protection gives an order to definite trip the circuit breaker [7].

Generator protection of hydro aggregates No. 1 and No. 2 are identical to protection on hydro aggregate No. 3, they have an identical setting and operated identically.

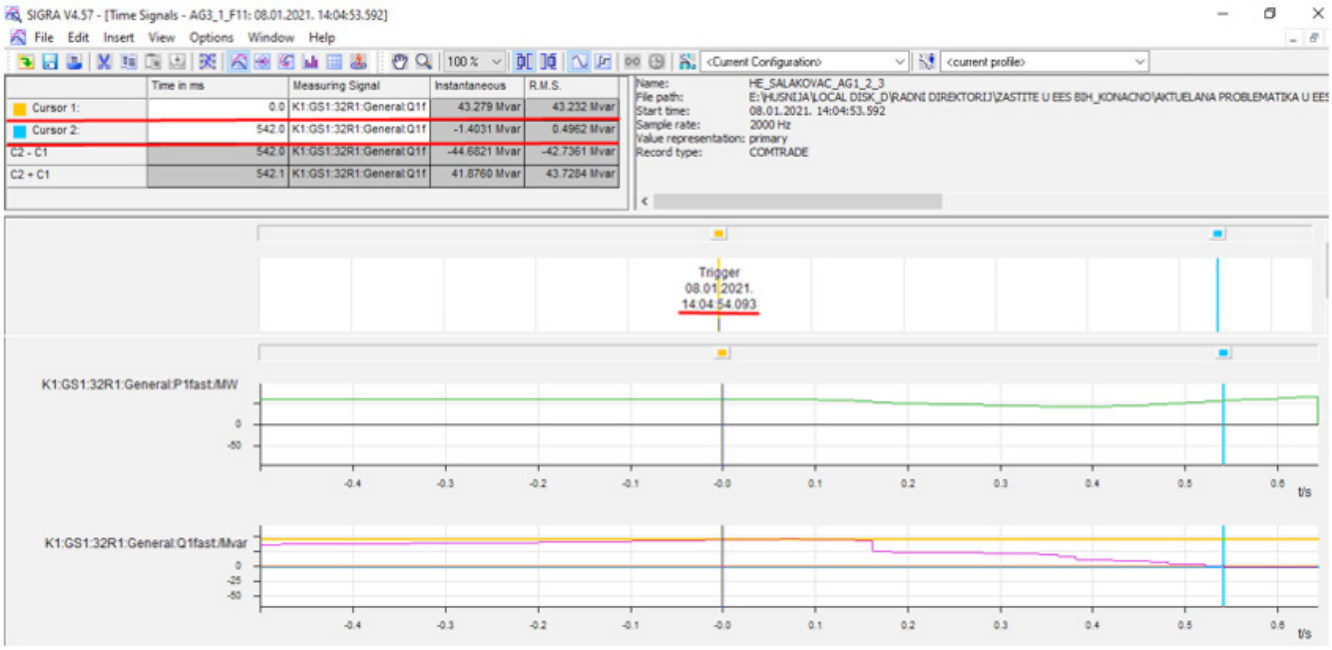


Figure 11: Values P and Q of hydro aggregate No. 3 in period 14:04:53.594 h - 14:04:54.693 h

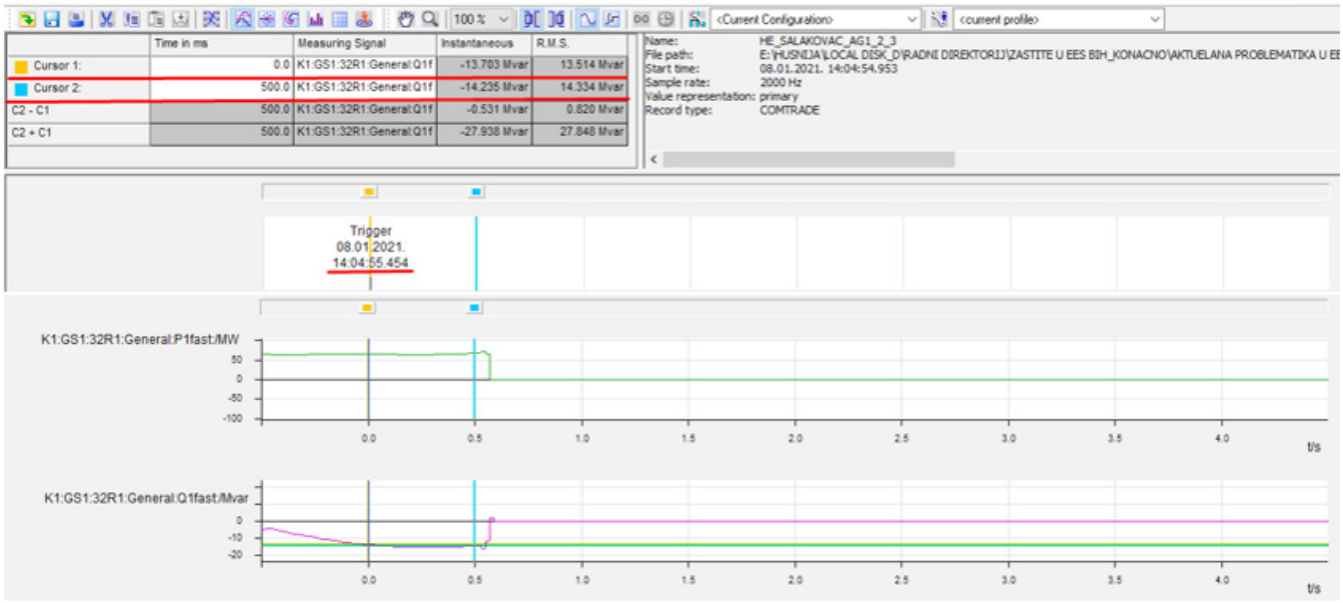


Figure 12: Values P and Q of hydro aggregate No. 3 in period 14:04:54.954 h - 14:04:55.984 h

```
08.01.2021  14:04:55.984"   =" 00:00:00:00.530"   =" "   =" 15"  =" Q0 220 kV:Circuit break."    =" Definitive trip"     =" on"  =" good (process)"
08.01.2021  14:04:55.984"   =" 00:00:00:00.530"   =" "   =" 14"  =" EX1_2_DTL:Circuit break."    =" Definitive trip"     =" on"  =" good (process)"
08.01.2021  14:04:55.970"   =" 00:00:00:00.516"   =" "   =" 13"  =" Q0 220 kV:Circuit break."    =" Break. current 3I0/IN"       =" 7 A" =" good (p
08.01.2021  14:04:55.970"   =" 00:00:00:00.516"   =" "   =" 12"  =" EX1_2_DTL:Circuit break."    =" Break. current 3I0/IN"       =" 0.2 A"       ="
08.01.2021  14:04:55.970"   =" 00:00:00:00.516"   =" "   =" 11"  =" Q0 220 kV:Circuit break."    =" Break.-current phs C"        =" 2920 A"      ="
08.01.2021  14:04:55.970"   =" 00:00:00:00.516"   =" "   =" 10"  =" Q0 220 kV:Circuit break."    =" Break.-current phs B"        =" 2915 A"      ="
08.01.2021  14:04:55.970"   =" 00:00:00:00.516"   =" "   =" 9"   =" Q0 220 kV:Circuit break."    =" Break.-current phs A"        =" 2894 A"      ="
08.01.2021  14:04:55.970"   =" 00:00:00:00.516"   =" "   =" 8"   =" EX1_2_DTL:Circuit break."    =" Break.-current phs C"        =" 22.6 A"      ="
08.01.2021  14:04:55.970"   =" 00:00:00:00.516"   =" "   =" 7"   =" EX1_2_DTL:Circuit break."    =" Break.-current phs B"        =" 17.7 A"      ="
08.01.2021  14:04:55.970"   =" 00:00:00:00.516"   =" "   =" 6"   =" EX1_2_DTL:Circuit break."    =" Break.-current phs A"        =" 16.0 A"      ="
08.01.2021  14:04:55.954"   =" 00:00:00:00.500"   =" "   =" 5"   =" Q0 220 kV:Circuit break."    =" Trip/open cmd."      =" on"  =" good (process)"
08.01.2021  14:04:55.954"   =" 00:00:00:00.500"   =" "   =" 4"   =" EX1_2_DTL:Circuit break."    =" Trip/open cmd."      =" on"  =" good (process)"
08.01.2021  14:04:55.954"   =" 00:00:00:00.500"   =" "   =" 3"   =" Generator stator:40 Underexc. prot. 1:Characteristic"         =" Operate char 1"
08.01.2021  14:04:55.454"   =" 00:00:00:00.000"   =" "   =" 2"   =" Generator stator:40 Underexc. prot. 1:Characteristic"         =" Pickup char 1"
08.01.2021  14:04:55.454"   =" 00:00:00:00.000"   =" "   =" 1"   =" Recording:Fault recorder:Control"    =" Fault number"        =" 190" =" good (p
```

Figure 13: Trip Log of generator protection hydro aggregate No. 3

2.3. HPP Bočac

Turbine governors on units in HPP Bočac are set in the manner that in case of major frequency disturbances, when the absolute frequency deviation is above 233 mHz automatically, with a time delay of 2.5 s, they enter the "island mode" (isolated operation of the generator on its own network). Then the turbine governors stop regulating the given active power, they control only speed regulation (i.e., frequency). There is no tightening nor hysteresis to exit this mode and return to parallel synchronous operation. In addition to the specified threshold, the turbine governors also have a protective threshold for shutting down the unit from operation, which is activated when the absolute frequency disturbance is higher than 400 mHz with a time delay of 5 s.

According to the record from SCADA system, the behaviour of the units is shown in Figures 14, 15 and 16, which show the active and reactive powers of the hydro aggregates No. 1 and No. 2 at the power plant threshold with system values of frequency and voltage on 110 kV busbars. During the occurrence of frequency disturbances, for minor disturbances the hydro aggregates reacted by reducing the power according to the defined droop (primary regulation), at the moment of transition to island operation (disturbance greater than 233 mHz with a delay of 2.5 s) the hydro aggregates start to regulate the speed of rotation and since the frequency is higher than the nominal one, they reduce the power but of course, they fail to reduce the frequency on their own because this is not a real island. When the frequency error is below the entering the island operation threshold, the turbine governors return to the power regulation with previous power setting, now corrected by droop of units, which can be seen in Figure 14, for example at 14:04:40 h frequency was still good (there was a disturbance in voltage and flows of the reactive power but the frequency was still good) and hydro aggregates work with the given power. In the period from 14:04:58:083 h to 14:05:04:020 h the unit is in island operation and the power drops to almost 0. After leaving the island operation, the hydro aggregates power changes to new value, reduced by droop of hydro aggregates (primary regulation).

Figure 15 suggests that there were multiple entries into and out of the island work regime. During one of the entries and the reduction of power, there was a trip of the reverse power protection on the hydro aggregate No. 1 and this aggregate was out of operation at 14:10:46 h. It was put into operation, upon a dispatcher's order, only after the frequency stabilization (see Figure 16). From the presented Figures it can be seen that the frequency disturbance was higher than 400 MHz but lasted less than 5 s, and this protection was not activated and the hydro aggregate was not switched off. Hydro aggregate No. 2 remained in operation. After the hydro aggregate No. 1 outage, the operator, in agreement with a dispatcher of CUP Trebinje, adjusted the power on hydro aggregate No. 2 to slightly larger value than the initial. After this, there were no more entries into the island operation, and the changes in the hydro aggregate's power were the result of the primary frequency regulation (the operator did not change the power in the period from approx. 14:22 h to 15:25 h when the hydro aggregate No. 1 was put into operation).

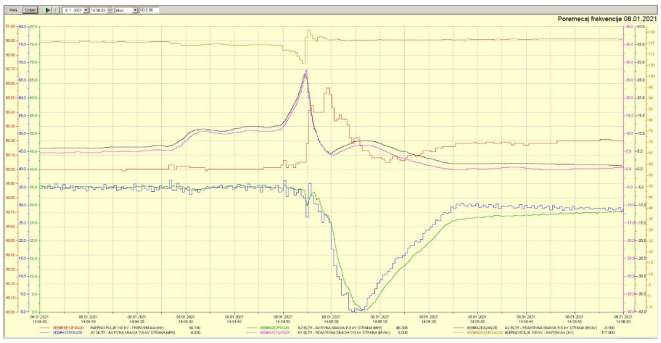


Figure 14: Values P, Q hydro aggregates No. 1 and No. 2, f and U from busbars 110 kV, in period from 14:04 h to 14:06 h,

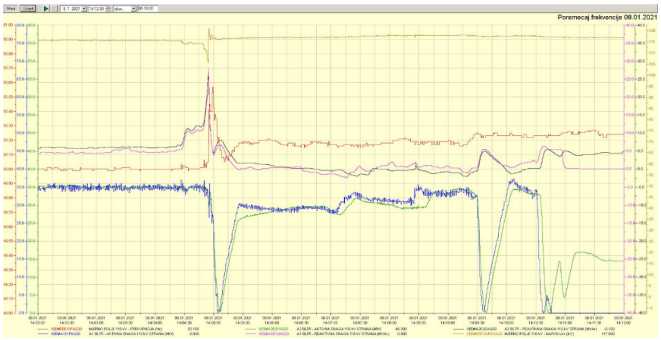
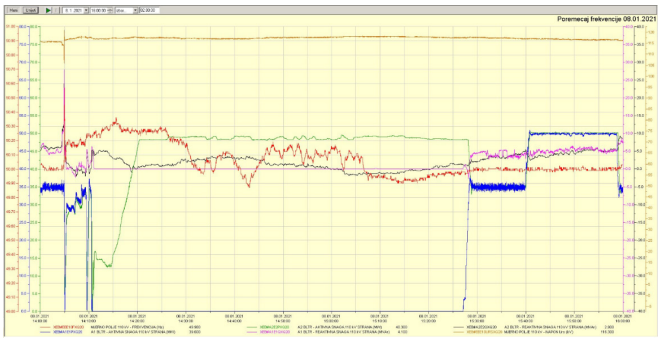


Figure 15: Values P, Q hydro aggregates No. 1 and No. 2, f and U from busbars 110 kV in period from 14:02 h to 14:12 h



Label of colours: Blue line: P of h. aggregate No. 1; Green line: P of h. aggregate No. 2; Red line: system values of frequency f; Gold line: system values of voltage U; Pink line: Q of h. aggregate No. 1; Black line: Q of h. aggregate No. 2;

Figure 16: Values P, Q hydro aggregates No. 1 and No. 2, f and U from busbars 110 kV in period from 14:00 h to 16:00 h

2.4. TPP Kakanj

On generator protections, 7UM622 Siemens, for thermal power units No. 7 and No. 6, time synchronization was not correct and the protections internal time is shifted in relation to synchronized time at SCADA system (thermal power unit



Figure 17: List of events of generator at thermal power unit No. 7



Label of colours: Green line: P of generator; Black line: Q of generator; Red line: system values of voltage U; Light blue line: system values of frequency f.

Figure 18: Values P and Q on generator at thermal power block No. 7, f and U from busbars 220 kV

no 7 approx. 1:10:13 h; thermal power unit no 6 approx. 1:06:25 h) so the sequence of events is easier to follow from the list of events and diagrams P, Q, U, from SCADA system than from the trip log.

2.4.1. Thermal power unit No. 7

As the record from the list of events suggests, Figure 17, at 14: 04:54:965 h, it an increase in the system frequency above 50.5 Hz was registered, and diagrams P, Q, U, f suggest that there was a sudden decrease in power, Figure 18. At 14:04:59.876 h, the system frequency was still above 50.5 Hz and there was a power drop of 222 MW according to the diagram in Figure 18. The turbine governor failed to stop a sudden decrease in power and the generator of unit No. 7 entered the engine mode and took around 18 MW from the network. In the considered period of 5 s, according to trip log, there were multiple cases of pick up and stop pick up reverse power protection of generator. In the next 5 s, the power of the generator oscillated around "zero", and at 14:05:05 h there was a pick-up of reverse power generator protection, which after a time delay of 10 s gave an order to trip the circuit breaker. According to the "Trip log - 002683", Figure 19, the system frequency at the time of tripping was 50.11 Hz and the generator was taking power from the network -5.80 MW [8].

Trip Log - 002683 / 08/01/2021 15:15:20.587 - TE Kakanj - blok 7 / +7CHA01 / -F11 7UM

Number	Indication	Value	Date and time
00301	Power System fault	2683 - ON	08.01.2021 15:15:20.587
00302	Fault Event	2683 - ON	08.01.2021 15:15:20.587
00501	Relay PICKUP	ON	0 ms
05096	Reverse power: picked up	ON	0 ms
00511	Relay GENERAL TRIP command	ON	10000 ms
05097	Reverse power: TRIP	ON	10000 ms
00576	Primary fault current IL1 Side1	1.02 kA	10030 ms
00577	Primary fault current IL2 Side1	1.02 kA	10030 ms
00578	Primary fault current IL3 Side1	1.06 kA	10030 ms
00579	Primary fault current IL1 Side2	1.02 kA	10030 ms
00580	Primary fault current IL2 Side2	1.02 kA	10030 ms
00581	Primary fault current IL3 Side2	1.06 kA	10030 ms
05012	Voltage UL1E at trip	9.19 kV	10030 ms
05013	Voltage UL2E at trip	9.14 kV	10030 ms
05014	Voltage UL3E at trip	9.16 kV	10030 ms
05015	Active power at trip	-5.80 MW	10030 ms
05016	Reactive power at trip	27.86 MVAR	10030 ms
05017	Frequency at trip	50.11 Hz	10030 ms

Figure 19: Trip Log of generator protection at thermal power unit No. 7

2.4.2. Thermal power unit No. 6

There is a similar situation with unit No. 6. At 14:04:58:356 h, it was registered an increase in the system frequency above 50.5 Hz, and diagrams P, Q, U, f suggest that there is a sudden power decrease, Figure 20. At 14:04:59.556 h, an increase in the system frequency above 50.5 Hz was still present and the decline of power continued until 14:05:05 h. Turbine governor's activities stopped further power decline and the generator of unit 6 at 14:05:31 h switched to a new, reduced power, in accordance with the droop of the governor. In this period, according to the trip log, several times there was a pick-up and 100 ms after drop off of reverse power generator protection. In the period until the trip of the generator of thermal power unit No. 6, the frequency of the system was still increased, there were new declines of power and action of the turbine governor, and at 14:11:31 h there was a pick-up of reverse power protection of a generator, which after a time delay of 44.347 s gave an order to trip the circuit breaker. According to the Trip Log of the protection [8], the system frequency at the trip time was 50.27 Hz and the generator was taking -3.11 MW power from the network.

In addition to the outages discussed above, there were also outages of production units in: HPP Mostar, HPP Jajce II and HPP Peć Mlini. According to information and letters submitted by responsible persons from these production facilities, HPP Mostar and HPP Peć Mlini were tripped by the action of reverse power generator protection and HPP Jajce II by the action of reverse power generator protection and under-excitation generator protection.

In the remaining production facilities of EPS BiH (TPP Ugljevik, TPP Gacko, TPP Tuzla, HPP Jajce I) during the the disturbance caused by the separation of ENTSO-E interconnection, there were registered an increase in frequency, voltage oscillations, active and reactive powers, but by the action of the turbine governor and by switching from the "inductive" to the "capacitive regime of operation" of the generators, there were no outages of production units.

3. CONCLUSIONS

1. The initial event of separation of ENTSO-E interconnection into two synchronous zones, in SS 400/110 kV Ernestinovo, resulted with BiH power system having frequency higher than nominal, appearance of active and reactive power oscillations and voltage oscillations. Protection devices trips were activated and there were outages of OHL and generator units. In the considered period of disturbance all protective devices performed correctly and prevented damage to expensive equipment in the production and transmission facilities of the BiH Power System and they also maintained the stable operation of the BiH Power System.
2. It should be necessary to check the turbine governors parameter settings as well as the under excitation limiter parameter settings and generator under excitation protection in the production facilities where the generator outages had occurred.
3. The stated facts clearly point out to the importance of correct synchronized time when analysing large-scale disturbances in EPSs. Using a global common source for time synchronization, GPS clocks, in different system substations enables



Label of colours: Black line: P of generator; Green line: Q of generator; Red line: system values of frequency f; Light blue line: system values of voltage U.

Figure 20: Values P and Q on generator at thermal power unit No. 6, f and U from busbars 110 kV

easier comparison and analysis of operational events and disturbances recorded registered by protective devices at different locations in the power system as well as more accurate display of the actual sequence of operational events.

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BIOGRAPHY

Husnija Ferizović was born in 1958 in Drvar. He graduated from the Faculty of Electrical Engineering in Sarajevo in 1982, where he also obtained his Master's degree in 2003. Employed at NOSBiH in Sarajevo in the Strategic Planning Department. He works on analysing the operation of the power system in steady state and dynamic conditions, coordinating the settings of protection, using modern software Power System Simulator for Engineering (PSS/E), Siemens PTI, ASPEN (Advanced Systems for Power Engineering, Inc.). He previously worked at JP EP B&H, on tasks related to analysing and planning of the power system development.

Branislav Koprena was born in 1972 in Ključ. He graduated from the Faculty of Electrical Engineering in Belgrade in 2000. His professional career has been developing at Elektroprenos BiH, the power transmission company, in Relay Protection Department, mostly as the head of the Department. In last two years he is also a technical manager of Banja Luka area. His main focus lies on protection devices and substation automation systems design, engineering and commissioning, fault analyses and maintenance.