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Protection Coordination and Anti Islanding Protection Solution for Biomass Power Plant Connected on Distribution Network

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ABSTRACT

Protection coordination as well as anti-island protection play significant role in the process of biomass power plant connection on the distribution network. Distribution generation island operation in Croatia is unacceptable according to the existing National grid code Paper presents a protection coordination of all passive protections used in the real biomass power plant and connected distriubution network feeder. Short-circuits three phase, two phase and single line to ground faults and generator islanding simulations have been performed and simulated in the time domain at the different network locations using DIgSILENT Power Factory software. The time-current plots coordination of protective devices are made using Smart PDC module in Easy Power Protector software tool.

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1. INTRODUCTION

Before the integration of the renewable power plants to distribution network, it is necessary to make a study of coordination and setting of all protection devices to meet the conditions of selectivity, fast operation, reliability and the redundancy. Particularly important is the anti-islanding protection. In the literature, the problem of passive and active methods of protection of isolated operation is well elaborated [1-4].New methods of active protection especially for PV power plants are based on 3rd harmonic component of output current to diagnose an anti islanding [5]. Also, an algorithm which is a combination of slip mode frequency-shift (SMS) and reactive power versus frequency (Q−f) represents an active method forthe islanding phenomena detection [6]. A passive islanding detection scheme for both synchronous and inverter based distributed generations interfaced to a microgrid using Decision Tree method is presented in [7].

For synchronous generators, different new algorithms are investigated, for example in the paper [8], an algorithm that can detect the islanding condition based on load voltage using d and q-components of local load voltagehas been proposed. Interesting solution for anti-islanding protection was presented in [9], a new passive-based islanding detection method, according to change in $\partial V_{DG} \partial Q_{DG}$ index. Paper [10] presents a passive islanding detection method based on the change of the 5th harmonic voltage magnitude at the point of common coupling between thegenerator and the grid. connection. Protection coordination and integration of PV power plant in distribution network was well present in [11]. This paper will present protection coordination and anti islanding protection for biomass power plant using modified method from [10]. Criteria for overcurrent protection coordination were followed from Croatian National Grid code lit [12].

2. TECHNICAL DESCRIPTION OF BIOMASS POWER PLANT

Thebiomass power plant of 6.3 / 10 (20) kV of Slavonian timber industry, hereinafter Slavonia DI, is the cogeneration plant integrated into the distribution system of Croation distribution system operator-HEP ODS Elektra, the distribution area of SlavonskiBrod. The installed capacity of the plant is Sn=6 MVA, with nominal$cos\varphi$=0.85, an active powerat the generator terminals is P=4.66 kW. Generator is a synchronous, three-phase, rated voltage U_n= 6.3 kV, equipped with rotation contactless system of excitation and voltage regulation. The rated speed of generator isn_n= 1500 rev/min and efficiency for retesvakues is is 97%. Cogeneration plant producesthermal energy from biomass for its own needs, and electricity for the needs of the surrounding consumers. The facility has a contract with HROTE- Croatian electricity market operator [12]. All system is modeled in the purchase of electricity (NN 63/12) as a privileged power producer in the category of power producer 1001 kW to 5000 kW. The planned annual electricity produstion is 32 000 MWh with the expected availability of 8200 h per year, and 40150 MWh of thermal energy at the level of hot water (160-180°C) and 17370 MWh at the level of hot water (90-110°C).

This plant belongs to the type of steam power plants with combined cycle in which fuel is burned in a steam boiler, and a prime mover is a steam turbine. In addition to generating electricity, it also generates steam, and indirectly, it generates the hot water used for heating and technological processes within the plant timber industry. Dueto the combined production of heat and electricity (cogeneration), a coefficient of fuel efficiency up to 90% is achieved. To allow a greater flexibility in operation, condensing turbines with controlled steam extraction are used. Such turbines enable a change inthe electricity and thermal power ratio depending on the load, and consist of high-pressure and low-pressure part. In the combined production, all steam supplied from the boiler first expands in the high-pressure condensation turbine. This steam is after expansion by the heat exchanger, which act as capacitorsexploited for the technological processes in the industry (heating, cooking and drying of wood mass), while the rest goes to the low pressure turbine. At the entrance into the low pressure turbine, a gate valve which regulates the amount of steam for expansion is positioned. Constant pressure of the steam can be maintained by changing the amount of steam (subtracting) via above mentionedvalvefor changing the steam through thelow pressure turbine, the amount of vapor in the high-pressure turbine is affected (Figure 1).

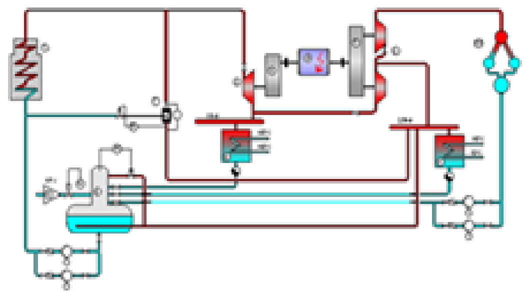

Figure 1. The Scheme of Cogeneration Plant with Condensing Turbine with Two Regulated Abstractions

where:

1) is steam boiler on wood waste (biomass)
2) is condensing turbine with two regulated abstractions
3) is reducer
4) is generator
5) is feed water tank
6) is chemical water treatment
7) is reducing cooling station
8) is high pressure thermal station
9) is low pressure thermal station
10) is air condenser

The plant’s of own consumption cogeneration plant consists of the following independently powered subsystems with their own subsections on 0.4 kV: boiler plant, landfill and transportation of biomass, turbine plant and electro-filter. On the basis of these data, generator power 6000 kVA of rated voltage of 6.3 kV was selected from INDAR manufacturer.The connection between the generator and the distribution network will be realized through transformers 6.3 / 10 (20) kV ± 2x2.5%, enabling the future transition to the distribution voltage of 20 kV. Single line diagram of biomass power plant and utility TS 35/10 kV substation, 10 kV distribution network and own industrial process using cogeneration is shown in Figure 2.

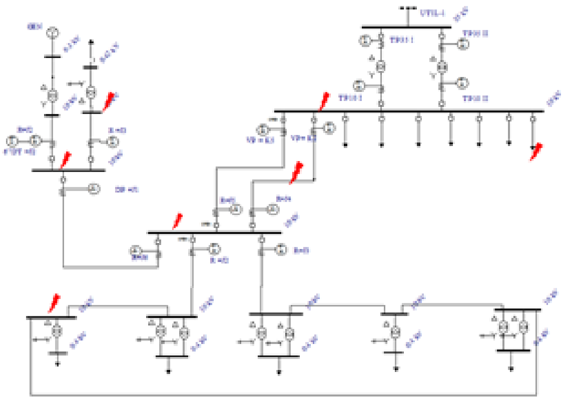

Figure 2. Single line diagram of power plant wiith own industrial consumers and distribution network

Generator data are given in Table 1:

Table 1. Generator Data

Generetor Data	Type LSA-710-K/4	Reactences	Unsaturate	Saturate
Rated power	6000 kVA	Synchronous Xd	269 %	206,1 %
Rated voltage	6300 V	Synchronous Xq	265,1 %	169.0 %
Rated current	549,9 A	Transient X'd	27,4 %	25.9 %
Power factor -cos φ	0,85	Subtransient X"d	19,1 %	16,7 %
Frequency	50 Hz	Subtransient X"d	26,4 %	20,8 %
Rated Speed	1500 o/min	Inverse X2	22,2 %	18,5 %
Max speed	1800 o/min	Zero Xo	11,1 %	9,7 %
Nr. of poles	4 poles	Stator lekageXl	10,8 %	10,1 %
Nr. of phases	3	Transient time comstant	$T_{do'}$	1,93 s
Connection	wye	Subtransient time constants	$T_{do''}$	0,03 s
Temperature	40 ^{o}C	Subtransien time constant	$T_{qo''}$	0,17 s
Class of isolation	H/H	Transijent time constant	$T_{d'}$	0,24 s
Type of cooling	IC 31	Subtransient time constants	$T_{d''}$	0,02 s
		Subtransient time constant	$T_{q''}$	0,02 s
		Armature time consant	T_a	0,08 s
		DC resistance of stator at 20 ^{o}C	R_a	35,65 mΩ
		DC resistance of rotorat 20 ^{o}C	R_f	270,7 mΩ

Network data consists of transformer data and distribution lines data given in Table 2 and Table 3

Table 2. Transformer Data

Voltage Level	Rated Power (kVA)	Reletve Short Circuit uk (%)	Connection	Number of Units
10/0,4	50	3.98	Yzn5	2
10/0,4	100	od 3.8 do 4.03	Yzn5	6
10/0,4	160	od 3.9 do 4.14	Yzn5	5
10/0,4	250	od 3.81 do 4.4	Yzn5	7
10/0,4	400	od 3.84 do 4.5	Dyn5	12
10/0,4	500	3.89	Dyn5	1
10/0,4	630	od 3.9 do 5.76	Dyn5	19
10/0,4	1000	4	Dyn5	10

Table 3. Distributionline Data

Voltage Level(kV)	Type of Line	Cross Section (mm2)	Ampacity (A)	Line Lengt 8km)
		Overhead line		
10	Al/Fe	3 x 25	125	4,050
10	Al/Fe	3 x 50	170	1,770
10	Al/Fe	3 x 70	235	2,095
10	Al/Fe	3 x 95	290	9.730
		Cables		
10	IPO 13	3 x 70	205	0,300
10	IPO 13	3 x 95	255	0,100
10	IPO 13 A	3 x 120	290	0,480
10	PHP 81	2 x (3 x 95)	380	0,380
10	PP 41 A	3 x 95	245	0,200
10	PP 41 A	3 x 120	280	2,596
10	PP 41 A	3 x 150	320	3,250
10	XHE 49 A	3 x 150	360	3,530
10	XHE 49 A	3 x 150	360	0,610
10	XHP 48 A	3 x 150	335	1,212
10	XHP 48 A	4 x 150	345	3,785
10	XHP 81 A	3 x 120	315	4,980

In accordance with the Technical conditions for connection of small power plants to the electric power system of Croatian Electricity power industry [1], when connecting power plants of total capacity up to and including 5000 kW protection system consists of:

a. Overcurrent stator protection I>
b. Overcurrent ground falult roor protection I_E>
c. Overvoltage protection U>
d. Undervoltage protection U<
e. Overfrequency protectiion f>
f. Underfrequency protection f<
g. Revers power protection P_R>
h. Unbalance protection Ii>
i. Diferential protection ΔI>
j. Termal proetction θ>
k. Lost of exitation
l. Protection of exitation I_f>,
m. Overspeed protection n>
n. Underspeeed protection n<
o. Antivibration protection
p. Protection of fault in secondary circuits
q. Cooling system protection

Figure 3. SIEMENS 7UM 621 Generator Protection and KONCAR RFX 652 Feeder Terminal Fields

Multifunctional microprocessor relay SIPROTEC 4 type 7UM621 is situatedin thebiomass power plant 10 kV switching box + J2 to protect the generator of 6000 kVA and block transformer of 6000 kVA, while the relays KONČAR RFX 632 are situated in all other switching boxes in power plant, substations and connection distribution network feeder as shown in Figure 3.

3. TIME DOMAIN FAULT ANALYSIS AND PROTECTION SIMULATION

The simulations and calculations are performed by licensed software DIgSILENT Power Factory 14.1 versions. Malfunctions of three-phase short-circuit, two-phase short-circuit and single-line to groung faults were performed at locations:

a) Simulation of three-phase short-circuit and two-phase short-circuiton the cable between TS 35/10 kV Brod 2 and switrchyardSlavonia DI 10(20)kV
b) Simulationofthree-phase short-circuit and two-phase short-circuiton switchyard Slavonia DI 10(20) kV
c) Simulationofthree-phase short-circuit and two-phase short-circuiton cable between switchyards Slavonia DI 10(20) kV and the place of common coupling.
d) Simulation of three-phase short-circuit and two-phase short-circuiton 10 kV busbar - place of common coupling.
e) Simulationof three-phase short-circuit and two-phase short-circuiton10 kV busbar-power plant block transformer
f) Simulation of three-phase short-circuit and two-phase short-circuiton 10 kV busbar -power plant own consumption transformer
g) Simulation of three-phase short-circuit and two-phase short-circuit on 10 kV busbar TS 10/0,4 kV impregnation
h) Calculation of single-line to groung faulton 10 kV busbar of switchyard Slavona DI 10(20) kV
i) Calculationof single-line to groung faulton cable between switchyardsSlavonia DI 10(20) kV and the place of common coupling
j) Calculationof single-line to groung faulton 10 kV busbar -the place of common coupling
k) Calculationof single-line to groung faulton 10 kV busbar - power plant block transformer
l) Calculationof single-line to groung faulton 10 kV busbar of power plant own consumption transformer
m) Calculation of single-line to groung faulton 10 kV busbar TS 10/0,4 kV impregnation P Parquet factory
n) Calculation of single-line to groung fault on the beginning of the passive statement –VP 10-3 (Sv. Lovre) from TS 35/10 kV Brod 2
o) Calculationof single-line to groung faulton the end of the passive statement –VP 10-3 (Sv. Lovre) from TS 35/10 kV Brod 2

Due to the lack of space, in this paper only five cases of short circuit simulation will be presented:

a) SC1–three-phase short-circuit on cable between TS 35/10 kV Brod 2 and the switchyard Slavonia DI 10(20) kV
b) SC3 – three-phase short-circuiton busbars in RS Slavonia DI
c) SC7 – three-phase short-circuit on busbars in RS cogeneration plant Slavonia DI
d) SC11– three-phase short-circuit on 10 kV busbars of power plant own consumption transformer

At the timeinstant t=100 ms from the beginning of the simulation, the three-phase short-circuit of impedance 0 Ω at the middle of 10 kV cable between TS 35/10 kV Brod 2 and a switchyard Slavonia DI 10 (20) kV is performed:

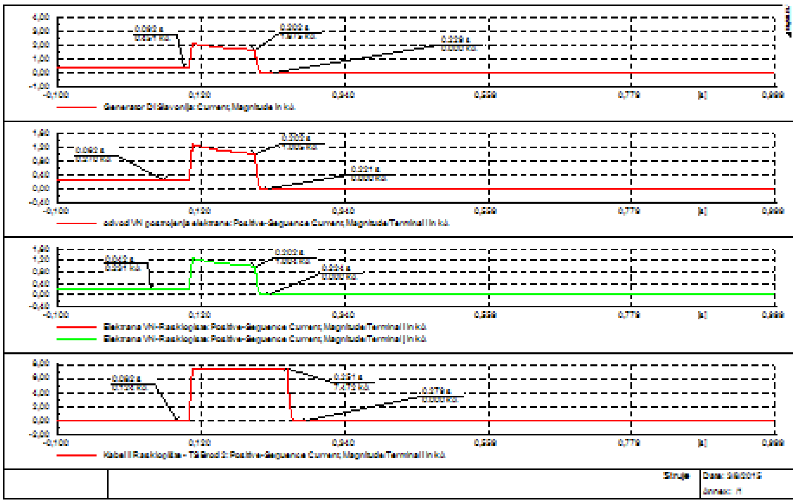

Figure 4. RMS Values of Currents During Short Circuit Simulation for Case SC1

The first oscillogram in the Figure 4 shows the short-circuit contribution of the generator current. The second oscillogram shows the current in cable from the high-voltage outlet of power plant. The third oscillogram indicates the current between the separation of power plant and switchyard Slavonia DI 10 (20) kV, and the fourth oscillogram denounces currentof the cable between TS 35/10 kV Brod 2 and a switchyard Slavonia DI 10 (20) kV. At time t=200 ms from the start of the simulation overcurrent protection of the relay in the field J2 trips generator. At time t=250 ms from the beginning of the simulation overcurrent protection I >> relay PRIL 2000 in 10 kV field K2 trips. TTC-Time Current Curves were plotted using for al protection devicesusing software tool [14] as shown in Figure 5.

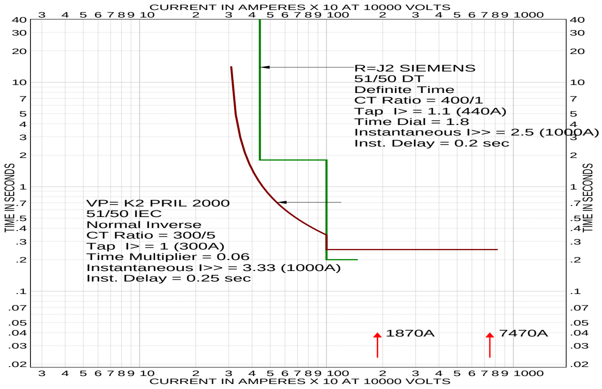

Figure 5. TCC Plots Of Overcurent Protection for Case SC1

At time t=100 ms from the beginning of the simulation, 3F-SC (three-phase short-circuit) of impedance 0 Ω at 10 kV busbar of switchyard Slavonia DI 10 (20) kV is performed.

The first oscillogram shows the short circuit contribution of the generator current.The second oscillogram shows the current in cable from the high-voltage outlet of power plant.The third oscillogram indicates the current between the separation of power plant and switchyard Slavonia DI 10 (20) kV, and the fourth oscillogram denounces current of the cable between TS 35/10 kV Brod 2 and a switchyard Slavonia DI 10 (20) kV as shown in Figure 6.

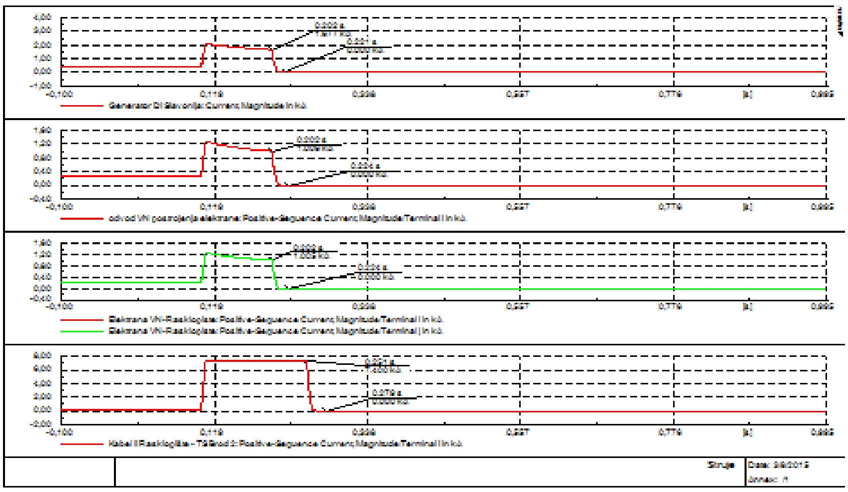

Figure 6. RMS Values of Currents During Short Circuit Simulation for Case SC3

At time t=200 ms from the beginning of the simulation, there is a switching event of a switch in the field J2 by tripping of the SIEMENS overcurrent generator. At time t=250 ms from the beginning of the simulation, non-directional overcurrent protection I >> relay PRIL 2000 in 10 kV field K2 works through in

TS 35/10 kV Brod 2 with the separation of the contacts of the respective switches, which causes the mutuall switching to exclude. t-I TCC curves are the same as for the previous case.

For the case SC7:

At time t=100 ms from the start of the simulation, 3F-SC (three-phase short-circuit) of the impedance 0 Ω at 10 kV busbar is generated - the place where the plant separates from the grid, Thecurrent of generator is shown by the first oscillogram in Figure 7. Currentin the cable of high voltage switch gear of the power plant is on the second oscillogram, whereas the current through the cable between the point of separation of the powerplant and switchyard Slavonia DI 10 (20) kV is on the third oscillogram. The fourth oscillogram shows current of thecable between TS 35/10 kV Brod 2 and a switchyard Slavonia DI 10 (20) kV.

At time t=110 ms from the start of the simulation there is tripping of the overcurrent I >>relay in thefield J6 and the disconnection of the switch in the field J6 which isolated the fault from TS Brod 2. Atthe time t=200 ms from the start of the simulation there is aswitch disconnection in the field J2 by tripping of overcurrent protection generator, which causes a mutually isolated breakdown. At time t=201 ms from the start of the simulation there is excitation of an undervoltage member U<, and Δδ member in the relay of the field J2.

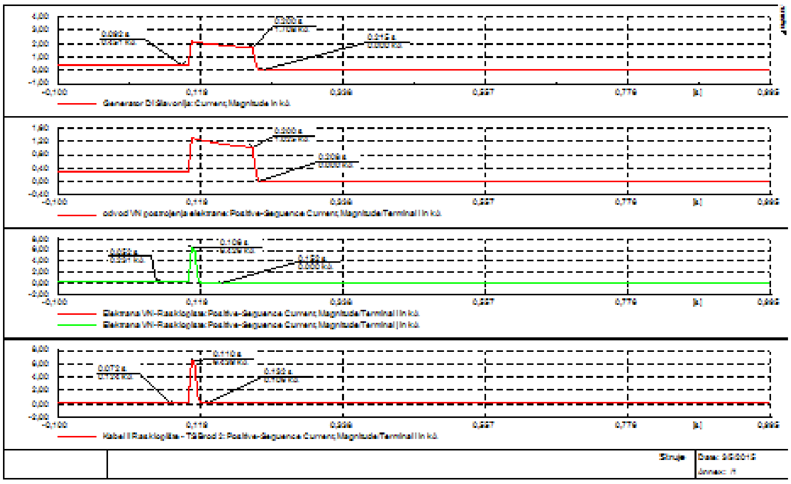

Figure 7. RMS Values of Currents During Short Circuit Simulation for Case SC7

TTC plots are presented in Figure 8

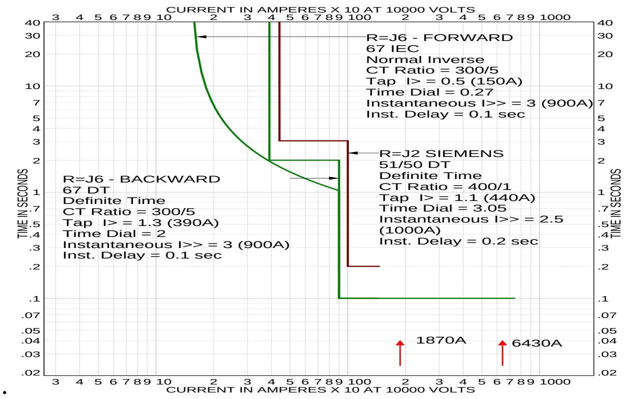

Figure 8. TCC Plots of Overcurent Protection for Case SC7

In the case SC11:

At time t=100 ms from the start of the simulation 3F-SC of the impedance 0 Ω at 10 kV busbar unit transformer power is generated:
The current ofgenerator is presented on the first oscillogram in Figure 9. The current through the cable – ofhigh voltage switchgear of powerplant is on the second oscillogram and current in the cable between the place where the plant separates and switchyard Slavonia DI 10 (20) kV is on the third oscillogram. The current through the cable between TS 35/10 kV Brod 2 and a switchyard Slavonia DI 10 (20) kV is on the fourth oscillogram.

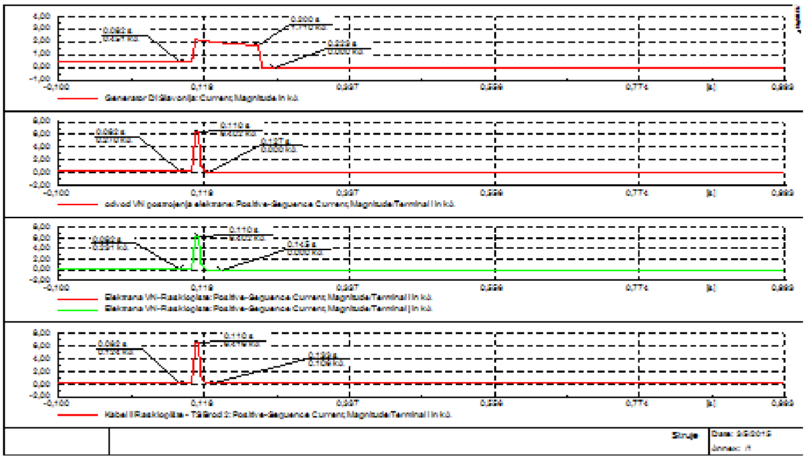

Figure 9. RMS Values of Currents During Short Circuit Simulation for Case SC11

At time t=110 ms from the start of the simulation there is tripping of the overcurrent I >> relay in the field J6 and the disconnection of the switch in the field J6 which isolates the fault from the side of TS Brod 2. At time t=100 ms from the start of the simulation there is the switching event in the field J3 by tripping SIEMENS short-circuit protection transformer of own consumption and protection of the generator in the field J2, which is a mutually isolated breakdown. At time t=201 ms from the start of the simulation there is excitation of an undervoltage of member U <, and Δθ member of the relay in the field J2.

TTC plots are presented in Figure 10

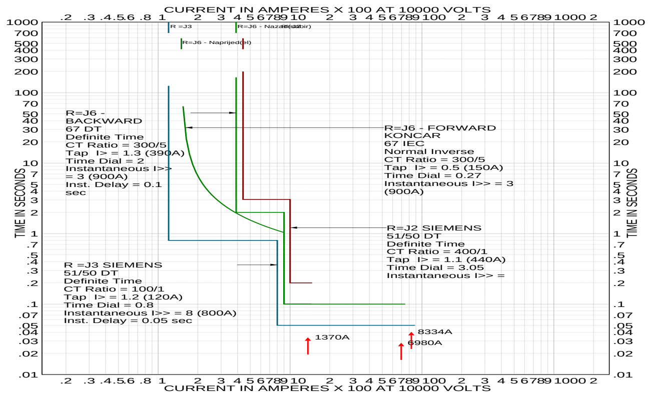

Figure 10. TCC Plots of Overcurent Protection for Case SC11

4. ANTI –ISLANDING PROTECTION

The protection system of distributed synchronous generators must follow the demands that have been placed, and one of them is the detection of isolated operation within the recommended time interval. By definition, the isolated operation occurs when the part of the distribution network becomes electrically separated from the rest of the grid, but remains powered by the distributed sources. The protection system of distributed synchronous generators must be able to follow the demands that have been placed, and one of them is the detection of isolated operation within the recommended time interval.

Supplying the isolated part of the system can cause a number of problems, both for the distributed generator and for the connected consumers. It can also endanger personnel responsible for maintaining the system considering that the system, after a failure, is in the voltage-free state after the disconnection of the switches. Therefore, all networks must include the protection of isolated operation. For this purpose, the relay is typically used for detection of the angle shift of voltage. All synchronous distributed generators are also equipped with under / over frequency relays.In the case of isolated operation, frequency and voltage are controlled by the turbine and excitation regulators whose dynamics are difficult to model in making EAA (Study Tuned Protection). Smaller generators are often not equipped with devices to control voltage; therefore the amount of power within the island network can have values greater or smaller than permitted. Frequency instability can also be a result of the island preformance. Tripping times of short-currentprotection are in the order of several hundred milliseconds. If there is “AR”-Automatic reclosing of the overhead linethat can cause problems if the generator is not protected against reverse power.Also, during the network separation there is active power imbalance, and thus the change in frequency. Automatic closing of the switch would mean connecting two asynchronous systems. In order to allow the removal of a fault, between the separation of the generator and reverse power occurring there must be a certain time lag. The usual time delay by the relay with the APU re-closing is between 100 ms and 1000 ms (for Croatian distribution system operator “HEP ODS”standard value is 300 ms or 400 ms). The rate of change of frequency is expressed as a function of the imbalance of active power (1) and inertial constant generator H, apparent power of the generator S_n and frequency before the island operation f_s (2).

$$\Delta P = \sum P_{dg} - P_i \tag{1}$$

$$\frac{df}{dt} = \frac{\Delta P \cdot f_s}{2 \cdot S_n \cdot H} \tag{2}$$

where:

ΔP - active power debalance
P_{dg} - output power of the generator
P_i - power consumption in the insular part of the network
f_s - frequency before the island's labor
H - constant inertia of the generator
S_n - apparent power of the generator

From this we calculate the frequency change (3):

$$\Delta f = \frac{\Delta P \cdot f_s}{2 \cdot S_n \cdot H} \cdot t_i \, . \tag{3}$$

This approach takes into account only the frequency change due to the island operation, but not a fault change of frequency. From the equation it is shown that if the experiment of isolated operation according to “PIPI” (Croatian abbreviation for Testing Plan and Program that is required by HEP ODS) is working with power imbalance ΔP=0.00 kW or small imbalance of power between consumers and generation, there will be no change in frequency in such a short period of time, especially since the dynamics of the turbine and excitation regulator is not taken into account in the calculation. The protection of isolated operation is performed with SIEMENS numerical relay function ROCOF df/dt> 0.2 Hz/s, as the shift of vector voltage angle between generator and network $\Delta\theta > 7^o$, as well as passive protection under/overvoltage, under/over frequency as shown in Table 4.

Table 4. Anti Islanding Protection Settings

Function	Settings	Time Delay
Undervoltage U<<	0,85 Un	0.15 s
OvervoltageU>>	1.15 Un	0.15 s
Underfrequency f<<	49 Hz	0,1 s
Overfrequency f>>	51 Hz	0,1 s
ROCOF df/dt>	0,2 Hz/s	0.2 s
Delta thetaΔθ>	7^o	0,0 s

At time t=100 ms from the beginning of simulation, the circuit breaker in the field J1 – high voltage switchgear of power plant is simulated.

Experimantal measurments od electrical parameters during the starting of turbine-generator set are presented in Figure 11

Figure 11. Experimantal Measurments od Electrical Parameters During the Starting of Turbine-Generator Set

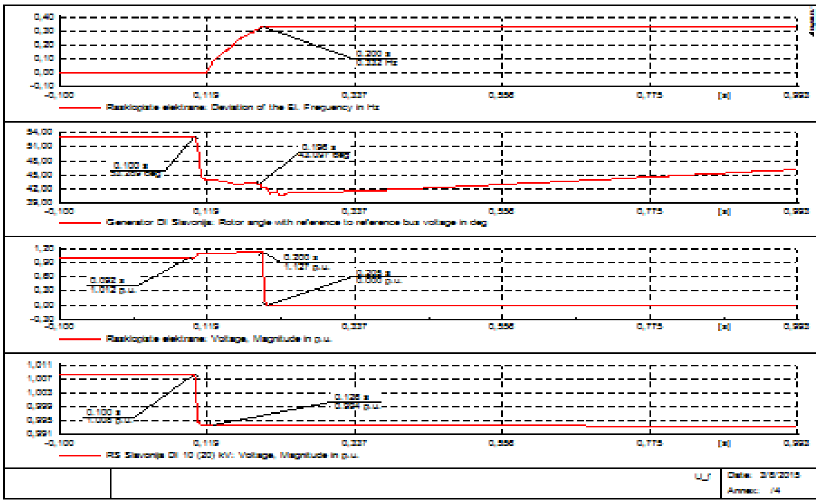

Figure 12. RMS Values of Frequency, Rotor Angle an Voltagres During Opening Generator Braker J1

The frequency deviation in the field J2 is shown on the first oscillogram in Figure 12; angle of the generator rotor in relation to the angle of voltage busbar is on the second oscillogram. The voltage on switchyard busbars of power plant is on the third oscillogram; voltage on busbars of Slavonia DI is on the fourth oscillogram.

5. CONCLUSION

The paper describes the process of simulation and coordination of short-circuit protection, under/over voltage, under/over frequency protections, as well as protection from isolated operation of biomass power plant rated power of 6 MVA, or 4.66 MW active power in parallel operation with 35 kV distribution network. The time-simulation is shown for various shortcircuit events and oscillograms of current, voltage, frequency, rotor angle and other important characteristics of the generator, adjacent switchyard and part of the distribution network of “HEP ODS” are presented. Iterative procedure resulted with proper coordination of all necessary protection devices in order for the plant to work properly on the network and to be protected fromfaults in the network and vice versa, in order to protect distribution network from faults and disturbances inthe power plant.

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