CO-ORDINATED FORTIFICATION BY MEANS OF ANGLE IMPEDANCE RELAY IN A MULTI-INFEED DISPERSED GENERATION INCLUDED TO GRID

Dr. S. THANGALAKSHMI
Mohamed Sathak A. J. College of Engineering, Rajiv Gandhi Salai (OMR), Inside Sipcot IT Park, Siruseri,
Chennai – 603103, Email – thangalakshmiprakash@yahoo.com

Abstract: *There are few practical restrictions in the assimilation of dispersed generation (DG) in the distribution scheme. Adding fairly big quantity of generation to the distribution network can affect the normal assumptions used in the protection plans of overcurrent fortification. This problem becomes more predominant when the DG capacity within the given area counter balances the load. The availability of DG is not constant and is dynamic in nature. The nature and the severity of fault current should also be accounted. The anti-islanding, the temporary over-voltages at the time of fault, reduction of sensitivity for extended feeder are the key issues which are discussed in this paper. This paper focuses on solving few issues related to integration of DG with the help of impedance relays which is used for distribution line protection.*

Key words: *Feeder protection, Distributed Generation, Distribution system, Distance relay, Angle impedance.*

1. Introduction

A distribution feeder regularly contains of a main stalk with adjacent circuits originating lengthwise as presented in Fig.1.

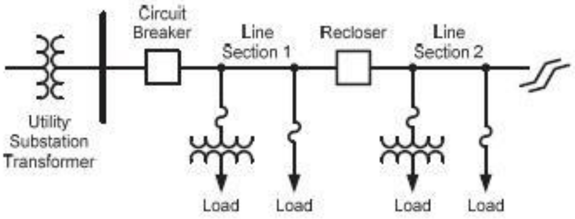

Fig. 1. Typical Distribution Feeder.

The adjacent circuits are naturally connected to the main circuit by means of a fuse. The fortification of feeder circuit only with fuse ultimately ends with outage of adjacent circuits from main circuit especially in the case of enduring fault.

For lengthy feeders provided with reclosers in between, the feeder fortification is fixed to avoid tripping of the fundamental breaker for faults happening after the reclosers. Traditionally, overcurrent scheme of protection has been applied to the distribution or dispersed network for instant and scheduled tripping of breakers provided in feeders. It is projected that majority of distribution line errors are short-term errors. As a result of this , the number of times of usage of auto-reclosing becomes more to decrease client continued disruptions.

The zone that is disapprovingly affected by DG intervention is the fortification harmonization of the utility dispersal scheme.

The conservative overcurrent defense scheme is intended for radiated distribution network with omnidirectional stream of fault current. On the other hand, linking of DG into dispersal grids change the singly-fed radial nets to complex ones with numerous sources [1].

This alters the stream of fault currents from omnidirectional to two-directional [2]. Twofold tactics are employed in the demonstration of fuses in dispersal networks: fuse-redeemable and trip-redeemable outlines. A fuse-redeemable arrangement unlocks the breaker or recloser beforehand the fuse starts melting which is then followed by an auto-reclose of the path. This approach is useful in the case of non-permanent faults and ultimately results in non-blowing of fuse.

On the other hand, in a trip-redeemable arrangement the fuse is permitted to knock-back completely for each and every fault. A fuse-saving procedure creates extra fleeting disruptions but less continued disruptions in comparison with trip-redeemable procedure. But, whichever be the application, the aim is to clear the short-lived faults and to limit the customers suffering due to faults on fused adjacent circuits.

Most of the utilities merge these two procedures. In the former scheme, the feeder breaker is tripped by the non-timed protection component before the fuse starts melting. The instant protection components are jammed temporarily, following the primary trip.

Subsequently, with adequate period of interval, the recloser of breaker is planned. The time of reclosing is decided by the thermal and electrical conditions. In other words, enough stretch is provided to dispel the high temperature due to ionization of air molecules and the air particles are permitted to recombine to return to the non-conducting state.

In the later scheme of stable faults, the concept of delayed operation of breakers based on time is employed. This is especially true when the protection focuses on the fault at the supply side of the breaker at the feeder. This needs synchronization of components like transformers, bus-bars, high voltage lines and the fuses. For errors nearby the feeder breaker, a prompt high-set security section is afforded to quickly detach the faulty section to curtail the amassed injury to foundation transformers.

The idea of additional directional features and load infringement is used for the purpose of refining the sensitivity and security of overcurrent relays used for feeder fortification. The protection arrangement is more trustworthy with distance elements in terms of selectivity and sensitivity because this is a kind of non-unit system of protection [3].

While the overcurrent relay is a magnitude based relay, the distance relay is a ratio relay and it works on the measurement of impedance of the line to be protected which is actually the ratio between the voltage and current. During most of the fault conditions, the current increases and the voltage reduces leading to low impedance. Henceforth, the impedance relay whose impedance is proportionate to the space works when the calculated impedance is lesser than the predetermined impedance. This specific impedance and the conforming distance are denoted as reach. The distance relays offer a stable reach, while the overcurrent relays have a fluctuating reach which hinges on the source impedance and scheme design. Distance elements have inherent directional feature and propose a better discrimination between internal and external faults.

2. Distance-dependent feeder protection design

Benefits are obvious when relating distance cantered feeder fortification with overcurrent feeder security. The distance relays are well flexible on feeders in which abundant sizes of DG are attached.

Distance influenced feeder protection strategy has speedy trip principles and has steady zones of protection. Also, these are not reliant on mutable structure environments. For instance, when there is any change in the source, it is reflected as a variation in fault currents at any position. Nevertheless, the impedance of the endangered feeder remains constant since, the remoteness of the section is the same.

The arc resistance is a pertinent difficulty in distance protection. Anyway, the exposure can be improved for resistive fault by modelling the characteristics of the distance element. Load encroachment is another valuable practice applied for stoppage of operation of directional section during heavy load condition. The measured voltages and currents are pivotal in designing the operating and polarizing element of the directional units. These signals eventually decide the magnitude and the angle of the comparator which is used for tripping during error circumstances. The operating characteristics of angle comparator is shown in Fig 2 which is determined by Eqn. (1)

$$Angle\left(\frac{IZ-V}{V}\right) < |90°| \tag{1}$$

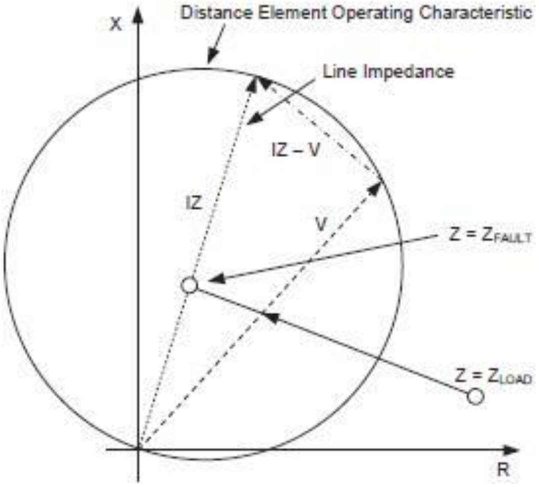

Fig. 2. Mho impedance characteristic

During standard working circumstances, the calculated impedance (Z = Z_{LOAD}) is the impedance of the load conveyed by the feeder which embraces feeder impedance also. The load impedance is archetypally immediate to the real axis (R) of the R-X diagram.

During error circumstances, the predetermined impedance changes to an impedance of larger inductance value which is actually decided by the feeder impedance [4]. This is the case when the arc resistance is very less and completely deserted. The positive sequence line impedance of the condemned segment of line is given by Eqn (2).

$$V = V_A - V_B, I = I_A - I_B,\ Z = \frac{V}{I} = mZ_{1L} \tag{2}$$

where,
Z_{1L} is the positive-sequence line impedance.
m is the distance to the fault in per unit of Z_{1L} [2].

The distance centered feeder fortification questioned in this writings is a blend of traditional overcurrent security harmonization and distance mechanisms. Both mho and quadrilateral components are comprehended in carrying out of distance centered feeder fortification.

3. Current infeed due to dispersed generation

The accretion of electricity production has superior effect on distance centered feeder fortification [5]. Seeing the occurrence of a 3 phase fault for the circuit shown in fig. 3, the fault current can be calculated at the feeder end without generation as given by Eqn. 3.

$$IF_{NDG} = \frac{V_{SYS}}{Z_{SYS}+Z_S+Z_H} \qquad (3)$$

where,

Z_{SYS} is the impedance of the system/generator.

Z_S is the distance covered between the substations and the generator.
Z_H is the impedance from generator.
V_{SYS} is the voltage of the system/generator.

When the generation alone is supplemented neglecting the load, the entire fault current is calculated using Eqn. 4

$$IF_{DG} = \frac{V_{SYS}}{Z_H+\left(Z_{DG}\times\frac{Z_{SYS}+Z_S}{Z_{DG}+Z_{SYS}+Z_S}\right)} \qquad (4)$$

where,

Z_{DG} is the joint impedance of the electricity production and power transformer.
Z_{SYS} is the impedance of the system/generator.

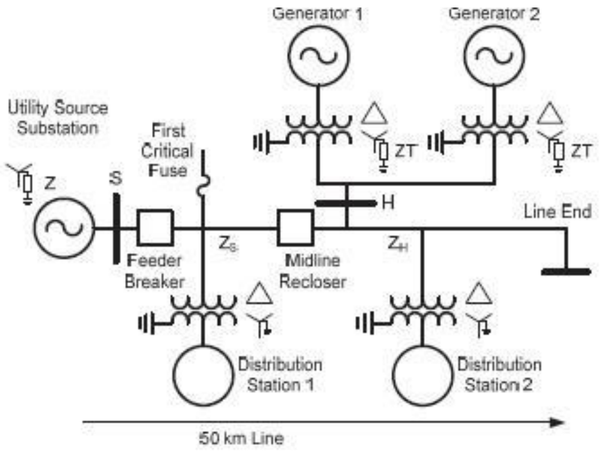

Fig. 3. Test System.

4. Distance partition setting criterions for DG demonstrations

In this distance centered feeder fortification, the high - fixed rapid overcurrent constituents 50H or 50NH are replaced with immediate quadrilateral distance features [6]. The representation with H and L are adapted commercially and refers to high sensitivity and low sensitivity respectively.

The subtle low - fixed rapid elements 50L or 50NL are replaced with an immediate mho element, while the period-overcurrent machineries are conserved and torque is organized by mho elements.

The topmost objectives of the impedance centric feeder fortification arrangement are

- To clear stopgap faults up to the end of the zone, supporting the fuse-redeemable procedure
- To provide treaded remote backup fortification for feeder divisions outside downstream reclosers.
- To provide a secured directional supervision to distinguish the forward and reverse faults.
- To curtail the transformer through-fault impairment.
- To provide obligatory rapid removal of faults till the very first severe main fuse. In the meantime, it is also ensured to afford augmented attention for high-resistive proximity faults.
- To regulate the reach on the tapped burden localities.
- To aptly plan the decisive characteristics.

Moreover, the flexibility settings are to be adjusted with varying sensitivity of dispersed generation and disparity in source impedance. In long feeders with DG, the failure of adjacent feeder circuits is controlled by unbalanced load infringement [7-9].

5. Feeder model with dispersed generation

The test scheme for experimentation is shown in Fig.3. The intended model helps to evaluate the use of impedance defenses on feeders. Table 1 & 2 offer the bounds of system, fuse and feeder. Fig. 3 affords the statistics for the considered system. The test scheme has base kV of 27.6 p.u and base MVA of 100.

Table 1 – System and fuse considerations

	Real pu	**Imag pu**	**Mag pu**	**Ang**
Z1SYS	0.0265	0.3681	0.3691	85.9
Z0SYS	0.0004	0.3099	0.3099	89.9
Z1Fuse	0.1340	0.5310	0.5476	75.8
Z0Fuse	0.3640	1.4380	1.4834	75.8
Z1S	0.2680	1.0620	1.0953	75.8
Z0S	0.7280	2.8760	2.9667	75.8
Z1H	0.9255	1.7105	1.9448	61.6
Z0H	2.2159	4.9648	5.4369	65.9

Table 2 – Feeder parameters

	Real pu	Imag pu	Mag pu	Ang
Z0 Feeder	1.1935	2.7725	3.0185	66.7
Z0 Feeder	2.9439	7.8408	8.3753	69.4
Z1TX (G1,G2)	0.0000	0.5750	0.5750	90.0
Z0TX (G1,G2)	0.0000	0.5000	0.5000	90.0
Xd" (G1,G2)	0.0000	1.6060	1.6060	90.0

The ratio of voltage to current is calculated in ohms primary.

Customarily, relay spread locales are detailed in Ω secondary, challenging a variation by means of the current transformer (CT) and VT ratios. It is presumed that the distance relay licenses the ground fault compensation factor K_0 to be used unswervingly, permitting ground distance reach locations to be designated with positive-sequence impedance [10-12].

$$K_0 = \frac{\frac{Z_0}{Z_1} - 1}{3} = 0.5921\ \Omega \text{ at } 4.2° \qquad (5)$$

where:

Z_0 is the zero-sequence impedance of the Z_0 feeder.

Z_1 is the positive-sequence impedance of the Z_1 feeder from Table 1.

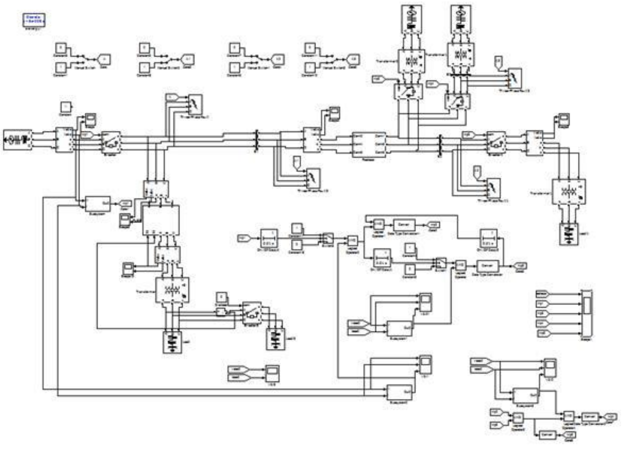

Fig. 4. MATLAB model

These components offer inattentive removal for close-in feeder errors and govern the effect of through-fault current on substation transformers. The positive-sequence impedance to the first serious fuse is 4.17 Ω at 76° as studied using the records from Table 1.

For security commitments, the 21p1 zone is fixed to spread 80 percent of this value [13]. Meanwhile the element is partaking a quadrilateral characteristic, this will encounter the reactive axis at

$$0.8 \times 4.17\ \sin 76 = 3.23\ \Omega$$

The left unsighted element is fixed to traverse the resistive axis at the identical value of 3.23 Ω while the right unsighted element is fixed to a value which is almost 5 times the reactive reach, or

$$5.0 \times 3.23\ = 16.15\ \Omega$$

In this example, the right unsighted element is fixed to 12.0 Ω.

The confirmed extreme load at the right unsighted element reach,

$$\frac{(27.6\ kV)^2}{(12 + j3.23)\ \Omega} = 61\ MVA$$

To evade the inrush current to intrude on 21p1, the resistive reach is abridged consequently. Hence, the 21G2 rudiments are set to spread up-to 75 percent of the positive-sequence line distance to the recloser [14].

The positive-sequence line distance is 8.33 Ω at 76°. The 21G2 spread is thus

$$0.75 \times 8.33\ at\ 76° = 6.25\ \Omega$$

The corresponding locale for a relay with a line characteristic of 60° is planned as

$$\frac{6.25\ \Omega}{\cos(76 - 60)} = 6.50\ \Omega\ at\ 60°$$

This setting of 6.50 Ω at 60° offers a spread of 6.25 Ω at 76°, which is 75 percent of the positive-sequence distance at 76°.

In the considered example, the 21P2 and 21G2 are well below the reach of midline recloser.

The 21P3 spread is

$$2.0\ \times 42.3\ \Omega\ at\ 59° = 84.6\ \Omega$$

This setting is attuned for a relay distinguishing angle of 60°,

The setting thus turns out to be

$$\frac{84.6\ \Omega}{\cos(59 - 60)} = 84.7\ \Omega\ at\ 60°$$

The maximum load is currently tested in MVA at the maximum predictable load angle of 30°,

$$\frac{(27.6\,kV)^2}{84.7\,\Omega\times\cos(60-30)} = 10.38\,MVA$$

The load infringement would be involved if the maximum load intrudes on the 21P3 characteristic [15].

The 21G3 rudiments are fixed to 200 percent of the maximum seeming distance.

The peak fault current from DG for a single-phase-to-ground feeder-end error, with lowest fault current from the load is planned as 43.6 Ω at 59°.

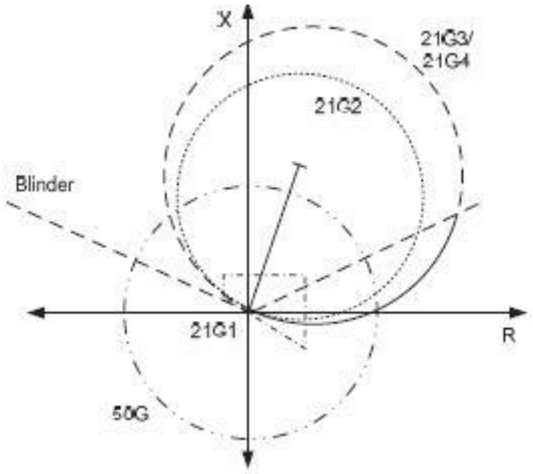

Fig. 5. Ground distance elements.

The distance assembly branded in Section 5 had been applied in numerous cases.

The following cases validate errors on rare feeders and the subsequent relay actions. Figure 6 displays the relay function for a feeder with midline recloser together with DG.

In this group, the feeder is transporting electric power earlier to an ABC fault display. Clearly, the fault is within the Zone 2 characteristic.

The relay receipts a half cycle to realize the fault and subsequently, the feeder recloses by the aforementioned.

The load current is deliberately larger next to the reclose, due to the damage of indigenous power production.

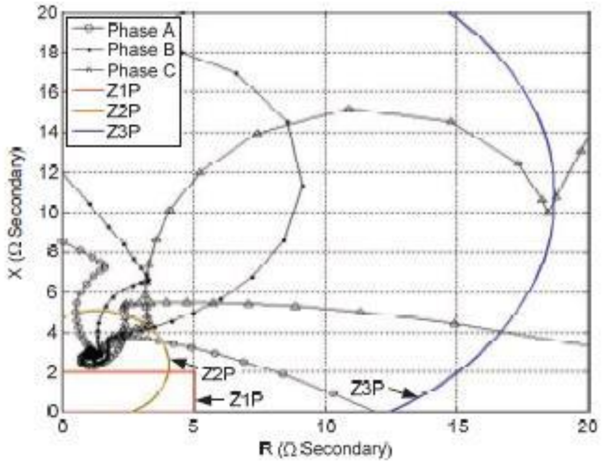

Fig. 6. Impedance plot

6. Effect of impedance relaying on feeder security value

The buildup of power production typically demands directional supervision of overcurrent tasks. At present, the difference in engineering cost amongst a distance relay and a reversing overcurrent relay is trifling and is reliant on the setting up cost. The defense engineer desires only to stipulate what security structures are vital, and the several solutions are very close in material, engineering, and setting up costs. The feeder breaker is usually situated in a substation wherever VTs previously exist and joined to the bus.

These VTs can not only be implemented for impedance safety scheme and reversing overcurrent safety scheme, as but also for burden information of all feeders with an assistance of a smart electronic device (SED). The SEDs have great input impedance and attaches multiple feeder self-protective relays to a distinct set of bus [16].

7. Conclusion

Adding of DG in the existing feeder can cause considerable reduction of protection sensitivity, harmony of the system, and tripping for external faults. The fortification yielded by distance relaying is relatively useful when compared to overcurrent relays. The challenges faced in the safety of feeders with reclosers and DG can be effectively managed by properly designing the distance relays. The inherent directional feature available in the family of distance relays allows shaping and modifying the characteristics according to the varying nature of system parameters which is especially true in the case of errors happening very near to the boundary of the specified zone. The reactive and resistive elements as well as the characteristic and polarising elements are properly designed in this paper according to the required angle using proper equations which are referred through various literatures and case studies.

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