AN ADAPTIVE PROTECTION SCHEME IN ACTIVE DISTRIBUTION NETWORKS BASED ON INTEGRATED PROTECTION

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ABSTRACT

A considerable increase in the penetration of distributed generation (DG) to the distribution networks leads to a higher possibility of malfunction of present protection schemes of these systems. One of the major problems caused by higher levels of DG penetration is the reduction of the relay reach or relay access. This problem relatively relieves using adaptive overcurrent protection techniques but in certain conditions, the minimum relay access reduces to less than 20 percent of line length, in the presence of DGs and adaptive current protection cannot be used. In this paper a combined adaptive protection method is presented, which applies overcurrent and undervoltage protection simultaneously. Function of the protection system improves because of different action areas of these two types of protection. The feasibility of the proposed method authenticated through simulation.

INTRODUCTION

The excellent advantages achievable through the presence of DGs, such as environmentally-friendly generation and economic delivery of demanding power are major incentives to utilization of this type of generation [1]. In the presence of DGs in distribution systems, traditional protection of these networks meets various problems such as changes in the short-circuit power level, false tripping of feeders or generation units and miscoordination of protective devices and reduction of relay reach [2, 3]. Severity of these problems totally depends on characteristics of network and number, capacity, type and location of connected DGs and in cases with high penetration of DGs causes through changes in protection scheme [3].

To avoid above mentioned problems, the experts of distribution system protection convinced to design and implementation of adaptive protection methods. In adaptive methods, settings of protective devices change with change of some network conditions, such as connection and disconnection of DGs or changes in output power of them or change in system configuration [1].

This paper presents a combined adaptive protection method to get improvement in relay reach. In proposed method the adaptive overcurrent protection and adaptive undervoltage protection used simultaneously. Implementation of this algorithm requires relays able to receive not only the current or voltage signals, as relays of the traditional methods, but also both of them at the same time. The "Integrated Protection" term is used to denote the integration of these functions into one device.

The remaining of this paper is organized as follows. The second section presents impact of DGs presence on present protection scheme of distribution networks. Section 3 describes proposed method and a case study, simulation results and conclusions obtained from this work comes after.

DG IMPACTS ON PRESENT PROTECTION

Traditional electric distribution systems are radial in nature, supplied through a single subtransmission substation, hence a passive network. Accordingly, these networks have a unidirectional power flow and consequently a convenient and straightforward protection scheme, which is usually implemented using fuses, reclosers, and nondirectional overcurrent relays [5]. This is shown in **Error! Reference source not found.**, where *R1* can be a fuse, recloser or scarcely a couple of relay and breaker and *R2, R3* is usually a fuse. In traditional protection schemes, the settings principle of these protective devices is quite simple. These settings are invariant and hence not optimal for all operating conditions of the system.

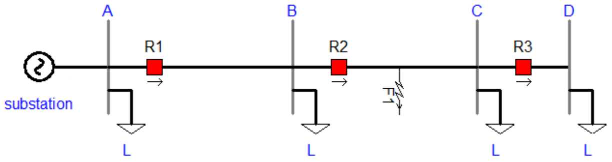

Fig. 1: Schematic diagram of a passive network with protective devises.

In the presence of DGs, distribution networks grow active networks having bi-directional power flow in some feeders laterals or sections depending on number, size and location of DGs. It is a well-established principle that directional protection is necessary to protect the system against fault currents that could circulate in both directions through a system element [4]. This type of protection cannot be implemented using only fuse or recloser and directional devices must be applied. This is shown in Fig. 2. *AB* and *BC* sections protection has been changed into directional protection due to the presence of *DG1* and *DG2*.

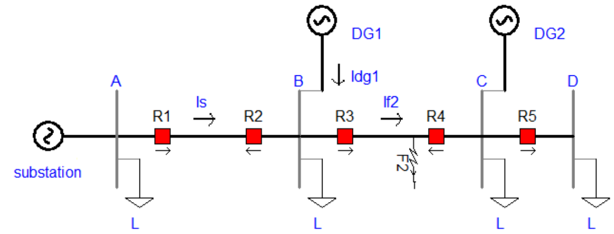

Fig. 2: Schematic diagram of an active network with protective devises.

In addition to those mentioned, change in range of load and short circuit currents of some sections is another problem caused by DGs and can be followed by a protective malfunction and thus security reduction, if the size or penetration of DGs grows high enough [6].

One of the major problems caused by DGs penetration in distribution systems is reduced reach of impedance relay. The reach of an impedance relay is the maximum fault distance that triggers the relay in a certain time due to its configuration. This maximum distance corresponds to maximum fault impedance or minimum fault current that is detected [7]. In the active distribution systems, the relay reach is affected by fault type, fault impedance and DGs conditions. As an instance, the effect of *DG1* on relay *R1* reach in the sample system indicated in Fig. 2, can be considered as follows. The voltage measured by the relay *R1* in case of a short circuit fault *F2*, E_{R3}, is

$$E_{R3}=Z_{AB}I_s+\alpha Z_l(I_s+I_{dg1}) \qquad (1)$$

where Z_{AB} is the impedance of section *AB*, Z_l is the impedance of section *BC* and α is the coefficient of fault distance from bus *B*. The measured impedance of *R3*, Z_{R3} can be calculated as

$$Z_{R3}=\frac{E_{R3}}{I_s}=Z_{AB}+\alpha Z_l+\alpha Z_l\frac{I_{dg1}}{I_s} \qquad (2)$$

Where last term is due to the presence of *DG1* and causes a variation of relay seen impedance due to infeeded current of *DG1*. Consequently, the relay may act in higher time or in a lower α .

Due to the above mentioned problems, it is essential that protection of active distribution networks implemented adaptively to some major changes in network characteristics such as connection or disconnection of DGs and fault type [8].

PROPOSED METHOD

Adaptive overcurrent protection

In distribution networks higher levels of current indicates the faulty condition and the type of protection which operates based on this fact is called overcurrent protection. This method usually implemented at two levels, first one is called primary protection and is faster than the second one called backup protection. Primary protection is provided by closest relay to each fault and backup level, with some delay, acts if the primary protection fails to clear the fault. As an instance, *R1* provides primary protection and *R2* provides backup level for fault *F1* in Fig. 1.

For distribution systems due to distance from main power generation units, the fault current does not have the transient component and hence can be approximated by its steady-state value. Considering this fact, the feeder and conventional DGs can be represented by a simple Thevenin equivalent circuit in the fault analysis and determining the pickup currents of relays [9]. Inverter based DGs model cannot be obtained through this assumption and are out of the scope of this work.

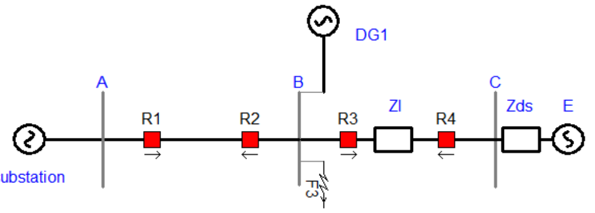

Fig. 3 : Thevenin equivalent of sample network for calculating R4 setting.

Primary protection setting of *R4*, I_{p4}, which is responsible for isolating the component of fault current flowing toward bus *B* in the case of a fault in section *BC* in sample network shown in Fig. 3, can be calculated as

$$I_{p4}=k_F k_R I_{R4}\ ,\ I_{R4}=\frac{E}{Z_{ds}+\alpha Z_l} \qquad (3)$$

where k_F is fault type coefficient and can be previously determined through negative sequence current and k_R is the reliability coefficient and has a value in the range of 1.1 to 1.3 and α =1.

In equation 3, E is variant by system configuration changes such as connection or disconnection of *DG2* and thus for adoption of relay setting to this changes, all the calculations must be done in real time and output settings be sent to relay through the communication infrastructure. In addition, pickup current obtained using this procedure is independent of operation mode of the network due to online calculation of system impedance Z_{ds}.

It worth be noted that, load at bus *D* in Fig. 2 can be considered in calculating Z_{ds} since despite of the faulty condition in section *BC*, this load can be totally or partially be fed by *DG2*. Other loads can be neglected in comparison with fault current.

In addition to above discussed advantages of adaptive method, it can be proved that the relay reach improved on this method, too. For *R4* in the sample network, the minimum of relay reach occurs in $Z_{ds}=Z_{ds\ max}$ and can be calculated using equation 3 as

$$\alpha_{ac\ \min}=\frac{1}{k_R}\left(1+\frac{Z_{ds\max}}{Z_l}\right)-\frac{Z_{ds\max}}{Z_l} \qquad (4)$$

Where subscript *ac* indicates the adaptive current method. Relay reach in traditional methods can be calculated through a similar procedure, except that in this case the maximum apparent power of load, equivalent to $Z_{ds\ min}$ used in pickup current calculation and k_F does not exist in resulting equation as

$$\alpha_{tc}=\frac{k_F}{k_R}\left(1+\frac{Z_{ds\min}}{Z_l}\right)-\frac{Z_{ds}}{Z_l} \qquad (5)$$

Where subscript *tc* indicates the traditional current method. Comparison of equations 4 and 5, knowing $k_F\leq 1$ and $k_R\geq 1$ shows that $\alpha_{ac\ min}>\alpha_{tc}$ for all typical values of parameters.

Adaptive integrated protection method

Adaptive undervoltage protection can be implemented through a similar method to adaptive overcurrent method. Once more, *R4* in Fig. 3is used to describe achieving the relay setting in adaptive undervoltage protection method. Pickup voltage for primary protection can be stated as

$$U_{p4} = \frac{U_{R4}}{k_R} \quad , \; U_{R4} = \frac{\alpha E Z_l}{Z_{ds} + \alpha Z_l} \qquad (6)$$

Parameters definition is similar to previous discussion. Preceding a familiar procedure, advantages of adaptive undervoltage protection in comparison with traditional method can be shown. Here relay reaches in two methods get into comparison as follows

$$\alpha_{tv} = \frac{Z_{ds}}{k_R Z_{ds\max} + (k_R - 1) Z_l} \qquad (7)$$

$$\alpha_{av\ \min} = \frac{Z_{ds\min}}{k_R Z_{ds\min} + (k_R - 1) Z_l} \qquad (8)$$

Subscripts *tv* and *av* indicate traditional and adaptive undervoltage methods, respectively. It is worthy of notice that, the minimum apparent power of system, equivalent to Z_{dsmin}, is used in the traditional undervoltage setting calculation, unlike the previous case for traditional overcurrent protection. Here $\alpha_{av\,min} > \alpha_{tv}$ for $k_R \geq 1$ similar to previous discussion.

In addition to the advantages of each adaptive method to corresponding traditional method, the more improvement in increasing relay reach can be achieved using this two type of protection simultaneously, and through a logical *or* in sending the trip signal. The source of this improvement is the difference in the action areas of these two types of protections according to equations 4 and 8. For further illustration of the issue, action areas of both methods for the case that the minimum relay reach is equal to 0.2 and k_R=1.1, is shown in Fig. 4. Coefficients of line length and the source impedance is defined as

$$\frac{Z_l}{Z_{S\min}} \square K_l \quad , \quad \frac{Z_{S\max}}{Z_{S\min}} \square K_s \qquad (9)$$

$$S_v : \alpha_{av\min} > 0.2 \quad , \; S_i : \alpha_{ai\min} > 0.2 \qquad (10)$$

In area *A* of the Fig. 4 the reach of adaptive overcurrentt protection is less than 0.2 and in other words, overcurrent protection is not available or efficient whereas undervoltage and thus integrated protection can function fairly and this case show the excellence of the integrated method in increasing relay reach in active distribution network with conventional DGs. The cost of this method is relays capable of receiving not only one of current or voltage signals but both of them at the same time.

Until this point primary protection setting of both modes obtained. According to what noted earlier the protection schemes should have two levels in order to provide backup protection in the event of a switching device failure. The next upstream device, or device combination, must operate to provide backup protection.

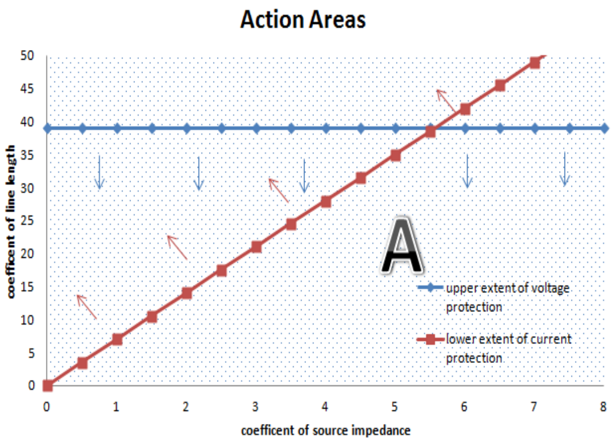

Fig. 4: Action areas of both adaptive methods for α-0.2.

Based on assumption of presence of conventional DGs and because of their conduction to faulty condition, calculation of backup protection is very close to designing the primary protection.

It must be noted that in presence of other kinds of DGs designing of these two levels of protection is different and can be taken into consideration in further works.

SIMULATION RESULTS

In order to demonstrate the advantages of proposed integrated adaptive protection scheme, sample 20kV network shown in Fig. 2 simulated using PSCAD/EMTDC. Subtransmission substation and DGs modeled as a voltage source series with impedance. Loads are equal and modeled as constant power loads. The length of sections, *L*, is equal. Simulation performed for various fault locations, fault types and source impedances and because of length restriction results of the two cases is represented here.

A. $Z_{ds}=Z_{dsmin}$ *, L=20km and single phase to ground fault occurred in 0.2 Sec and 15km from bus B or α=0. 75.*

The simulation results of this case are shown in Fig. 5. With the fault occurrence in 0.2 Sec, setting the values of both of protections change and this change cause overcurrent protection to recognize faulty condition and thus send a trip signal while undervoltage protection cannot recognize fault.

B. $Z_{ds}=Z_{dsmax}$ *, L=5km and 3 phase fault occurred in 0.2 Sec and 2km from bus C or* α_c*=0. 4.*

The simulation results of this case are shown in Fig. 6. In this case changes of setting values cause undervoltage protection to recognize faulty condition and send trip signal whereas overcurrent voltage cannot sense the fault.

According to simulation results in both cases *A* and *B*, it can be noticed that for distribution networks with short sections or high source impedances, undervoltage protection works fair and is an appropriate redundant facility for presently merely overcurrent protection of these networks.

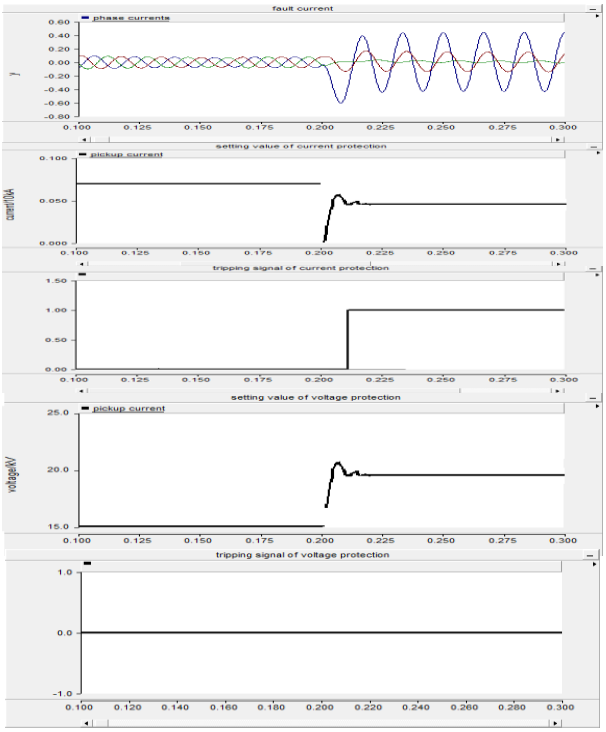

Fig. 5: simulation results of case A.

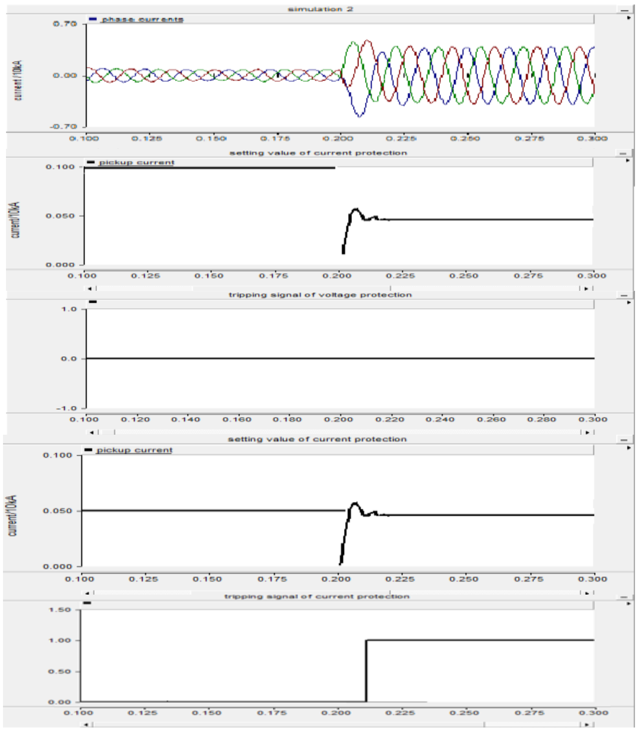

Fig. 6: simulation results of case B.

CONCLUSION

Penetration of distributed generation into distribution network is indispensable because of their benefits to the whole society. On the other hand, the presence of DGs causes some problems among them protection problem the most important. Here, these problems discussed first and then adaptive protection introduced as a solution to them. Increasing the relay reach, reduced in the presence of DGs, was the main scope of this work. In active distribution networks some improvement in the relay reach is achievable using the adaptive current protection method. In this work an adaptive integrated protection that assembles overcurrent and undervoltage protections simultaneously, proposed to more improvement in relay reach. Performance of the proposed method is shown through analytical process and simulation on sample network. The key concept of the proposed method is difference in action areas of these two types of protection and cause to correct function even if one fails to sense and act. The cost of this advantage is not considerable if communication infrastructures exist earlier.

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