Overcurrent Protection Analysis of Distribution Networks with Dispersed Generation

Metodija Atanasovski, Ljupco Trpezanovski, Blagoja Stevanovski and Nikolce Acevski[1]

Abstract – **The goal of this paper is to research and analyze the problem with distribution feeder protection selectivity when dispersed generation (DG) is present in the network. Typical example of distribution network (DN) is created and complete protection which is used for distribution feeders, buses and transformers in HV/MV station is modelled. The protection setting and testing of its selectivity is performed in conditions without DG. Then, DG is connected on the network. Set of problems with DN protection selectivity are identified. Several useful conclusions and solutions for overcoming the problems are presented at the end of the paper.**

Keywords – **Overcurrent protection, Distribution network, Dispersed generation.**

I. Introduction

DG by definition is not centrally planned and dispatched, so its commitment in generation of active and reactive power is out of control of power system operators. The installed capacity of DG has significant impact on which voltage level it will be connected. Typical voltage levels for DG connection are distribution ones from 400 V up to 110 kV [1]. DG has significant technical and economic impact on DN as it alters the power flows in the network from unidirectional to bidirectional, and by that DG affects network losses, voltage conditions and short circuit currents. Also DG changes the operating conditions and selectivity of installed protection devices into DN.

The goal of this paper is to research and analyze the problem with distribution feeder protection selectivity when dispersed generation (DG) is present in the network. Typical example of DN is created and complete protection which is used for distribution feeders, buses and transformers in HV/MV station is modelled. The protection setting and testing of its selectivity is performed in conditions without DG. Then, DG is connected on the network. Two types of generators are used in connected DG: synchronous and asynchronous generator. Set of problems with DN protection selectivity are identified. It is shown in the paper that DG connection causes serious problems with distribution feeder protection selectivity, especially in case when the fault occurred on neighbouring feeder with that where DG is connected. Island operation of DG is also analyzed as hazardous state which can be a case when fault is on the same feeder with DG independently upstream to the root or downstream to network ends from DG point of connection. Several useful conclusions and solutions for overcoming the problems are presented at the end of the paper.

The paper is composed of five sections. Section II elaborates the general concept of distribution feeders protection and the principles of protection setting. Section III is theoretical background of DG impact on protection of distribution feeders. Section IV is study case analysis of DG impact on protection. Section V is conclusion.

II. Distribution Feeders Protection

DNs are usually operated as radial networks. Protection from short circuit is mostly realized with overcurrent protection (OCP) with three modules: instantaneous OCP I>>, time delayed OCP I> and OCP for ground fault I0>. Complete functionality and setting of this protection has to be achieved for typical operating conditions of the network. OCP has two setting dimensions: current and time. Calculations for protection settings are performed for steady state operating conditions of DN. Power flow results for maximum load are mostly used for current settings of OCP. Short circuit calculations are used for testing OCP sensitivity and selectivity. Minimum short circuit current is calculated in protective device zone of operation.

Maximum value of current I_{max} through the protected element is used as basis for OCP current setting. This value has to be less or equal to element rated current I_n.

Instantaneous OCP I>> is usually located on primary side of transformer HV/MV (used as replacement or fast reserve of differential protection), at the beginning of feeder and also at longer feeders for increase of selectivity can be installed in few location downstream the feeder. Time setting of instantaneous OCP is zero by definition. When it is installed at the beginning of the feeder, then its current setting is calculated as:

$$I_{set} = k_m \cdot I_{\max} \cdot \left(1/CT\right) \tag{1}$$

Where k_m – is setting coefficient (usually has value 6), CT – is current transformer ratio.

Current setting of time delayed OCP I> is calculated with following expression:

$$I_{set} = k \cdot I_{\max} \cdot \left(1/CT\right) \tag{2}$$

Where: k – is setting coefficient (usually has value 1.5).

More about protection settings of DN elements can be found in reference [2].

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III. DG IMPACT ON DN PROTECTION

DG connection increases short circuit currents and has influence on voltage condition in DN. Also DG changes operation of installed protective devices. If fault occurs as depicted on Fig. 1, besides from the network, short circuit current will be fed from DG also, that results with greater impedance measured by line distance protection (if it is installed) and shortening of protected zone. OCP will measure increased current in comparison without DG. This problem can be overcome with usage of modern protection equipment which is sensitive and has possibility of precise setting [3].

However, at usage of this protection equipment, problem can occur during fault on neighboring feeder, which leads to false operation. During protection setting in DN with DG, it has to be taken into consideration that protection should function correctly when by any cause one or all DG will not be connected on the network.

Except mentioned problem, another one is possible when network is out of service and DG continues to work (islanded work). Islanded operation is not allowed by distribution companies. Also during any protection setting individually, network grounding and type of DG has to be taken into account for obtaining normal operation in any situation.

Feeders with DG can be out of service although there is no fault on them. This is most often case when fault is on feeders supplied from the same substation as feeder with DG (Fig. 2). In case of fault at location *K*, current will flow from the network and from DG. Fault location will be cleared by protection R_1. However, current I_{DG} will flow through protection R_2 and if it has enough great value and protection R_2 is not directional, it will put out of service feeder with DG although there is no fault on it. This is a problem with protection selectivity which is especially expressed in situation when fault location and DG connection are near to substation HV/MV. This phenomenon is influenced by the type of generator used at DG technology. Synchronous generators significantly contribute to the problem with selectivity. Asynchronous generators impact on selectivity is less expressed. DG with inverters practically has no influence on protective devices in the network.

Protection selectivity can be achieved with its precise setting. If the value of problematic protection setting current cannot be changed, problem can be solved with appropriate time setting of protection operation on neighboring feeder. But, it should be done without exceeding thermal capability of network elements. If problem of selectivity at unidirectional OCP cannot be solved with mentioned solutions above, then directional protection can be installed.

IV. STUDY CASE ANALYSIS

Theoretically analyzed problems with OCP selectivity in previous section will be illustrated on study case of typical DN (Fig. 3), which is modeled with complete protection used for distribution feeders, buses and transformers in substation HV/MV1/MV2. DN protection is set and tested in conditions without DG, because it is originally passive. The network is taken from reference [2], where complete network data can be found. DN model and complete analysis are done with software package NEPLAN 5.3.5 [4]. Analyzed DN is radial and consisted of substation 110/20/10 kV/kV/kV with two 3-windings transformers 110/20/10 kV, with rated power 31,5/31,5/10,5 MVA. Secondary side 20 kV of transformers is with grounded neutral through active resistance of 40 Ω. Used OCP in DN are shown on Fig. 3 (indicated with numbers from 1 to 9). They are used for protection of feeders, bus-bars and transformers. Table I summarizes current and time settings of each OCP. DN is consisted of three feeders. Feeder 1 supplies two nodes with three 20/0.4 kV transformers each 1 MVA, feeder 2 supplies three nodes with eight 20/0.4 kV transformers each 1 MVA and feeder 3 supplies two nodes with two 20/0.4 kV transformers each 1 MVA.

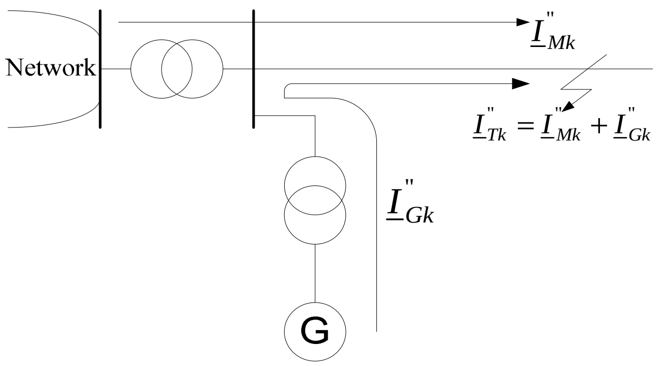

Fig. 1. Short circuit in DN with DG

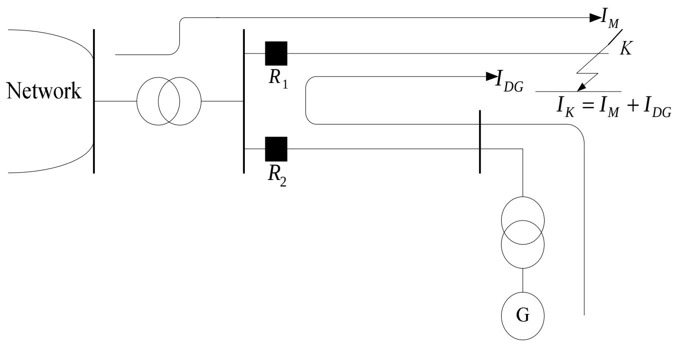

Fig. 2. Distribution feeder selectivity problem in DN with DG

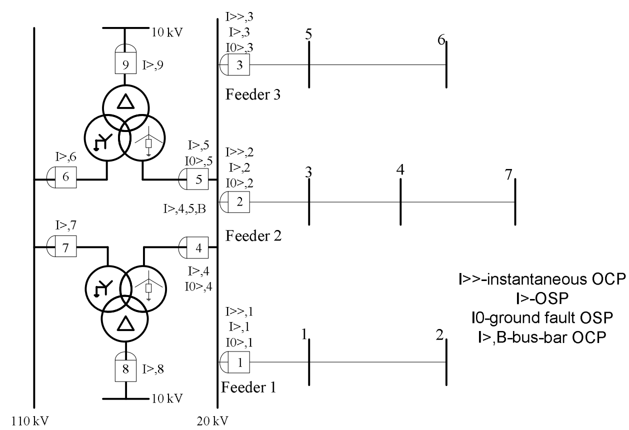

Fig. 3. Study case DN with OCP

110 kV network is modeled with Thevenin equivalent of power system with resistance 4.3 Ω and reactance of 8.07 Ω. For executed analysis it is assumed that equivalent parameters for sub-transient, transient and steady state period are equal. Same parameters are used for inverse and zero sequence. This is regular assumption for short circuit calculations in DN (except for calculations in the substation (HV/MV1/MV2).

TABLE I
SETTING OF USED OCP IN DN

OCP	Setting A/s			OCP	Setting A/s		
	I>>	I>	I0>		I>>	I>	I0>
1	540/0	150/0,5	60/0,2	6	-	260/2	-
2	1380/0	360/0,5	60/0,2	7	-	260/2	-
3	345/0	90/0,5	60/0,2	8	-	900/1,5	-
4	-	1400/1	200/0,5	9	-	900/1,5	-
5	-	1400/1	200/0,5	B	-	4000/0,1	-

Then, DG with synchronous generator with rated power 3 MVA and voltage 0.4 kV is connected to DN. Connection is realized with two transformers 0.4/20 kV with power 1.6 MVA. DG location is changed for investigation its impact on installed OCP in DN.

Four cases of problems with OCP selectivity are depicted on Fig. 4, with different DG and three phase fault location. Namely at Fig. 4a, location of three-phase fault is on half of line 3 and DG is connected on node 1. Through protection 1 will flow 570 A which lead to false operation of OCP I>> on feeder 1. In this case for selectivity only protection 2 has to operate.

Fig. 4b shows three phase fault on half of line 2 and DG is on node 5. Through protection 3 460 A will flow, which lead to false tripping of OCP I>> on feeder 3. In this case for selectivity only protection 1 has to operate.

Fig. 4c shows three phase fault on half of line 5 and DG is on node 2. Through protection 1 will flow 560 A, which lead to false operation of protection I>> on feeder 1. In this case for selectivity only protection 3 has to operate.

Fig. 4d shows case of three phase fault on half of line 4, DG is connected on node 6. Through protection 3 will flow 430 A, which lead to false tripping of OCP I>> on feeder 3. In this case for selectivity only protection 2 has to operate.

For analyzed study case it can be concluded that with DG connection with synchronous generator at any node on feeders 1 and 3, there is a problem with OCP selectivity for fault on neighboring feeder. But, when DG is connected at nodes on feeder 2, there is no problem with OCP selectivity on this feeder, when fault is on neighboring ones. This is because of the fact that this feeder supplies eight transformers TC 20/0,4 kV each 1 MVA and the setting of instantaneous OCP I>>,2 on this feeder is very high 1380 A. Practically when three phase fault occurs on neighboring feeder, this protection cannot be activated with short circuit current generated from DG.

Analysis is also performed in case when connected DG is with asynchronous generator with rated power 3 MVA and voltage 0.4 kV. Connection is realized with two transformers 0,4/20 kV with power 1.6 MVA.

On Fig. 5 are shown two cases for OCP selectivity problem with different DG and three phase fault location. Namely, at Fig. 5a three phase location is on the half of line 2 and DG is connected on node 5. Through protection 3 will flow 370 A which lead to false operation of OCP I>> on feeder 3. In this case for selectivity only protection 1 has to operate.

At Fig. 5b, fault location is on half of line 4 and DG is connected on node 6. Through protection 3 will flow 355 A, which will lead to false tripping of OCP I>> on feeder 3. In this case for selectivity only protection 2 has to operate.

According to performed analysis with DG connection with asynchronous generator, it can be concluded that at any node on feeder 3, there is a problem with OCP selectivity on this feeder for fault on two neighboring feeders. Connection of DG at nodes on feeders 1 and 2 does not lead to problems with OCP selectivity for fault on neighboring feeder.

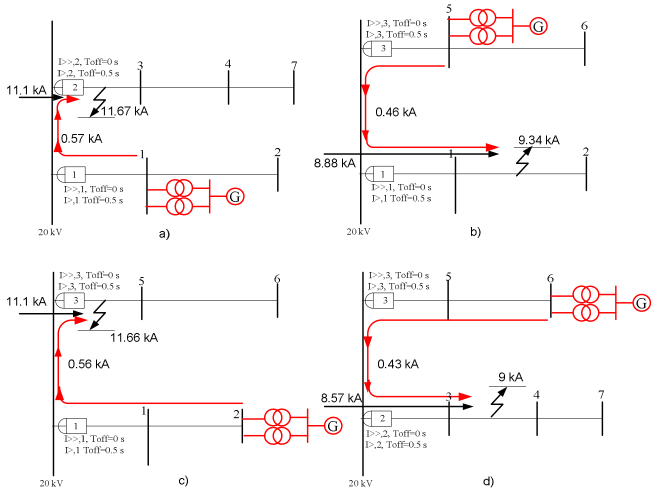

Fig. 4. OCP selectivity with different DG (synchronous generator) location and three phase fault location

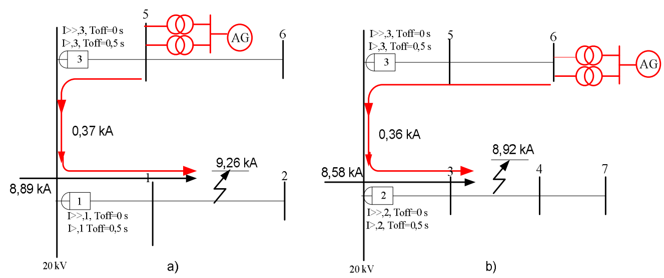

Fig. 5. OCP selectivity with different DG (asynchronous generator) location and three phase fault location

Another problem with DG connection on DN is islanded operation. This type of operation is usually not allowed by distribution companies. Islanded operation occurs in cases when fault is on the same feeder with DG. Using analyzed DN, several cases of possible islanded operation can be simulated with synchronous or asynchronous generator. Fig. 6 depicts two such cases for illustration of possibility and hazardous nature of islanded operation of DG with synchronous generator.

On Fig. 6a is shown example of islanded operation when fault is happening downstream from DG connection to network ends. Feeder 1 is observed for three phase fault on the half of line 2. The current that flows from the network is very high and it will cause operation of instantaneous I >> OCP of the feeder. However, DG will continue to supply the short circuit despite protection tripping. On Fig. 6b is shown case of islanded work when short circuit occurs upstream from DG connection to network root. Feeder 2 is subject of interest where DG is located in node 3 and three phase fault is on the half of line 3. The current that flows from the network is very high and it will cause operation of instantaneous I >> OCP of the feeder. However, DG will continue to supply the short circuit despite protection tripping.

Fig. 7 illustrates two possible cases of islanded operation of DG with asynchronous generator. On Fig. 7a is shown example of islanded work when for short circuit is located downstream from DG connection to network ends. Feeder 1 is analyzed where DG is connected on node 1 and three phase fault is happening on the half of line 2. The current that flows from the network is very high and it will cause operation of instantaneous I >> OCP of the feeder. However, DG will continue to supply the short circuit despite protection tripping. Same conclusions can be obtained for the case shown on Fig. 7b.

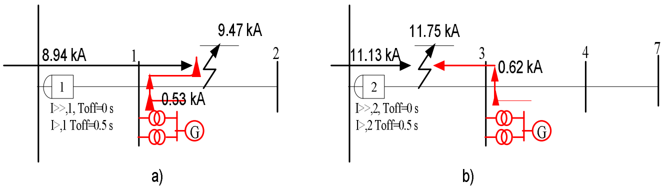

Fig. 6. Simulation of islanded operation of DG with synchronous generator

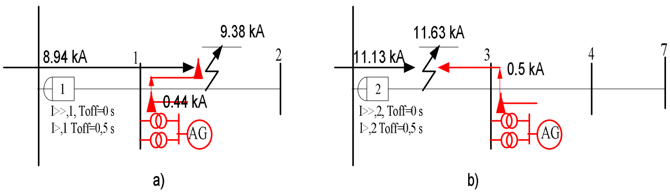

Fig. 7. Simulation of islanded operation of DG with asynchronous generator

According to performed simulations, it can be concluded that DG increases values of short circuit currents in average of 5-10 %.

V. Conclusion

DG connection in DN needs serious analysis of existing OCP. It is shown in the paper that DG causes serious problems with distribution feeder protection selectivity, especially when fault is located on neighboring feeder with the one with DG. Protection selectivity problem can be resolve with precise setting. If the problem with selectivity at unidirectional OCP persists, solution is installation of directional OCP, which will operate only for current directions from the feeding substation to network feeders.

Performed analysis on the used test DN, imposes conclusion that if feeder where DG is connected is more loaded in steady state (supplies more HV/MV transformers) in that case is mostly possible will be no problem with protection selectivity for faults on neighboring feeders. This is due to the fact that instantaneous OCP current setting in this case will have high value. Simultaneously, DG connection on heavily loaded feeders is beneficial for other technical conditions in the network, such as: reduction of losses, improvement of voltage profile especially in periods of maximum load, reduction of HV/MV transformer loading etc [5].

Islanded operation of DG as hazardous state can be a case when fault occurs on the same feeder with DG, independently upstream to network root or downstream to its ends from DG location. This state is not allowed by distribution companies. Because of this, for each DG is mandatory to install islanded work protection or so called “loss of mains protection”.

Also it can be concluded that DG increase values of short circuit currents. This imposes need for mandatory check of breaking current of commutation equipment and elements dimensioning before DG connection in DN.

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