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Adaptive Relaying of Radial Distribution System with Distributed Generation

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ABSTRACT

In this paper, the effect of DG penetration on the short circuit level has been studied in a distribution system. The number of DG sources is increased to study the effect that these changes may have on the coordination of protective directional over-current relays (DOCR). The relays in the distribution system have to be coordinated so as to avoid mal-operation and unnecessary outage of healthy part of the system. Results are compared to that of the normal case to investigate the impact of the DG on the short circuit currents of the network to deduce the effect on protective devices and some conclusions are documented. This paper presents the short circuit analysis of single phase to ground fault applied to simple radial distribution system and the corresponding Overcurrent relay coordination is presented using NEPLAN Software. Results obtained are verified by manual calculation.

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1. INTRODUCTION

Currently, most of the power systems generate and supplies electricity having into account the following considerations [1], [2]:

1. Electricity generation is produced in large power plants, usually located close to the primary energy source (for instance: coil mines) and far away from the consumer centres.
2. Electricity is delivered to the customers using a large passive distribution infrastructure, which involves high voltage (HV), medium voltage (MV) and low voltage (LV) networks.
3. These distribution networks are designed to operate radially. The power flows only in one direction: from upper voltage levels down-to customers situated along the radial feeders.
4. In this process, there are three stages to be passed through before the power reaching the final user, i.e. generation, transmission and distribution.

Nowadays, the technological evolution, environmental policies, and also the expansion of the finance and electrical markets, are promoting new conditions in the sector of the electricity generation [2]. New technologies allow the electricity to be generated in small sized plants. Moreover, the increasing use of renewable sources in order to reduce the environmental impact of power generation leads to the development and application of new electrical energy supply schemes.

In this new conception, the generation is not exclusive to generation. Hence some of the energy-demand is supplied by the centralized generation and another part is produced by distributed generation as shown in Figure 1. The electricity is going to be produced closer to the customers.

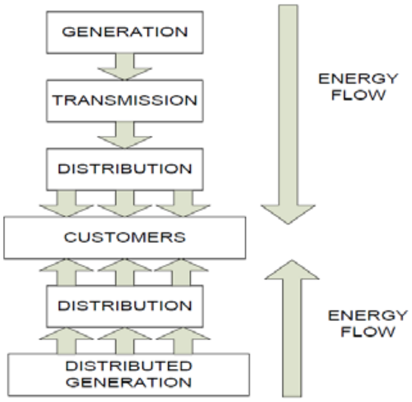

Figure 1. New industrial conception of the electrical energy supply

2. PROBLEM STATEMENT

Nowadays, the demand for power electricity is growing fast and one of the main tasks for power engineers is to generate electricity from renewable energy sources to overcome this increase in the energy consumption and at the same time reducing the environmental impact of power generation. The use of renewable sources of energy has reached greater importance as it promotes sustainable living and with some exceptions (biomass combustion) does not contaminant. Nevertheless, problems arise when the new generation is integrated with the power distribution network, as the traditional distribution systems have been designed to operate radially, without considering the integration of this new generation in the future. With the increase of penetration of DG, distribution networks are becoming similar to transmission networks where generation and load nodes are mixed (“mesh” system) and more complex protection design is needed. In this new configuration, design considerations regarding the number, size location and technology of the DG connected must be taken into account as the short circuit levels are affected and miss coordination problems with protection devices may arise [3], [4]. This paper addresses some of the issues encountered when designing the over-current protection coordination between protection devices, in case that a number of DG sources are connected to a radial system.

The fault contribution from a single DG unit is not large, however, the aggregated contributions from many small units, or a few large units, can significantly alter the short circuit levels and cause fuse-relay or fuse-fuse mis-coordination. This could affect the reliability and safety of the distribution system. It is also imperious to verify how harmful the new fault currents can be and if they flow towards the substation. They concluded that the Relay Operational Time (ROT) when a disturbance occurs in a system with distributed generation is much smaller than the operational time in the absence of distributed generation. If a fault lasts longer than the ROT in a system with a synchronous generator, it would lose its synchronism with the network. In case of an induction generator, it would draw high inrush currents from the network until the over speed or other protection interrupted the fault.

3. RELAY COORDINATION

Radial systems (distribution), usually employ non-directional over-current relays (inverse or definite time), recloser and switch fuses in protection systems. As these devices do not consider the flow direction, they may fail in cases when distributed generators (DGs) contribute to the fault. A form of evaluating the relay coordination is through the analysis of the time versus current curves of the devices involved in the part of the network where the fault occurred. The primary protection of system is the one closest to the fault point and backup protection is the next between the fault point and the source (substation or distributed generator). Backup protection should interrupt the fault only in cases when the primary protection fails to operate. It is important to remember that the utility objective is to maintain the load supply as long as possible, but the independent generator (DG) aims to protect its equipment from damage caused by the external system, so they must reach an agreement in questions related to low frequency/load curtailment situations or reclosing operations of a particular system.

Generally distribution systems are designed in a radial configuration with only one source, they have a very simple protection system, which is usually implemented using fuses, reclosers and over-current relays. To coordinate an over-current relay, as soon as a fault occurs in a system, it is sensed by both primary and backup protection. The primary relay is the first to operate when fault occurs, as its operating time of primary relay is less than that of the backup relay. In order to verify the coordination of the protection of a distribution system, the performance of all protection devices in the fault current path between the sources and the fault point should be verified. These sources are the substation or feeder and the distributed generator(s). The main aspect of the protection coordination of a system is that the primary protecting device, closer to the fault point, should act before the backup device. When the fault currents flowing in the chosen protection devices are different, the current scale presented in the coordination chart is valid for the backup device, and its curve is plotted directly from the tables of the NEPLAN database.

4. RELAY COORDINATION OF RADIAL SYSTEMS WITHOUT DISTRIBUTED GENERATION

Figure 3 shows a simple radial distribution system, where NETWORK FEEDER is the transmission system or feeder, GRID TRANSFORMER is the transformer, Bus-A, Bus-B, Bus-C and Bus-D are the buses of the system, their correspondent loads are load1, load2, load3 and load4, respectively, Line-AB, Line-BC, Line-CD are the lines between corresponding buses and Relay-1, Relay-2 and Relay-3 are the over-current relays. When a fault occurs in the network over-current protection takes place.

The characteristics of relays are based on IEC 255-3 standard (nearly inverse), which is expressed by the Equation (1) [5].

$$t_i = \frac{0.14\,TD}{\left(\frac{I_{fi}}{I_{pickup\ i}}\right)^{0.02} - 1} \tag{1}$$

Where:

TD = time dial setting of relay i. It is designed taking into account that the upstream relay provides a backup function to the downstream relay.

If Ifi = fault current seen by relay i.

Ipickup i = pick up current of relay i.

In the network shown in Figure 3, relay 2 will act as the backup of relay 1, and relay 3 will act as the backup of relay 2. The minimum difference between the operating times of primary/ backup protection is called coordination time interval (CTI). The CTI depends on number of elements or factors such as the operation time of circuit breaker, return and delay time of the measuring element, etc. The TD settings are set in such a way that the nearest relay (relay 1) has the lowest TD. As for relay 2, if a fault happen in line CD, its operation time should be larger than that of relay 1 at least by the CTI. For relay 3 the same philosophy is followed. When a single phase to ground fault occurs at downstream bus (bus-D), R-1 will sense the maximum fault current followed by R-2 and R-3, when fault occurs at bus-C R-2 will sense followed by R-3 and when fault occurs at bus-B then R-3 will operate. Figure 2 shows a selectivity diagram of relays for a down-stream fault.

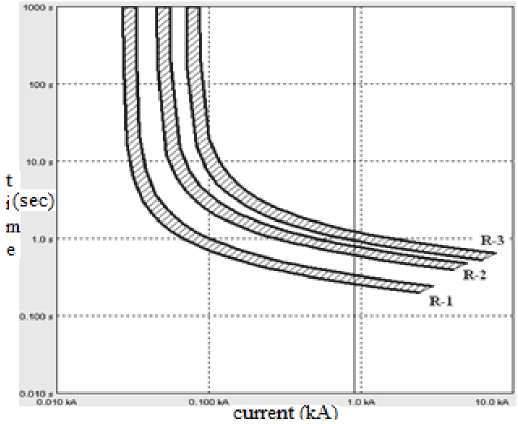

Figure 2. Selectivity diagram of Relays when fault applied to bus-D (with-out DG case)

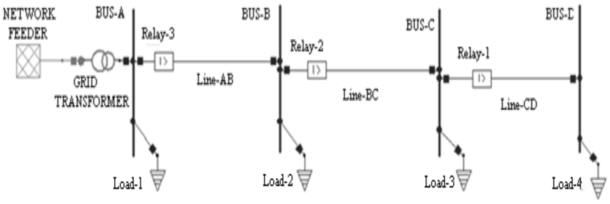

Figure 3. Distribution system with out distribution generation

5. RELAY COORDINATION OF RADIAL SYSTEM WITH DISTRIBUTED GENERATION

The coordination of the relays is changed with the presence of DG depending on number and location of these units. In this section the following cases are considered [5]. The type of DG used in the simulations is wind turbines, which are modelled as induction generators, using standard models available in the Neplan library.

A. Single DG interconnected case

Figure 4 shows a, DG1 is connected to bus B. If a downstream fault occurs, for instance in bus-D, relay 1, 2 and 3 will sense the downstream fault current, which it is greater than without DG due to the current contribution from the DG1. Then, relay 1 will clear the fault and the sensitivity will be enhanced because of the greater fault current. On the other hand, if a fault current is higher than permissible current limit, coordination between relays 1 and 2 may not hold [5]. If fault current is higher than permissible current limit, difference between the operating times of main and backup relay protection will be lower than the CTI and coordination may not hold [6].

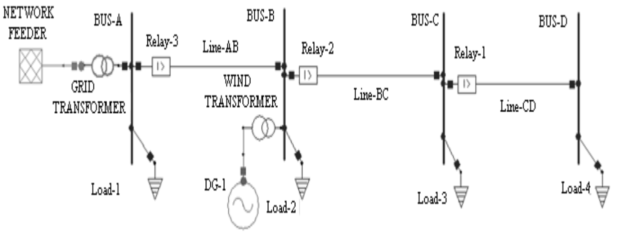

Figure 4. Single DG connected to BUS-B

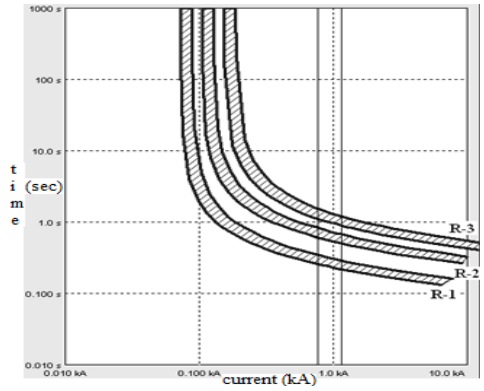

Figure 5. Selectivity Diagram of Relays when fault applied to Bus-D (with single DG case)

If a single phase to ground fault occurs in bus-C, relay R-2 will sense the fault current followed by R-3 and if a fault occurs in bus-B then relay R-3 will alone clear the maximum fault current. The line data for the above test system is given in Appendix Table 2. The type of DG usedin the simulations is wind turbines, which are modelled as induction generators, using standard models available in the Neplan library. Induction generators are connected to their respective buses through transformers (WTGXmr). Moreover, the distribution system is connected to the transmission network through another transformer (GridXmr). Their data is given in Appendix Table 5 and the transmission system data is presented in Table 3. The load values are collected in Appendix Table 4. Figure 5 shows a selectivity diagram of relays for a down-stream fault.

B. Two DG case

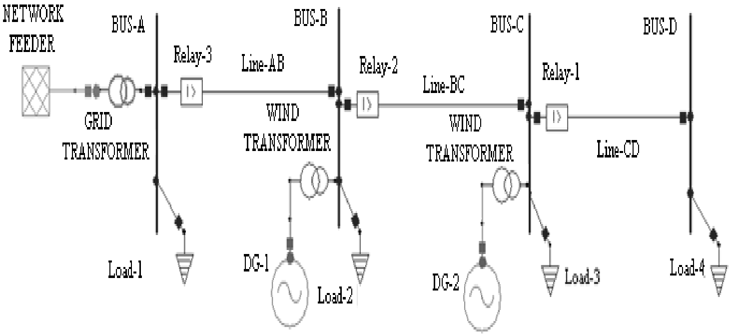

Figure 6. Two DG Connected to Radial System

Figure 6 shows, DG1 and DG2 (same characteristics as DG1) connected at bus B and bus C, respectively. For a downstream fault from DG2 the coordination of relays is the same as in the previous case and selectivity between them will hold if the fault is lower than the permissible current limit. For a fault in bus-C, relay 2 operates before relay 3 and for a fault in line bus-B relay 3 should trip while the loads, DG1 and DG2 will form an island. The proper coordination of the relays depends on the amount of fault current, which is increased when DG is connected to the system and should not exceed the predetermined current set range of the relays, if not, coordination may be lost. It can be said that with a downstream fault of DG, selectivity and coordination holds and sensitivity is improved as long as the fault current does not exceed the permissible limits. Whilst for an upstream fault the coordination is probable lost [6].

The short circuit current for a single phase to ground fault in bus-D when DG-1 and DG-2 are connected to bus B and bus C and when they are not is shown. As in the two previous cases not appreciable difference between the short circuit current with and without DG is noticed. However, a slight decrease in the short circuit current when DG it is connected. This is a contradictory to the situation experienced before. The decrease in the short circuit current level when DG is connected to the system is caused by an increase on the impedance seen by the fault. Before the DG is connected, the radial system has less impedance and therefore the current seen by the fault is higher. On the other hand, the connection of DG increases the impedance of the whole system in a proportion defined by the impedance provided by the DG technology, which in this case are wind turbines.

C. Three DG connected case

Figure 7 shows that DG1, DG2 and DG3 are connected in the system and there is a single phase to ground fault in bus-D (or further downstream), R3 will sense the maximum fault current, followed by R2 and R1. For a fault in bus-C R-2 will operate followed by R-3. For a fault in bus-B, for any other lines upstream beyond bus-B, R2 will sense more current than R3.

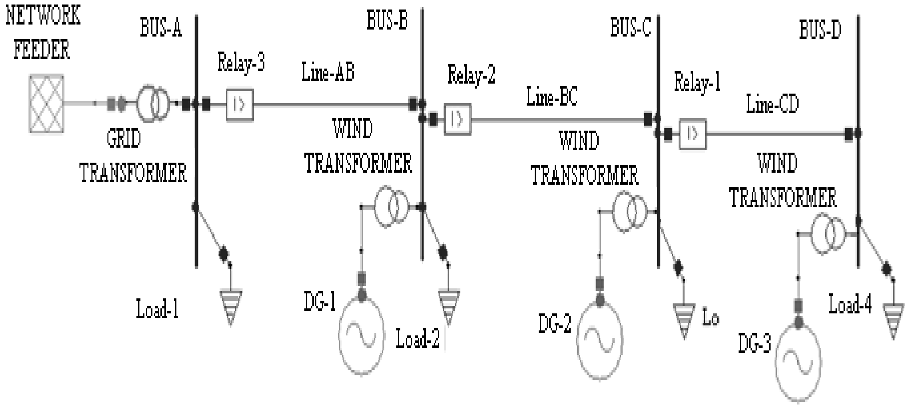

Figure 7. Three DG Connected to Radial System

According to the above analysis, the coordination impact under this situation can be summarized as follows. If the coordination relay pair detects a different current for a downstream or upstream fault, there is a margin available for coordination to remain valid. If disparity in the fault currents sensed by the devices is more than the margin, coordination holds. Coordination is likely to hold if the DG fault injection is greater than the margin.

6. RESULTS

The fault currents and corresponding tripping time of the relays with respect to that fault current are simulated using Neplan software and verified the results theoretically in Table 1.

Table 1. Comparison of Theoretical and Practical results

THEROTICAL RESULTS						**NEPLAN RESULTS**			
CASE	***FAULT LOCATION***	***FAULT CURRENT (kA)***	***RELAY OPERATING TIME (sec)***			***FAULT CURRENT (kA)***	***RELAY OPERATING TIME (sec)***		
			R-1	***R-2***	***R-3***		***R-1***	***R-2***	***R-3***
NO DG	BUS-D	**0.83645**	0.331	0.792	1.341	**0.806**	0.339	0.799	1.401
	BUS-C	**1.0317**	----	0.306	0.835	**0.916**	----	0.313	0.842
	BUS-B	**1.1915**	----	----	0.292	**1.113**	----	----	0.301
SINGLE DG	BUS-D	**1.0115**	0.319	0.762	1.306	**.0.919**	0.325	0.775	1.319
	BUS-C	**1.3738**	----	0.291	0.782	**1.210**	----	0.302	0.748
	BUS-B	**1.664**	----	----	0.265	**1.428**	----	----	0.282
TWO DG	BUS-D	**1.195**	0.293	0.736	1.218	**1.008**	0.301	0.746	1.232
	BUS-C	**1.6855**	----	0.248	0.692	**1.493**	----	0.261	0.721
	BUS-B	**2.0713**	----	-----	0.232	**1.995**	----	-----	0.241
THREE DG	BUS-D	**1.2817**	0.281	0.710	1.207	**1.1250**	0.287	0.721	1.310
	BUS-C	**2.057**	0.703	0.248	-----	**1.986**	0.691	0.255	-----
	BUS-B	**2.225**	-----	0.225	0.695	**2.107**	-----	0.214	0.679

7. CONCLUSION

The main type of fault that is focused in this thesis is the most commonly occurring fault that may arise in power systems, single phase to ground fault. The radial network was modified and analyzed for different situations, changing the location and increasing the penetration of DG. Some general conclusions were extracted:

1) Penetration of any DG into a distribution system causes an increase in the fault level of the network at any fault location.
2) Penetration of a DG in the system causes it to lose its radial power flow characteristics.
3) As the distance between the DG and the fault location increases the value of the fault current decreases.

APPENDIX

Table 2. Line Data for The Above Section

From	To	Resistance (ohms)	Reactance (ohms)
Bus-A	Bus-B	0.1256	0.1404
Bus-B	Bus-C	0.1912	0.2122
Bus-C	Bus-D	0.4874	0.5410

Table 3. Transmission System Data

Parameters	Value
Maximum R/X ratio	0.5
Maximum Z2/Z1 ratio	1
Maximum X0/X1 ratio	1
Maximum R0/X0 ratio	0.1
Maximum short circuit Power	100 MVA
Minimum short circuit Power	90 MVA

Table 4. Load Data

Bus	PL (MW)	QL (MVAR)
Bus-A	7.6517	1.1607
Bus-B	0.4523	0.2003
Bus-C	0.7124	0.3115
Bus-D	0.1131	0.05

Table 5. Transformer Data

Parameters	WTG TRANSFORMER	Grid TRANSFORMER
Rated Power	630 Kva	20 MVA
Rated Voltage HV Side	0.4 Kv	33 Kv
Rated Voltage LV Side	11 Kv	11 KV
Copper Losses	8.1 Kw	102.76 Kw
No-Load Losses	1.9 Kw	10.96 Kw

Table 6. Wind Turbine Generator Data

Parameters	**WTG (DG-1)**
Rated power	630 kW
Rated voltage	0.4 kV
Stator resistance	0.018 p.u.
Stator reactance	0.015 p.u.
Mag. Reactance	4.42 p.u.
Rotor resistance	0.0108 p.u.
Rotor reactance	0.128 p.u.
Inertia time constant	0.38 p.u.

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