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OVERVIEW OF THE EFFECT OF DISTRIBUTED GENERATION ON PROTECTION IN POWER DISTRIBUTION SYSTEMS

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ABSTRACT
The popularity of Distributed Generation (DG) is on the rise due to various reasons like deregulation of power systems, increasing difficulty faced in erecting new transmission and distribution infrastructure and technological advances in the area of alternate energy sources. This is likely to change the traditional radial nature of the power distribution system into a multi-source unbalanced network. Researchers have addressed issues like the effect of DG on protection, fault location, stability and power quality of distribution systems penetrated by DG. This paper presents an overview of research done to address the protection issues. The paper presents a brief description of different aspects with relevant references and summarizes the emerging issues

KEY WORDS
Fault current, Fuse, Power distribution system, Power system protection, Protective device coordination, Recloser, Relay.

1. Introduction

Traditionally, the bulk power has been very cheap. Even after adding the transmission and distribution expenses to it, this power was still cheaper to the customers as compared to that obtained from a small local generation unit. However, in recent years, the cost of transmission is getting higher, and sometimes, it is not even possible to build new transmission lines because of environmental constraints, aesthetic reasons and right of way restrictions. This trend could load the existing lines heavily and hence, could result in instability and blackouts.

On the other hand, due to technological advances, some traditional and non-traditional generation technologies like wind power, solar power, micro-turbines, gas turbines etc are getting cheaper. Moreover, electric power has become a market commodity. In many countries, vertically integrated utilities generating, transmitting and distributing power to customers are a matter of the past. Generation, transmission and distribution are now owned by different entities and electricity is sold and bought in a "market". This trend, called deregulation, has encouraged many small generation owners to sell power in the electricity market. Such generation typically gets connected to the distribution system and is known as Distributed Generation (DG). DG is by definition generation that is of limited size (few kilowatts to few megawatts) and interconnected at substation, distribution feeder or customer load level [1-5]. DG technologies include solar cells, wind turbines, fuel cells, micro turbines, gas turbines and internal combustion engines [2-5].

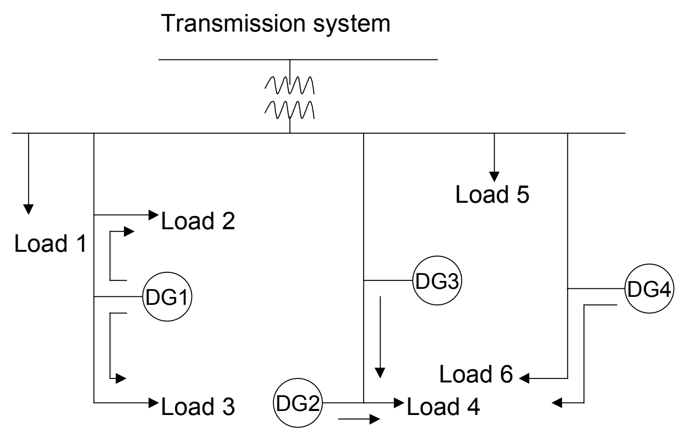

Fig. 1. A close-up of the distribution system of the near future

Thus, due to the difficulty in increasing transmission infrastructure and the pressures of deregulation, much future growth of electric load is likely to be met by DG. It is predicted that by 2010, 20% of new generation going on line will be DG [1]. Fig. 1 illustrates the resulting scenario. In such distribution systems, DG would feed loads around its location, thus relieving the burden on the substation source. This will change the nature of the system from a single source (radial) network to a multi-source unbalanced network. In the past, distribution system protection schemes were designed assuming the nature of the system to be radial [6-9]. This paper outlines the problems in this traditional protective device coordination between fuses, reclosers and relays due to penetration of DG and identifies relevant references for further reading. In summary, some emerging issues are mentioned.

It should be noted here that there have been some instances of local generation being interconnected with distribution systems. However, these were “special” cases and the protection schemes were designed accordingly. In the United States, IEEE Std 1547 [10] was followed to design the protection schemes in such cases. However, in the past, the power available from such DG was not essential to support the load on the system, and hence the standard suggested immediate disconnection of DG for any fault on the distribution system. Islanding was never encouraged. In future, since the DG will be expected to support a part of the feeder load, these practices will have to be modified. In fact, the Draft Application Guide for IEEE Std. 1547 [11] is already looking into the procedures for formation of intentional islands.

2. Problems in Fuse-Fuse Coordination

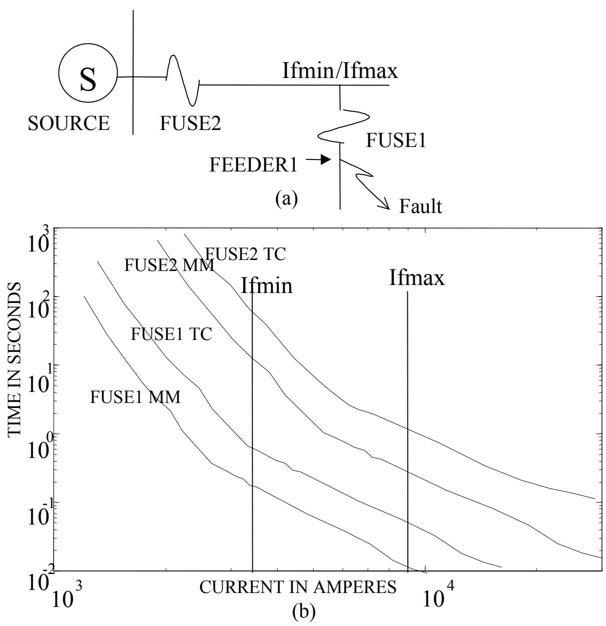

Fig. 2. Traditional fuse-fuse coordination without DG

Fig. 2 shows the coordination between fuses in radial systems [6-9]. A fuse has two characteristics, viz., Minimum Melting (MM) and Total Clearing (TC). Fig. 2 shows how fuse-fuse coordination is traditionally done in a radial distribution system without DG. Fig. 2 (a) shows the two fuses to be coordinated. In order that fuse1 and fuse2 be coordinated, the TC characteristic of fuse1 should be below the MM characteristics of fuse2 by a safe margin for any fault on feeder1. This would ensure that for any fault on feeder1, fuse1 would clear the fault (open) before fuse2 is damaged. It should be noted here that when the system is radial, the same fault current would pass through both fuses in case of a fault on feeder1. Fig. 2(b) shows the coordination graphs. As long as the fault current values for faults on feeder1 are within coordination range (Ifmin to Ifmax), the fuses will be coordinated. Fuse2 in this case would serve as back-up protection to fuse1 for all faults on feeder1. When DG penetrates the system, values and direction of the fault currents flowing in the system for any given fault will be modified [12,13]. It is also possible to have "back-feed" in case of a fault.

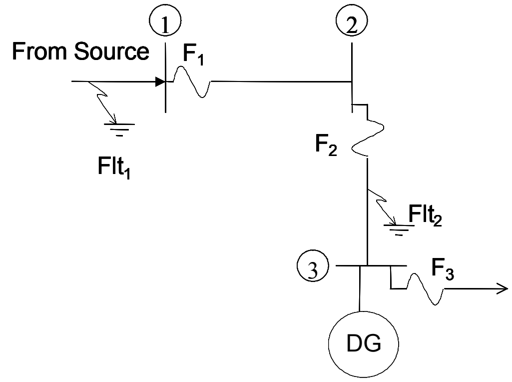

Fig. 3. Potential coordination problems between fuses due to distributed generation

Brahma and Girgis [14,15] look closely at the coordination problem between fuses. A typical case is shown in Fig. 3. Let us assume that fuses F_1 and F_2 are coordinated without considering any DG, for downstream fault currents for faults on feeder 2-3 (according to the procedure illustrated in Fig. 2). Now, suppose DG connects to bus 3 as shown in Fig. 3. Then, in case of fault Flt_2, the same downstream current passes through both the fuses and selectivity requires that F_2 operate before F_1. In case of fault Flt_1, the same upstream current flows through both fuses, and in this case, selectivity requires that F_1 operate before F_2. This is obviously not possible, since a fuse does not have direction-sensing capability. References [14,15] explain this through coordination graphs. Reference [15] analyzes part of an actual distribution system to identify some more potential cases of mal-coordination that depend on size and placement of DG in the system. The paper concludes that in general, if the protection scheme is not changed, the only way to maintain coordination in the presence of arbitrary DG penetration is to disconnect all DG units instantaneously in case of a fault. This would enable the system to regain its radial nature and coordination would withhold. But this would mean that DG is disconnected even for temporary faults.

3. Problems in Fuse-Recloser Coordination

About eighty percent of the faults taking place in a distribution system are temporary, i.e., they disappear by themselves in a short time. Obviously, it is not desirable to let a fuse blow and isolate a section in case of a temporary fault. Reclosers are therefore introduced in the system and coordinated with fuses to make sure fuses blow only for permanent faults, thus improving the reliability of power supply.

Fig. 4 shows a typical distribution line with a conventional recloser and a tapped load feeder protected with a fuse. Let us assume that DG is not connected yet. The recloser on the main line has to coordinate with this fuse for all faults taking place on the feeder. Different settings are usually employed for phase faults and ground faults. It should be noted here that for all the faults on the load feeder, currents in the fuse and the recloser would be the same in a radial system. The two devices must coordinate for all possible fault currents on the load feeder.

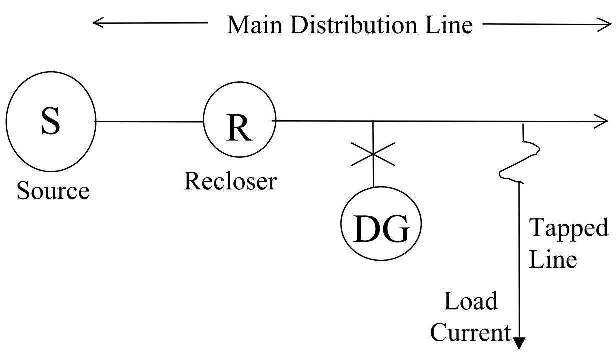

Fig. 4. A typical distribution system section with recloser and fuse

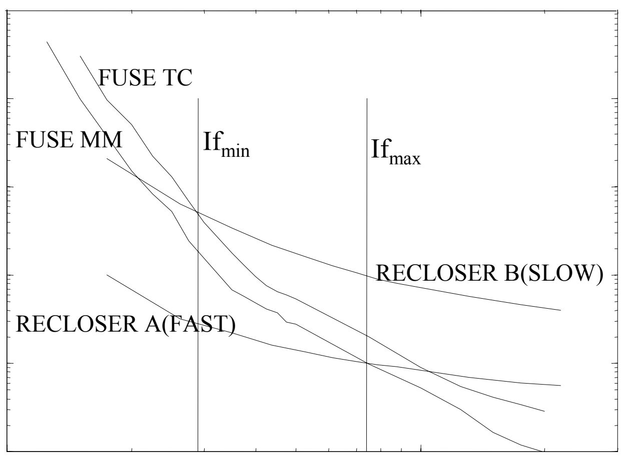

Fig. 5. Coordination between recloser and fuse shown in Fig. 4

The coordination is shown in Fig. 5 [9, 14]. It shows the MM and TC curves of the fuse. It also shows the "A" (fast) and "B" (slow) curves of the recloser. The philosophy here is that the fuse should only operate for a permanent fault on the load feeder. For a temporary fault, the recloser should disconnect the circuit with fast operation and give the fault a chance to clear.

In Fig. 5, it can be seen that the fast (A) curve of the recloser lies below the MM curve of the fuse between If_{min} and If_{max}. Therefore, for a current-value between If_{min} and If_{max}, the recloser operates in less time than the time required to damage the fuse. This will isolate the fault from the source. The recloser waits for some time and closes again. If the fault has cleared by this time, supply is restored due to closing of the recloser; if not, the recloser opens again in fast mode. It is customary to give two chances to a temporary fault to clear although there is some flexibility in choosing the operating sequence and the "opening" time interval. If the fault is temporary, it will clear before the recloser closes after the second fast operation; if not, the fault is interpreted as permanent and the fuse is allowed to open and isolate the fault. Fig. 5 shows that the TC curve of the fuse is below the "B" curve (the slow curve) of the recloser between If_{min} and If_{max}. Therefore, for a permanent fault, the fuse will open before the recloser operates in slow mode. If the fuse fails to operate, the recloser will back it up by operating in slow mode and finally locking out. The coordination curves of recloser and fuse have to be modified to account for heating and cooling effect of fuse [9,14]. The protection engineer has to make sure that the fault level for any type of fault along the load feeder is between If_{min} and If_{max}, since the coordination described above exists only in that range.

Brahma and Girgis [14], [16-17] discuss fuse-recloser coordination in the presence of DG. A typical case is shown in Fig. 4. Suppose the recloser and the fuse are coordinated for faults on the tapped lateral without considering any DG. Now DG is connected somewhere on the main feeder between the recloser and the fuse as shown in Fig. 4. In such a case, a fault on the lateral would cause more current to flow through the fuse than through the recloser. This can result in a loss of coordination between these devices. Moreover, fault current will flow through the recloser even for upstream faults. Reference [16] discusses this situation in detail and concludes that coordination in the presence of DG can be achieved with microprocessor-based reclosers available in the market. Such reclosers would have to be made directional towards the downstream side of the feeder. But in this case too, all DG units downstream of the recloser would have to be disconnected before the first reclose takes place to avoid connection of two live subsystems without synchronism. Thus, in this case too, DG has to be disconnected even for temporary faults. Reference [17] shows that even this coordination is likely to malfunction in the presence of significant fault resistance.

4. Problems in Relay Coordination

Fig. 6 (a) shows a main distribution feeder fed through source "S" and protected by inverse overcurrent relays R1, R2 and R3. The coordination between these relays is shown in 6 (b) [7-9]. The philosophy here is, for maximum fault current in line 3 (which would be for a fault at bus 3), time of operation of relay R2 is made larger than time of operation of R3 at least by a time interval called "Coordination Time Interval (CTI)". CTI depends on factors like errors in current transformers, potential transformer and relays and on circuit breaker opening time. In case of electromechanical relays, overshoot is also considered. Similarly, relays R2 and R1 are coordinated for a maximum fault at bus 2. The nature of inverse relay curves is such that once coordinated for maximum current, they will be coordinated for lower fault currents too. As is clear from fig. 6 (b), R2 will back up R3 and R1 will back up R2.

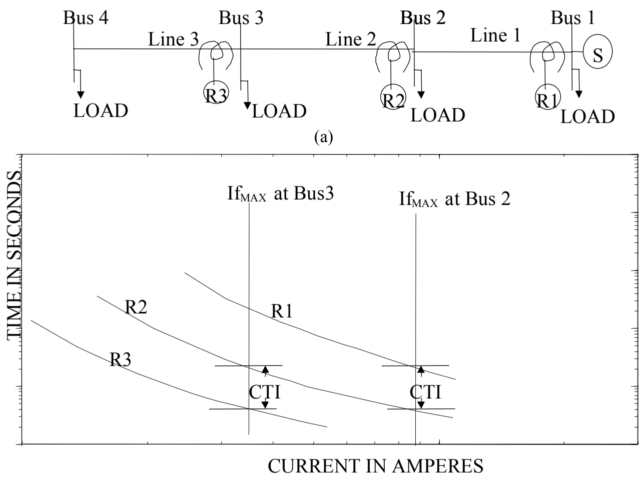

Fig. 6. Relay-relay co-ordination without DG

Now, let us assume DG is connected to the feeder as shown in fig. 7. Depending on placement of DG on the feeder, different possibilities will arise. These are discussed in [14-15]. Dugan et al [18] show that a relay in such condition may underreach for high resistance faults. References [14-15] conclude that introduction of directional relays can handle the new scenario that involves fault currents flowing both upstream and downstream in the system.

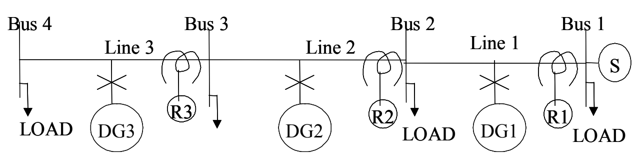

Fig. 7. Primary Distribution Feeder Penetrated with DG

5. Conclusion and Emerging Issues

From the discussion in sections 2-4, it is clear that the coordination involving fuses and reclosers can malfunction due to penetration of DG. The malfunction would depend on the placement, capacity and number of DG in the system. There is at present no guide to restrict either location or number of DG connecting to a distribution feeder. The following issues emerge as significant and require closer attention:

1) How to ensure disconnection of the faulted section from the supply in an environment where the protective devices do not coordinate? This requires location of the faulted section first. In the radial system, location of the faulted section was never an issue because protective devices correctly completed this function. Brahma and Girgis present a scheme to address this issue in [19]. They present a scheme that uses synchronized phasor measurements at the source and DG terminals and locates the faulted section without depending on the operation of protective device. However, some faulted sections in radial parts of the system are not identified correctly with this scheme. The scheme does not locate the fault exactly on the faulted section.
2) Having identified the faulted section, how to handle temporary faults? Since DG participates in feeding the feeder load, it would not be feasible to continue with the current protection practices of disconnecting DG for every temporary fault, especially because such faults form about 80% of the total faults occurring on the distribution system. This issue, therefore, translates to maintaining reliability of supply in a system supported by DG. Obviously, there is a direct conflict between requirements for reliability and requirement s for protection of such systems. Brahma et al [19] address this issue by proposing to divide the system into islands and isolating only the island in which fault is sensed. However, for reconnecting the isolated island after the fault is cleared, check-synchronizing relays are required at the switches connecting the island with the system.
3) How to form stable islands? Mao and Miu [20] propose a scheme to optimally place switches in the system to achieve this. The IEEE Power System Relaying Committee (PSRC) report [21] outlines the options available and concerns faced by a protection engineer in dealing with intentional islanding. This report also deals with issues like connection of interface transformers, device coordination problems, need and availability of communication circuits, safety concerns and synchronizing the intentional island to the system during restoration process.

It is important that the solutions must also consider the fact that the system configuration as well as DG connection status are likely to change from time to time. Mozina [22] claims there are no “standard” solutions, but only choices with undesirable drawbacks. This reference also evaluates IEEE standard P-1547 and identifies some specific issues that require further consideration. However, this “piece-wise” approach suggested in [22] is not likely to work unless there are restrictions on the amount and placement of DG in the system. More general solutions are required. Reference [23] includes a detailed analysis of problems and possible solutions discussed in this paper.

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