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Impact of Distributed Generation on Relay Protections of Distribution Grid

ZHOU Bin*[1,2], YING Liming[1], ZHU Yonggang[1,2], HUANG Chao[1]
[1]School of Electrical Engineering, Wuhan University, Wuhan 430072, Hubei Province, China;
[2]Hubei Electrical Power Company, Wuhan 430077, Hubei Province, China 、
*Corresponding author, e-mail: zhoub@hb.sgcc.com.cn

Abstract

Distributed Generation (DG) generates electricity from many small distributed energy sources or even customer's small power plants. It always comes up with the terminal customer power quality management and the technology of energy cascade utilization. DG has lots of characteristics such as one single point of access, being power and being load, two operating mode in a grid or as an island, a great deal of application of power electronic devices, easily influenced by natural environmental factors etc. DG has impacts to the original grid in terms of the grid structure, the direction of power flow, the fault current level when a fault happens, etc and subsequently the relay protection mechanism must be looked into. This paper analyses the impact of accessing the DG on the distributed grid in three cases which are the DG accessing to the end of the distributed feeders, to the middle, and the DG accessing to lines, on relay protections. At the end of the paper it also comes up with improvements in detail.

***Keywords**: distributed generation, distribution grid, relay protection, reclosure*

1. Introduction

Distributed generation (DG) is a new electric power technology, and it is the result of earth environment sustainable development policy and technical progress [1]. The IEEE defines distributed generation as the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system [2]. Distributed generation including the power of small internal combustion engines, micro-turbines, fuel cells, and various forms of renewable energy sources such as photovoltaic cells for solar power, wind power and biomass power generation. The benefits of DG can be concluded into the followed aspects: improving energy efficiency, increasing the diversity of energy use to solve the energy crisis and energy security, playing a role in peaking shaving, improvement of voltage profile, reduction of distribution and transmission losses, increased reliability, solving the problem of electricity supply in remote areas, reduction of carbon emission and investment deferral. [3-10]. However, introduction of numerous DGs with larger capacity has been reported to cause the increase of the short-circuit current as well as the mal-operation of the protective devices and the deterioration of the power quality [11-12]. Reference [13] analyses the impact of DGs in a power network to the operation of ARDs in different manners, by using of a Fault Current Limiter to avoid large current when fault happen was reported in [14]. For reliability and security, it is important to further investigate these impacts before DGs are interconnected to any MV network [13].

From the standpoint of the distribution grid, the DG is a controllable unit and that shows the load character and produces the power. When a fault occurs, the DG shows the power character and generates a fault current. From the relay protection perspective, distributed generation model can be represented as a power supply and a reactance connected in series. What needs to be considered is how large the fault current the distributed generation provides. For different types of DG, the reactance value is also different, it represents the power of the fault current injection capacity. Barker had the research on various types of distributed power fault current injecting ability, as shown in Table 1 [15].

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Table 1. Fault Current Insert of Different Kinds of DG

DG type	Fault current injection capacity
converter	100%~400%, the duration depends on the control devices
synchronous generator	500%~1000%, gradually decay to 200%~400%
asynchronous generator	500%~1000%, attenuated to the negligible level in 10 cycles

Base on this point, the distribution grid is seen as a double-ended power supply system rather than the single-ended after accessing the DG. The relay protections and even direction components should then be installed at both sides of lines between the DG and the distribution grid. Besides, the effect of the increased current must be considered in the downstream of the access point, and the branching factor should be calculated reasonably.

In this paper, the author analyzes several different impacts, especially the short-current faults, when DG in different location of the network. A method is proposed to make the original relay protections and automatic reclosing adjusted accordingly after accessing the DG.

2. Impact of DG on Distribution Grid Protection

Most of the distribution grid is a radial system; even for a mesh like grid, it is still running as a radial like system through the open loop grid points.

There are several ways of distribution grid relay protections in the traditional power system. Based on whether or not implementing the distribution automation, protections can be divided into three types: ① No distribution automation. The common protection strategy is the phased-current protection, the fuse, the circuit breaker and so on. ② The distribution automation based on the reclosure mode. Locate and isolate the fault by cooperation of the reclosure and the section switch. ③ The distribution automation is based on the feeder terminal unit (FTU) mode. The FTU and the main station locate and isolate the fault through communication and by using of circuit breakers. Protection devices follow the principle of selectivity in the above three methods. As to the configuration of protections, the coordination among protections may derive from the cooperation between two devices. A three-phase protection can be made up of two group protections, shown in Figure 1.

The P_l and P_2 divide the line into three segments: the upstream of A, the segment AB and the downstream of B. The DG access approaches have seven ($C_3^1+C_3^2+C_3^3=7$) ways. It is not reasonable that the DG accesses to the upstream of A since the coordination between P1 and P2 doesn't change. So the access approaches will be three ways ($C_2^1+C_2^2=3$): the DG accesses to the segment AB, to the downstream of B and to both the segment AB and the downstream of B. The protections coordination should be considered when a fault occurs at the downstream of B, at the segment AB and at the upstream of A. The asynchronous reclosure and the island situation should also be looked into [16].

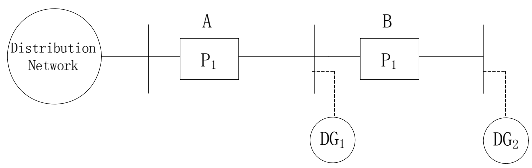

Figure 1. The coordination among two sets of protective equipment

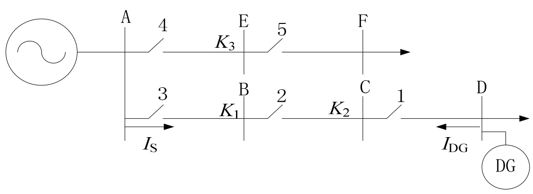

Figure 2. The DG accesses to the end of distribution feeders

2.1. DG Accesses to End of Distribution Feeders

As shown in Figure 2, the DG accesses to the feeder bus terminal D, the system becomes bilateral power supply system.

1）When a fault occurs at K_1, the fault current which comes from the DG will flow through the protection 1 and 2. We hope that protections can make the fault line AB isolated, however, the B side of the AB segment has no protections or breakers, so the protection 2 of BC segment cut the fault. According to the requirement of selectivity, the protection 2 should work before the protection 1, but When a fault occurs at K_2, the same fault current flows through the protection 1 and 2, therefore, the existing single-ended three-current protection cannot guarantee the selectivity of protection.

2）When a fault occurs at K_3, only protection 4 should work. But the reverse fault current which comes from the DG leads to the malfunction and non-selective of protection 1, 2 and 3. According to the feature of the three-current protection, protection 1 most likely malfunctions with the minimum starting current. Because the fault current from the DG is added to the one from the system side, the increasing fault current flowing through protection 4 makes loss the selectivity and the cooperation with the protection 5 by reason of the extension of the scope of protection 4.

2.2. DG Accesses to Middle of Distribution Feeders

1）As shown in Figure 3, when a fault occurs at K_1, protection 3 cuts the AD segment and no power at the downstream of the fault point in a system without the DG. After the DG connecting to the bus B, if protection 3 works alone when a fault occurs at K_1, the BD line would enter into the island operation. Whereas, because of no protection between the fault point and the bus B, the continuous supplement of the fault current from the DG to the fault point will result in the self-protection of DG making itself leaves the power grid in the end. So it is needed to install protection devices and direction components at the AB line close to the bus B side.

2）When a fault occurs at K_2, the DG causes the increase of the fault current flowing through the protection 2 and its extension of the scope. Particularly the protection 2 will lose the selectivity and the cooperation with the protection 1 when its scope reaches the CD segment. The same problem may happen to the limit current protection 2 and 3. By contrast, the fault current flowing through the protection 3 is reduced by the DG and its scope may become too short to be the back-up protection of the adjacent lines.

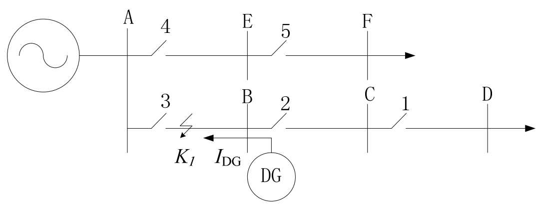

Figure 3. The DG Accesses to the Middle of Distribution Feeders and K1 has Fault

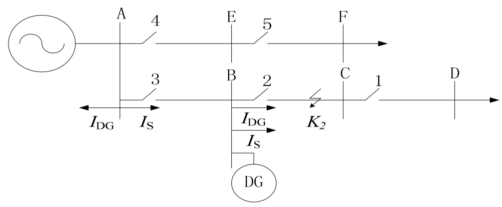

Figure 4. The DG Accesses to the Middle of Distribution Feeders and K_2 has Fault

3）When a fault occurs at K_3, if the fault current flowing through the protection 3 is strong enough, it perhaps misoperates unless installing direction components.

2.3. DG Accesses to Lines

As shown in Figure 5, to more clearly analyse the impact of DG connection on the protection 3, we ignore the effects from other feeders, simplified as shown in Figure 6.

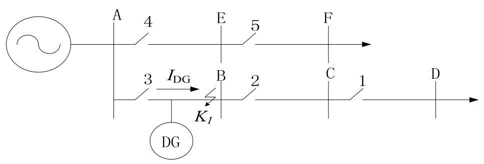

Figure 5. The DG Connects to the AB Line in a Distribution Grid

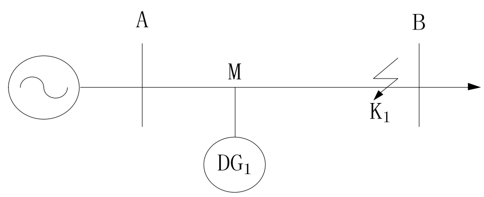

Figure 6. Simplified Diagram of the Distribution Grid

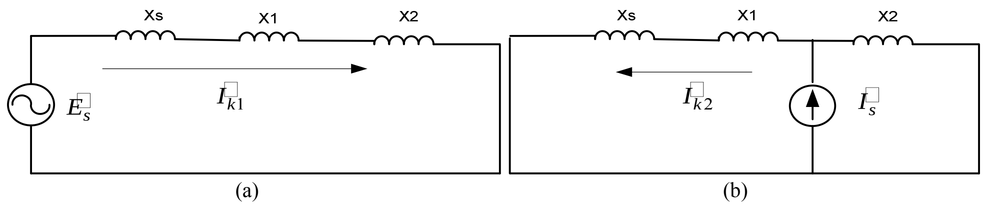

Figure 7. The Superposition Network

According to the superposition theorem, shown as Figure 7, the short current flowing through the head side

$$I_k = I_{k1} - I_{k2} \tag{1}$$

We assume that the system voltage $\dot{E}_S$ and the impedance x_s is constant. Then I_{k1} is constant and I_k depends on I_{k2} which is the position of the DG. x_1 is the impedance of the AM line. x_2 is the line impedance from M point to the fault point. Assuming that $x_1 + x_2 = l$, *l* is the line impedance from A point to the fault point. We get the following equation:

$$I_{k2} = \frac{x_2}{x_s + x_1 + x_2} I_s = \frac{l - x_1}{x_s + l} I_s \tag{2}$$

As shown in Figure 8, the position where the DG accesses is farther away from the head side, the smaller impact on the protection.

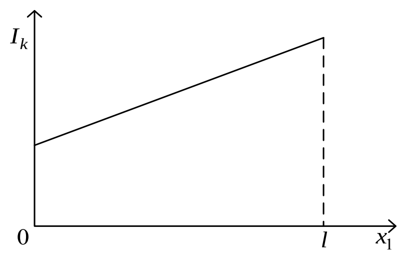

Figure 8. The Curve of the Current Flowing through the Protection 3

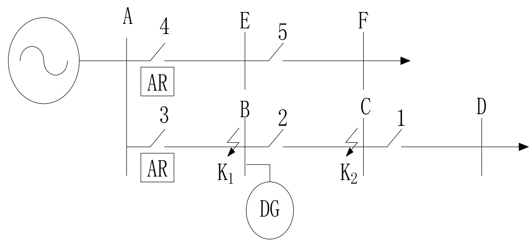

Figure 9. DG Feeder in Failure

3. Impact of DG on Automatic Devices of Distribution Grid

3.1. The Line Fault at the Feeder to where the DG Accesses

Power system operation experience has shown that on overhead lines the majority of failures are instantaneous and permanent fault is about 10%~20% among all of them. The automatic reclosing applications can significantly improve the reliability of power supply distribution network. The automatic former acceleration reclosing is generally used for radial line with paragraphs series, which is only mounted to a line close to the power.

Figure 9 shows two feeders adopt the automatic former acceleration reclosing devices which are installed at the protection 3 and 4. In the case without the DG, when a transient fault occurs at K_1, the protection 3 acts instantaneously and recloses to eliminate the transient fault. In this case, the protection 3 breaks instantaneously to make the arc blowout, and then recloses after cutting the fault. If the same fault when the DG connects to the bus B happens, although the system side doesn't supply the fault current any more, the continuous supplement from the DG makes the arc keep on. So the reclosure failure of the protection 3 may lead to a permanent fault and the expansion of the blackout range. Similarily when a transient fault occurs at K_2, the former acceleration reclosing trips off immediately. But the supplement of the fault current from the DG will make the reclosing failed. To avoid the failure of the automatic former acceleration reclosing, there are two schemes:

1） When a fault occurs, cut out the DG to guarantee the success of reclosing by the additional protection. But the DG's power supplement to the downstream load will be interrupted if the fault is a permanent one.

2） Install protection devices on the AB line close to the bus B. When a fault occurs at K1, protections on both sides of the AB line take effect so the fault is cut off reliably. The DG side and the downstream load will turn into an island. This approach ensures the continuous power supply to the downstream load, but problems due to the island comes up, such as how to adjust the voltage and the frequency to keep the power quality, how to deal with the asynchronous problems after cutting off the fault. It requires feeder protections, the adjustment of automatic devices and the control of the DG to solving these problems.

3.2. The Adjacent Feeder Line Fault

As shown in Figure 10, when a transient fault occurs at K_1, the protection 4 works and cuts off the fault and then recloses. But the protection 3 which locates the upstream of the feeder may malfunction when the fault current flowing through K_1 is strong enough. So does the automatic former acceleration reclosing of the protection 3. If there is a permanent fault at K_1, the protection 4 can't reclose successfully and protections of the feeder will act orderly by setting time limits. When the fault point K_1 is out of the range of protection 4, it is needed the time delay limit current protection to cut off the fault. But it is probably that the protection 3 will malfunction because of the continuous fault current from the DG. So it is necessary to consider about installing direction components on upstream protections to judge the anti-power flow from the DG.

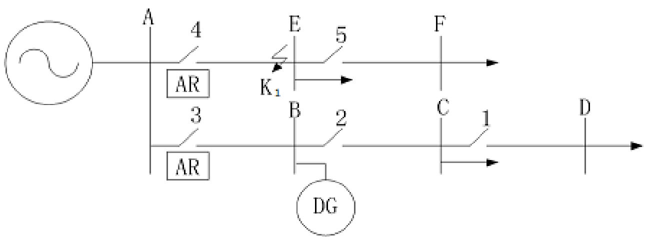

Figure 10. The Structure of the Adjacent Feeder Line Fault

According to the analysis of the two cases, we can find that the existence of the DG contributes to the failure of reclosing, becoming a permanent fault and spreading the range of the blackout when a transient fault occurs at the feeder with the DG. The upstream protections and reclosure devices of the feeder with the DG may malfunction when a fault occurs at the adjacent feeder.

4. Conclusion

Through the above analysis, due to the introduction of DG, the traditional distribution grid in which only single directional power flow from the supply to the loads is not valid any more. Therefore, the initial operating characteristics of protections on the distribution grid are also affected by the access of the DG. ① Partial protections not functional, selectivity lost and the sensitivity reduced, and is related to the location of the access points distributed generation; ② Protections of the line or the adjacent line malfunction. The impact on the reclosure is that a synchronizing switching on, the failure of reclosing, the arc renewing, becoming a permanent fault and the spread of the blackout range. To eliminate these impacts, one approach is considering about the double direction character of the flow after accessing the DG to install direction component. The other method is turning the DG into the island state immediately when a fault occurs. But how to configure protections of the DG working as an island state needs more study.

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