Scientific Journal of Impact Factor(SJIF): 3.134
e-ISSN(O): 2348-4470
p-ISSN(P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 1,Issue 12, December -2014

IMPACT OF DISTRIBUION GENERATION ON PROTECTION COORDINATION

Pragnesh H Shah[1]

[1] Electrical Engineering Department, A. D. Patel Institute of Technology, pragneshshah2002@gmail.com

---

Abstract -*The future of electric power distribution systems is one that incorporates extensive amounts of advanced metering, distribution automation, and distributed generation technologies. Most distribution systems were designed to be radial systems and the major philosophies of their protection, namely, selectivity and sensitivity, were easily achieved. Settings for overcurrent protective devices were static and based on the maximum load downstream of its location, with little concern of major configuration changes. However, the integration of Distribution Generators (DGs) in radial distributions systems causes bidirectional power flows and varying short circuit currents to be sensed by protective devices, thereby affecting these established protection principles. Since the protective coordination will be lost if the fault current flowing through any protective device is changed, this may lead to the large damage in system and the decrease in system reliability. Due to the fast-paced changing technologies in the field of electricity market liberalization, the incorporation of DG along with its various distributed resource technologies have led to a profound change in electrical power system. Besides many positive impacts of incorporation of DG into the electrical power system, it has introduced many inherent technical problems such as miscoordination, reliability degradation and stable islanding.*

Kewwords - *Distributed Generation, Relay Coordination, Fuse-Recloser Coordination, Islanding, transformer Interconnection*

I. INTRODUCTION

Distributed Generation (DG) is by defined as ‘generator of limited size (roughly 10 MW or less) and interconnected at the substation, distribution feeder or customer load levels’. The concept of DG contrasts with the traditional centralised power generation concept, where the electricity is generated in large power stations and is transmitted to the end users through the transmission and distributions lines. In conventional structure of power system, power is generated in large generating stations at a relatively small number of locations. In these stations, the voltage is stepped up to High Voltage (HV) to be transmitted over long distances through an interconnected HV transmission network. The voltage is then stepped down to medium voltage and low voltage, and distributed through radial distribution networks to the end users, simply referred to as “loads”.

Due to restrictions on right-of-way, difficulty faced in erecting new transmission and distribution infrastructure, ever-increasing customer demand for highly reliable electric supply and technological advances in the area of alternate energy sources, the popularity and share of DG is growing rapidly [1]. A study by the Electric Power Research Institute (EPRI) indicates that by 2020, 25% of the new generation will be due to distributed resources. A study by the Natural Gas Foundation concluded that this figure could be as high as 30% [2]. The electric power system is developed from a system with large centralised generators into a system with smaller generators interconnected at low voltage levels. The power flow is thus changed from centralised into bidirectional power flow as shown in Figure 1. Energy resources interconnected in the Medium Voltage (MV) or Low Voltage (LV) distribution grid is known as DG [3] other common names are decentral, dispersed or embedded generation. The presence of the DG, especially when contribution of DG share is significantly high, will obviously impact the way the power system is operated.

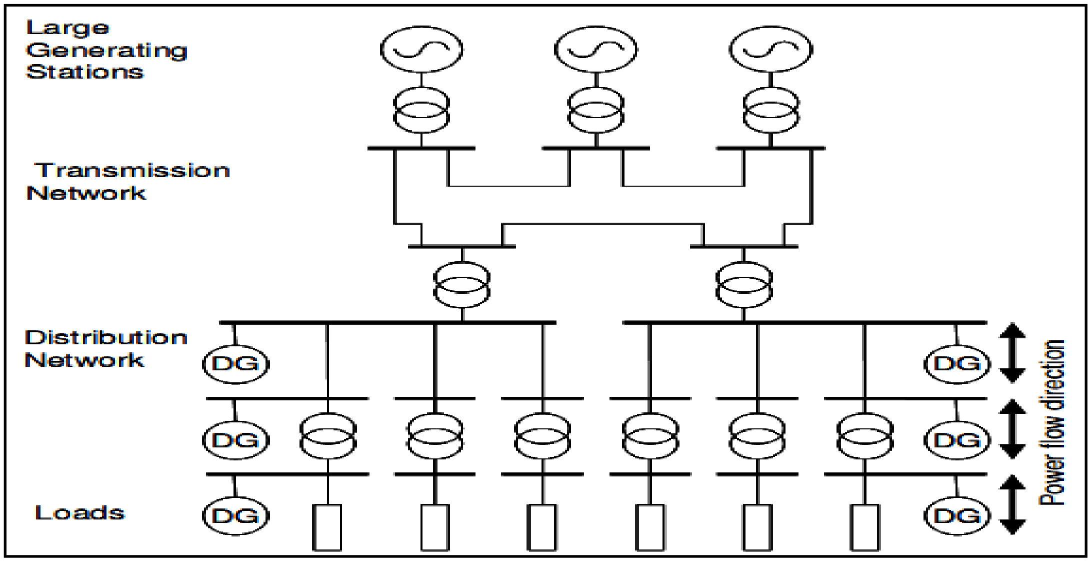

Figure 1 Decentralised power systems

A wide range of power generation technologies are currently in use or under development, these technologies include: small combustion turbines and micro turbines, small steam turbines, fuel cells, small-scale hydroelectric power, photovoltaic, solar energy, wind turbines, energy storage technologies etc [4]. The benefits which we can get from distributed resources (DR) are reduced line losses, voltage profile improvement, reduced emissions of pollutants, increased overall energy efficiency, enhanced system reliability and security, improved power quality, relieved T&D congestion, reduced health care costs due to improved environment, reduced fuel costs due to increased overall efficiency, lower operating costs due to peak shaving, increased security for critical loads. There are some inherent technical, economical and environmental problems [5].

Distribution networks are designed to conduct current from high to low voltages and protection devices are designed to reflect this concept. Under the conditions of current flow in the opposite direction, protection mal-operation or failure may occur with consequent increased risk of widespread failure of supply. Due to reverse current flow, the reach of relay is shortened, leaving high impedance faults undetected. When a utility breaker opens, a portion of the utility system remains energized while isolated from the remainder of the utility system that may result into injuries to the consumers and utility personnel [6].

II. TECHNICAL CHALLENGES FACING DG

DG faces a series of integration challenges, but one of the most significant overall problems is that the electrical distribution and transmission infrastructure has been designed in a configuration where few high power generation stations that are often distant from their consumers, ”push” electrical power to many small consumers. DG systems are often smaller systems that are locally integrated into the low voltage distribution system, which conflicts with the existing power network design paradigm. An example of a similar radial system is with a large city’s water distribution where one very large pipe of water slowly becomes narrower and narrower until it reaches the customer’s tap at a low flow and minimum pressure. Adding DG to the existing electric power distribution system can lead to a reduction of protection reliability, system stability and quality of the power to the customers. More specifically, the technical challenges that the installations of distributed generation face have been listed in Table I.

Table I Different technical challenges for distributed generations

Sr. No	Issue
1	Voltage Regulation and Losses
2	Voltage Flicker
3	DG Shaft Over-Torque During Faults
4	Harmonic Control and Harmonic Injection
5	Increased Short Circuit Levels
6	Grounding and Transformer Interface
7	Transient Stability
8	Sensitivity of Existing Protection Schemes
9	Coordination of Multiple Generators

10	High Penetration Impacts are Unclear
11	Islanding Control

The current state-of-the-art in this area and the opportunities for further research work are as follows:

2.1. Over current relay coordination in distribution systems in presence of DG

Traditionally, power flowed in one direction from the source to the load. In the future, currents will routinely flow in indeterminate directions depending on the size, placement and operational status of multiple power sources -DG units. When DG is not connected to the radial system, the flow of power is unidirectional during normal as well as in faulty condition. This situation permits the usage of time graded overcurent relays.

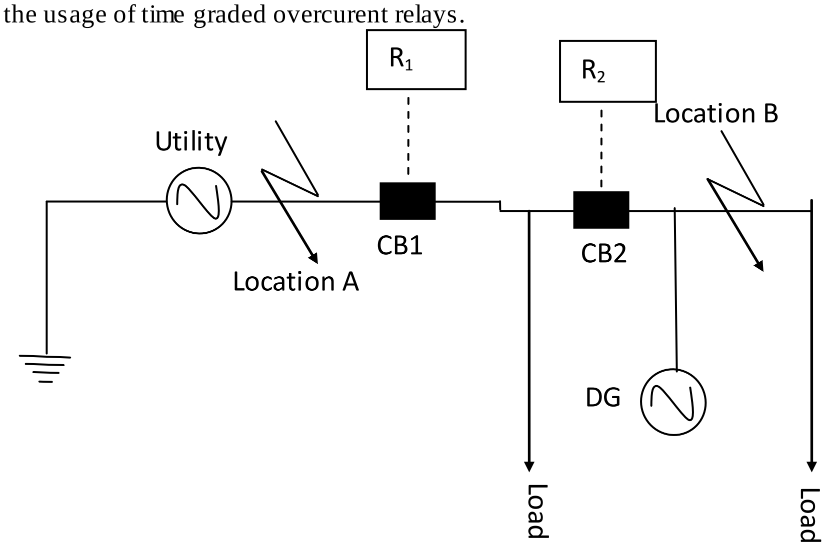

Figure 2 Effect of insertion of DG on relay-relay coordination

Figure 2 shows a distribution line protected by the circuit breakers CB1 and CB2, controlled by relays R_1 and R_2, respectively. For a fault occurring at location B, in the absence of the DG, CB1 and CB2 would see the same fault currents, and for reliability purposes, relay R_2 would trip before relay R_1. This is the conventional protection scheme used on radial lines with no downstream power supply sources. But, the insertion of the DG could have serious effect on the above protection strategy.

For fault at location A, both circuit breakers see the same fault current which is injected by the DG. In this case, CB1 should trip before CB2. However, this relay coordination is in contradiction with what was originally planned for radial system without DG.

In order to achieve coordination of overcurrent relays in ring-fed distribution network containing DG, So *et al.* [7] presented time coordinate method based on evolutionary programming. However, the prime limitation of this method is that it cannot handle many fault current redistributions at a time. After that, Jager *et al.* [8] suggested a coordination method for ring and radial distribution network containing DG. But the above scheme suffers with the problem of sympathy trips depending upon the location and level of fault [9]. Brito *et al.* [10] discussed the impact of the insertion of DG in the protection coordination using simulation software. James *et al.* [11] presented an analysis of several protection coordination problems such as fault detection ability, the characteristic contribution of fault current, effects of increased short circuit capacities and islanding of DGs due to integration of DGs into the electric distribution system. However, no malfunctioning of protection device has been reported due to incorporation of DGs. Salman *et al.* [12] presented an investigation on the impact of the integration of embedded synchronous generators and embedded induction generators on the settings of protective devices installed on the distribution systems. It has been observed that the conventional distribution overcurrent protection schemes do not have sufficient capacity to protect radial distribution network with all possible configurations and operating conditions of DG. In order to overcome the above limitations, a new directional relaying scheme for three phase radial distribution network in the presence of DG for miscoordination between relays has been presented.

In case the same radial feeder is fed from both the ends (double-end fed) with necessary modification in the protection scheme using directional feature at relay point R_2, R_3, R_4, and R_5, as shown in Figure 3, zones are created for different sections between any two buses.

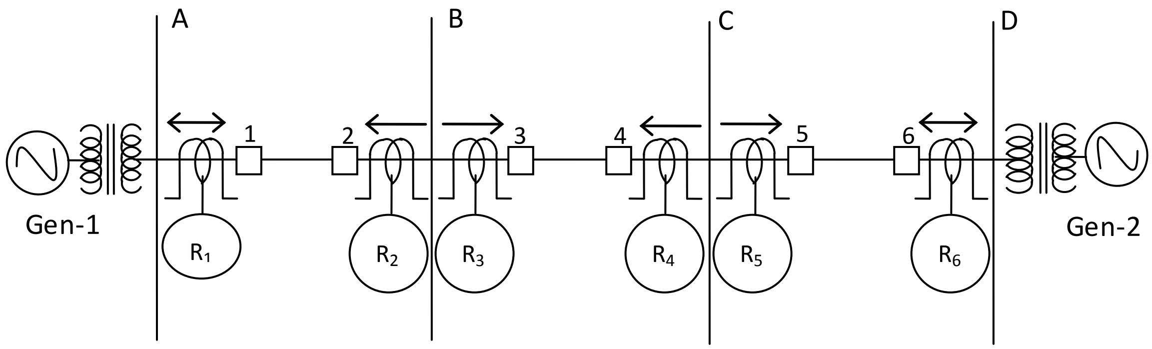

Figure 3 Double-end feed radial feeder

In the event of any abnormalities (fault) in section between bus A and bus B, the breakers 1 and 2 will isolate the faulty section, without interrupting the supply to load the connected at the buses A, B, C, and D. Hence, to discriminate the faulty section, the relay R_2 should be direction sensitive so that it operates only in the direction indicated by the arrows as shown in Figure 3. It can be concluded that the relays R_2, R_3, R_4, and R_5 should operate for a current that flows away from the bus where the relay is located, and it restrains if the current flows towards the bus. The proposed directional relaying scheme for radial distribution network has the ability to resolve the problem of maloperation of the conventional overcurrent relays of radial distribution system in the presence of DG.

2.2. Recloser-Fuse coordination of radial distribution systems in presence of DG

In practice, about 80% of faults on distribution systems are temporary in nature. Therefore, in order to improve the reliability of power supply, reclosers are introduced in the system and coordinated with fuses to make sure that fuses blow only for permanent faults. A typical distribution system with fuse and recloser in the presence of DG is shown in Figure 4. If the fuse and recloser are coordinated for a fault at F, without DG and with DG, more current would flow through the fuse than through the recloser. This results in the loss of coordination between fuse and recloser.

In order to mitigate miscoordination between recloser and fuse, several methods have been proposed by researchers. Fazanehrafat *et al*. [13] proposed analytical based method which determines the maximum capacity of DG that would ensure proper coordination between fuse and recloser. However, the prime limitation of the said method is that it is very difficult to define an equation for each fuse on a feeder as it is characterized by different curves. Thereafter, Brahma and his colleague [14] presented microprocessor based method, which maintains proper coordination between recloser and fuse for faults on a feeder with a high penetration level of DG.

However, the requirement of continuous monitoring of DG status is the main disadvantage of the above scheme. Moreover, the proposed scheme may provide unreliable operation due to disconnection of DG at every fault occurrence even when faults are temporary

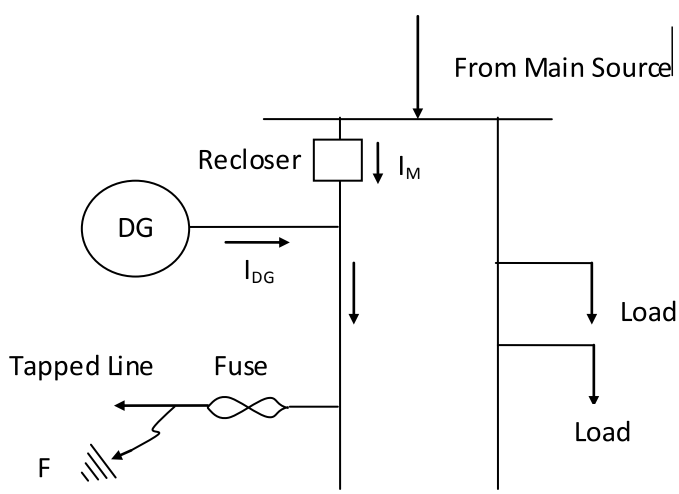

Figure 4 A typical distribution system with fuse and recloser

in nature. Chaitusaney *et al*. [15] proposed a method to find the threshold value of DG capacity beyond which recloser-fuse coordination is lost. Though the above scheme has investigated the issue of recloser-fuse miscoordination, they have not suggested any solution to enhance coordination margin between recloser and fuse. Expert systems and multi-agent approaches have been discussed in [16] and [17] to solve protection coordination problems in distribution systems. However, these systems are expensive as well as difficult to realize and maintain due to their complexity.

Javadian *et al*. [18] proposed a scheme which divides the distribution network into various zones with a reasonable balance of load and DG in each zone. The scheme aims at maintaining protection coordination, while keeping most of the DG online during a fault by allowing islanded operation of DG. However, due to the location of DG units with respect to the loads, the fluctuating nature of power from these DG units and uncertainty of utility loads, it might not be possible to establish zones that fulfil the required criteria. Moreover, islanded operation of DG may not be desirable. According to the current utility practice, islanding is not allowed. However, none of these schemes has completely solved the problem of miscoordination between recloser and fuse in radial distribution system containing DG.

2.3. Islanding detection scheme for radial distribution systems with DG

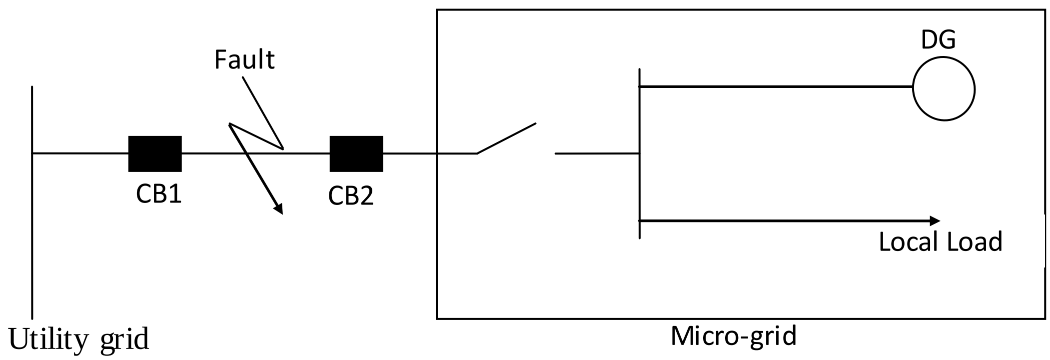

Figure 5 Scenario of islanding operation

Figure 5 shows a DG source connected to an existing utility line near a load centre. For a fault between two breakers, CB1 would trip, but the DG may not be able to inject enough current to trip CB2. This condition where the portion of the grid in between CB1 and the DG is energized solely by the DG (and the utility has no control over it), is called islanding. For safe operation of power systems to which DGs are connected, unintentional islanding should be properly detected.

2.3.1. Review of islanding techniques

Different islanding detection schemes have been proposed and applied to solve the problems associated with protection of loss of mains for synchronous distributed generator. Some of them are very popular and widely used.

(a) Communication based detection techniques

Refern and his colleagues [19] proposed communication based transfer trip scheme in which the status of circuit breakers and reclosers are monitored with the help of Supervisory Control and Data Acquisition (SCADA) system. The principle of the SCADA to detect unintentional islanding is to monitor state of entire distribution system such as voltage, frequency and other characteristics. This information is then sent through the communication links to a central station. After the utility is disconnected, if the parameter (voltage or frequency) can still be detected from the disconnected area, then the occurrence of islanding is hereby detected. The said scheme is highly effective to detect unintentional islanding and the non detectable zone (NDZ) is eliminated. However, the main drawback of this scheme is that the cost and potential complexity, due to requirement of signal transmitters for all possible disconnecting points in the system. If there are many reclosers and the feeder topology varies, a transfer trip scheme can become quite complicated.

In [20], [21], various researchers have presented communication based islanding detection scheme using Power line signaling. This scheme utilizes a signal generator at the transmission system continuously. It broadcasts a signal to all DG and/or distribution feeders using the power line as the signal path. This method has multiple strengths: it does not have an NDZ, the DG inverter's output power quality is not degraded, the number of inverters on the system does not affect its performance, and would be effective at any penetration level. However, the high cost associated with the signal generator and its installation may make this scheme unattractive, especially when there are only a few DG units sharing this service.

(b) Passive detection techniques

Schemes employing under/over voltage and under/over frequency, which operate according to the relative changes of voltage and frequency, are described in [22], [23]. One of the key features of this scheme is that, this method is required for several reasons other than islanding detection and some of the other islanding detection methods rely on this method to detect the island. However, this scheme fails to detect the island under the circumstance where generation and load are closely matched. Moreover, they have a large NDZ where they fail to detect the islanding condition.

Freitas *et al.* [24] proposed islanding detection technique based on rate of change of frequency (ROCOF). However, the said scheme gives satisfactory operation only in case of occurrence of islanding with high (15%) active power mismatch. Further, the said scheme is highly susceptible to nuisance tripping. Hence, in order to reduce the numbers of spurious trip, a higher threshold value need to be set on the relay, which increases the non-detection zone.

Pai *et al*. [25] presented a scheme of rate of change of frequency over power (df / dP) for islanding detection. Test results have shown that for a small power mismatch between the DG and local loads, rate of change of frequency over power is much more sensitive than rate of change of frequency over time. Thereafter, Mahat *et al*. [26] presented a technique based on the rate of change of voltage, which easily detects islanding events when reactive power mismatch is very high. But the prime limitation of the above scheme is that it fails to provide effective discrimination between islanding and non-islanding situation particularly when the reactive power mismatch is very small.

(c) Active detection techniques

Many researchers have proposed various islanding detection schemes based on reactive power export error detection [27], [28]. This technique is based on the set value of reactive power flow between the DG site and grid or at the point where the Reed relay is connected. However, this method is slow and it cannot be used in the system where DG has to generate power at unity power factor. Afterwards, Maki *et al.* [29] presented a method for islanding detection which utilizes impedance between phase and earth. However, the result obtained by the said method is same as given by ROCOF method.

Garmrudi *et al.* [30] suggested a novel hybrid islanding detection method, which depends on the average rate of voltage change and tap switching of the capacitor bank. However, the prime limitation of the above scheme is that it takes longer time (more than half a second) to detect islanding conditions with very small power mismatch. Afterwards, Fuzzy rule based approach and Wavelet transform based islanding detection techniques have been presented by different researchers [31], [32]. However, these schemes fail to detect islanding condition during lower values of active and reactive power mismatch. Gaonkar *et al.* [33] presented islanding detection technique by estimation of phase angle using phase-locked loop which easily detects islanding events under matching distributed generation and load power ratings. Samantaray *et al*. [34] proposed a probabilistic neural network (PNN) based islanding detection techniques for distributed generation considering multiple parameters in order to secure the detection of islanding for any possible network topology. However, large training sets, tedious training process, and large number of neurons are the several disadvantages of the neural network (NN) based schemes. In addition, the said scheme takes longer time (more than 0.85s) to detect islanding conditions in a large power distribution network with multiple DG. Jing *et al.* [35] proposed islanding detection scheme based on the positive feedback of voltage harmonics distortion. Later on, Samui *et al*. [36] proposed wavelet singular entropy based islanding detection technique for lower power mismatches. However, real time implementation of the said scheme is very difficult due to hardware limitations. Moreover, all of the above scheme has not considered various other non-islanding events such as switching (ON/OFF) of capacitor bank, energization/de-energization of medium transmission lines; short-circuit on an adjacent feeder and switching (ON/OFF) of transformer. Further, aforementioned non-islanding events may produce noise due to which said Wavelet based scheme does not provide effective discrimination between islanding and non-islanding conditions. Hence, none of these schemes are capable to distinguish islanding condition with various non-islanding situations irrespective of power (both active and reactive) imbalances.

2.4. Interconnection transformer connections

The selection of the interconnection transformer connection has a major impact on how the distributed generator will interact with the utility system [37]. There are commonly two types of transformer winding connection, “Y” connection and “Δ” connection. Figure 6 shows five kinds of transformer after the combination of primary winding and secondary winding [38]. Each of these connections has advantages and disadvantages to the utility with both circuit design and protection coordination affected. The “Y” connected transformer offers nature neutral point. It is possible for DG to cooperate with the earthling system by choosing different earthling type of transformer.

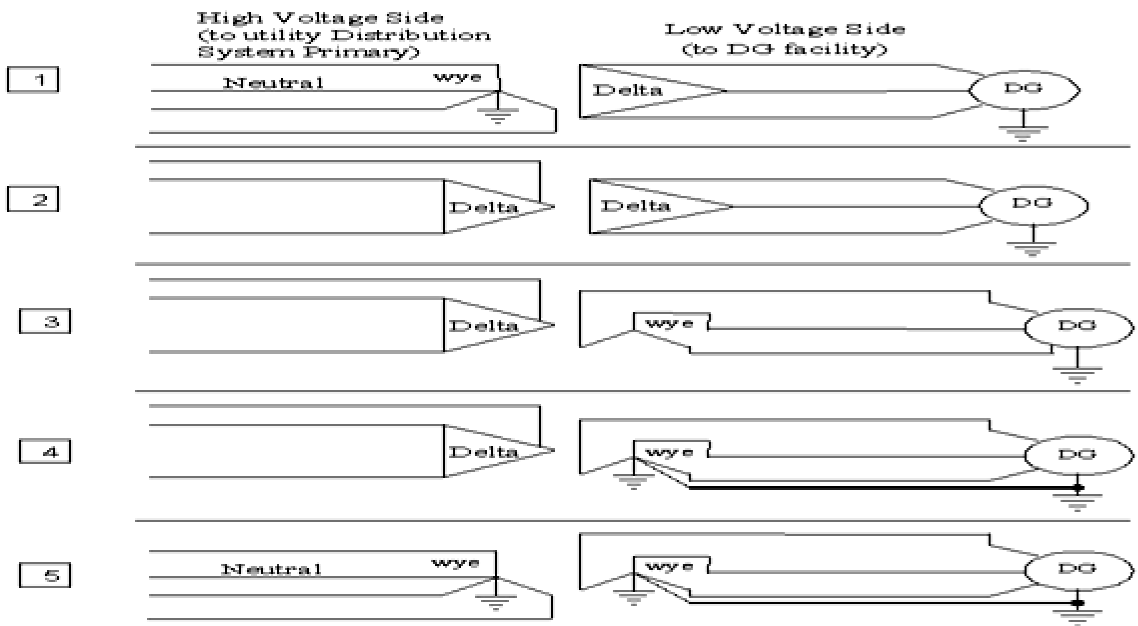

Figure 6 Interconnect Transformer connections

IEEE 1547 addresses the question of overvoltage that can be caused by a DG operating in parallel with the utility distribution system with a single sentence that states: "The grounding scheme of the DG interconnection shall not cause overvoltage that exceed the rating of the equipment connected to the area electric power system and shall not disrupt the coordination of the ground fault protection on the area electric system" [39].

The utility and DG owner have only two choices in selecting the primary winding configuration of the interconnection transformer.

1. Unground the primary windings (delta or wye ungrounded)
2. Ground the primary windings (wye grounded)

2.4.1. Ungrounded primary transformer windings

Consider the first three connections: Delta (HV)/Wye-Gnd (LV), Delta (HV)/Delta (LV), and Wye-Ungnd (HV)/Delta (LV) where (HV) indicates the primary winding and (LV) indicates the secondary winding. The major concern with an interconnection transformer with an ungrounded primary winding is that after substation breaker A (Figure 7) is tripped for a permanent ground

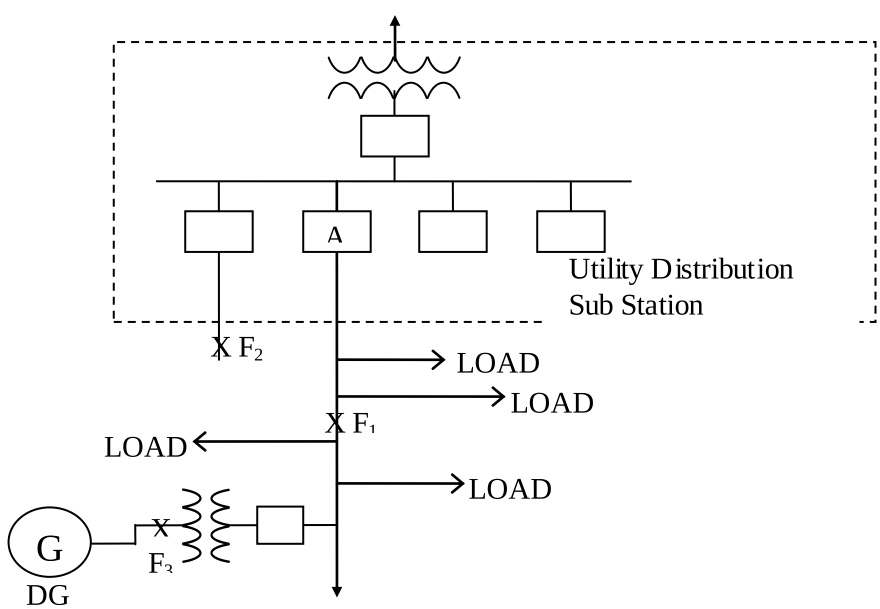

Figure 7 Single line representation of system

fault at location F1, the multi-grounded system is ungrounded. This subjects the L-N (line-to-neutral) rated pole-top transformer and lightning arrestors on the unfaulted phases to an overvoltage that will approach LL voltage. This occurs if the DG is near the capacity of the load on the feeder when breaker A trips. The resulting overvoltages will saturate the pole-top transformer which normally operates at the knee of the saturation curve. Many utilities use ungrounded interconnection transformers only if a 200% or more overload on the DG occurs when breaker A trips. During ground faults, this overload level will not allow the voltage on the unfaulted phases to rise higher than the normal L-N voltage, avoiding pole-top transformer saturation. For this reason, ungrounded primary windings should generally be reserved for smaller DGs where overloads of at least 200% are expected on islanding.

An advantage of this connection is that there is no source of zero sequence current to impact the utility ground relay coordination. Referring to Figure 7, for ground faults at F1 and F2, all of the fault current will come from the utility. In addition, any ground fault on the secondary of the transformer at F3 will not be detected at the breaker A location.

2.4.2. High side grounded Wye/ Low side delta connection

The next connection Wye-Gnd (HV)/ Delta (LV) establishes a zero sequence current source for ground faults on the distribution system, which could have a significant impact on the utility's ground relay coordination. As Figure 7 shows, for a ground fault at F1, the zero sequence fault current will be divided between the breaker A location and the grounded neutral of the distributed generator interconnection transformer. The distribution of this fault current will be dependent on the circuit and transformer impedances. During serious unbalance conditions such
as a blown lateral fuse, the load carrying capability of the interconnection transformer can be reduced. The advantages are that the relaying at breaker A will not see a ground fault at location F3 in Figure 7 and no overvoltage problems are associated with this connection.

2.4.3. Wye-wye connection

The last interconnection transformer connection to be considered is the Wye-Gnd (HV)/ Wye –Gnd (LV). This connection establishes a zero sequence current source as in the previous example if the generator is wye connected with a grounded neutral. The absence of a delta connection to circulate the zero sequence currents adds additional complexities for the relay engineer. Referring to Figure 7, sensitive settings on ground overcurrent relays at breaker A can detect and trip for ground faults at F3.

III. CONCLUSION

DG has much potential to improve distribution system performance and it should be encouraged. However, distribution system designs and operating practices are normally based on radial power flows and this creates a special challenge to the successful introduction of distributed generation. This paper has described a few of the issues that must be considered to insure that DG will not degrade distribution system power quality, safety or reliability. This paper focused on radial systems, although some of the issues discussed are common to low voltage distribution networks. Due to incorporation of DG, the traditional protection scheme for electric power distribution system lost its radial nature and behaves more like a transmission system feed from many ends. In a scenario such as this, the conventional protection philosophy needs to be revised. Hence, there is a need to develop a new protection relaying scheme for electric power distribution system which remains stable in all conditions.

REFERENCES

[1] W. El-Khattam and M. M. A. Salama, "Distributed generation technologies, definitions and benefits," Electric Power System Research, Vol. 71, pp. 119-128, 2004.

[2] Vu Van Thong and Ronnie Belmans, "Distributed generation overview: current status and challenges," International Review of Electrical Engineering, Praise Worthy Prize, Vol. 1, No. 1, pp. 178-189, April 2006.

[3] P. P. Barker and R.W. De Mello, "Determining the impact of distributed generation on power systems-I. Radial distribution systems," In Proceedings of the Power Engineering Society Summer Meeting IEEE, Vol. 3, pp. 1645–1656, 2000.

[4] P. Dondi, D. Bayoumi, C. Haederli, D. Julian and M. Suter, "Network Intergration of Distributed Power Generation," Journal of Power Sources, Elsevier Ltd, pp. 1-9,2002.

[5] M. M. Morcos and J. C. Gomez, "Letter to the Editor: On Overcurrent Protection/Voltage Sag Ride through in Systems with Embeded Distributed Generation," Electric Power Components and Systems, Vol. 37, No. 7, pp. 813-816, 2009.

[6] T. Hammons, and L. L. Lai, "International Practices in Distributed Generation Development Worldwide," IEEE Power Engineering Society, Energy Development and Power Generation Committee, Tempa, FL, USA, 2007.

[7] C. W. So and K. K. Li, "Protection Relay Coordination on Ring-fed Distribution Network with Distributed Generation," In Proceedings of IEEE Region 10 Conference on Computers, Communications, Control and Power Engineering, Beijing, China, Vol. 3, pp. 1885-1888, 28-31 Oct. 2002.

[8] J. Jager, T. Keil, L. Shang and R. Krebs, "New Protection Coordination Methods in the Presence of Distributed Generation," In Proceedings of 8th International Conference on Developments in Power System Protection, Amsterdam, The Netherlands, pp. 1-4, 5-8 April 2004.

[9] Dinesh Birla, R. P. Maheshwari and H. O. Gupta, "An Approach to Tackle the Threat of Sympathy Trips in Directional Overcurrent Relay Coordination," IEEE Transactions on Power Delivery, Vol. 22, No. 2, pp. 851-858, April 2007.

[10] Tales M. de Britto, Diego R. Morais, Marco A. Martin, Jacqueline G. Rolim, Hans H. Zurn and Raul F. Buendgens, "Distributed Generation Impacts on the coordination of Protection Systems Distribution Networks," Transmission and Distribution Conference and Exposition, Latin America, pp. 623-628, 8-11 Nov. 2004.

[11] James. B. Patton and David Curtice, "Analysis of utility protection problems associated with small wind turbine interconnections," IEEE Transactions on Power Apparatus and Systems, Vol. PAS-101, No. 10, pp. 3957-3966, October 1982.

[12] S. K. Salman and I. M. Rida, "Investigating the impact of embedded generation on relay settings of utilities," IEEE Transactions on Power System, Vol. 16, No. 2, pp. 246-251, April 2001.

[13] A. Fazanehrafat, S. A. M. Javadian, S. M. T. Bathaee and M. R. Haghifamt, "Maintaining The Recloser-Fuse Coordination in Distribution Systems in Presence of DG by Determining DG's Size," In Proc. 2008 IET 9th International Conference on Developments in Power System Protection, Glasgow, Scotland, United Kingdom, pp. 132-137, 2008.

[14] S. M. Brahma and A. A. Girgis, "Development of Adaptive Protection Scheme for Distribution Systems with High Penetration of Distribution Generation," IEEE Transactions on Power Delivery, Vol. 19, No. 1, pp. 56-63, 2004.

[15] S. Chaitusaney and Akihiko Yokoyama, "Prevention of Reliability Degradation from Recloser–Fuse Miscoordination Due to Distributed Generation," IEEE Transactions on Power Delivery, Vol. 23, No. 4, pp. 2545-2553, October 2008.

[16] K. Tuitemwong and S. Premrudeepreechacharn, "Expert system for protection coordination of distribution system with distributed generators," International Journal Electrical Power Energy System, Vol. 33, No. 3, pp. 466–471, 2011.

[17] H. Wan, K. K. Li and K. P. Wong, "An adaptive multiagent approach to protection relay coordination with distributed generators in industrial power distribution system," IEEE Transactions Industrial Application, Vol. 46, No. 5, pp. 2118–2124, Sep./Oct. 2010.

[18] S. A. M. Javadian, M. R. Haghifam and P. Barazandeh, "An adaptive over-current protection scheme for MV distribution networks including DG," in Proc. IEEE Int. Symp. Ind. Electron., Cambridge, U.K., pp. 2520–2525, 2008.

[19] M. Baran and I. El-Markabi, "Adaptive over current protection for distribution feeders with distributed generators," in Proc. IEEE/Power Engineering Society Power System Conference, Expo., Vol. 2, pp. 715–719, 2004.

[20] W. Xu, G. Zhang, C. Li, W. Wang, G. Wang and J. Kliber, "A power line signaling based technique for anti-islanding protection of distributed generators—part i: scheme and analysis," IEEE Transactions on Power Delivery, Vol. 22, No. 3, pp. 1758-1766, July 2007.

[21] G. Wang, J. Kliber, G. Zhang, W. Xu, B. Howell and T. Palladino, "A power line signaling based technique for anti-islanding protection of distributed generators—part ii: field test results," IEEE Transactions on Power Delivery, Vol. 22, No. 3, pp. 1767-1772, July 2007.

[22] Ye Zhihong, A. Kolwalkar, Zhang Yu, Du Pengwei and Reigh Walling, "Evaluation of anti-islanding schemes based on non-detection zone concept," IEEE Transactions on Power Electronics, Vol. 19, Issue 5, pp. 1171 – 1176, Sept. 2004.

[23] J. C. M. Vieira, W. Freitas, Xu Wilsun and A. Morelato, "Performance of frequency relays for distributed generation protection," IEEE Transactions on Power Delivery, Vol. 21, Issue 3, pp. 1120 – 1127, July 2006.

[24] W. Freitas, W. Xu, C.M. Affonso and Z. Huang, "Comparative Analysis Between ROCOF and Vector Surge Relays for Distributed Generation Applications," IEEE Transactions on Power Delivery, Vol. 20, No. 2, pp. 1315-1324, April 2005.

[25] F. Pai and S. Huang, "A Detection Algorithm for Islanding-Prevention of Dispersed Consumer Owned Storage and Generating Units," IEEE Transactions on Energy Conversion, Vol. 16, No 4, pp 346 - 351, December 2001.

[26] P. Mahat, Z. Chen and B. Bak-Jensen, "A hybrid islanding detection technique using average rate of voltage change and real power shift," IEEE Transactions on Power Delivery, Vol. 24, No. 2, pp. 764-771, April 2009.

[27] P. D. Hopewell, N. Jenkins and A. D. Cross, "Loss of mains detection for small generators," IEE Proc. Electric Power Applications, Vol. 143, No. 3, pp. 225-230, May 1996.

[28] J. E. Kim and J. S. Hwang, "Islanding detection method of distributed generation units connected to power distribution system," in Proc. 2000 IEEE Power System Technology Conference, pp. 643-647, 2000.

[29] Kari Maki, Anna Kulmala, Sami Repo and Pertti Jarventausta, "Problem related to islanding protection of distributed generation in distribution network," Power Tech 2007 conference, Lausanne, Switzerland, pp.1-6, 1-5 July 2007.

[30] M. Garmrudi, H. Nafisi, A. Fereidouni and H. Hashemi, "A Novel Hybrid Islanding Detection Technique Using Rate of Voltage Change and Capacitor Tap Switching", Electrical Power and Components Systems, Vol. 40, No. 10, pp. 1149–1159, 2012.

[31] S.R. Samantaray, K. El-Arroudi, G. Joos and I. Kamwa, "Fuzzy rule based approach for islanding detection in distributed generation," IEEE Transactions on Power Delivery, Vol. 25, No. 3, pp. 1427-1433, July 2010.

[32] Y. Zhu, Q. Yang and J. Wu, "A novel islanding detection method of distributed generation based on wavelet transform," International Conference Elect. Mach. Syst., Wuhan, China, 2008.

[33] D. N. Gaonkar, G. N. Pillai and R. N. Patel, "Seamless Transfer of Microturbine Generation System Operation between Grid-connected and islanding Modes", Electrical Power and Components Systems, Vol. 37, No. 2, pp. 174–188, 2009.

[34] S. R. Samantaray, B. Chitti Babu and P. K. Dash "Probabilistic Neural Network Based Islanding Detection in Distributed Generation", Electrical Power and Components Systems, Vol. 39, No. 3, pp. 191-203, 2011.

[35] Jing Ma, Chao Mi, Shuxia Zheng, Tong Wang, Xinbin Lan, Zengping Wang, S. James and A. G. Phadke, " Application of Voltage Harmonic Distortion Positive Feedback for Islanding Detection", Electrical Power and Components Systems, Vol. 41, No. 6, pp. 641-652, 2013.

[36] A. Samui and S.R. Samantaray, "Wavelet Singular Entropy based islanding detection in distributed generation," IEEE Transactions on Power Delivery, Vol. 28, No. 1, pp. 411-418, Jan 2013.

[37] C.J.Mozina, “Interconnect protection of Dispersed Generators”, proceedings of the Georgia Tech Relay conference, May 1999.

[38] Zhang Hao, Zhu Shouzhen, etc. “Study on grounding project of distributed generation connecting electric grid ” ,Journal of Shenyang Institute of Engineering (Natural Science) ,Vol.2, No.3, Jul. 2006, pp.198~202

[39] IEEE Std. 1547, “Standard for Interconnecting Distributed Resources with Electric Power Systems.”,2003.

