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APPLICATION OF ADAPTIVE PROTECTION SCHEME IN DISTRIBUTION NETWORKS WITH DISTRIBUTED GENERATION: A REVIEW

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ABSTRACT

Integration of renewable energy-based distributed generations (DGs) in power systems has become an active research area for the last few decades due to various economic, environmental, and political factors. The integration of DGs brings several challenges even if it offers many advantages. These challenges include protection schemes in transmission and distribution networks with the possibility of bidirectional power flow. Power system protection is one of the major issues of penetrating DGs into an existing distribution network. Besides increasing fault current level of the system caused by the interconnection of the DG, Integrating DG causes the system to lose its radial power flow. The loss of coordination between primary and backup relays is one of the disadvantages of integrating DGs, since traditional relay settings may fail or work incorrectly under new conditions. Hence, new protection schemes able to maintain protection coordination are strongly needed in distribution networks with a significant integration of DG. The trend is to use the Adaptive protection scheme which changes the settings of protection relays depending on the prevailing network configuration. In this paper, the literature on the Application of Adaptive Protection Scheme in distribution networks with DGs, is reviewed where the necessity for this scheme is clearly shown.

Keywords: Adaptive protection; distribution networks; distributed generation

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1. INTRODUCTION

Currently, distribution systems are in a significant transition phase where the system is shifting from a passive distribution system with unidirectional power flow to an active distribution network with bidirectional flow and small-scale generators called Distributed Generators (DGs). Future power systems are encouraged by the necessity to diminish the impact of global climate change and lower the concentration of greenhouse gases in the atmosphere. [1].

Distributed Generation (DG) can be defined as "small-scale generating units located close to the loads that are being served" [2]. It is possible to classify DG technologies into two broad categories: non-renewable and renewable energy sources. The former comprises reciprocating engines, combustion gas turbines, micro-turbines, fuel cells, and micro Combined Heat and Power (CHP) plants. The latter includes biomass, wind, solar PV, geothermal and tide power plants [2]. Many terminologies are used to refer this new type of generation such as embedded generation, distributed generation, and distributed energy resources [3].

Augmentation of distributed energy resources (DER) are motivated by economical, environmental, technical and political factors. There is an increasing interest in the penetration levels of DGs specifically of renewable energy based technologies like wind turbines and photovoltaics. Given the suitability of business, regulatory and policy landscape, decreasing technology prices, It is expected that penetration levels of DGs will continue to increase [4].

When DGs are integrated into existing systems, they can offer numerous advantages. These include: increasing network reliability, reduction of line congestion, transmission loss reduction, generation cost reduction, postponement of investments in network expansion, and lowering capital investment costs [5],[6],[7]. Apart from these advantages, integrating DGs in the network can result in different problems such as: increase in short circuit level, bidirectional power flow, need for new protection techniques, and voltage fluctuation [7]. Increase in short circuit level and bidirectional power flow affect the protective relays because they are not designed to operate under these new conditions. Some of the consequences are like false tripping, under or over reach of relays, and loss of coordination between primary and backup relays [8],[9],[10].

2. PROTECTION COORDINATION OF OVERCURRENT RELAYS IN RADIAL DISTRIBUTION NETWORKS

The electrical power system may be subjected to many types of faults during its operation that can damage the equipment connected to this system. Hence, there is a great need for designing a reliable protective

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system. In order to obtain such reliability, there should be a backup protection in case of any failure in the primary protection. The backup protection should operate if the primary fails to take the appropriate action. This means it should operate after a certain time delay known as coordination time interval (CTI), giving the chance for the primary protection to operate first. The above mentioned scenario leads to the formulation of the protective relay coordination. It consists of selecting a suitable setting of each relay so that their fundamental protective functions are met under the required attributes of protective relaying, which are sensitivity, selectivity, reliability, and speed [11].

Commonly, distribution networks are designed in a radial configuration with only one source and single power flow. Their protection is simple and it is usually implemented using fuses, reclosers and overcurrent relays. When the fault occurs in a system, it is sensed by both primary and backup protection. If the relays are coordinated, the primary relay will be the first to operate when fault occurs, as its operating time is less than that of the backup relay. In order to verify the system protection is well coordinated, the performance of all protection devices in the fault current path between the sources and the fault point should be verified. These sources are the substation or feeder and the DGs. The main aspect of the protection coordination of a system is that the primary protecting device, closer to the fault point, should operate before the backup device [12].

There are different methods used to achieve correct relay coordination, and these include the following: time based, current based, and logic coordination.

Time Based Coordination

For this method, coordination settings are done by giving a proper time to each of the relays controlling the circuit breakers. This should be done making sure that the breaker closer to the fault opens first and the one closer to the source has long time delay [13].

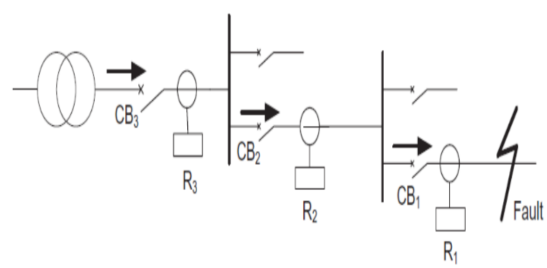

Figure 1: Time based coordination [13]

From Figure 1, relays R_1, R_2 and R_3 will detect the fault, and relay R_1 should operate first because it is near the fault. R_2 should operate after a given CTI if R_1 fails, while R_3 should operate lastly if R_1 and R_2 fail.

Current-Based Coordination

Due to change in value of impedance between the source and the fault, the fault current also varies for different locations of the fault. This brings the idea of current based coordination where relays are set to operate at different values of fault current.

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Relays setting are done so that the relay near to the fault will trip its circuit breaker first. [13].

Logic Coordination

Both time based coordination and current based coordination have some limitations which are overcome by using logic coordination. Coordination time intervals between two successive relays are not needed. In addition, there is a reduction of tripping time delay for the Circuit breaker which closer to the source.

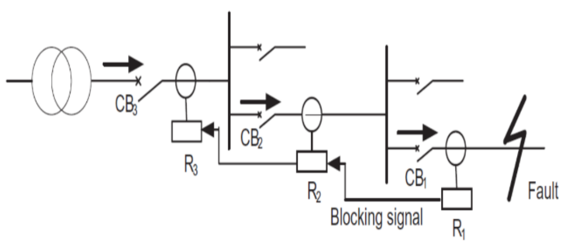

Figure 2: Logic coordination [13]

Considering Figure 2, relays R_1, R_2, and R_3 which are in an upstream direction from the fault, will be activated when the fault occurs. If R_1 is activated, it will send the blocking signal to R_2 as an order to increase the upstream relay time delay. This will also happen to R_3 if R_2 get activated.

3. IMPACT OF INTEGRATING DGS ON PROTECTION

Apart from offering many benefits, integrating DGs in the network can result in different problems. It changes the original network topology and fault current directions and values. The severity of these changes depends on the location, capacity and number of DGs.

False Tripping and Loss of Coordination

When DG is interconnected with distribution feeder it may cause a false tripping on a healthy feeder. If the fault occurs on any adjacent feeder then the fault current is contributed by connected DG in that feeder. If contributed fault current values are greater than protective device rating then healthy feeder also goes out of service till the fault is clear on the faulty feeder [14].

The definition of protection coordination loss can be taken as " violation of coordination time interval (CTI) constraint between the primary and backup relay " [15]. Figure 3 shows an example for the loss of coordination due to penetrating DG. When a fault occurs at point F, R7-R8 and R7-R9 (primary-backup) can be considered as coordination pairs. Due to the penetration of DG, these relays all sense an increase of short-circuit current. For R7, this is not critical as it is the primary relay. But for R8 and R9, their CTI with respect to R7 may not be fulfilled as when there was no presence of DG. Therefore, there is a loss of coordination between pairs R7-R8 and R7-R9.

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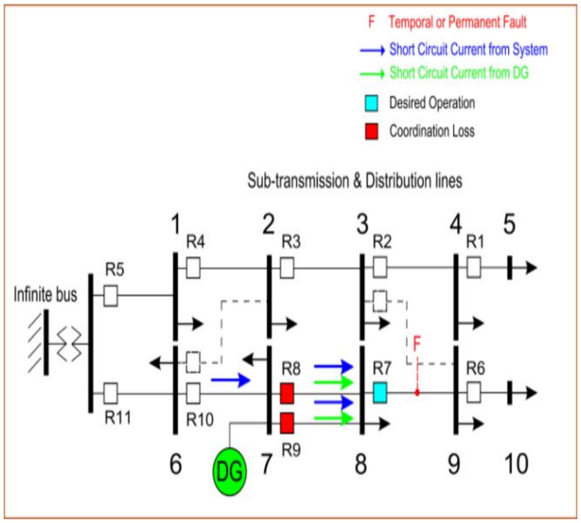
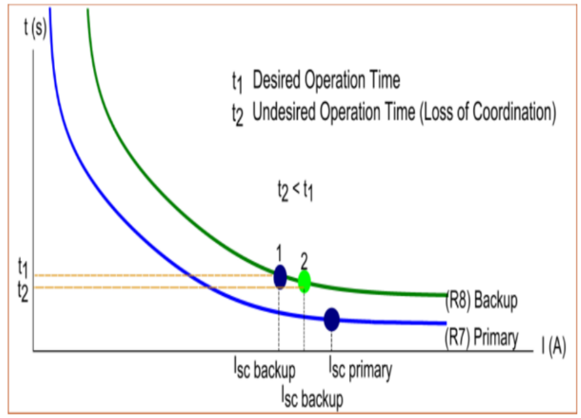


Figure 3: Loss of coordination caused by DG penetration [15]

Figure 4 illustrates the loss of coordination using inverse time relay characteristic curve for the coordination pair R7-R8. It can be clearly seen that after the integrating the DG, the backup relay R8 accelerates its tripping time due to the increase of fault current; whereas the primary relay R7 is barely affected because its tripping time is already located at the horizontal asymptote curve. Hence, there is a loss of coordination because CTI is no longer preserved for the coordination pair R7-R8.



Protection Blinding

Integrating DGs to modern distribution networks introduces additional fault current sources, which can increase the total short circuit level in the network; this changes the magnitude and direction of fault currents detected by protective relays. If the DG is located between the utility substation and the fault location as in Figure 3, the total fault current will increase due to the partial contribution of DG. Contrary, the fault current seen by relay R10 will decrease for the same fault, because of fault current division between the sources, which may not exceed the pickup current setting of relay R10. This unwanted protection performance is generally known as protection blinding. The blinding phenomenon causes delayed protection operation or even total reduction of sensation in case of weak upstream system and large DG penetration. This phenomenon can also be called protection under-reach, since the actual reach of the feeder relay is decreased due to fault current contribution from the DG [16].

Nuisance Tripping of Feeder

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Nuisance Tripping term is related to disconnection of DG, and this may occur due to power surge in the DG facility. In distribution system, power surge occurs due to loss of large load such as a motor in presence of a DG. This results in loss of large power flow in a grid and causes a relay to trip. A fault occurring outside the protective zone may cause nuisance tripping of DG means a sudden loss of generation from DG [14].

Islanding Operation

The islanding operation can be defined as isolation of a certain part of a network from the main network due to dispatch or natural condition [15]. Figure 5 shows how the island is formed. Assuming a permanent fault at point F, relay R10 will clear the fault by tripping the circuit breaker. The remaining circuit from bus 7 to 10 will form an island network supplied by the DG (assuming that the DG has enough capacity to maintain stable operation for the islanded network).

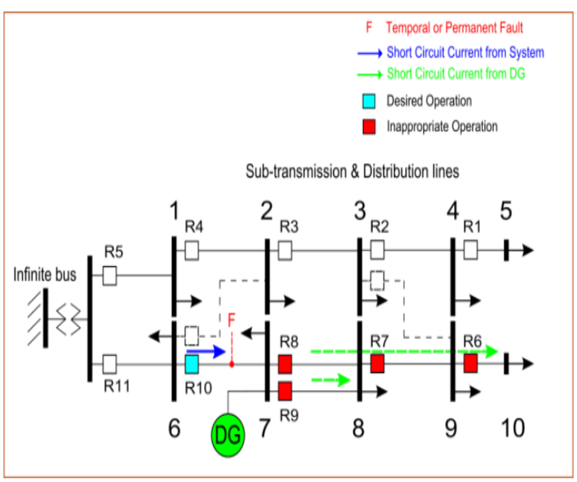

Figure 5: Islanding operation [15]

Figure 6 illustrates an inappropriate relay delay operation using inverse time relay characteristic curve for the coordination pair R7-R8. It can be seen that after entering island operation mode, the backup relay R8 increases its tripping time due to the fault current decrease; whereas the primary relay is barely affected because its tripping time is already located at the horizontal asymptote curve. Hence, there will be an undesired backup tripping time if a fault occurs during island operation mode.

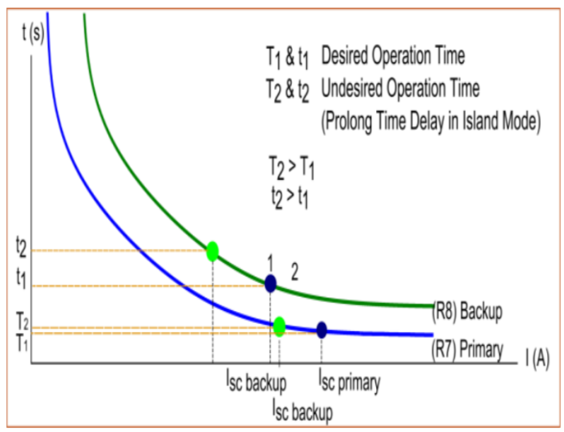

Figure 6: Relay delay operations caused by intentional or unintentional islanding [15]

4. REVIEW ON TECHNIQUES USED TO MITIGATE THE IMPACT OF PENETRATING DGs

Various researchers have proposed different solutions to mitigate the negative impact of penetrating DGs on sub-transmission and distribution networks. These solutions include the following:

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- Disconnecting the DGs immediately after fault detection [17]
- Limiting the capacity of installed DGs [18],[19]
- Modifying the protection system by installing more protective devices [20]
- Installing the fault current limiters (FCLs) to preserve or restore the original relay settings [21][22][23][24]
- Employing fault ride through control strategy of inverter based DGs [25][26]
- Controlling the fault current by solid-state-switch-based field discharge circuit for synchronous DGs [27]
- Adaptive protection schemes (APS) [28][29][30]

Conti [17], identified and discussed through examples several potential conflicts between DG and distribution operation considering structure and protection schemes of typical distribution networks. He highlighted the need for distribution protection philosophies that should be made by planners and distribution operators in order to deliver improved service continuity to consumers with increasing DG penetration in distribution networks. He found that It could be thought that if generators are able to detect the fault and rapidly disconnect from the network, they cannot disturb the normal operation of protection system, especially when their fault currents contribution seams relatively small and the system is not depending on DG to support the load. According to [17], most interconnection standards, included the Italian ones, besides limiting DG installed capacity, were requiring the disconnection of DG when a fault occurs.

Surachai Chaitusaney and Akihiko Yokoyama [18] reported on a way to prevent degradation of reliability caused by recloser-fuse miscoordination. To maximize the DG utilization, they have found the largest acceptable DG that should be considered as the limitation level in order to reduce the impact of DG. They used Mathematical equations of protective devices to set up protection coordination and to calculate the largest possible value of DG. Jinfu Chen et al. [19] in their work , they did calculation of penetration level of DG mainly based on the reliable action of relay protection device in distribution network.

Hamed B.Funmilayo, Karen L. Butler-Purry [20] Presented a new approach that revises the existing Over Current Protection scheme of a radial feeder to address the presence of DG. Their work discussed a non-communication based approach to maintain coordination between the recloser and fuses and mitigate the identified Overcurrent Protection issues. This approach involved adding multi-function devices (recloser and relay) on the lateral with DG. They discussed this approach to alleviate the impact of DG on the overcurrent protection scheme for radial distribution systems. The Overcurrent Protection issues like fuse misoperation, fuse fatigue, and nuisance fuse blowing have been addressed by this approach.

Walid El-Khattam and Tarlochan S.Sidhu [21] proposed an approach that used a Fault Current Limiter to limit the DG fault current locally, and restore the original relay coordination. This approach was proposed in order to solve the coordination problem of directional overcurrent relay, caused by connecting DG in looped power delivery systems. This method was performed without changing the original relay settings or disconnecting DGs during fault. Youngwood Kim et al. [22] proposed a systematic procedure to analyze the impacts of Superconducting Fault Current Limiter (SFCL) placement on DG expansion in a power system while maintaining the original protective relays coordination. In their work, the SFCL-placement problem was solved to determine the placement location for optimizing the maximum fault-current level reduction, while maintaining the original relay settings.

Abbas Esmaeili et al.[23] used a simultaneous network reconfiguration and optimal planning FCLs (thyristor-controlled impedances) that could either be resistive, inductive, or capacitive, to maintain fault current levels and reduce power losses in a smart grid under various operating conditions. They discussed two methods which are: the reconfiguration of a distribution network for efficient operation and protection coordination in the form of a multi-objective optimization problem. They did the optimal programming of fault current limiters using a two-stage stochastic model to achieve their objectives, which were to reduce losses and maintaining short circuits levels under different utilization scenarios of DGs.

A. Elmitwally et al. [24] in their work, they investigated the optimal utilization of Fault Current Limiters in order to sustain the coordination of the directional over current relays without any need of resetting the relays for all status of DGs. They formulated a multi-objective optimization problem for the size and location of FCLs. To determine the optimal location and size of FCLs, multi-objective Particle Swarm Optimization was used to solve the optimization problem. Their focus was to maintain the coordination of the relays in Power Distribution System with DGs. The authors have seen that using FCLs is an effective solution that does not need resetting of overcurrent relays for any change of DG status.

E. Ebrahimi et al. [25] in their work, they used fault ride through approach to decrease the impacts of integrating the DGs in the grid. The inverter based DGs were properly controlled in the fault condition instead of disconnecting them from the grid. The simulation results showed that the fault current was kept in the desired range by using the proposed algorithm and the protection coordination before connection of DG remained intact even after the connection of DG. Control strategy was proposed and applied to the voltage source converter (VSC) so that the protection coordination remains unchanged and there is no need to change the protection system coordination and devices. The authors have seen that not only the DG output current can be reduced to the value that keeps the protection device coordinated, but also the voltage sag is improved during the fault condition due to the reactive power injection by IBDG.

Seyed Behzad Naderi et al. [26] in their work, they proposed an optimum resistive type fault current limiter as an efficient method to get maximum fault ride-through capability of fixed speed wind turbines during different faults conditions. They designed a control circuit for the proposed ORFCL and by means of this control circuit, the ORFCL calculated an optimum resistance value with respect to pre-fault operation conditions, including the fault location and the pre-fault output active power of the induction generator.

H. Yazdanpanahi et al. [27] proposed a field discharge circuit to limit the generator's fault current, in order to mitigate the impacts of synchronous-machine DG on the protection of distribution network. The method was implemented by equipping the generator with a solid-state-switch-based field discharge circuit. Authors studied the operation this circuit and investigated its effects on the output current of generator during the fault. It was seen that the proposed scheme were able to remove the steady-state component of the fault current and accelerate the decay of the transient AC component of the current. It was shown through results that the proposed field discharge circuit is competent to avoid miscoordination of inverse-time overcurrent relays used for network protection.

Even though these approaches can sufficiently mitigate the negative impacts of penetrating DGs on the way protective relays perform, they can have various limitations as well. Disconnecting large DGs immediately after fault detection may lead to severe voltage sags as the contribution of reactive power from DGs will be cut off. Moreover, most faults are temporary, thus disconnecting the DGs is not economically beneficial since the DGs will need to be reconnected to the network after the clearance of temporal fault in order to profit from the renewable energy. Also, stability problem may occur if there were high penetrations of DGs in the network.

Limiting the DGs capacity is a provisional solution, since renewable energy is cheap, it should be fully exploited to gain more profit and also to avoid excess CO2 emission mostly generated from conventional power plants. Modifying the protection scheme by installing extra protective devices like circuit breakers for sectionalization, reconfiguration of networks or change of

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protection principles is costly, and also the use of numerous protection principles in a certain area of the power system may lead to more complicated protection coordination scenario and difficult post-event analysis.

Both the fault ride-through control strategy of inverter based DGs and control of fault current by solid-state-switch-based field discharge circuit for synchronous DGs are low-cost solution compared to the previous ones. The first consists of a commutation control strategy of the inverter switches in order to limit the fault current contribution. The second consists of installing a solid-state-switch-based field discharge circuit for synchronous DGs in order to drain the excess fault currents. However, both are only partial solutions to the problem since the first solution is only applicable to inverter-based DGs and the second only to synchronous DGs.

These shortcomings lead to another alternative called Adaptive Protection Scheme. The exceptionally good aspect of this protection scheme is that it can monitor the network and immediately update the relay settings according to the variations that occur in the network.

5. ADAPTIVE PROTECTION SCHEME

Adaptive protection is “an online activity that modifies the preferred protective response to a change in system conditions or requirements in a timely manner by means of externally generated signals or control action [31]. Adaptive protection of distribution systems penetrated with distributed generation can be realized with the use of microprocessor-based relays that have the advantage of easily changing their tripping characteristics. Implementing adaptive protection increases the sensitivity and achieves faster operating times. When adaptive protection scheme is employed for the mitigation of DG penetration impacts, additional benefit can be obtained other than maintaining selectivity for all coordination pairs; namely the increase of sensitivity [15].

Authors in [28] used an adaptive protection scheme to provide protection for microgrids by utilizing microprocessor-based over current relays . They also used auto reclosers, through which the proposed adaptive protection scheme recovers faster from the fault and increase the consistency of the microgrid as result. Rahmati and Dimassi [29] proposed an Adaptive protection that uses a least square algorithm to determine the Thevenin circuit equivalent using local measurements. This method does not require any online-information and communication facilities regarding varying short-circuit levels caused by distributed energy resources infeed. Yen et al [30] proposed an APS using differential evolution algorithm (DE) in order to mitigate the impacts of integrating DG on DOCR coordination. The scheme consisted of automatic online re-adjustment of relay settings so that the relays are best attuned for different network operating condition due to dispatch or natural condition.

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6. CONCLUSION

In this review article, a literature review for protection coordination for distribution systems with DGs is discussed, and covers the review of the notable protection coordination methods. Penetrating DGs in distribution systems creates new protection coordination issues, and their impact on the network protection mainly depends upon their size and location. This penetration of DGs results in bidirectional flow of fault current over the feeder and existing unidirectional designed protection coordination schemes fail to clear the fault or work incorrectly for such fault conditions. These problems are addressed by localizing the DG impact and updating the protection relay setting wherever required in order to maintain good coordination after DG integration.

With the advancement in technology and development in computer based relaying, protection engineers now have many options to choose a reliable protection scheme based on the network topology and requirement. Introduction of microprocessor-based protective devices, Intelligent Electronic Devices (IEDs) and communication systems stimulated this very important aspect of adaptive relaying. The adaptive protection schemes are likely to have widespread and being used in the current and future complex structure of distribution systems in the presence of renewable energy-based DG penetration.

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