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Effects of the Presence of Distributed Generation on Protection and Operation of Smart Grid Implemented in Iran; Challenges and Solutions

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Abstract

Installation of distributed generation (DG) in distribution networks, in addition to the benefits, will also cause drawback and disadvantages which can bring difficulties for grid operator. Thus, prior to installation of DGs, it is essential to have deeply studied about their installation in the network and it is needed to make some changes in traditional network. Implementation of smart grids is one of the main requirements for the proper and efficient operation of DGs. In Iran, Smart grid is also being implemented, but with the development of DGs, electricity distribution companies face new problems related to DGs every day. One of the most important problems is about effects of the DGs on proper operation of protective equipment which is mainly due to radial distribution network. That is because in Iran, despite the implementation of smart grids, distribution networks are designed and implemented radially and airlines with isolated neutral point is usually used in the distribution network. So, in this article, the impacts of distributed generation resources on distribution networks in Iran and Protection and operational problems which may cause in this area are studied and solutions to these problems are provided.

Keywords: *distributed generation (DG), operation, protection, distribution networks smart grid relay*

1. Introduction

One of the most important factors that have a huge impact on international relations and progress in the world today is supplying the required energy of consumers. Now, the most important sources of energy that provide a large part of the world's energy needs are fossil energy sources. These resources which are named as nonrenewable resources is running out and their price is influenced by political and economic situation in the world and they have currently an upward trend. In addition, using these energy resources has changed focus of researchers and administrators of this section to other sources of energy due to some issues such as insecurity of energy supply and the great value of this type of fuel, including petroleum and petrochemical industries and the most important, environmental issues resulting from using these fuels which has led many problems in earth's ecosystems. Hence, it is imperative to find alternative sources of energy supply for human needs due to population increase and demand for energy. According to these reasons, using renewable energy resources in the form of distributed generation (*DG*) has expanded in most parts of the world in recent years. These resources are not only endless, but also they have not problems related to fossil fuels such as increasing global temperatures and pollution of harmful gases and there are various types of these energy resources freely in most regions of the world. Although the phrase of *"DG"* is a new concept in economic literature of power industry, but it is not so new. In the early days of electricity generation, *DG* was a universal principle. So that, the first power plants feed only nearly subscribers and their neighbors. But it should be noted that connecting *DG* systems to global network influences on the load flow direction, voltage profile, network stability, power quality and protection of distribution systems [1].

In current and traditional networks proper operation and connecting *DGs* to grid is difficult and complicated, because such networks don't have enough adequacy to integrate these resources. The reason is hierarchical structure and centralized control style in such networks which is not designed for two-way electrical current flow. Also, extensive use of hybrid

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electric vehicles and all-electric battery vehicles is practically impossible in such networks, because these vehicles are able to face network with some problems such as overload. Also, users of these vehicles may do not have information about the optimal time to charge their car battery. So, it is recommended to make electricity networks intelligent to expand and correct operation of the distributed generation sources (*DGR*) [2].

Better and monotonic integration of *DGR* such as solar and wind energy sources is one of the achievements in the implementation of smart grid in power industry. So, with implementing smart grids, we can use these systems in control *DG* system to minimize its impact on the distribution network. Figure 1 shows an example of the restructured and smart power grid with presence of the *DGRs*.

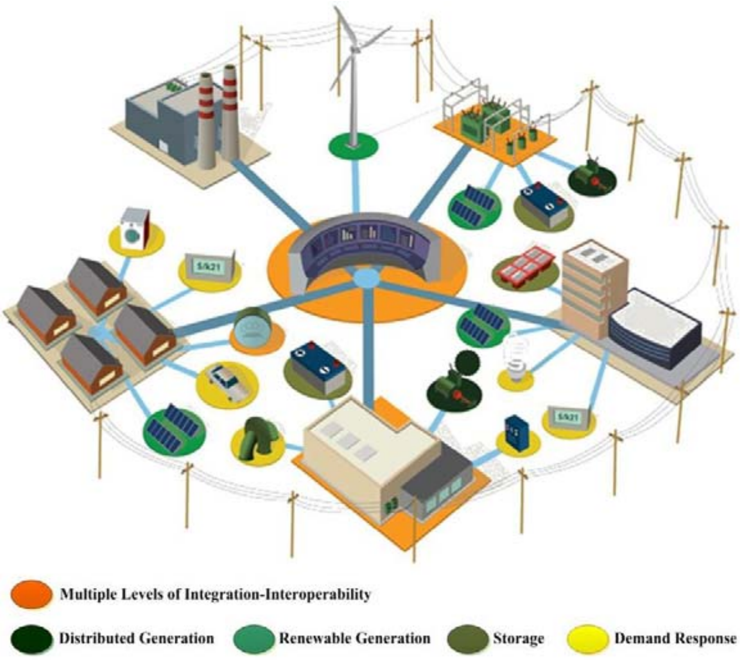

Figure 1. The structure of intelligent networks with presence of distributed generation sources (*DGR*)

Also, we can control generated power by the *DGs* using smart grids and produce power according to demand. It also causes voltage regulation, improving the voltage profile and power quality control. It should be said that, the presence of *DG* in distribution system causes to impair relay settings and to disorder protection systems. *DGRs* impact on traditional protection of buses in different ways such that: increased levels of short-circuit, islanding network, prevent automatic reclosing, non-synchronous reclosing, blind protection, relay function delay, Etc. These factors can cause lack of proper functioning of the relay, disrupt the fast reclosing and also security risks at earth fault. Of course, we can solve these problems with the implementation of specific measures in the smart grids [3].

In Iran, many actions are being done in order to make intelligent electricity networks, but since distribution networks are designed passively and operated radially yet, there is not any generator or transmission in parallel manner. In Iran, protection is appeared as one of the main obstacles against widespread use of *DG*. So, the effect of connecting the new *DG* units to the distribution network should be investigated so that necessary planning to enhance network reliability be done. In this article, we will discuss about existing safety problems in widespread use of the *DGR* in Iran and we will tell the solutions to this problem [4-6].

2. Status of Intelligent Distribution Network in Iran

According to studies on the roadmap for the power industry in the decades 2030 and 2050, it is expected that the electricity industry in the coming years will have a large changes. So, it is essential to implement smart grids in distribution networks regarding to the changes facing this industry. Distribution networks in Iran, like other parts of the world, are moving towards automation network or smart grid. Implementation of automation network in the distribution networks is very important and costly and due to its high cost and lack of economical benefits, we can say that only 15 percent of distribution networks be intelligent in many countries. Moreover, make distribution networks intelligent is required to telecommunications network, capable experts and long-term process [7].

In Iran, smart grids and automation has not been implemented completely. Moreover, in Iran, distribution networks are designed and are operated essentially in radial from and that is one of the big problems facing the network intelligence in Iran. But, it is necessary to use *DGRs* regarding to the upward trend of population and network subscribers. So, *DGR* usage in the distribution network causes issues such as security problems in existing distribution networks. Due to increase of presence of *DGs* in the network, paying attention to the protection matters has enhanced and, it is expected to introduce new methods for planning to interconnection of *DG*.

In Iran, knowledge and practical experience about potential problems of system is very low among designers due to rapid increase in demand and rapid development of *DG*. In Iran, distribution networks are designed and are used normally in radial form. In distribution networks usually use overhead lines with isolated neutral point. These studies have focused on short-circuit faults due to isolate neutral point and transformer type (Y_n □) using in *DG* units. In such a network, protection is done by over current and fixed timing relays that each one protects a feeder. Also, a separate relay is used to detect ground faults. In the following sections, we will review effects of *DGRs* in distribution networks in Iran and created problems in this context. Also, some strategies will be presented to fix these problems at the end of each part [8].

3. The Effects of DG on Operation and Protection of Distribution Network

By adding *DGRs* in distribution networks, radial nature of these networks is destroyed and it causes problems in design of protection and operation. It is essential to have the basic information of distribution network structure and their protection criteria to illustrate protection problems in presence of *DG*. Traditional performance of distribution networks based on one-way flow of electricity. Therefore, it is not complicated to design protection systems for this type of networks and this matter is true during flowing the fault current. This situation will change considerable with arrival of *DG* [9].

The amount and direction of fault current varies due to *DG* participation and consequently, all of transmission and distribution system exchange some properties together. In general, basic security problems existing due to the presence of *DGs* in distribution networks in Iran are classified into the following five factors:

a) Protective uncoordination and unplanned feeder trip
b) Reducing the short circuit current at the beginning of the feeder
c) Failure to detect Single phase faults by *DG*
d) Fast reclosing fault
e) Islanding operation of *DGs*

In the following, these issues will be studied with examples and appropriate solutions will be offered to fix them [10].

3.1. Protective Uncoordination and Untimely Exit of Feeder

Wrong function of protection is the first security issue that is emerged in the presence of the *DGRs* in distribution networks. When two feeder are fed by a busbar of medium voltage distribution substations and a fault occurs in one of them, because *DG* feeds fault current related to connection point throw busbar, it is possible the current passes through the relay setting boundaries and current direction not found, so it leads to act feeder protection. If relay sense larger current within a fault, disconnect command will send. This relay misdiagnosis can cause negative effects on the power quality of the network so that network subscribers experience long disconnecting. When the relay is adjusted properly, it is able to identify faults in the end points of feeder [11]. It is impossible to increase setting of relay's current to prevent wrong disconnected of protection without loss of this performance at the end of the line. There is no problem until feeder's relay 2 disconnect faster than feeder's relay 1. But, delay in disconnecting *DG* the is impossible because of temperature range of wires and other equipment, feeder especially about fixed timing relays. If there is a point on an adjacent feeder that its fault effect for both R_1 and R_2 relays have equal or approximately equal performance time, we can change relay operating time by using performance characteristic curve or change current setting and time. Expressed status is shown in Figure 2.

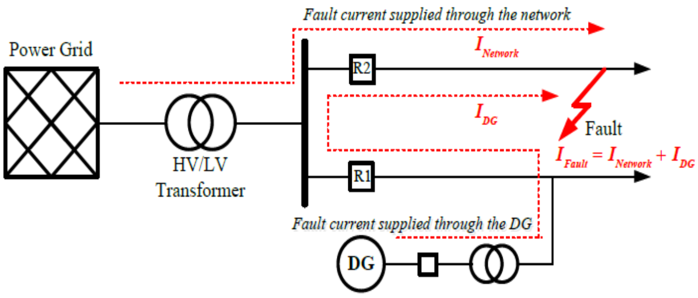

Figure 2. Untimely Trip of Feeder due to Addition of *DG*

We can use one of following methods to solve this problem:

a) Fine-tuning of relays based on existence of *DG*,
b) Using directional over-current relay in feeder including *DG*.

The first method is not possible due to other problems in protection. Therefore, the second method can be recommended as an appropriate method for solving the problem of untimely trip of feeder including *DG*.

3.2. Reducing Short Circuit Current at the Beginning of the Feeder

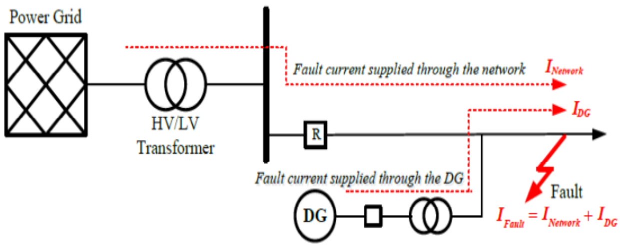

Figure 3. Blind Protection due to Addition of *DG*

Blind protection is one of the major problems that may occur in the network by installing *DG* which can reduce the passing short circuit current from the beginning of feeder due to increase the voltage drop from *DG* connecting point to fault location and consequently reduce the relay sensitivity. This problem appears when the fault occurs on the feeder which *DG* units are located on. In this case, *DG* is located between the fault point and the feeder relay. Measured fault current by the relay decreases due to presence of *DG* and this is because of the impedance of various short circuits between the fault point and the feeding point. The total fault current of the network increases permanently with the presence of *DG* and consequently decreases protected area of relay. Hence, high impedance faults and two-phase short circuit that occurs at the end of the feeder ignores or it causes delay in protection operation. In such situations, it is important to disconnect the *DG* as soon as possible to correct operation of feeder relay [12]. The delay of feeder relay is equal to performance time of *DG* protection and affect negatively on the thermal limit of system equipment's that may eventually cause damages. Also, this delay causes voltage drop elsewhere in the network and impacts negative effects on power quality. On the other hand, very sensitive protection on the connecting point with the tripping of *DG* from the network causes voltage fluctuations and other fluctuations and also power quality problems. Expressed status is shown in Figure 3.

We can express the reason of circuit current reduction in the beginning of feeder as follows. If it is assumed *DG* is not available on the network shown in Figure 3, observed impedance values from the beginning of feeder to connecting point is in Equation (2).

$$u_r = I_{mw} Z_{12} + I_{mw} Z_{2f} \tag{1}$$

$$Z_r = \frac{u_r}{I_{mw}} = Z_{12} + Z_{2f} \tag{2}$$

If it is assumed that a distributed generation add to system in Figure 2, observed impedance values from the beginning of feeder is in Equation (4).

$$u_r = I_{mw} Z_{12} + (I_{mw} + I_{dg}) Z_{2f} \tag{3}$$

$$Z_r = \frac{u_r}{I_{mw}} = Z_{12} + Z_{2f} + \frac{I_{dg}}{I_{mw}} Z_{2f} \tag{4}$$

By comparing the two Equations (2) and (4), it can be observed that $\frac{I_{dg}}{I_{mw}} Z_{2f}$ impedance added in equation (4). Then the passing current from the beginning of the feeder decreases. In this case, fixed timing relay is the best option to disconnect the fault. Using the inverse time relay has some problems [13]. Because, when a fault occurs at the end of the line, delay time will be very long due to the low current. We can use the following two methods to solve this problem:

a) Using the technique of logical coordination in side of medium voltage distribution substation,
b) Lake of installing the switch and relay within the medium voltage (*MV*) feeder.

The first method is recommended regarding to the installation of digital relay in medium voltage distribution substations. Other options such as network support, change or modification of *DG* units are not recommended due to additional costs.

3.3. Failure to Detect of Single Phase Faults by DG

Output power of the most DGs is produced in Low Voltage (*LV*) level and it requires to inject this production into medium voltage network by transformers base on its production rate. A *DG* connected to the grid through a transformer should provide an effective ground for single phase fault to ground to prevent overvoltage of phases that they don't have fault. An effective ground is a system with small impedance for all system conditions where zero sequence ratio of reactance to positive sequence of reactance is the positive number and smaller than three and also zero sequence ratio of resistance to positive sequence of reactance is the positive number and less than one. We can obtain best wiring mode of the transformer that connect *DG* to the network depend on which type of transformer which is used in the medium voltage distribution substations. The medium voltage side of power transformers in high voltage substations has delta (Δ) connection and ground-auxiliary transformers in these substations in the medium voltage side are used to fix the problem of failure detection of Single phase faults. Using (YnΔ) wired mode is a case for detection of phase fault by *DG*. In this case, *DG* is connected to delta coil and medium voltage (*MV*) network is connected to (YnΔ) coil. Figure 4 shows the described situation. The existence of (YnΔ) connection in the medium voltage side of the transformer related to *DG* causes to close current direction for single phase faults, occurred in the medium voltage side and the fault can be identified by *DG* [14-15].

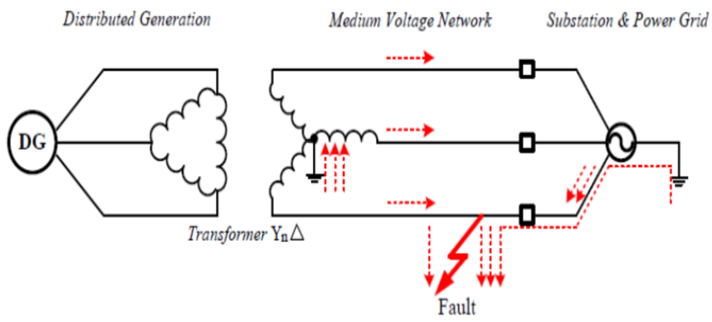

Figure 4. Detection of Single Phase Fault by Generator

Therefore, it is no need to ground-auxiliary transformer with this type of wiring related to *DG*. The benefits of expressed wiring are as follows:

a) Detection of single phase fault to ground by *DG*,
b) Reduce the possibility of Resonance and Ferro-resonance,
c) Prevent to transforming third harmonic, produced by the generator to high voltage network.

However, this type of wiring related to *DG* has disadvantages including: increase the level of single phase short circuit current, need to keys with high disconnecting and possibility of destruction of the transformer, and to solve short circuit level enhancement problem, the natural point of transformer related to *DG* can be grounded.

3.4. Fast Reclosing Fault

This problem is related to reclosers that are used extensively in overhead distribution systems. When a fault occurs, automatic reclosing function is for a short period of time and then circuit breaker connect again. Transient faults usually disappear during reclosing and it returns to its normal operating by reconnecting circuit breaker. Specially, faults due to lightning and spark without long time disconnecting can be controlled, because lightning and spark disappear quickly by loss of network voltage. Automatic reclosing is an appropriate method to control transient faults in the overhead networks. According to statistics of distribution companies, 90 percent of network faults resolve by reclosing function and only 10 percent of them are permanent. In cable networks, it is not possible to use reclosers due to effects of heat and created stress. There are potential of problems in the networks in that fast reclosing breaker are used. If both of *DG* and network feed fault location, *DG* may remain connect to the network and it feeds fault location during reclosing interruption time. Therefore, the arc remains in connection point and the existence of the arc leads to a fault in recloser and the fault will be permanent. This situation is shown in Figure 5. If *DG* do not isolate from the network at recloser's disconnect time, there will be a non-synchronous connection in the network due to reconnect of recloser that will damage *DG* and equipment of consumers. The reason of this issue is concurrent increase in *DG* speed due to feeding of short circuit location.

Synchronizing check relay is needed for accurate and reliable connection. Recloser's disconnect time should be coordinated with *DG* protection to avoid such problems as shown above. But, reliability of *DG* protection remains still unreliable from the point of view of distribution companies. In this case, there is possible to increase reclosing disconnect time to ensure proper operation [16].

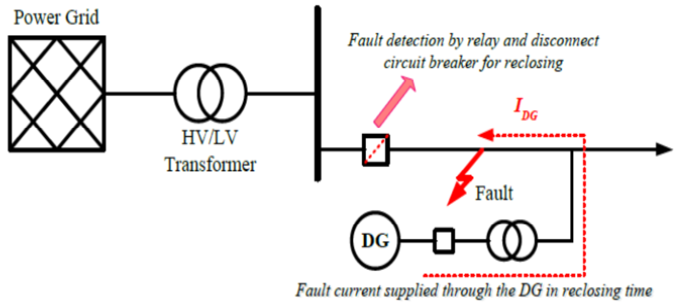

Figure 5. Fast Reclosing Fault due to Addition of *DG* Generator

We can use one of three following ways to fix the problem of fast reclosing:

a) Using synchronizing check relay that is used for reconnecting *DG* to the network
b) Remove the reclosing operation
c) Reasonable adjustment in disconnect time of fast reclosing key.

It is needed to set disconnect time of reclosing desirably regarding to the installation of reclosers in the network so that if the *DG* be installed in downstream of reclosers, it cannot be able to damage electrical equipment of consumers and *DG*.

3.5. Islanding Operation of DGs

Islanding of distribution network arise from disconnecting of main source and remaining the *DG* in the network. The islanding can cause new problems in the utilization of the network. If *DG* will continue to its work after blackout in network, it is possible to occur following problems:

a) Safety problems for maintenance personnel and operators,
b) Feeding of Short circuit location during interruption of reclosing relay,
c) Working in non-standard conditions in terms of voltage and frequency unstability and creating a power swing,
d) Lack of consistence of network and *DG*

Safety of maintenance personnel and operators is one of the important issues that can occur during islanding operation of *DG*. It is not recommended to operate the network in islanding situation and it is required to remove *DG* from the network as quick as possible in the islanding detection situation. Expressed status is shown in Figure 6.

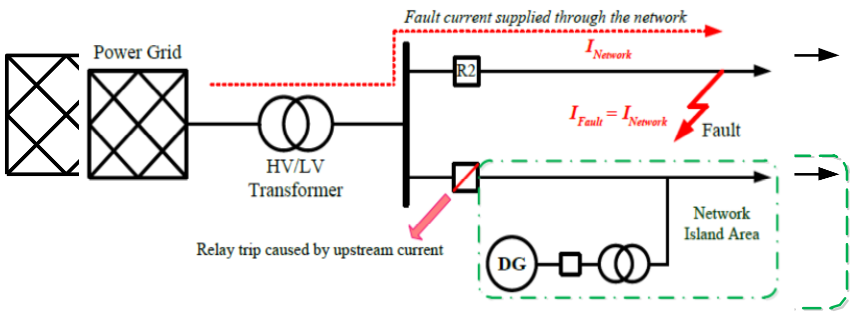

Figure 6.Phenomenon of network islanding in presence of *DG*.

We can use one of the following two methods for detection of network islanding:

a) Installation of the frequency relay
b) Protection of voltage vector shift (*VS*)

Of course there are other methods for detection of network islanding that is not recommended due to network structure and communication problems [17].

4. Conclusion

In recent years, privatization, environmental issues, creation of electricity market and especially increase renewable energy has prepared the condition presence of *DG*. But, despite the technical and economic benefits that recommend using of *DG*, their presence in distribution networks causes problems and interfere in the normal operation of the system. As was observed, design and operation of radially distribution networks was one of the main reasons for the problems caused by installation of *DG*. In Iran, despite the implementation of smart grids, the distribution networks design and operate radially. This operation has faced using *DG* in Iran's electricity network with the difficulties in operation and maintenance. So, in this article, it was expressed the effects resulting from installation of *DG* in terms of utilization and conservation in new smart grid implementation in Iran. Also, it was presented solutions to solve caused problems. Of course, many of these obstacles and difficulties will resolve if some changes in the design and operation of distribution networks and also full and proper implementation of smart grids in Iran be done.

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