Coordination of relay protection system of a biomass power plant Spin Valis

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***Abstract* — In this paper coordination of overcurrent relay protection of biomass power plant Spin Valis International among with surrounding distribution network was performed. Paper described working process of power plant, all electrical parameters of the facilities of which the simulation model was made of and the way of achieving coordination and selectivity by using results of short-circuit simulations. System check of overcurrent protection system coordination is conducted by simulations of three phase and single phase short-circuit faults for different places in grid. Main and backup relay trip check was based on short-circuit current values and current-time characteristics of relays near short-circuit fault location.**

I. INTRODUCTION

As humankind's energy needs grew through 20th century, electric grid developed into the most complex system in the world. Because electrical engineers couldn't manage system like grid without help of automation, they developed protection system which consist of relays. This paper's goal is to achieve coordination of overcurrent relay protection of biomass combined heat and power (CHP) power plant Spin Valis International. Power plant International shown in Fig 1. is owned by wood industry Spin Valis Ltd. located in Požega, Republic of Croatia. Overcurrent protection system protects elements of network from harmful effects like thermal overheating, mechanical stresses and humans from high touch voltages. Requirements that every protection system must fulfill are fastest time of reaction, selectivity, sensitivity and reliability. In this paper, coordination of overcurrent protection system was realized with modern computer software tool for analysis of electric power systems in short-circuit states and relay system coordination. First chapter described technical specification of the power plant and surrounding distribution network. In second chapter, modelling process of power plant and surrounding distribution process is described. Last two chapter dealt with coordination of overcurrent system using short-circuit analysis and time-current curves of relays. Coordination check of overcurrent protection was also done by observing individual relay trip in a case of short-circuits for various of places in simulation model. In a case that main relay doesn't trip, backup relay should clear the fault if it exists.

Figure 1. Biomass CHP biomass power plant Spin Valis International

II. TECHNICAL SPECIFICATION OF POWER PLANT AND SURROUNDING DISTRIBUTION NETWORK

Biomass CHP power plant Spin Valis International is integrated into existing 10 kV distribution network. Power plant uses Organic Rankine Cycle for electricity and heat production. Three phase squirrel cage induction generator produces 1525 kW of power. Generator data is given in Table 1. Facility produces 4 MW of excess heat for district and industrial use [1].

TABLE I.
INDUCTION GENERATOR

Type	Squirrel cage three phase induction generator
Rated power	1818 kVA
Vector group	Delta
Rated voltage	660 V ± 5%
Frequency	50 Hz
Rated rotor speed	3028 min^{-1}
Rated stator current	1583 A
Power factor	0.88 ind.

Nearby power plant a 110/35/10 kV supply substation Požega 1 which is operated by national transmission system operator HOPS is placed. According to Ref. [2] there are two operating states of surrounding distribution network and power plant, normal and auxiliary. Normal operating state is accomplished with connection of distribution network and power plant to the 110/35/10 kV substation Požega 2 over 10 kV line bay Spin Valis. Substation consists of four transformers. First pair consists of two parallel connected 110/35 kV transformers. Second pair consists of two parallel connected 35/10 kV transformers. 110/35 kV transformers have a rated power of 40 MVA with star point grounded through a small impedance value of 70 Ω which is used for single line-to-ground fault current limitation to 300 A. 35/10 kV transformers have a rated power of 8 MVA with star point grounded through a small impedance value of 40 Ω which is used for single line-to-ground fault current limitation to 300 A. Auxiliary operating state is accomplished with connection of distribution network and power plant to the 35/10 kV substation Požega 1 over 10 kV line bay Elektra. Same 35/10 kV transformers as in substation Požega 2 are situated in 35/10 kV substation Požega 1 with same star point treatment. Due to the integration of the power plant into distribution network, a 10 kV switchyard Spin Valis 5 is built. Switchyard Spin Valis 5 allows the direct connection of power plant to the 10 kV distribution network. Transformation of generator voltage of 660 V to 10 kV distribution network voltage and from 10 kV to 0.4 kV for power plant self-consumption is realised in 10(20)/0.66/0.4 kV substation Spin Valis International which is placed in power plant building. Substation data is given in Table 2.

TABLE II.
10(20)/0,66/0,4 KV TRANSFORMER SUBSTATION SPIN VALIS INTERNATIONAL

Data	No.	TS 10(20)/.66/0.4 kV Spin Valis International
Transformers voltage transformation	1	10(20)/0.66 kV
	2	10(20)/0.4 kV
Rated power	1	2000 kVA
	2	400 kVA
Vector group	1	Dyn5
	2	Dyn 5
Short circuit voltage	1	6 %
	2	4 %
Star point treatment	1	Directly grounded
	2	Directly grounded

III. SIMULATION MODEL OF OBSERVED DISTRIBUTION NETWORK

Data available from Ref. [1, 2, 3, 4] is used for designing a simulation model. Simulation model given in Fig. 2 represents observed distribution network with power plant Spin Valis International made in EasyPower software. Simulation model can be divided into four areas. Area 1 represents normal operating state in which supply substation 110/35/10 kV Požega 2 connected to transmission system ensures supply for 10 kV distribution network. Connection of switchyard Spin Valis 5 and substation Požega 2 is accomplished via 10 kV cable. Second area represents auxiliary operating state in which substation 35/10 kV Požega 1 connected to 35 kV buses in substation 110/35/10 kV Požega 2 via 35 kV line bay Požega 1 provides supply for 10 kV distribution network. 10 kV buses of substation Požega 1 are connected via 10 kV cable to switchyard Spin Valis 5. Third area represents Spin Valis Ltd. company's consumption which consists of four 10/0,4 kV substations supplied by 10 kV feeder Tvrtka. Area number four represents power plant Spin Valis together with 10 kV switchyard Spin Valis 5. Switchyard Spin Valis 5 consists of 4 10 kV line bays and 10/0,4 kV transformer with a rated power of 50 kVA for switchyard's self-consumption. Other elements of this area are three phase induction generator, substation 10(20)/0.66/0.4 kV Spin Valis International, capacitor banks for generators power factor compensation, power plant's self-consumption and 10 kV cable for connection power plant-switchyard Spin Valis 5. After modelling, current transformers and relays are added on specific places in network.

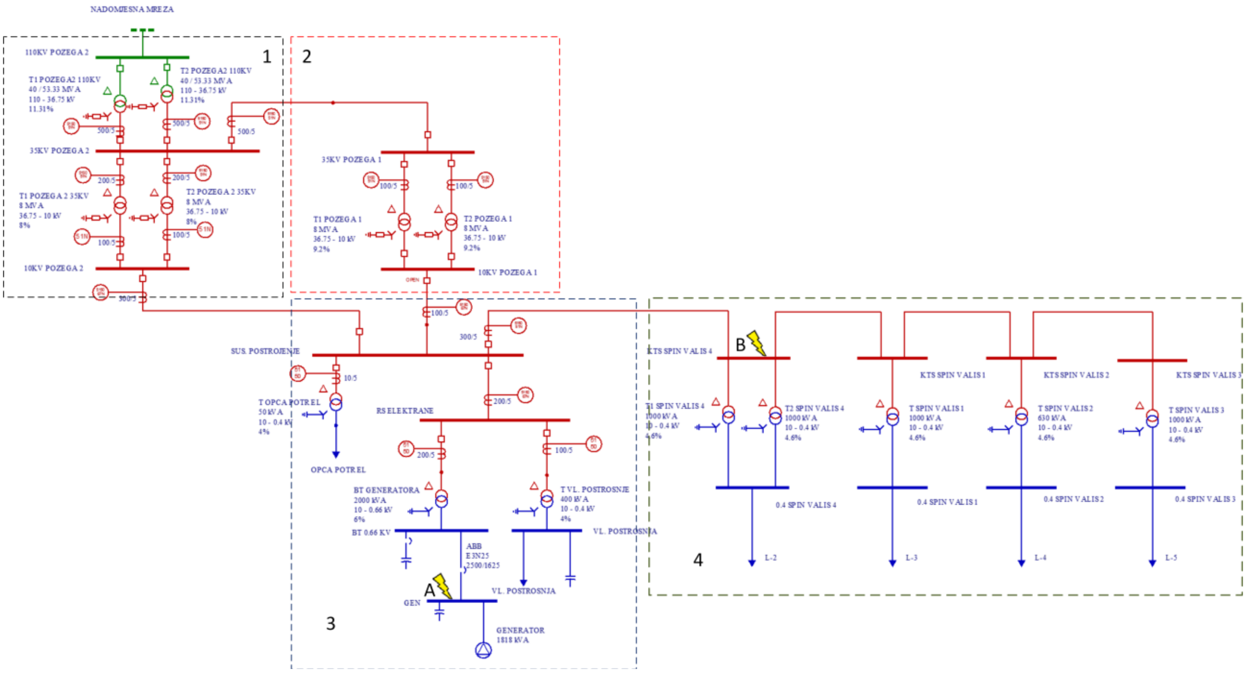


Figure 2. Simulation model of observed 10 kV distribution network

IV. SHORT CIRCUIT ANALYSIS AND PROTECTION COODRINATION

A computer model given in Fig. 2. which represents distribution network with integrated biomass power plant Spin Valis International is used for short-circuit analysis.

Three phase short-circuit power at 10 kV bus at the switchyard Spin Valis 5 with power plant connected in normal operating state is 126.51 MVA. Three phase short-circuit power at 10 kV bus at the switchyard Spin Valis 5 with power plant connected in auxiliary operating state is 75.81 MVA. Three phase and single line-to-ground short-circuit were simulated for different locations in simulation model. Due to the lack of space, results were shown for two location only. Location marked with the letter A represents 0.66 kV generator bus as shown in Fig. 2. Location marked with letter B represents 10 kV bus in TS 10/0.4 Spin Valis 4 substation. Table 3 and 4 are showing short-circuit current values for normal and auxiliary operating state of distribution network, consecutively.

TABLE III.
SHORT CIRCUIT CURRENT CALCULATION RESULTS FOR DIFFERENT LOCATIONS IN THE NETWORK FOR NORMAL OPERATING STATE

Location	Initial three phase short-circuit current I''_{k3} $[\mathrm{kA}]$		Initial single line-to-ground short-circuit current I''_{k1} $[\mathrm{kA}]$	
	From network	From power plant	From network	From power plant
A (0.66 kV)	22.752	5.451	26.112	3.865
B (10 kV)	6.51	0.281	0.276	0.008
	Total: 6.791		Total: 0.284	

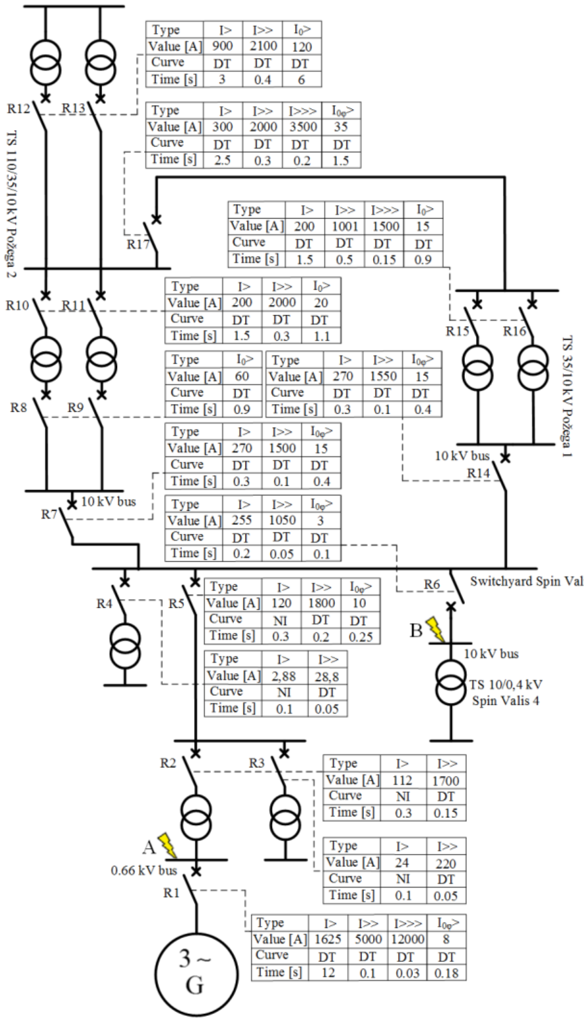
TABLE IV.
SHORT CIRCUIT CURRENT CALCULATION RESULTS FOR DIFFERENT LOCATIONS IN THE NETWORK FOR AUXILIARY OPERATING STATE

Location	Initial three phase short-circuit current I''_{k3} $[\mathrm{kA}]$		Initial single line-to-ground short-circuit current I''_{k1} $[\mathrm{kA}]$	
	From network	From power plant	From network	From power plant
A (0.66 kV)	20.029	5.451	23.89	3.982
B (10 kV)	3.903	0.288	0.264	0.013
	Total: 4.191		Total: 0.277	

According to Table 3 and Table 4 largest three phase and single line-to ground short-circuit current values occur at the lowest voltage level because as well as short-circuit current depends on impedance of elements it depends scientifically on voltage level. Single line-to ground short-circuit current, besides reasons listed before, depends on grounding treatment of the network. In our case, low voltage side star point of 10/0.66 kV transformer in substation Spin Valis International is directly grounded, and current is not strictly limited to a specific value. As opposed to that, in 10 kV network single line-to-ground short-circuit current is limited at 300 A as shown in Table 3 and Table 4. Simplified single-line diagram with overcurrent protection relay settings after process of coordination is shown in in Fig. 3. Overcurrent protection types used for coordination are: Instantaneous overcurrent protection *I*>>, overload protection *I*>, earth fault overcurrent protection I_0>, and directional earth fault overcurrent protection $I_{0\varphi}$>.

V. COORDINATION CHECK

Overcurrent relay settings for relays marked from R1 to R17 in Fig. 3 are shown in tables next to circuit breakers on which relays are connected. In order to test coordination of overcurrent protection system, by testing main and backup relay trip, three phase and single line-to-ground short-circuit simulations are simulated and time-current curves of relay are printed. Relay trip check was done for normal and auxiliary operating state of distribution network.



Type	I>	I>>	I_0>
Value [A]	900	2100	120
Curve	DT	DT	DT
Time [s]	3	0.4	6

Type	I>	I>>	I>>>	$I_{0\varphi}$>
Value [A]	300	2000	3500	35
Curve	DT	DT	DT	DT
Time [s]	2.5	0.3	0.2	1.5

Type	I>	I>>	I>>>	I_0>
Value [A]	200	1001	1500	15
Curve	DT	DT	DT	DT
Time [s]	1.5	0.5	0.15	0.9

Type	I>	I>>	I_0>
Value [A]	200	2000	20
Curve	DT	DT	DT
Time [s]	1.5	0.3	1.1

Type	I_0>
Value [A]	60
Curve	DT
Time [s]	0.9

Type	I>	I>>	$I_{0\varphi}$>
Value [A]	270	1550	15
Curve	DT	DT	DT
Time [s]	0.3	0.1	0.4

Type	I>	I>>	$I_{0\varphi}$>
Value [A]	270	1500	15
Curve	DT	DT	DT
Time [s]	0.3	0.1	0.4

Type	I>	I>>	$I_{0\varphi}$>
Value [A]	255	1050	3
Curve	DT	DT	DT
Time [s]	0.2	0.05	0.1

Type	I>	I>>	$I_{0\varphi}$>
Value [A]	120	1800	10
Curve	NI	DT	DT
Time [s]	0.3	0.2	0.25

Type	I>	I>>
Value [A]	2,88	28,8
Curve	NI	DT
Time [s]	0.1	0.05

Type	I>	I>>
Value [A]	112	1700
Curve	NI	DT
Time [s]	0.3	0.15

Type	I>	I>>
Value [A]	24	220
Curve	NI	DT
Time [s]	0.1	0.05

Type	I>	I>>	I>>>	$I_{0\varphi}$>
Value [A]	1625	5000	12000	8
Curve	DT	DT	DT	DT
Time [s]	12	0.1	0.03	0.18

Figure 3. Simplified single-line diagram with proposed protection settings of observed distribution network with power plant Spin Valis International

Due to the lack of space, only three cases of relay trip check are done in this paper. First coordination check is done for the case of three single line-to-ground at location A for normal operating state of distribution network. Main and backup relay trip are checked. Time-current curves of relays that are relevant for this case of fault are shown in Fig. 4. According to Table 3, short-circuit current for this case from power plant is 3.865 kA. Short-circuit current from the side of distribution network equals to 26.112 kA. As it can be seen in Fig. 4., fault is isolated from the side of power plant by relay R1 after 180 ms. From the side of distribution network, fault is isolated by relay R5 after 250 ms. In case that relay R5 doesn't trip, backup relay R7 will trip after 400 ms.

Second overcurrent protection system coordination check is done for three phase short-circuit at location B for auxiliary operating state of distribution network. Main and backup relay trip are checked. Time-current curves of relays that are relevant for this case of fault are shown in Fig. 5. According to Table 4, short-circuit current from the power plant is 0.288 kA. Short-circuit current from the side of distribution network equals to 3.903 kA. Total short-circuit current that flows through outgoing feeder which leads to substation TS 10/0.4 kV Spin Valis 4 is 4.191 kA. As it can be seen in Fig. 5., fault is isolated by relay R6 after 50 ms. If relay R6 doesn't trip, backup relay R14 from the side of distribution network will clear fault after 100 ms. From the side of the power plant, backup relay R5 will clear fault after 2.3 s.

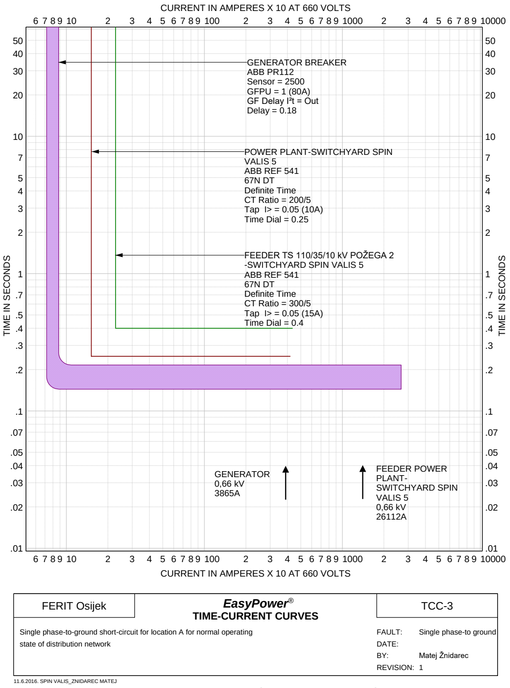


Figure 4. Relay time-current curves for the case of single line-to-ground short-circuit at location A for normal operating state of distribution network

Last coordination check is conducted for the case of three phase short-circuit at location B for normal operating state of distribution network. Main and backup relay trip are checked. Time-current curves of relays that are relevant for this case of fault are shown in Fig. 6. According to Table 3, short-circuit current from the power plant is 0.281 kA. Short-circuit current from the side of distribution network equals to 6.51 kA. Total short-circuit current that flows through outgoing feeder which leads to substation TS 10/0.4 kV Spin Valis 4 is 6.791 kA.

As it can be seen in Fig. 6., fault is isolated by relay R6 after 50 ms. If relay R6 doesn't trip, backup relay R7 from the side of distribution network will clear fault after 100 ms. From the side of the power plant, backup relay R5 will clear fault after 2,5 s.

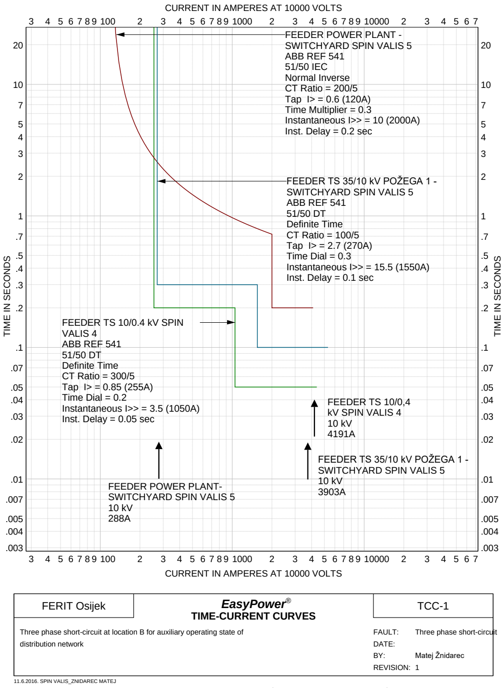


Figure 5. Relay time-current curves for the case of three phase short-circuit at location B for auxiliary operating state of distribution network

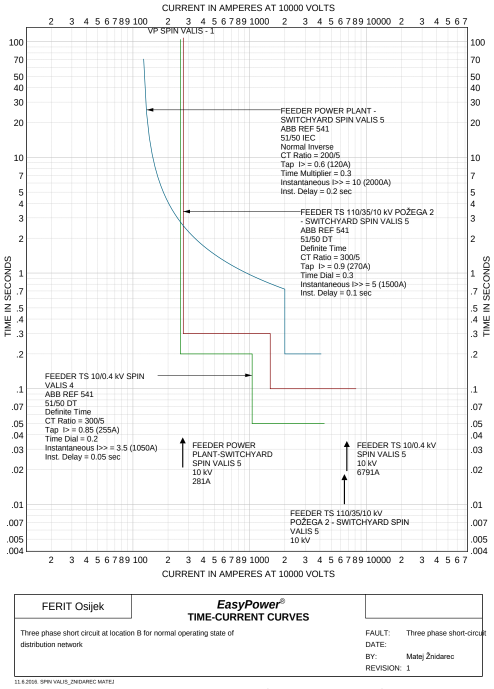


Figure 6. Relay time-current curves for the case of three phase short-circuit at location B for normal operating state of distribution network

VI. CONCLUSION

Today, relay protection system is mandatory system that operates in every grid. This paper observed small part of distribution network with distributed generator integrated in it. This case is inevitable case which every modern distribution network will meet sooner or later. Distribution generation implemented into distribution network changes former principles of functioning. Power flow is no longer unidirectional, voltage state is changed and short-circuit currents are raised which are important for overcurrent protection system. Coordination of overcurrent protection system in this paper was achieved with software EasyPower in which simulation model is made. After coordination is reached, main and backup relay trip check is done and explained with the help of time-current curves of relays.

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