International Journal of the Physical Sciences Vol. 6(16), pp. 3999-4007, 18 August, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.674
ISSN 1992-1950 ©2011 Academic Journals

Full Length Research Paper

Impact of distributed generations on power system protection performance

Hadi Zayandehroodi[1]*, Azah Mohamed[2], Hussain Shareef[2] and Marjan Mohammadjafari[1]

[1]Department of Electrical Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran.
[2]Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan Malaysia (UKM), Selangor, Malaysia.

Accepted 20 June, 2011

Though distributed generators (DGs) have significant economic and environmental benefits, increased penetration of DGs will impose significant technical barriers for the efficient and effective operation of bulk power systems. Increased fault current contribution and load flow changes are the major two impacts on utility systems, and these will affect existing protective relaying, especially overcurrent relays. To ensure safe and selective protection relay coordination, the impact of DGs should be taken into account when planning DG interconnection. This paper presents an introduction of DGs and an overview of the impacts of DGs on system protection relay coordination. Several protection issues are identified to study the requirements for protection in the presence of DGs are also discussed.

Key words: Distributed generator (DG), protection coordination, distribution network, overcurrent relay.

INTRODUCTION

The electric power system normally includes a generating system, a transmission system, power substations and the distribution network. The distribution networks were designed to extract power from the power substations and distribute it to the loads. It was not designed to have generators directly connected to it. The distribution networks topology, control, and protection are all designed assuming that power is flowing in one direction, from transmission to loads (Zayandehroodi et al., 2009). In the recent years, the electrical power utilities are undergoing rapid restructuring process worldwide. Indeed, with deregulation, advancement in technologies and concern about the environmental impacts, competition is particularly fostered in the generation side thus allowing increased interconnection of generating units to the utility networks. These generating sources are called as distributed generators (DGs). The increase in interconnection of DG to utility networks can lead to reverse power flow violating fundamental assumption in their design. This creates complexity in operation and control of existing distribution networks and offers many technical challenges for successful introduction of DG systems. Some of the technical issues are islanding of DG, voltage regulation, protection and stability of the network (Gaonkar, 2010; Zayandehroodi et al., 2011). A typical distribution protection system consists of fuses, relays and reclosers. An inverse overcurrent relay is usually placed at a substation where a feeder originates. Reclosers are usually installed on main feeders with fuses on laterals (Zayandehroodi et al., 2010, 2011). Reclosers are necessary in a distribution system as 80% of all faults that take place in distribution systems are temporary. It gives a temporary fault a chance to clear before allowing a fuse to blow. The coordination between fuses, reclosers and relays is well established for radial systems; however, when DG units are connected to a distribution network, the system is no longer radial, which causes a loss of coordination among network protection devices (Brahma and Girgis, 2004). The extent to which a DG affects protection coordination depends on the DG's capacity, type and location (Burke, 1994; Doyle, 2002; Kumpulainen and Kauhaniemi, 2004).

The introduction of a DG into a distribution system brings about a change in the fault current level of the

*Corresponding author. E-mail: h.zayandehroodi@yahoo.com.

Abbreviations: DGs, Distributed generators; **ac,** alternating current; **dc/DC,** direct current; **CB,** circuit breaker; **LV,** low voltage.

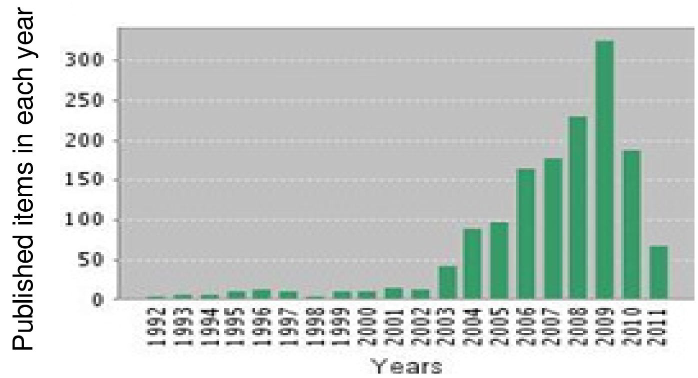

Figure 1. The number of published papers on the subject of distribution networks with DG units (Source, Web of Science 2011).

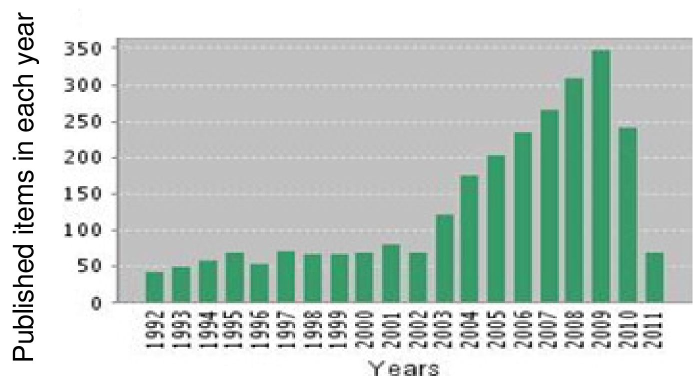

Figure 2. The number of published papers on the subject of protection for distribution systems (Source, Web of Science 2011).

system and causes many problems in the protection system, such as false tripping of protective devices, protection blinding, an increase and decrease in short-circuit levels, undesirable network islanding and out-of-synchronism reclosers (Doyle, 2002; Kumpulainen and Kauhaniemi, 2004; Pepermans et al., 2005; Fazanehrafat et al., 2008; Khederzadeh et al., 2010; Massoud et al., 2010). However, when a fault occurs in a distribution network, it is important to quickly locate the fault by identifying either a faulty bus or a faulty line section in the network (Zayandehroodi et al., 2010). Depending on the location of the fault with respect to the DG and the existing protection equipment, problems like bi-directionality and changes in the voltage profile can arise. To ensure selectivity, proper coordination between relays, reclosers, fuses and other protective equipment is necessary. However, this coordination may be severely hampered if a DG is connected to a distribution system (Hussain et al., 2010). This paper presents an introduction of DGs and an overview of the impacts of DGs on system protection relay coordination. Several protection issues are identified to study the requirements for protection in the presence of DGs and also discusses.

REVIEW OF LITERATURES

For the aim of this paper, a literature overview has been carried out in web of science database, which is the largest abstract, and citation databases of research literature and quality web sources. The survey spans over the last 20 years from 1991 to 2011. Figure 1 statistically illustrates the number of published research papers on the subject of the distribution networks in presence of DGs during the last 20 years, which are 1513 papers. On the other hand, the importance of protection for distribution systems is observable because as shown in the Figure 2 the number of publication on this subject is 2751 papers during the last 20 years. However, the number of published papers on the subject of protection of DG units is 446 papers as shown in Figure 3. In addition, the number of publications on the subject of the

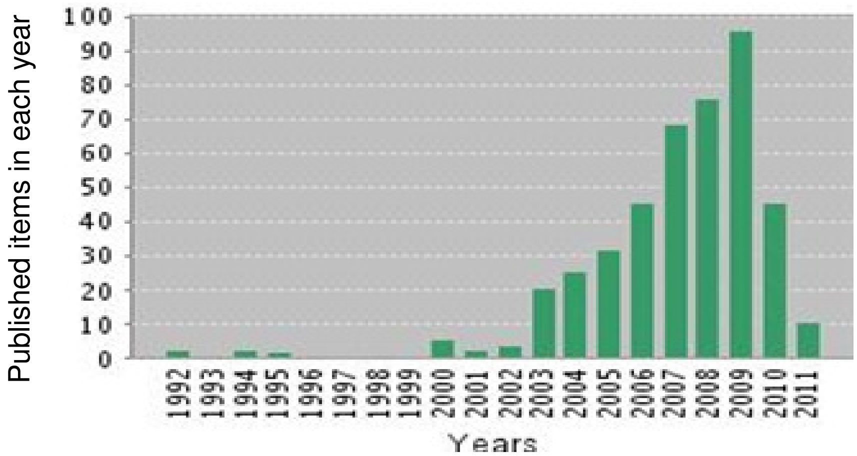

Figure 3. The number of published papers on the subject of protection of DG units (Source, Web of Science 2011).

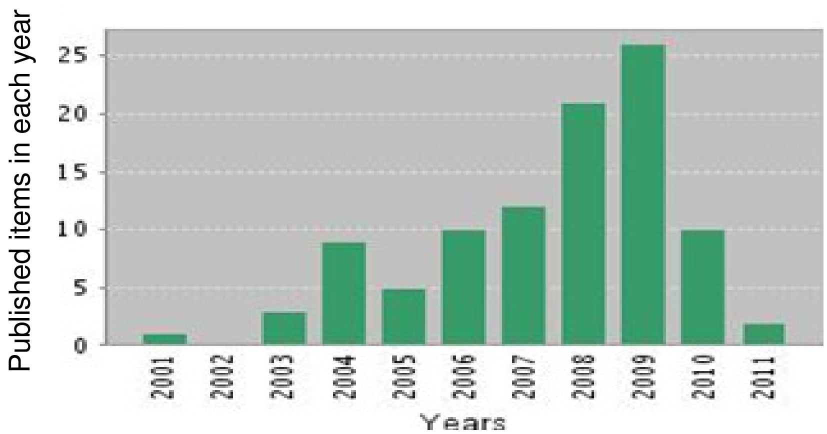

Figure 4. The number of published papers on the subject of protection of distribution networks with DG units (Source, Web of Science 2011).

protection of distribution networks with DG units during the last 20 years is only 98 papers as shown in Figure 4. From Figures 1, 2, 3, and 4 it is observable that presence of DG units in distribution network is an important issue in the power system and especially the protection of distribution systems with DG units is the researcher interested in recent issues.

DISTRIBUTED GENERATORS

Distributed generation (DG) apply to the notion of generating power using a set of small sized generators that produces power at low voltage levels and usually uses alternative fuel. Distributed generators have been categorized as micro (~1W < 5kW), small (5 kW < 5 MW), medium (5 MW < 50 MW), and large (50 MW < 300 MW). The DGs are mainly designed to be connected directly to the distribution network near load centers. There are several types of DGs in the market. Some are conventional such as the diesel generators and some are new technologies such as the micro-turbines. The major DG alternatives have described briefly in the following.

Fuel cells

A fuel cell is an electrochemical device that converts chemical energy directly into electrical energy. The fuel cell unit uses hydrogen and oxygen to perform the required chemical reaction and produce power as shown in Figure 5. Fuel cells are inverter interfaced DGs, meaning the unit produces dc power that is converted to ac power via a 3-phase converter (Hirschenhofer et al., 1998; Larminie et al., 2003).

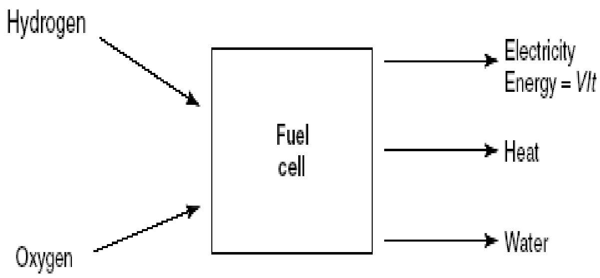

Figure 5. Fuel cell inputs and outputs.

Micro-turbine

Micro-turbines are small gas fired turbines rotating at a very high rate of speed (90,000 rpm). A high rpm DC generator is used to generate dc power. The DC generator is coupled to a dc/ac power converter to produce voltages at the rated frequency (Suter, 2001).

Photovoltaic cells

Photovoltaic cells convert solar energy directly into electrical energy. Like fuel cells, the power produced is dc power and a power electronics converter is needed to interconnect with the utility grid (Joos et al., 2000).

Wind turbines

The wind turbine operates by extracting kinetic energy from the wind as it passes through the rotor. The wind turbine shaft is connected either to an induction or synchronous generator. A transformer is then used to step up the output voltage to the utility grid level (Jenkins, 1995).

Biomass

Biomass is a renewable energy source, and biological material from living, or recently living organisms such as wood, waste, (hydrogen) gas, and alcohol fuels. Any plant, human or animal derived organic matter are source of biomass. The electricity production from biomass is being used, and is expected to continue to be used, as base load power in the existing electric-power system. Worldwide, biomass ranks fourth as an energy resource, providing approximately 14% of the world's energy needs. In developing countries, biomass accounts for approximately 35% of the energy used, and in the rural areas of these nations, biomass is often the only accessible and affordable source of energy (McGowan, 1991).

Diesel generator

This is the most commonly used DG now. A small synchronous generator is coupled with a reciprocating piston engine to produce ac power. They are usually operated standalone during utility power outages.

Table 1 shows the summary of distributed generation technologies. The size ranges given for each technology are approximate since distributed generation technology is modular and the economics of each site will determine the number of units or mix of technologies that will be used (WISCONSIN 2000; Pepermans et al. 2005).

PROTECTION COORDINATION FUNDAMENTAL

To operate a power system appropriately, the system should have a well-designed and practically-coordinated protection system. The protection requirements of a power system must take into account the following basic principles (Short, 2004).

Reliability

This is the ability of the protection to operate correctly.

Speed

This is the minimum operating time to clear a fault to avoid damage to equipment.

Selectivity

This is the maintaining continuity of supply by disconnecting the minimum section to isolate the fault.

Cost

This is the maximum protection at the lowest possible cost. Because distribution systems are typically designed in a radial configuration and with only one source, they have a very simple protection system, which is usually implemented using fuses, reclosers and over-current relays. In a distribution feeder, fuses must be coordinated with the recloser installed at the beginning or middle of the feeder. The coordination means that a fuse must operate only if a permanent fault affects the feeder (fuse saving scheme). For a temporary fault, however, the recloser must rapidly open to isolate the feeder and to give the fault a chance to self-clear. If the fuse fails to operate for a permanent fault, the recloser will act as a backup by operating in its slow mode. The feeder relay will then operate if both the recloser and the fuse fail

Table 1. Summary of distributed generation technology

	Type	Capacity range	Efficiency (%)
Fuel cells	PEM	1-500 kW	40
	PAFC	50kW-2MW	40
	PEMFC	1kW-250kW	30
	MCFC	250kW-2MW	55
	SOFC	1kW-5MW	45
	COFC	1Kw-25 mw	45-65
Combustion turbines	Micro-turbine	25-500 kW	26-30
	“Small” turbines	1-100 MW	33-45
Renewable	Photovoltaic cells	1kW- 1MW	6 – 19
	Wind turbines	10 kW-1 MW	25
	Biomass	1-1000kW	10-20
Engines	Diesel	50 kW-6 MW	33-36
	Internal combustion natural gas	5 kW-2 MW	33-35
	Stirling cycle	1-25 kW	20

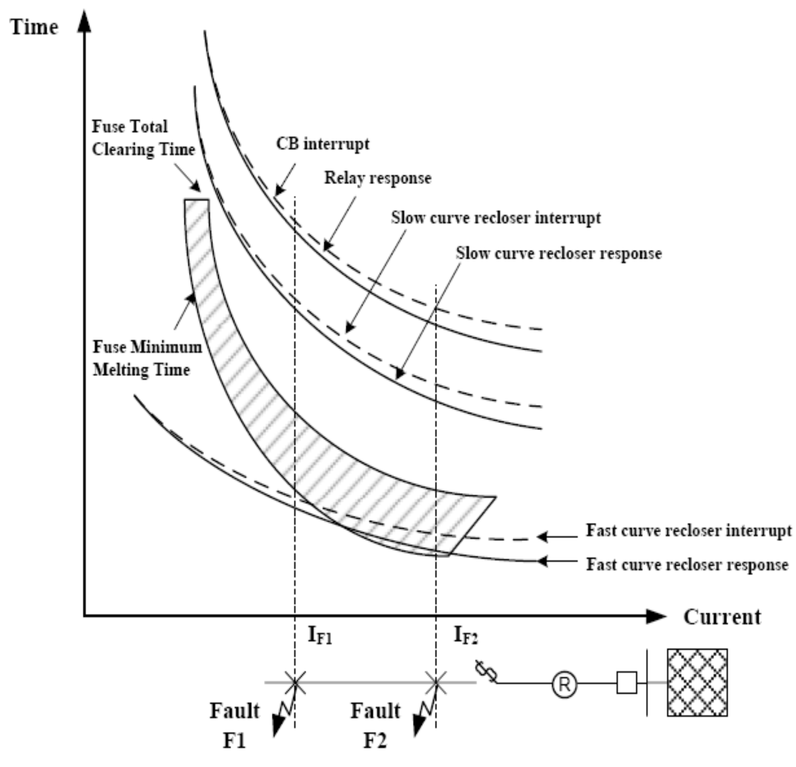

Figure 6. Protective device coordination.

(Chaitusaney and Yokoyama, 2005; Gers and Holmes, 2005). Figure 6 illustrates the conventional coordination practice for the relay, recloser, and fuses in a typical distribution network. To coordinate an overcurrent relay, as soon as a fault takes place, it is sensed by both primary and backup protection. The primary relay is the first to operate, as its operating time is less than that of the backup relay. A relay protection scheme in a simple

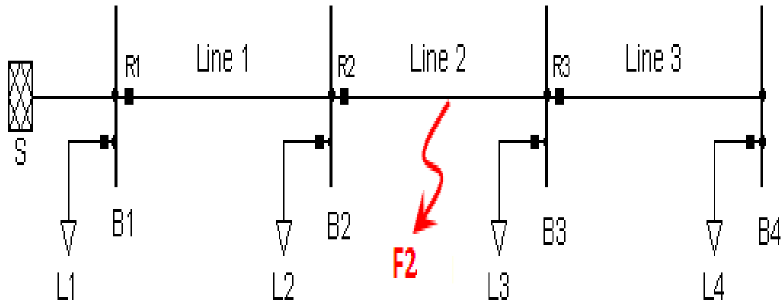

Figure 7. A simple radial feeder with non-directional relays.

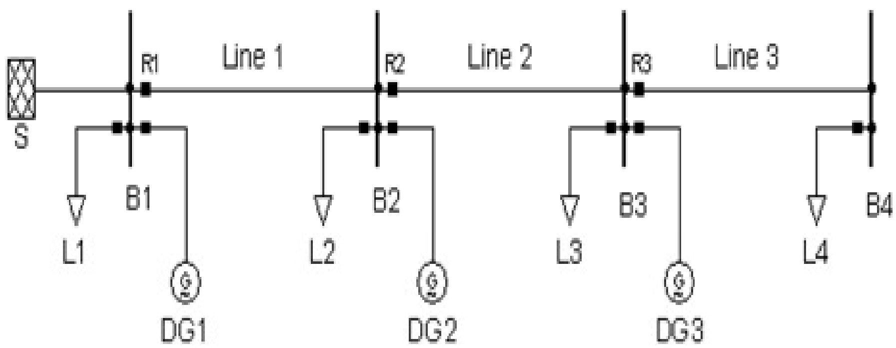

Figure 8. Simple distribution network with three DG units.

radial feeder with 4 busbars (B1, B2, B3, and B4) is shown in Figure 7. For a fault at point F2, relay R2 is the first to operate. If the operating time of R2 is set to 0.1 second, then the relay R1 should wait for 0.1 second plus a time equal to the operating time of the circuit breaker (CB) at bus B2 plus the overshoot time of relay R1 (Paithankar and Bhide, 2004). This is necessary to maintain the selectivity of the relays at B1 and B2.

EFFECT OF DG ON OVERCURRENT RELAYS COORDINATION IN DISTRIBUTION NETWORK

Figure 8 shows a distribution network with several DG units. Depending on the placement of the DG in the feeder, different protection scenarios will arise, as described in Figure 8.

Only DG1 is connected

In this case, for a downstream fault, e.g., a fault in line 3 relays R1, R2, and R3 will see the downstream fault current, which is greater than the fault current without DG1. Then R3 will have to eliminate the fault with greater sensitivity because of the larger fault current. The situation will be similar for a given fault in line 2 or line 1. For an upstream fault, that is to say, a fault that occurs before busbar B1, relays R1, R2, and R3 will never see the upstream fault current and will not be activated. Meanwhile, the overcurrent relay of DG1 (R4) will sense a fault current and then separate DG1 from the utility system. Thus, the selectivity and coordination of R1, R2, and R3 will hold for downstream faults.

Only DG2 is connected

In this scenario, relays R1, R2, and R3 will sense downstream fault currents. The fault current sensed by R2 and R3 is greater than that without the DG, while the fault current seen by R1 is less than it was before. For a fault in line 1, relays R2 and R3 will never see the upstream fault current, while R1 will sense a downstream fault current and operate. However, the fault is not isolated because DG2 feeds fault current into this line, as shown in Figure 9. When a fault occurs in line 2, if R2 does not trip, R1 cannot provide backup protection because the DG2 still feeds the fault current. Similarly, for a fault in line 3, relay R1 cannot provide backup protection if R3 and R2 do not trip as a primary protection. When a fault accrues before busbar B1, relay R1 will see a reversed fault current and operate when the fault current value is greater than the set value. Meanwhile, DG2 and the downstream loads will form an island.

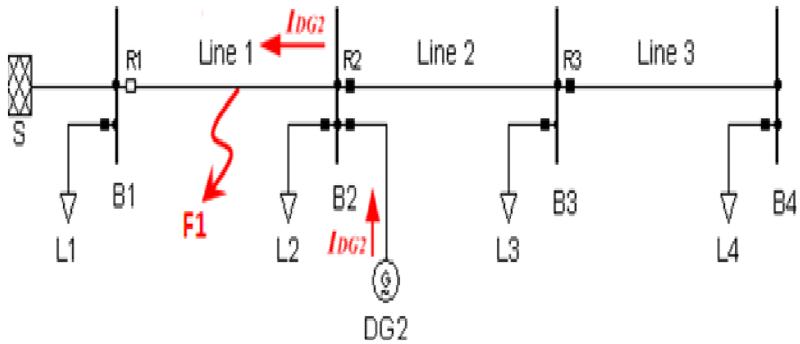

Figure 9. Distribution network with DG2 and fault in line 1.

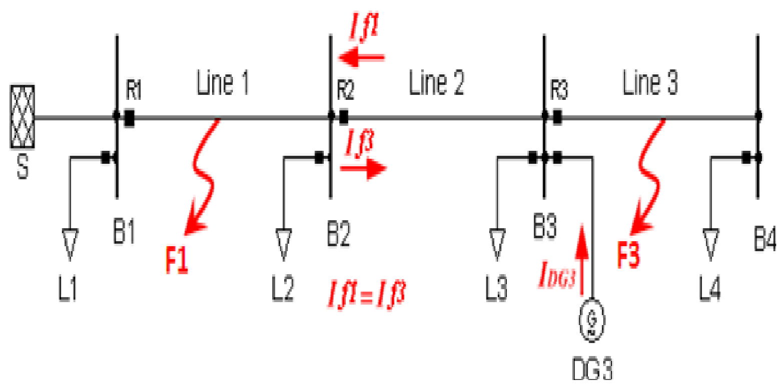

Figure 10. Distribution network with DG3 and faults in line 1 and line 3.

Only DG3 is connected

When only DG3 is connected, relays R2 and R3 will sense the downstream current for faults in line 3 and upstream current for faults in line 1. It is important to note here that for any given downstream or upstream fault, these relays will sense the same fault current, as shown in Figure 10. This result will create a conflict as these relays sense the same current for either of these faults, and it is impossible to achieve coordination with the existing scheme. Because it is required to clear only the faulted section, R3 must operate before R2 for any fault in line 3, and R2 must operate before R3 for a fault in line 1. Relays R1 and R2 cannot isolate the fault in lines 1 and 2 because the DG3 feeds the faults upstream.

DG1 and DG2 are connected

For the case when DG1 and DG2 are connected in the system, the maximum and minimum currents for a fault downstream of DG2 will change. However, R3 will never sense a backflow for an upstream fault, which will require R3 and R2 to be coordinated under different current settings. As inverse relays have sufficient tap and time settings available, coordination of relays should not pose any problem. Relay R1 cannot isolate the faults in line 1 because DG2 feeds the faults upstream.

DG2 and DG3 are connected

When DG2 and DG3 are connected and there is a fault in line 1, relay R1 will response to a fault in line 1, and relay R2 will see the reversed fault currents contributed by DG2 and DG3. In this case, the upstream currents are proportional to the capacities of DG2 and DG3; therefore, the corresponding operation time of R1 and R2 is related to the fault injection capabilities of DG2 and DG3. Relays R1 and R2 cannot isolate the faults in their lines because DG2 and DG3 feed the faults upstream.

Three DGs connected

When DG1, DG2 and DG3 are connected in the system and there is a fault in line 3 (or further downstream), R3 will sense the maximum fault current, followed by R2 and R1. For a fault in line 1 or for any other lines upstream beyond line 1, R2 will sense more current than R3, as shown in Figure 11.

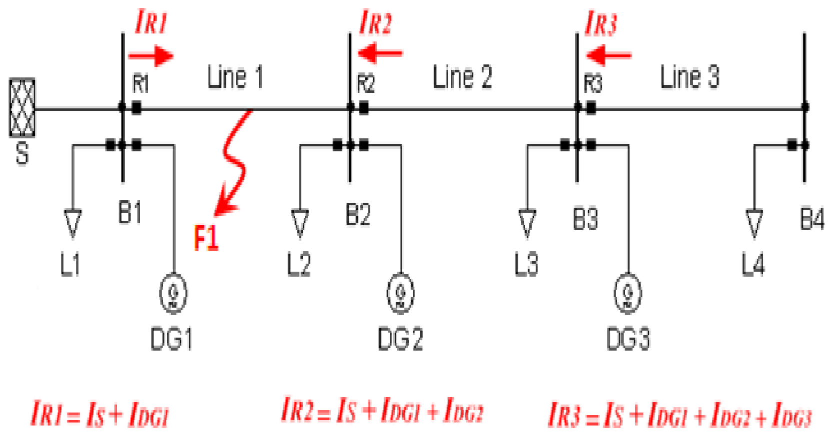

Figure 11. Upstream fault in the distribution network with DG1, DG2, and DG3 connected.

According to the analysis in Figure 11, 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 (Girgis and Brahma, 2001).

DISTRIBUTION PROTECTION ISSUES IN PRESENCE OF DGS

Participation of DGs in the energy network can cause various problems related to incorrect operation of system protections. Conflicts between DG and protection schemes are typically due to unforeseen increase in short circuit currents, lack of coordination in the protection system, ineffectiveness of line reclosing after a fault, undesired islanding and untimely tripping of generator interface protection. Conflicts between DG and protection schemes have been discussed in the literature, but effective and practical methods to solve protection malfunction due to the presence of DG have to be further investigated. Some practical cases related to the aforesaid issues in a typical low voltage (LV) distribution network will be discussed in the following sections.

Increase in short circuit currents

The consequence of incorporating DG may result the mal-operation of existing distribution networks by providing flows of fault currents which were not expected when protections get originally designed. Generally, fault current increase largely depends on number of factors, such as capacity, penetration, technology, interface and connection point of DG, besides other parameters such as system voltage prior to the fault, etc. (Conti, 2009).

Protection coordination

Protection of power systems is typically tuned in such a way that only the faulted part of the system gets removed when a fault happens. This tuning is called protection coordination and this becomes worse when DGs are connected because they can negatively affect the system coordination. By connecting DGs into the grid, the issues related to system protection turns to be very significant. For instance, the protection devices downstream of the last DG will never see fault current for an upstream fault. If these devices can see the increased fault current due to penetration of DG, there will be no problem in coordinating them. However, if the protection devices observe fault currents for upstream faults, there are two possibilities: firstly, if they see the same fault current for a fault downstream as well as for a fault upstream, then coordination will be lost. Secondly, if they see different current for a downstream or upstream fault, there is a margin available for coordination to remain valid. If disparity in fault currents seen by devices is greater than the margin, then coordination holds. Therefore, coordination is likely to hold if DG fault injection is excessive.

In the case of fuse-recloser coordination, there is also a margin available for coordination to remain valid. In this case, if the disparity in fault currents seen by these devices is less than the margin, then coordination holds. Therefore, coordination is likely to hold if DG fault injection is small (Girgis and Brahma, 2001).

Temporary faults

In radial systems, fault clearing requires the opening of only one device because there is only one source contributing current to the fault. In contrast, meshed transmission systems require breakers at both ends of a faulted line to open. Obviously, when DG is present, there are multiple power sources and opening only the utility breaker does not guarantee that the fault will clear quickly. Therefore, DG will be required to disconnect from the system when a fault is suspected, before the fast reclosing time has elapsed, so that the system reverts to a true radial system and the normal fault clearing process may proceed. Actually, there is the possibility that DG will disconnect either too quickly or too slowly with a detrimental impact on the distribution system. This creates numerous potential operating conflicts with respect to overcurrent protection and voltage restrictions. In this perspective DG seems to be rather incompatible especially with fast reclosing during temporary faults. This procedure may not allow the DG units to have enough time to be disconnected from the network. In this case DG units may sustain the voltage and fault arc, preventing successful reclosing in case of temporary faults.

CONCLUSION

DGs are a viable alternative for developing countries where grid supply has reliability below desirable levels. Since utilities are no longer embarking on building large generating plants, DG serves as an alternative to generating energy resources. The connection of DGs to distribution networks greatly impacts the networks performance. This paper focuses on the DG's impact on the networks control and protection schemes. Several protection issues are identified to study the requirements for protection in the presence of DGs also discusses.

REFERENCES

Brahma SM , Girgis AA (2004). "Development of adaptive protection scheme for distribution System with high penetration of distributed generation." IEEE Trans. Power Deliv., 19(1): 56-63.

Burke JJ (1994). Power distribution engineering: fundamentals and applications, CRC.

Chaitusaney S , Yokoyama A (2005). Impact of protection coordination on sizes of several distributed generation sources. Power Engineering Conference, 2005. IPEC 2005. The 7th International.

Conti S (2009). "Analysis of distribution network protection issues in presence of dispersed generation. Elect. Power Syst. Res., 79(1): 49-56.

Doyle MT (2002). Reviewing the impacts of distributed generation on distribution system protection. Power Engineering Society Summer Meeting, 2002 IEEE.

Fazanehrafat A, Javadian SAM, Bathaee SMT , Haghifam MR (2008). Maintaining The Recloser-Fuse Coordination in Distribution Systems in Presence of DG by Determining DG's Size. Developments in Power System Protection, 2008. DPSP 2008. IET 9th International Conference on Developments in Power Systems Protection DPSP 2008.

Gaonkar DN (2010). Distributed Generation. Croatia, InTech. intechweb.org. ISBN 978-953-307-046-9.

Gers J , Holmes T (2005). Protection of electricity distribution networks, Peter Peregrinus Ltd.

Girgis A, Brahma S (2001). Effect of distributed generation on protective device coordination in distribution system. Power Engineering, 2001. LESCOPE '01. 2001 Large Engineering Systems Conference on Power Engineering, LESCOPE '01, pp. 115-119.

Hirschenhofer J, Stauffer D, Engleman R , Klett M (1998). "Fuel cell handbook." 3.

Hussain B, Sharkh S M , Hussain S (2010). Impact studies of distributed generation on power quality and protection setup of an existing distribution network. International Symposium on Power Electronics Electrical Drives Automation and Motion (SPEEDAM).

Jerkins N (1995). "Embedded generation." Power Eng. J., 9(3): 145-150.

Joos G, Ooi B, McGillis D, Galiana F , Marceau R (2000). The potential of distributed generation to provide ancillary services. IEEE Power Engineering Society Summer Meeting, IEEE.

Kauhaniemi K , Kumpulainen L (2004). Impact of distributed generation on the protection of distribution networks. 8th IEE Int. Conf. Developments Power System Protection, 5-8 April 2004, Amsterdam. pp. 315-318.

Khederzadeh M, Javadi H , Ali Mousavi S M (2010). Source type impact of distributed generation (DG) on the distribution protection. 10th IET International Conference on Developments in Power System Protection (DPSP 2010).

Kumpulainen L K , Kauhaniemi K T (2004). Analysis of the impact of distributed generation on automatic reclosing. Power Systems Conference and Exposition, 2004. IEEE PES.

Larminie J, Dicks A , Knovel A (2003). Fuel cell systems explained, Wiley New York.

Massoud AM, Ahmed S, Finney SJ , Williams BW (2010). Inverter-based versus synchronous-based distributed generation; fault current limitation and protection issues. Energy Conversion Congress and Exposition (ECCE), 2010 IEEE.

McGowan F (1991). "Controlling the greenhouse effect The role of renewables", 19(2): 110-118.

Paithankar Y, Bhide S (2004). Fundamentals of Power System Protection, PHI Learning Pvt. Ltd.

Pepermans G, Driesen J, Haeseldonckx D, Belmans R , D'Haeseleer W (2005). "Distributed generation: definition, benefits and issues." Energy Policy J., 33(6): 787-798.

Short T (2004). Electric power distribution handbook, CRC.

Sufer M (2001). Active filter for a microturbine. 23rd Telecommunication Energy Con.IET.

Zayandehroodi H, Mohamed A, Shareef H , Mohammadjafari M (2009). An Overview of Protection Coordination Methods in Distribution Network with DGs. International conference electrical energy and industrial electronic systems (EEIES 2009). Penang, Malaysia.

Zayandehroodi H, Mohamed A, Shareef H , Mohammadjafari M (2010). "Automated Fault Location in a Power System with Distributed Generations Using Radial Basis Function Neural Networks." J. Appl. Sci., 10(23): 3032-3041.

Zayandehroodi H, Mohamed A, Shareef H , Mohammadjafari M (2010). "A New Protect.Scheme for Distribut. Network with Distributed Generation. Using Radial Basis Funct.Neural Network." Int. J. Emerg. Electr. Power Syst., 11(5): 3.

Zayandehroodi H, Mohamed A, Shareef H , Mohammadjafari M (2010). Performance Comparison of MLP and RBF Neural Networks for Fault Location in Distribution Networks with DGs. IEEE International Conference on Power and Energy (PECon 2010), Kuala Lumpur, Malaysia.

Zayandehroodi H, Mohamed A, Shareef H , Mohammadjafari M (2011). "A Comprehensive review of protection coordination methods in power distribution systems in the presence of DG." J. Elect. Rev., 87: 142-148.

Zayandehroodi H, Mohamed A, Shareef H , Mohammadjafari M (2011). An Automated Protection Method for Distribution Networks with Distributed Generations Using Radial Basis Function Neural Network. 5th International Power Engineering and Optimization Conference (PEOCO 2011), Malaysia, IEEE.