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Implementation of Adaptive Zone-2 Protection for Transmission Lines

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***ABSTRACT**: Series-compensation in the transmission line modifies the apparent impedance observed by the distance relay. This may cause relay mal operation due to improper protection and coordination. The Zone characteristics of distance relay needs to be modified with respect to the level of compensation in order to avoid such wrong operation. In this paper, the distance relay characteristics are adapted using synchrophasor data of both ends of the series compensated line. The method first calculates the level of compensation using prefault voltage and current phasors and then modifies the trip boundary. The proposed method tested for 400kV series compensated power system simulated in EMTDC/PSCAD and found to be accurate.*

***Keywords:** Phasor Measurement Unit (PMUs), Discrete Fourier Transform's (DFT), Phasor Data Concentrator (PDC), Open Systems Interconnection (OSI), Electronics Industry Association (EIA), National Electric Manufacturer's Association (NEMA), Independent System Operator (ISO)*

I. INTRODUCTION

Analysis of blackouts reveals that one of the major causes is inappropriate operation of relays during such disturbances. Available relays are of fixed characteristic type and they have limitations in a changing power system scenario. Relay mal-operation can be prevented by changing the relay characteristic in accordance with the prevailing power system condition. This became possible with the help of digital relaying and faster communication systems which can sense accurate system conditions. In the recent time Phasor Measurement Unit (PMUs) with the help GPS satellite system provides synchronized phasors which are beneficial for adaptive protection. But due to communication delays the adaptive protection is not feasible for Zone-1 protection. Whereas the present system condition information received from PMUs can be useful for slow protection schemes like Zone-2 protection.

In this paper, an adaptive technique to change the distance relay zone characteristics for series-compensated line is proposed in order to maintain proper coordination with adjacent relays.

The proposed algorithm compute the level of compensation using synchrophasor data obtained from phasor measurement unit (PMU) at both ends of the line. Then the zone characteristics are generated using the compensation level. The algorithm is applied to adapt zone 2 characteristics of the distance relay to avoid the over/under reach problem.

II. PROPOSED METHOD

In realistic conditions, it is not accurate to get the instantaneous protection for the entire length of the line due to relay mal function, improper installation or deterioration in service, incorrect system design including instrumentation transformers (e.g. CT saturation), wrong selection of the relay type, circuit breaker failure (stuck breaker). Thus the relay A would not be very much good in distinguishing between a fault at 99% of the distance AB and the one at 101% of distance AB. This difficulty is reduced and overcome by using 'three zone' protection of distances shown in Fig.1 below:

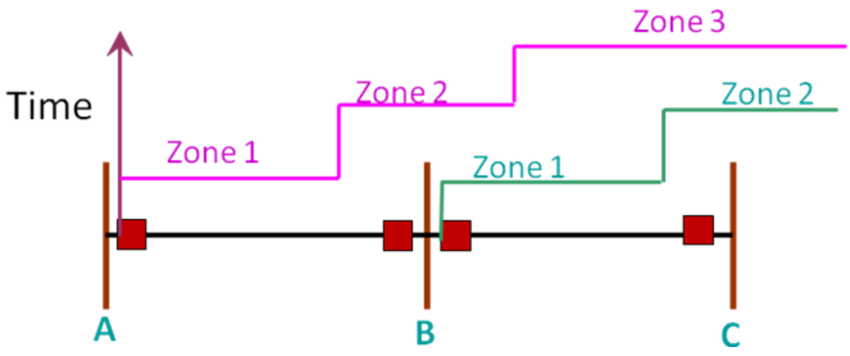

Fig.1. Three Zone protection of distances

In this protection scheme, three distance elements are used at each terminal. The zone 1 element covers first 90% of the line and is arranged to trip instantly for faults in this portion. The zone 2 element trips for faults in the remaining 10% of the line and for faults in the next line section, but a time delay is introduced to prevent the line from being tripped if the fault in the next section. The zone 3 element provides back-up protection in the event a fault in the next section is not cleared by breaker.

2.1 Adaptive Protection Schemes

Adaptive protection scheme is defined as, "A protection thinking which permits and seek to make adjustments automatically in a variety of protection functions in order to make them more in sync too established conditions." As defined in the above statement relay has to sense the correct situation of the power system and there must be some arrangement so that adjustments can be made in that relay according to the present conditions. The various cases where the distance relay face problem due to the change in system conditions are Series compensated line, Multi terminal line and Parallel feeder. The adaptive protection scheme for series compensated line is explained below:

2.1.1Series Compensated Line

In a competitive and deregulated market to meet the energy demand and to transfer more power through the available lines, series compensating devices [1] are being used. But the series compensation in the line puts challenges to difficult protection schemes. The block diagram of the series compensated line is shown in Fig.2.

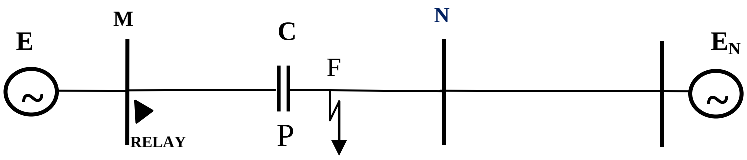

Fig.2. Block diagram of the model

The problems caused by these compensating devices include the change in impedance, the phase angle, voltage magnitude, currents and transients produced by the fault and the consequent control actions. Most of the high voltage transmission lines which are protected by distance relays face problem due to the series compensation as the fault impedance beyond the capacitor changes. The number of capacitor banks connected in series decides the total level of compensation of the transmission line and at times there may not be any compensation (series capacitors by-passed). As shown in Fig.3 below for a series compensated line having 50 % compensation at the middle after the midpoint P the impedance seen by the relay at M changes suddenly where only the reactive part is compensated. If the level of compensation is not known then the relay setting for the line will be improper. However if the series compensation is known then the adaptive zone-2 distance relaying can be achieved.

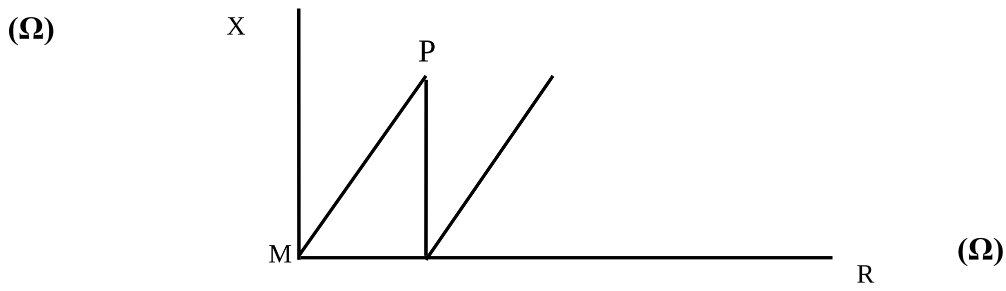

Fig.3. Impedance diagram for 50% series compensation at middle

2.1.2. Different Protection Schemes Available

Digital relaying makes it possible to change the settings of the relay [2,3]. The trip characteristics of the distance relay needs to be modified for series compensated lines for proper line protection [10]. Different techniques are available for protection of series compensated lines.

There are several approaches available in the literature for the series compensated line. The high speed protection of the series compensated line using parallel working algorithms is used to adapt the relay setting [4]. Real time simulation tool is used to see the relay setting mistakes for the series compensated line at different power system conditions and uses the best relay characteristics before installation [5]. An impedance measurement algorithm with other parallel and adaptive algorithms is applied for correct operation of relay [6].

A wavelet transform technique is applied for trip boundary characteristic of series-compensated line and also for classification of fault [7]. Voltages and phasors available at both ends of the line are applied to find out the voltage drop across the series capacitor which is used to compensate the effects of the series capacitor for zone-1 settings of the relay [8].

2.1.3. Adaptive setting for series-compensated line

Available techniques suggest that adaptive protection of a line can be carried out using information from both the ends with dedicated communication system. Adaptive setting of distance relay for series compensating line is possible, if series-compensation level and system conditions are known. In this paper, Synchrophasor data availed through Phasor Measurement Units [9] installed at two ends of a line is utilized to compute the compensation level of the series capacitor.

Using the series compensation level and line parameters, the trip boundary of the distance relay is adapted in order to detect the fault in transmission system reliably. The performance of the proposed method is tested for a 400 kV system simulated in PSCAD/EMTDC software.

A transmission system with Series-compensation at middle of the transmission line is considered as depicted in Fig. 4. The distance relay used for line protection at bus M is adapted with synchrophasor data in accordance with the prevailing condition for which two PMUs are placed at bus-M and N linked through communication channel.

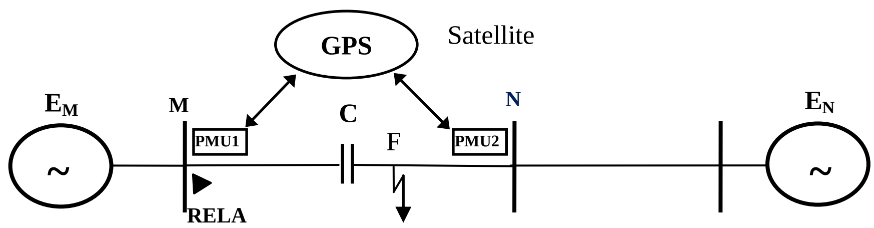

Fig.4 Block diagram of the Model with PMU

The reporting rate of PMU data is considered as 50 phasors/sec. The level of series-compensation is estimated using the voltage and current phasors obtained through PMUs at bus-M and N.

PMU1 and PMU2 will give the positive sequence voltage, current phasors of bus M and N respectively. From the time synchronized data line impedance can be calculated by:

$$Z_{1MN} = \frac{\overline{V_M} - \overline{V_N}}{\overline{I_L}} \tag{1}$$

Where $\overline{V_M}$ = Bus-M positive sequence voltage

$\overline{V_N}$ = Bus-N positive sequence voltage,
$\overline{I_L}$ = Positive sequence current flowing through the series compensated line.

Series capacitors present in the transmission line will compensate the inductive reactance of the line.

Since series capacitor reduces the reactive component of the line impedance, the effective impedance of the line can be computed as follows:

$$Z_C = \mathrm{Im}(Z_{1L}) - \mathrm{Im}(Z_{1MN}) \tag{2}$$

where Z_{1L} = Actual line impedance,
Z_C = Series capacitor reactance.

As per the calculated compensation the tripping zone is set. The flow diagram of the proposed algorithm for setting the relay characteristic is shown in Fig.5. In the first two steps the compensation is calculated and in the third step trip boundary is generated.

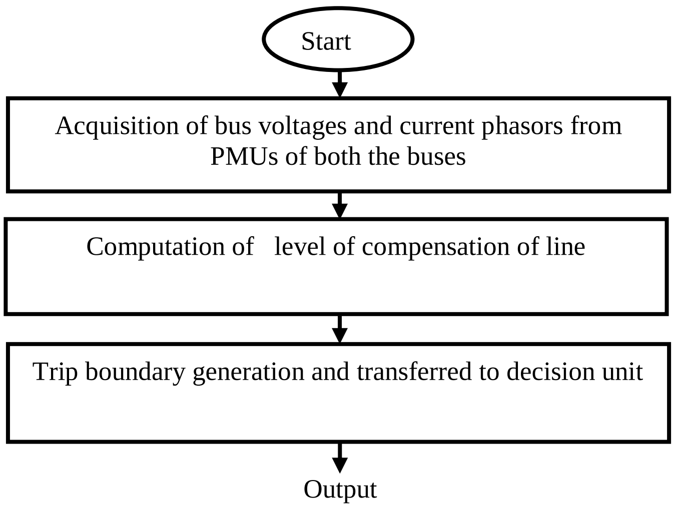

Fig.5. Flow diagram for the proposed adaptive technique

2.1.4. Apparent Impedance Calculation

A simple system with two buses and sources at both the end is considered as shown in fig below. The series capacitor with 50 percent compensation is present at middle of the line. Latter the same capacitor can be taken at one end or at both the ends. The performance of proposed adaptive algorithm is verified for phase-to-ground fault, other type of faults also can be computed in similar procedure. The relation of pre-fault voltage phasors for the two source system in Fig. 4 can be formulated as:

$$E_M = (he^{-j\delta})E_N \tag{3}$$

Where h= voltage magnitude ratio
δ=phase angle difference between the two buses

The impedance seen by the distance relay can be expressed as:

$$Z_{APP} = \frac{V_{AM}}{I_{AM} + K_{0L} * I_{LM0}} \tag{4}$$

Where K_{0L} is known as zero sequence compensating factor.

$$K_{0L} = \frac{Z_{0L} - Z_{1L}}{Z_{1L}} \tag{5}$$

In the above expression,

Z_{0L} = Zero Sequence impedance of the line,
Z_{1L}= Positive Sequence impedance of the line.

Using above equations, the trip boundary can be set by fixing the reach of the relay and the maximum R_F. The apparent impedance can be calculated by creating faults at different points on the transmission line. For Zone-2 setting 100% of the line between M and N, 50% of the line between N and P is set on the relay.

III. RESULTS AND DISCUSSION

The performance of the proposed algorithm is verified for 400 kV, 50 Hz system simulated in EMTDC/PSCAD. The positive sequence phasors obtained from PMUs is used to compute the compensation level and the boundary of zone characteristic using (4). The lower and upper sides of quadrilateral characteristic are calculated by changing the arc resistance from 0 to 200 ohm at 150% of the line from the relay end. Similarly, left and right sides of trip characteristic are are computed by changing the relay reach to 150% of the line with 0 and 200 ohm respectively. The phasors are calculated from voltage and current samples using one cycle discrete fourier transform (DFT) technique.

3.1 Boundary settings of the relay at h=1 and delta = 10^0 for 50% of compensation

The synchrophasor data of prefault conditions are utilized to estimate series-compensation. The prefault condition for the case is taken as h=1, delta=10^0. The proposed algorithm applied and found the compensation correctly as Z_C= -j15.67 Ω (refer Table.1). Zone characteristics are computed using (4) and shown in Fig. 6 as estimated plot. To verify the estimated characteristics various line-to-grounds faults are simulated at similar operating conditions with boundary conditions. The results are given in Fig. 6 as actual impedance plot of the fault. It was found that actual impedance plots of faults simulated for boundary conditions exactly matches with the estimated characteristics and shows the accuracy of proposed algorithm.

PMU	Voltage (kV)	Current (kA)	Z_{MN} (Ω)	Estimated Z_C(Ω)
PMU1	227.15-j*37.85	0.69+j*0.065	2.93+j*15.68	-j15.67
PMU2	226.15-j*48.89	0.695-j*0.07		

Table.1 PMU data for 50 % compensation with h=1, δ=10^0

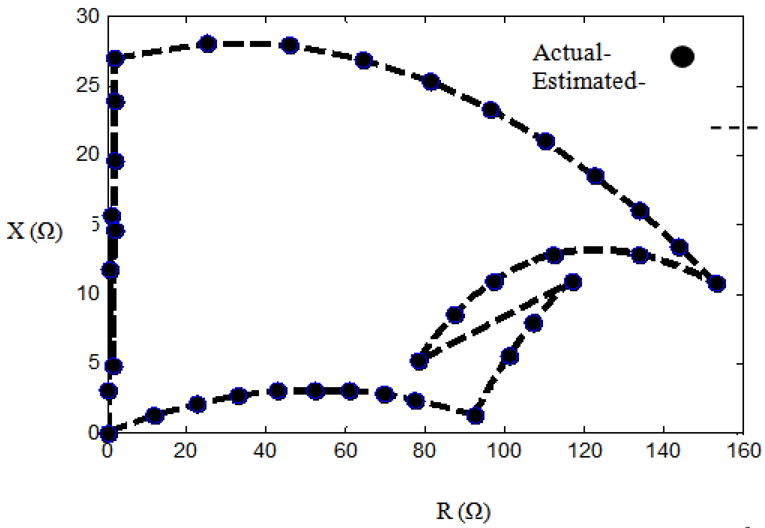

Fig.6. Trip boundary with 50 %series compensation with h=1, δ=10^0

3.2 Boundary settings of the relay at h=1 and delta = 10^0 for 30% of compensation

Compensation level is considered as 30% in this case with prefault conditions as h=1 and delta = 10^0. The reactance of the series-capacitor computed using sychrophasor data at both ends of the line is found that Z_C=-j9.41Ω (refer Table.2) which is exactly matches with the actual value.

Using the compensation level, the zone characteristics are developed and depicted in Fig. 7. The characteristics are verified by simulating line-to-ground faults at boundary conditions keeping the same operating conditions. It was found that proposed algorithm can adapt accurate zone characteristics using prefault synchrophasor data.

PMU	Voltage (kV)	Current (kA)	Z_{MN} (Ω)	Estimated Z_C(Ω)
PMU1	227.2-j*37.61	0.029+j*0.35	3.32+j*21.94	-j9.41
PMU2	226.17-j*49.93	0.0299-j*0.36		

Table.2 PMU data for 30 % compensation with h=1, δ=10^0

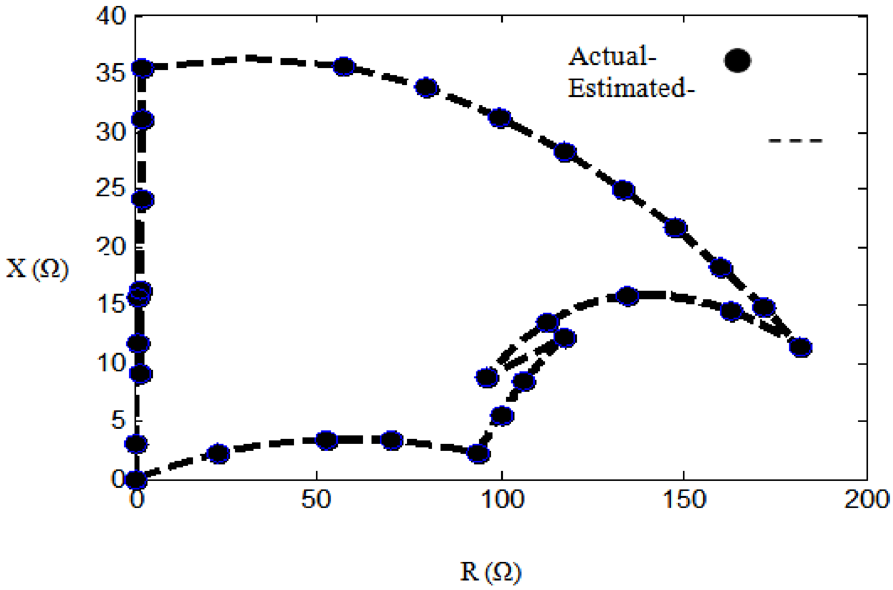

Fig.7. Trip boundary with 30 %series compensation with h=1, δ=10^0

3.3 Zone boundary characteristics without series-compensation

Series-capacitor is bypassed in this case and the proposed technique is applied to adapt the zone characteristics for the operating condition. The series capacitor reactance is found as Z_C= -j0.03Ω (refer Table.3) which is correct. The zone characteristics are calculated for this case and results are shown in Fig. 8. Simultaneously, the line-to-ground faults simulated at boundary conditions also provided the similar results. This shows the strength of proposed method.

PMU	Voltage (kV)	Current (kA)	Z_{MN} (Ω)	Estimated Z_C(Ω)
PMU1	227.34- j*36.99	0.033+j*0.4378	4.27+j*31.33	-j0.03
PMU2	226.16- j*52.58	0.039-j*0.445		

Table.3 PMU data for no compensation with h=1, δ=10^0

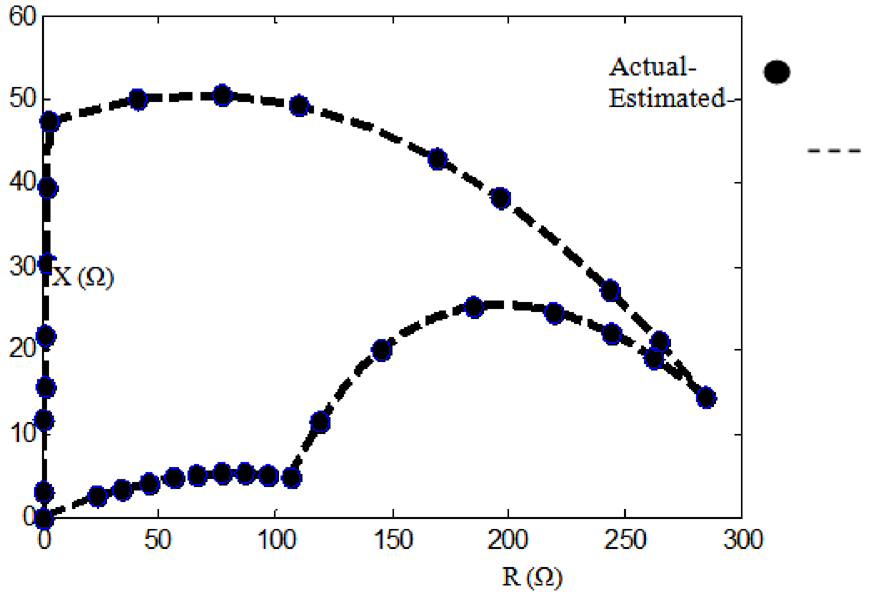

Fig.8. Zone boundary characteristics without series-compensation with h=1, δ=10^0

Besides the variation of compensations level, the voltage magnitude ratio h may change for different operating conditions. With the help of PMU data the adaptive boundary can be set for other operating conditions.

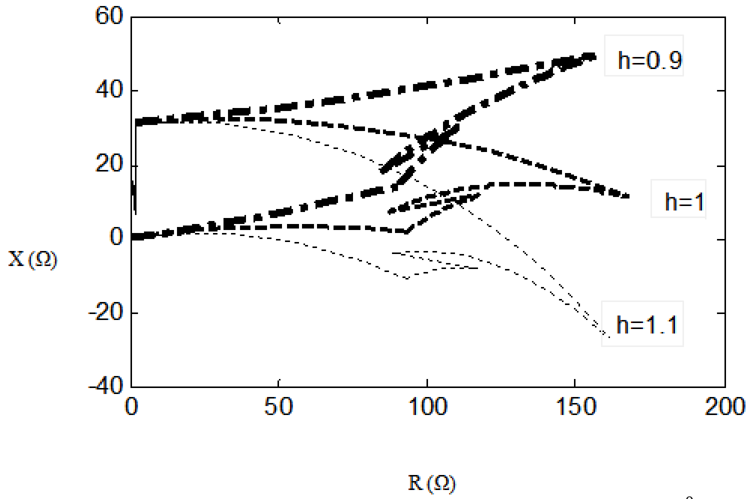

Fig.9. Zone boundary characteristics for series-compensation With δ=10^0 , h=0.9, 1, 1.1

IV. CONCLUSION

Synchrophasor data availed through PMUs at both ends of a series-compensated transmission line is applied to adapt the trip boundary of the distance relay according to system conditions. The proposed method is applied for zone 2 trip boundary of quadrilateral characteristics. The method is tested for 400 kV power system simulated using EMTDC/PSCAD software at different series-compensation and operating conditions. The proposed method is found to be accurate.

APPENDIX

The 400 kV, 50 Hz power system data is as follows:

Impedance Parameters of the source:
Z1=Z2=-3.42+j9.49 Ω
Z0=-3.42+j9.49 Ω

Transmission line parameters:
Length of the transmission line: 100 km

Z1=Z2=1.78+j*31.35Ω
Z0=-29.52+j*9.49 Ω
Positive sequence shunt capacitance -0.0163 μF/ km
Zero sequence shunt capacitance -0.00768 μF/ km

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