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# Numerical Distance Relay in Scheme for Transmission Line Fault Using IOT.

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***Abstract—Impedance reach of numerical distance relay is severely affected by Fault Resistance (RF), Fault Inception Angle (FIA), Fault Type (FT), Fault Location (FL), Power Flow Angle (PFA) and series compensation in transmission line. This paper presents a different standalone adaptive distance protection algorithm for detection, classification and location of fault in presence of variable fault resistance. It is based on adaptive slope tracking method to detect and classify the fault in combination with modified Fourier filter algorithm to locate the fault. To realize the use of the planned technique, simulations are performed in PSCAD using multiple run facility & validation is carried out in MATLAB® considering wide variation in power system disturbances. Due to adaptive setting of quadrilateral characteristics in accordance with variation in fault impedance, the proposed technique is 100 % accurate for detection & classification of faults with error in fault location estimation to be within 1 %. Moreover, the proposed technique provides significant improvement in response time and estimation of fault location as compared to existing distance relaying algorithms, which are the key attributes of multi-functional numerical relay.***

***Keywords— Computer numerical control; Discrete Fourier transforms; Electrical fault detection; Phasor measurement; Power system faults; Power system protection.***

## I. INTRODUCTION

According to ministry of power, India, Energy sector is growing at rapid pace. During the financial year 2017-18, the peak demand of India was 164.1 GW with the installed capacity of 330.8 GW with generation mix of Thermal (66.2%), Hydro (13.6%), Renewable (18.2%) and Nuclear (2.0%). Powergrid Corporation of India Limited governs planning and distribution of power through Inter-State Transmission System (ISTS). State Electricity Boards (SEBs) are mainly responsible for the successful operation of ISTS. Smart power grids have been developed for evacuating power produced by numerous generating plants and distributing the power to the end users. The transmission lines are constructed with different voltage levels by taking into consideration of quantum of power and the distance involved. The Extra High Voltage (EHV) lines in trend are ± 800 kV High Voltage Direct Current (HVDC) along with 66 kV, 110 kV, 220 kV, 400 kV and 765 kV AC lines. The length & capacity of transmission system of 220 kV and above voltage levels, in the country as on 30th November 2017 was 3,81,671 ckm of transmission lines and 7,91,570 MVA respectively. The transmission grids are in operation following regulations directed by Central Electricity Regulatory Commission (CERC) and State Electricity Regulatory Commissions (SERC). The loading on transmission grids must be controlled by considering voltage magnitude and angle stability, power flow conditions and security aspects.

With this huge power transmission infrastructure, the secure uninterrupted power transmission & distribution network must have smart protective devices to avert unwanted faults and widespread blackouts. The USA – Canada task force on the August 14, 2003 black out and subcommittee on grid disturbance in India that affected 250 million people, concluded that inappropriate and uncoordinated relay protection settings were one of the principle reasons of cascade outage and widespread blackout [1]. This research work presents the challenges and proposed remedies for the future electric power industry to implement new adaptive state of the art techniques in the field of transmission grid protection. The main issues for power transmission utilities are to sustain stability and reliability of the network with implementation of smart protection schemes. The power grid must be sheltered from variety of disturbances developing in the system. A small breakdown of protection scheme can result in huge amount of power loss which ultimately reflects large wastage of fossil fuels. The current situation urges development of dedicated adaptive numerical relaying scheme for implementation of new ideas in the field of power system transmission line protection technologies. This section outlines protection schemes of power transmission network along with the necessity of advanced protection technologies in brief.

## II. LITERATURE REVIEW

Taskforce on grid disturbance in India has insisted that numerical relays used for protection of EHV transmission line must remain stable during power swing. In the event of a major power system disturbance, control and security actions must shelter the power system degradation, minimize impacts and enable system restoration. today protections and controls actions were not well designed and coordinated for a fast-developing disturbance and may be too slow to minimize the impact. Protection engineers normally analyze dynamic situations through simulation software using off-line analysis. As a result, technocrats are sometimes forced to address complex issues by relying on static company policies and past experience. A large percentage of major system disturbances can be traced to ‘‘hidden failures’’ in protective elements which remain undetected until the system is exposed to certain system disturbances. The ability of a numerical relay to detect type of disturbance occurring in smart power grid network before an incorrect operation occurs is prime requirement of digital protection. In order to minimize impacts, protective relaying should be able to monitor the real time system disturbances and execute corrective actions. To justify these, advanced numerical relay based schemes, which incorporates adaptive techniques in pace with disturbances occurring externally can be implemented. In the following topics, the traditional transmission line protections are outlined along with in depth literature review.

**TRADITIONAL TRANSMISSION LINE PROTECTION**

Transmission lines are generally provided with following protection schemes:
Time graded protection
Distance protection
Carrier Aided Protection
In order to justify the area of research, basic operation and set back of each protection schemes are described here in brief.

## SYSTEM ARCHITECTURE OVERVIEW

**TIME GRADED PROTECTION**

In this scheme of protection, discrimination of time is incorporated. In other words, time setting of relays is so graded that in the event of fault, the smallest possible part of the system is isolated by operating the relay nearer to the fault location. In time graded protection system, the time of operation of the each relay is kept fixed as shown in Fig. Whenever fault occurs at E, the relay located at point D will operate within 0.5 sec. In case it fails, then the successive relays will provide backup protection and operate after the definite time lag as shown in Fig. 1.1 for the fault at point E. It is independent of the magnitude of operating current.

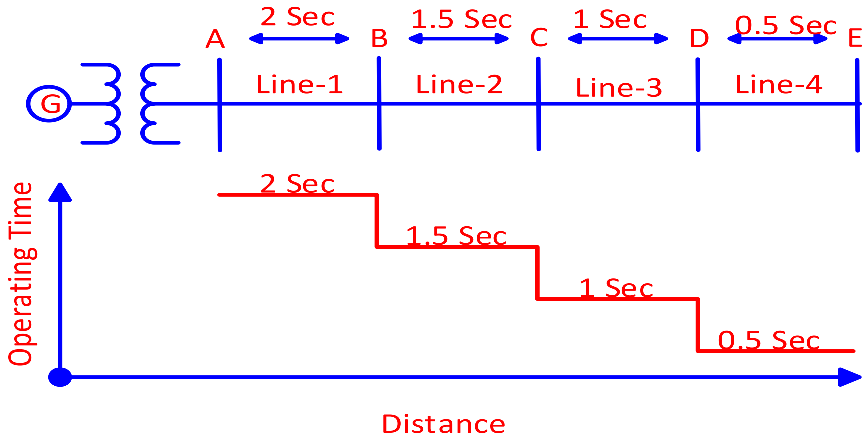


**Figure: Time Graded – Ring Main System**

**DIFFERENTIAL PROTECTION**

It is further classified into current differential protection scheme and Merz- price voltage balance scheme. The principle of operation of both the schemes is based on differential circulating current protection. The basic operation along with its main setbacks, are outlined here in brief.

In Merz – price voltage balance scheme as shown in Fig, Current Transformers (CTs) are connected in series with a relay in such a way that under normal conditions, their secondary voltages are equal and in opposite direction i.e. they balance each other. Therefore there is no driving force for circulation of current through relay coils.

When a fault occurs in the protected zone of transmission line then more current will flow through CT of supply side than through load side CT. Therefore, their secondary voltages become unequal and circulating current flows through the pilot wires and relays. The circuit breaker at both the ends of the line will trip out and the faulty line will be isolated.

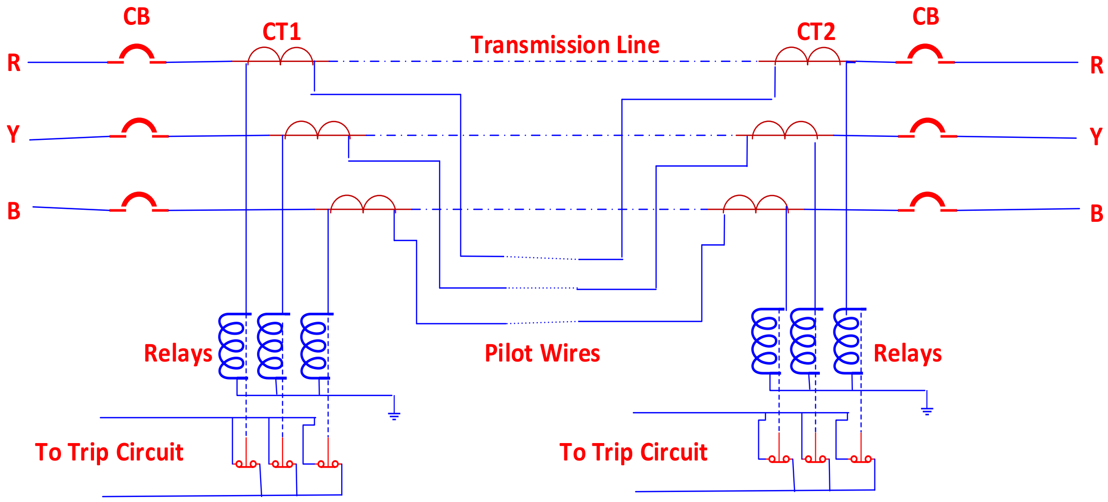


**Fig:Price Voltage balance differential protection scheme**

Though, it provides very fast protection against ground faults and it can be used for ring mains / parallel feeders and reduces the damage, still it has some major drawbacks:

1. Current transformer at both the ends should be exactly identical, which is very difficult.
2. If there is a break in pilot – wire circuit, the system will not operate.
3. This system is very expensive due to greater length of pilot wire.
4. Due to charging current of pilot wire capacitance, relay may operate even during normal operating conditions.

## DISTANCE PROTECTION

As time graded system gives long time delay in fault clearance at the generating station and differential protection becomes too expensive owing to its greater length of pilot wires, these protection schemes are not suitable for very long and high voltage transmission lines. Therefore, there is need of distance protection in which the action of relay depends upon the distance (or impedance) between the point where relay is installed and the point of fault. At present, majority of all the transmission lines are protected by different kinds of distance relays for primary and backup protections, hence its basic fundamentals along with research issues are described here in detail. Fig. explains basic principle of operation for distance relay.

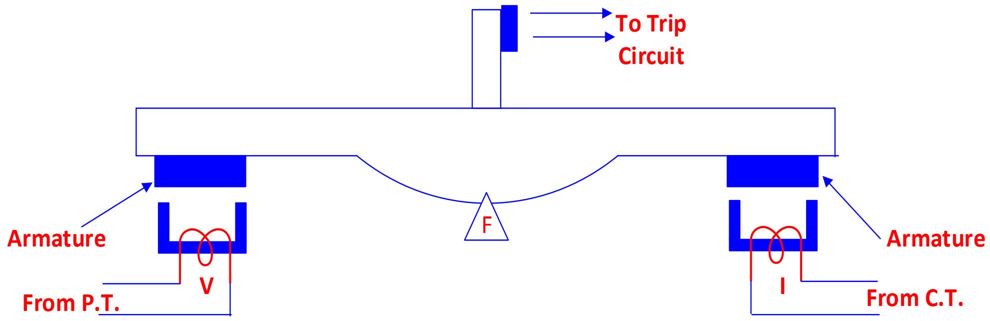


**Figure: Basic principle of operation of Distance Relays**

It is double actuating quantity relay with one coil is energized by voltage and the other coil is energized by current. The relay operates when the ratio V/I is below the set / threshold value. Distance relays measures impedance using bus voltages and line currents as shown in Fig. at the relay location. When the fault occurs, it calculates the impedance ($Z_F$) between relay location and fault. If calculated impedance is less than the set value ($Z_{set}$) then relay will generate the trip signal to operate the circuit breaker and relay deems this fault $F_1$ as internal fault. On the other side, if calculated value of impedance is more than the preset threshold value then the trip signal will not be issued instantaneously and this fault is considered as external fault. When fault occurs on the transmission line, the fault current increases and the voltage at fault point reduces. The ratio is measured at the location of Current Transformer (CT) and Potential Transformer (PT). The current gives operating torque and voltage gives restraining torque. The voltage at PT depends on the distance between the PT and the location of fault. Farther is the distance of fault from PT, more will be the voltage available at PT and smaller is the distance, less will be the voltage. The ratio of voltage and current reflects impedance seen by the relay. It is proportional to the distance between the relaying point and the fault along the line. Hence such relay provides protection only up to certain length of the line equivalent to its impedance setting and hence it is called distance relay or impedance relay.

## III. PROPOSED SYSTEM

### ISSUES IN NUMERICAL DISTANCE RELAYS

There are various factors associated with implementation and operation of distance protection schemes. Out of the many issues, the potential issues are presented in this section along with mathematical and technical fundamentals for each of them. The main influencing parameters are:

1. Effect of DC component
2. Close in fault
3. High resistance fault
4. Fault Inception Angle (FIA) and Power Flow angle (PFA)
5. Load encroachment and uncoordinated Zone 3 relay settings
6. Transient faults & Auto-reclosing schemes
7. Power Swings
8. Series compensation in transmission lines

Due to effect of above listed factors, the distance relays can mal-operate. The main reason behind it is accuracy of phasor estimation of applied analog signals which can result in either delayed or false tripping. Here, the protective issues arise due to above factors are outlined in subsequent sections.

### EFFECT OF DC COMPONENT

The accuracy of distance protection relaying algorithms depend on proper extractions in fundamental complex circute. when the fault occurs, the DC components of harmonics will superimposed on this real phasors resulting incorrect estimations. The most widely used phasors estimation technique in Discrete Fourier Transform (DFT) for proper result extractions of fundamental component from the analog signal on separating DC component and harmonics.

### FAULT INCEPTION ANGLE AND POWER FLOW ANGLE

As EHV and UHV transmission lines are protected by distance relays and majority of all distance relays are operated based on calculated impedance at the time of fault. The impedance depends not only on values of fault voltage or current, but it also depends on fault inception angle. The fault inception angle is the angle between fault voltage and fault current which mainly governs the value of impedance at the time of fault. Hence, for a fault at particular distance, if impedance has been set by considering only magnitudes of voltage and current, then at the time of fault due to fault inception angle, calculated impedance can be much higher than the impedance setting which results in under reaching problem. the equations;

$$\mathrm{Ao} = \mathrm{An}\sin(\Theta - \alpha)e^{\frac{-t}{\tau}} \qquad 2.5$$

In the exactly same way, during the power swing and / or overloading condition, due to the angle separation between the generator and infinite busbar, the power flow angle could cause the locus of the impedance to enter in the zone of the relay, which results in mal-operation of the relay and cause overreaching problem of the relay.

### CLOSE-IN FAULT

One of the serious problems in case of distance relaying is close-in fault due to which relay will not get enough polarizing voltage as specified in the data sheet of the relay and it will fail to operate because of its lower sensitivity. It is frequent in Mho relay which is widely used for primary and backup protection. When the fault occurs on heavily loaded line, especially when PT is on the secondary side of the busbar, the origin may get excluded from the relay operating zone and relay may fail to operate. There are various techniques to avoid close-in fault. One technique is to use offset Mho characteristic to bring the origin inside its operating zone which can make the relay directionally insensitive. Another technique is cross polarization in which polarization signal is derived from the healthy phase but this technique can fail during three – phase fault.

### INFLUENCE OF FAULT RESISTANCE

When fault involving ground occurs, the fault resistance ($R_F$) is given by

$$R_F = R_{arc} + R_T + R_g \qquad 2.6$$

Where, $R_{arc}$ = Arc resistance which depends on fault MVA.
$R_T$ = Tower footing resistance which depends on resistivity of the soil, its typical values are 0.5 – 50 ohms.
$R_g$ = Ground resistance which depends on ground surface.

Fig. shows simple two-terminals transmissions line between two buse. If fault occurs on the middle of transmission line (between bus A & B), the impedance seen by the relay can be given by

$$Z_{seen} = d.Z_L + R_F.\left(1 + \frac{I_B}{I_A}\right) \qquad 2.7$$

Where $Z_L$ is the unit line impedance and *d* indicates fault location. Also, $I_F$ = fault current = $I_A + I_B$.

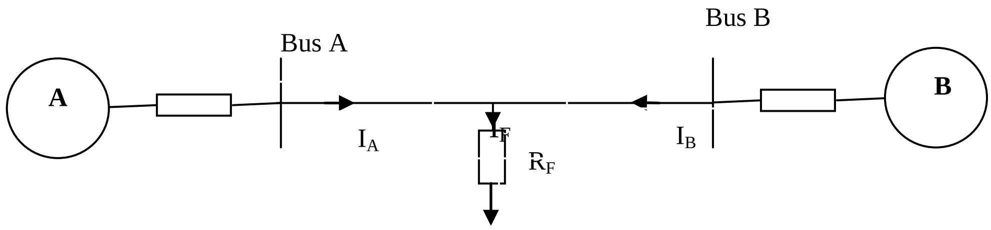


Figure 2.1: High Resistance Fault in Transmission Line

## LOAD ENCROACHMENT AND EVALUATION OF ZONE 3 RELAY SETTINGS

The third zone relay, often considered a remote relay or breaker backup, is slower acting and monitors for faults outside the length of the line. This relay should not trip the breakers under typical overloading conditions. If zone 3 relay senses a fault in the immediate reach of the line and its zone 1 and zone 2 settings, it waits for 1 to 2 seconds to allow the primary line protection to act first. The length and configuration of some lines require higher apparent impedance setting. Hence, the zone 3 settings are designed with overload margins close to the long-term loadability limit of the line. In such situations, zone 3 relay could cause a breaker to trip in an extreme overload situation even though a fault does not exist.

The final reports on black out concluded that if the relay setting is sensitive to the load encroachment on the transmission system then it can result in cascade tripping and wide spread blackout. While all of the relays operated according to their settings, some zone 3 relays (and few zone 2 relays acting like zone 3 relays) acted so quickly in response to line overload that they did not provide time for the electric system transients to settle. This is so called overreach of the distance relay. There are two possible solutions to avoid this overreaching problem. Firstly by proper coordination between primary and backup protection. Secondly, use of relay with quadrilateral characteristic which has better loadability limit.

Hence, the relay with quadrilateral characteristic also mal_operate during load encroachment. The only possible solution is to develop a state of the art system which must block the trip signal during such scenario.

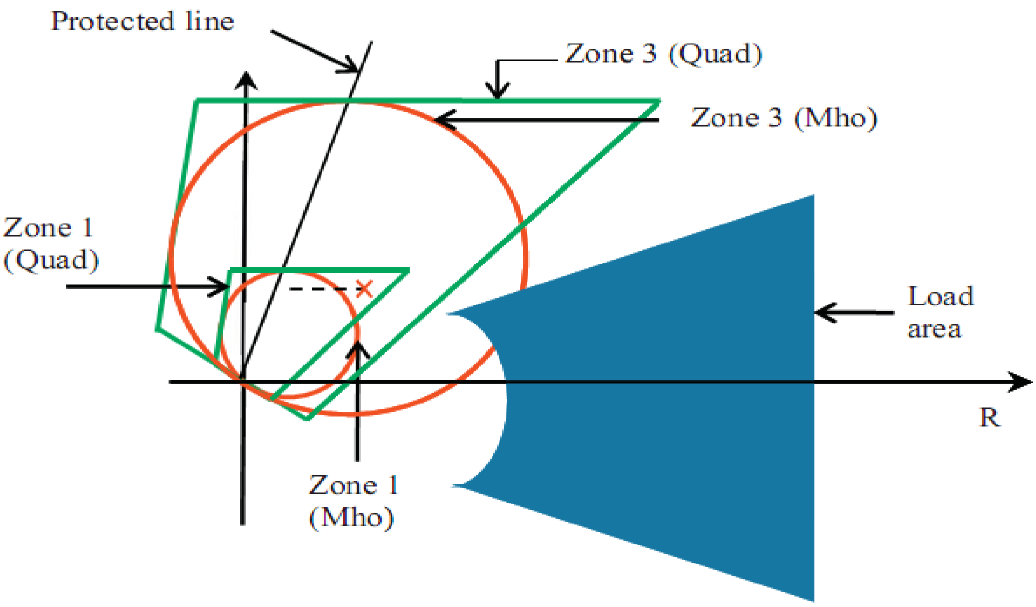


Figure : Comparison between Mho and Quadrilateral settings for load encroachment

## TRANSIENT CONDITION AND IMPLEMENTATION OF AUTO RECLOSURE

Almost 80 % of the faults involving the ground are transient in nature. The transient faults are normally cleared in 1 – 2 seconds. Once the fault is occurred, the protective element will generate the trip signal to isolate the faulty system from healthy section. The generation of trip signal subsequently results in stoppage of power supply continuity. In order to provide uninterruptable power supply to the potential consumers, service continuity must be regained automatically as soon as transient fault is cleared. Thus, there should be proper discrimination between transient fault and permanent fault.

However, transient conditions can exist in two cases.

(i) Switching transient due to system reactance.

(ii) Transient fault

Whenever fault or dynamic switching occurs on the transmission line, the magnitude of the current is very high and asymmetrical in nature. The time response of the fault current consists of transient part and steady state component. The transient part consists of DC Component and sub-harmonic components exponentially decaying in nature. The time response of the system will be oscillatory and unstable if the system is un-damped. The damping factor mainly depends on system reactance and series capacitance of the series compensated transmission line. Due to the presence of DC component super imposed on fundamental frequency component, there can be overreaching problem for first zone of distance relaying.
Similarly, in case of transient fault which mainly die out in few cycles, there should be proper discrimination of transient fault and permanent fault in order to automatically reclose the circuit breaker. To mitigate these problems, digital distance relays and auto-reclosures use Discrete Fourier Transform (DFT). However, it provides more time delay and also suffers from sensitivity problems for processing the algorithm. Hence, proposed solution is to implement Least Square Error (LSE) technique and Fast Fourier Transform (FFT) using Decimation in Time (DIT) or Decimation in Frequency (DIF) algorithm using which mathematical computations can be greatly reduced. It can be also analyzed using modified Fourier transform, wavelet transform, support vector machine or artificial neural network to improve its performance.

## EFFECT OF POWER SWING

The fluctuations of voltage and current because of abrupt change in the mechanical input to generator, switching of transmission line dueto fault or suddenly application/removal of loads is called power swing. Due to power swing condition, the impedance locus falls under the zone 3 characteristics of the relay momentarily. It complicates the operation of the relay to discriminate between three-phase faults and power swings. The conventionally used load blinder technique works on the rate of change of impedance with respect to time as shown in Fig. between two blinder A & blinder B. During fault its magnitude will be more, whereas during power swing its value will be less. However, proper determination of threshold limits for the same is the challenging task for the protection engineers. Thus, the swing impedance trajectory may enter the fault detection zone of distance relays as shown in Fig.

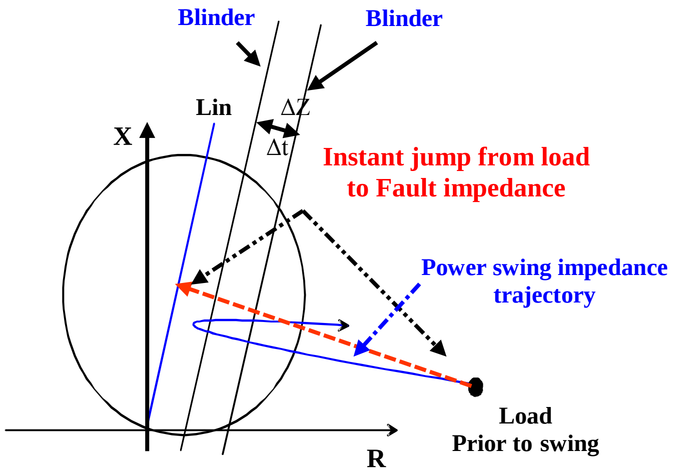


Figure: Fault and swing impedance trajectory
With stable swings, the swing impedance trajectory returns to the actual load impedance locus. Thus all distance relays in the power system subjected to swings need to be securely blocked for the time the swing impedance remains within the distance relay characteristic in order not to disrupt the power system integrity. The swing impedance moving along its trajectory needs some time to travel through the two blinders as shown in Fig.. Its travelling speed is slow compared to the sudden impedance jump into the characteristic during faults occur. Traditional power swing detection is based on the measurement of time $\Delta t$ that elapses as the traveling swing impedance trajectory enters and leaves two thresholds (circles or blinders). If the time, the swing impedance requires to pass through the two impedance set points is longer than set time $\Delta t$, the swing detector will block the distance relays.
The common predictive method to determine loss of synchronism is the Equal-Area Criterion. It assumes that the power system behaves like a two-machine model where one area oscillates against the rest of the system. In reality a power system is more complex and changes its parameters over time. The time $\Delta t$ as criterion does not fully cover all possible situations. The set points are fixed and do not adapt to power system changes. Finding proper settings for traditional swing detectors is not simple and often requires comprehensive grid studies. If the study does not consider worst case conditions, then the relays may lack security. When single pole auto-reclosure is applied, the swing detector may not assume symmetrical conditions during the auto-reclose dead time. A more comprehensive logic is required to cope with open pole conditions in the presence of power swings.

Another challenge is the clearance of line faults during power swings. The swing detector blocks the ordinary distance processing under those conditions. Thus, the distance relay itself requires extra provisions to cover faults during power swings. For all asymmetrical faults, the negative or zero sequence current or voltage which are not affected by power swings, may be used for line fault calculation. In conclusion, new swing detectors and their associated distance relays must

- Cover extremely fast swings frequencies
- Block the trip signal during power swing
- Generate the trip signal during potential faults
- Clear all kinds of internal fault during power swings
- Should be virtually setting free

## IV. RESULTS

Undesirable operation of numerical relays may lead to catastrophic breakdown in the power grid. The digital numerical relays used for in-system operation nowadays must be adaptive in order to avoid the undesirable effects of conventional protective system as described in section 2.1. As outlined in previous sections, there are numerous factors influencing the performance of numerical distance relays. As shown in Fig. 2.5, the power swing, load encroachment and fault occurring in the transmission lines are the three main dynamic situations occurring in power grid.

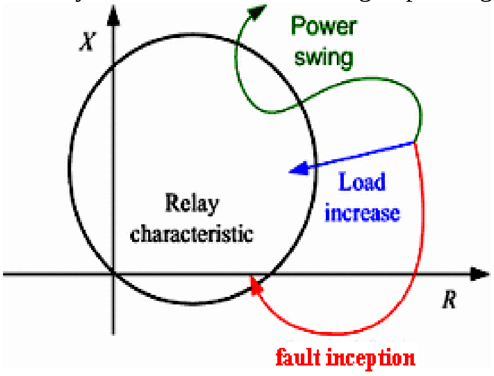


Figure: Influence of Dynamic Situations on Conventional Distance Relays

During power swing and load encroachments, impedance trajectory enters in the trip characteristic of impedance relays even without occurrence of fault and hence the relays will generate false tripping on such events.

On the contrary, there are some fault situations during which the conventionally used numerical relay fails to operate. Majority of distance relay incorporates certain amount of arc resistance and reactance at the time of fault. However during the fault, if the resistance and reactance seen by the relay are more than the reach setting of the distance relays then impedance trajectory will fall outside the trip region as shown in Fig. It will ultimately leads to under reach operation of the relay.

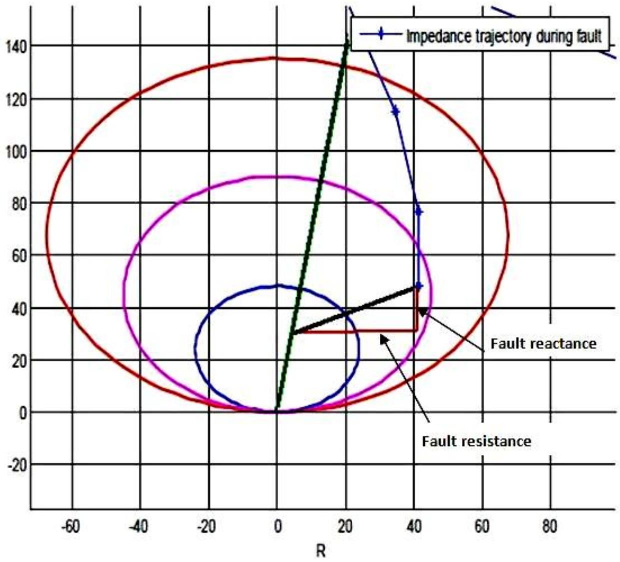


Figure : Effect of Fault Impedance

Hence, main objective of this research is to develop the adaptive quadrilateral distance relay which modifies its characteristics adaptively based on the variation in fault and system parameters. The developed relay must be fast and accurate as compared to existing schemes of protection to maintain power system stability and reliability. The protective scheme must be sensitive enough to critical parameters because of which currently adopted relaying scheme mal-operates. It makes modern relay capable enough to effectively settle down disturbances and communicate in better way with Phasor Measurement Units (PMUs). The major factors that need to considered, are high resistance fault, load encroachment problem, power swing, close-in faults, saturation of instrument transformer and transient faults occurring in the transmission line.

Secondly, majority of blackouts reported are due to power swing scenario. Conventionally used distance relays adopt Power Swing Blocking (PSB) feature. These relays mainly operate on the rate of change of single operating quantity. However, these developed schemes fail to operate for the faults occurring during power swing. Recently, soft computing based disturbance classifiers found many applications in the field of smart grid protections against power swing. Hence, there is always a scope of improvement for the development of powerful classifier algorithm which can properly discriminate between fault and swing scenario. The developed scheme must be sensitive for the symmetrical and asymmetrical faults for both compensated and uncompensated transmission lines.

Apart from these, the transient fault occurring in the transmission line also needs critical attention as it severely affects the stability of the system. Presently used auto-reclosure scheme provides fixed dead time for detection of fault. It also provides multi-shot operation in order to monitor the clearance of transient fault. The multi-shot operations are practically not feasible on heavily loaded lines. Additionally, detection of transient fault is very much complicated task in series compensated transmission lines. Hence, Auto-reclosing schemes are mainly applied to short transmission lines. With the advancement of synchro-phasor technology, the phasors can be monitored continuously in order to set the dead time of auto-reclosing system adaptively. It can also improve the dynamic stability of the system.

## V. CONCLUSION

The research presents novel decision logic on improve this impedance reach of numerical distance relay System modeling and simulation is performed in PSCAD software package using multi-run facility for capturing samples of faulty signals and during varying power system disturbances or the developed algorithm is validated in MATLAB. The High Impedance Faults (HIFs) are successfully detected the implementing GDF calculation, slope tracking method and adaptive quadrilateral relay characteristic. The proposed technique is found to be highly precise and faster than the existing methods during close-in fault, high resistance fault, load encroachment, influence of DC component or CT saturation. Fault classifier modules are designed for each phase and line to identify the type of fault occurs on transmission line. In order to estimate accurate fault location, a fault locator module is also designed and error in fault location estimation is found within 1 % for each zone of protection. The outcome of the proposed algorithm highlights significant contribution to improve stability, sensitivity and speed of the numerical distance relays in comparison to existing schemes of protection. Moreover, the proposed fault identification on the algorithm can accurately estimate fault instances, fault location and type of fault, was the desirable attributes of multifunctional numerical relays.

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