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Detection of Different Types of Fault and its Location in Transmission Line by using Negative Sequence Component

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Abstract— In recent years, voltage instability has been a major issue in power systems. There are many factors contributing to voltage collapse which might cause blackouts, such as demands of consumption growth, the influence of harmonic component and reactive power constraints. These factors are very difficult to predict in real environment.

High-voltage transmission lines are an important part of the power system. As the operation of the power grid expands, the demands on long distance transmission lines will increase. These lines are often exposed to large diverse geographical areas with complex terrain and weather conditions. If a fault occurs in a transmission line, it can be very hard to find and report it. Even if the fault is fixed, the new steady state of the power systems needs to be monitored to avoid failure again.

The paper aims at studying the technology which overcomes various limitations of the power system.

Index Terms— *Symmetrical component, overcurrent relay, WAMS, GPS, PMU, Internal fault, external fault.*

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1. Introduction

Symmetrical components consist of positive-, negative-, and zero-sequence quantities. Basically, positive-sequence quantities are present during balanced, three-phase conditions. Positive sequence quantities makeup the normal voltages and currents observed on power systems during typical, steady-state conditions. Whereas Negative-sequence quantities are a measure of the amount of unbalance existing on a power system. Zero-sequence quantities are most commonly associated with ground being involved in an unbalanced condition. Negative- and zero-sequence quantities are usually only present in substantial levels during unblanced, faulted conditions on a power system.

The equations to calculate positive-sequence negative-sequence and zero sequence are given as

$V_1 = 1/3\ (V_a + aV_b + a^2V_c)$
$V_2 = 1/3\ (V_a + a^2V_b + aV_c)$
$V_0 = 1/3\ (V_a + V_b + V_c)$

Where V_1, V_2 and V_0 are positive-sequence negative-sequence and zero sequence voltages respectively.
a is operater whose value is 1<120° and a^2 is 1<240°.

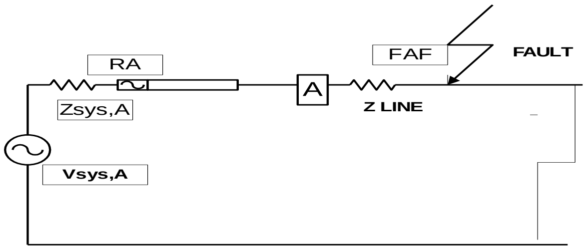
2 Overcurrent Relaying

Directional overcurrent relaying refers to relaying which can use the phase relationship of voltage and current to determine direction of a fault. Directional decisions are made by protective relays. Numeric directional relay uses the phase relationship of sequence components such as positive sequence (V_1 vs I_1), negative sequence (V_2 vs I_2), and zero sequence (V_0 vs I_0) to sense fault direction.

Many modern microprocessor relays use the angular relationships of symmetrical component of currents and voltages and the resultant angular nature of Z_1, Z_2 and Z_0 as calculated from Vphase/Iphase to determine direction of fault. These three impedances are used to create three directional assessments that are used in relay logic in various ways by each manufacturer. These variations depend upon manufacturers and in most cases the angular relationship is the only concern, the magnitude is not calculated. The common concept is that in faulted conditions there is an approximate 180° difference of calculated Z_1, Z_2 and Z_0 for faults in the two directions from the relay location. This high variation in phase angle is a reliable indication of detecting direction of fault.

2.1 Mathematical Expression For Overcurrent Relaying

Figure 2.1 below shows single source system with relay.



The three phase voltage drop equation for a system that can be represented by voltages of two defined locations, that is VSys and VFault

$$\begin{bmatrix} V_{ASYS} \\ V_{BSYS} \\ V_{CSYS} \end{bmatrix} - \begin{bmatrix} V_{A\ FAULT} \\ V_{B\ FAULT} \\ V_{C\ FAULT} \end{bmatrix} = \begin{bmatrix} Z_{AA} & Z_{AB} & Z_{AC} \\ Z_{BA} & Z_{BB} & Z_{BC} \\ Z_{CA} & Z_{CB} & Z_{CC} \end{bmatrix} \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix}$$

When the impedances are highly balanced i.e., the diagonal self impedance elements Z_{AA}, Z_{BB} and Z_{CC} are all of same value and all off diagonal mutual impedance elements are another value, hence equation (2-1) can be written as,

$$\begin{bmatrix} V_{0SYS} \\ V_{1SYS} \\ V_{2SYS} \end{bmatrix} - \begin{bmatrix} V_{0\,FAULT} \\ V_{1\,FAULT} \\ V_{2\,FAULT} \end{bmatrix} = \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix} \begin{bmatrix} \boldsymbol{I_0} \\ \boldsymbol{I_1} \\ \boldsymbol{I_2} \end{bmatrix}$$

In the typical power system, usually at the remote system, voltage has very low V_0, V_2 *and* $V_1 \cong 1$

At the other end that is at fault location every type of fault will have different values of V_0, V_1 *and* V_2 , If Z_1, Z_2 and Z_0 are divided into two impedances line impedance and source impedance as seen fromthe relay location.

$$\begin{bmatrix} 0 \\ V_{1SYS} \\ 0 \end{bmatrix} - \begin{bmatrix} V_{0\,FAULT} \\ V_{1\,FAULT} \\ V_{2\,FAULT} \end{bmatrix} = \left\{ \begin{bmatrix} Z_{0SYS} & 0 & 0 \\ 0 & Z_{1SYS} & 0 \\ 0 & 0 & Z_{2SYS} \end{bmatrix} + \begin{bmatrix} Z_{0LINE} & 0 & 0 \\ 0 & Z_{1LINE} & 0 \\ 0 & 0 & Z_{2LINE} \end{bmatrix} \right\} \begin{bmatrix} \boldsymbol{I_{0RELAY}} \\ \boldsymbol{I_{1RELAY}} \\ \boldsymbol{I_{2RELAY}} \end{bmatrix}$$

If we solve for the impedances, since V_{0SYS} = 0 and V_{2SYS} = 0,

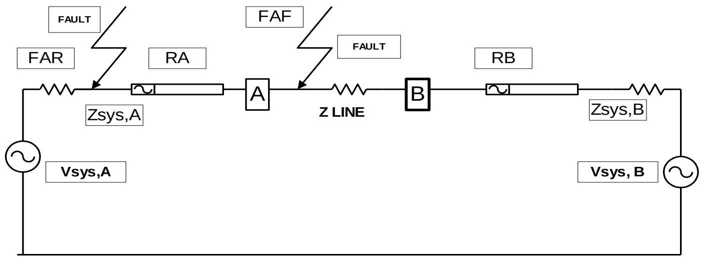
$$-\mathrm{Z}_{2\mathrm{SYS}} = \mathrm{Z}_{2\mathrm{RELAY}} = \frac{\mathrm{V}_{2\mathrm{RELAY}}}{\mathrm{I}_{2\mathrm{RELAY}}}$$

$$-\mathrm{Z}_{0\mathrm{SYS}} = \mathrm{Z}_{0\mathrm{RELAY}} = \frac{\mathrm{V}_{0\mathrm{RELAY}}}{\mathrm{I}_{0\mathrm{RELAY}}}$$

For $\mathrm{Z}_{0\mathrm{RELAY}}$ and $\mathrm{Z}_{2\mathrm{RELAY}}$, the impedance seen by the relay for the fault indicated will be dependent solely upon the source impedance. The angle of $\mathrm{Z}_{0\mathrm{RELAY}}$ and $\mathrm{Z}_{2\mathrm{RELAY}}$ is the source of determining the direction to a fault.

A CT polarity orientation can cause the apparent Z_0 and Z_2 at the relay to either match the source impedance angle or to be inverted by 180°. The current polarity would be the signature of a fault that is either forward or reverse from the relay's location.

For the two source system with relay, as shown below,



The impedance as seen by relay A will vary according to the direction of the fault. For faults on the two different sides of the breaker, the relay will sense two completely different impedances. For fault $F_{A,F}$, i.e. fault is in forward direction for relay A and $F_{A,R}$, i.e. fault is in reverse direction for relay. A the impedance seen by relay R_A will be

$$\mathrm{Z}_{0\mathrm{RELAY}\ ,\mathrm{FAULT}\ \ \mathrm{A\ FOR}} = -\mathrm{Z}_{0\mathrm{SYS}\ ,\mathrm{A}}$$

$$\mathrm{Z}_{0\mathrm{RELAY}\ ,\mathrm{FAULT}\ \ \mathrm{A\ REV}} = \mathrm{Z}_{0\mathrm{SYS}\ ,\mathrm{B}} + \mathrm{Z}_{0,\mathrm{LINE}}$$

$$\mathrm{Z}_{2\mathrm{RELAY}\ ,\mathrm{FAULT}\ \ \mathrm{A\ FOR}} = -\mathrm{Z}_{2\mathrm{SYS}\ ,\mathrm{A}}$$

$$\mathrm{Z}_{2\mathrm{RELAY}\ ,\mathrm{FAULT}\ \ \mathrm{A\ REV}} = \mathrm{Z}_{2\mathrm{SYS}\ ,\mathrm{B}} + \mathrm{Z}_{2,\mathrm{LINE}}$$

2.3 Wide Area Measurement Principle And Structure Of The System

The conventional technology used by grid operators for situational awareness is supervisory control & data acquisition (SCADA). SCADA data are used to derive State Estimation (SE) solution. Fault recorder can only record a few seconds before and after the failure of the transient waveforms. But this large amount of data is hard to save. SCADA provides about four seconds to update a steady-state data; it cannot provide any help in predicting of the dynamic power, low frequency vibration or fault analysis. WAMS technology is well suited to supplement and eventually replace the SCADA technology.

In a practical power system, the number of dominant inter-area is often larger than the number of controllable devices available to control them. Researcher attention, therefore, has been focused on designing new control structures to improve the damping of multiple swing modes. With the rapid advancement in WAMS technology, the transmission of measured signals to remote center has become relatively simpler.

A wide-area measurement system (WAMS) uses GPS (Global Positioning System) to provide the synchronous clock for wide-area power system state measurements. Wide area measurement systems will be installed in all sub-stations with PMU synchronized phasor data underlying communication network via high-speed data transmission to the control centre. The control centre

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can evaluate these data in real time and dynamic monitoring to analyze network security and stability.

Wide area Measurement Systems (WAMS) are systems based on the transmission of analogue and/or digital systems and allowing synchronization (time stamping) of the measurements using a common time reference SCADA uses available time signals for synchronization with an accuracy of 1-10ms. Whereas measuring devices using WAMS have their clocks synchronized with the reference that is set for all the devices. Hence the accuracy of the system increases to ≤1 μs.

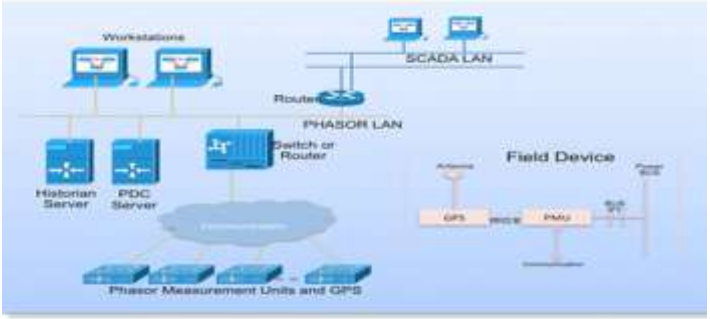
A wide area measurement system structure includes a phasor measurement unit, system master station and communications network. It directly measures the operating parameters, such as phase angle, voltage and current. On the one hand it can monitor the operational status of equipment, on-line fault diagnosis and protection and post-fault analysis. On the other hand, through an efficient communication network, real-time measurement data can be transmitted to the control centre, which monitors the operational status of the whole network to predict the stability of the future.

2.4 NATIONAL WAMS PROJECT ARCHITECTURE

At the National level one central PDC is installed at National Load Dispatch Centre (NLDC), Delhi. The architecture of pilot project taken up at National Load Dispatch Center for all India Synchrophasor data integration is shown in Fig 2-1

In addition to above 6 numbers of PDCs, one at National andfive at regional control Centers, 4 no of local PDCs are also installed in Eastern Region and one Lab PDC alsoinstalled at Western Region control Centre. Hence as on December 2013 total 11 numbers of PDCs are functional in India.

There are Fifty-seven PMUs installed by RLDCs / NLDC under different Pilot Projects, apart from these, three more PMUs are installed by IPPs. PMUs installed in a region are reporting to PDC (Phasor Data Concentrator) of that region. At NLDC PMUs data are available through regional PDCs. PMU measures the Voltage Phasors, Current Phasors, Frequency, Rate of change of frequency etc. The inputs given to the PMUs are 110 Volt from the secondary side of PT/CVT of 400 KV/220 KV/132 KV buses and 1 ampere three phase current inputs from CTs of the selected feeders (list of the PMUs and feeders in given in Appendix-B) PMUs are GPS clock synchronized and reporting torespective Regional PDCs at 25 Frames/Second i.e. every control center is updating Phasor data every 40 milliseconds, with the integration of Regional PDC to National PDC has facilitated all India level monitoring.



Apart from the Pilot projects some of the PMUs are also installed by the vendors as a demo project. These demo project PMUs are also integrated with the Regional PDCs alongside the PMUs of Pilot projects. MSETCL also installed few PMUs in Maharashtra EHV network.

Geographical locations of PMUs.

3 Systems Studied

The above model shows a single machine power system. It consisted of a synchronous machine connected to step up transformer (step up the voltage) then a Transmission line (Distributed Parameter) connected to an infinite bus (Three phase source). Project mainly focused on protection of transmission line hence two voltage and current Measurement Blocks are placed at receiving and sending ends of transmission line, which symbolically represent PMU.

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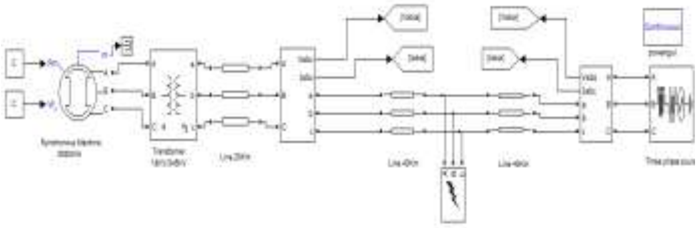
Positive sequence, negative sequence, zero sequence voltage and current are measured and accordingly impedances are calculated. Various calculations are done here which are useful for making decision of directional relay.

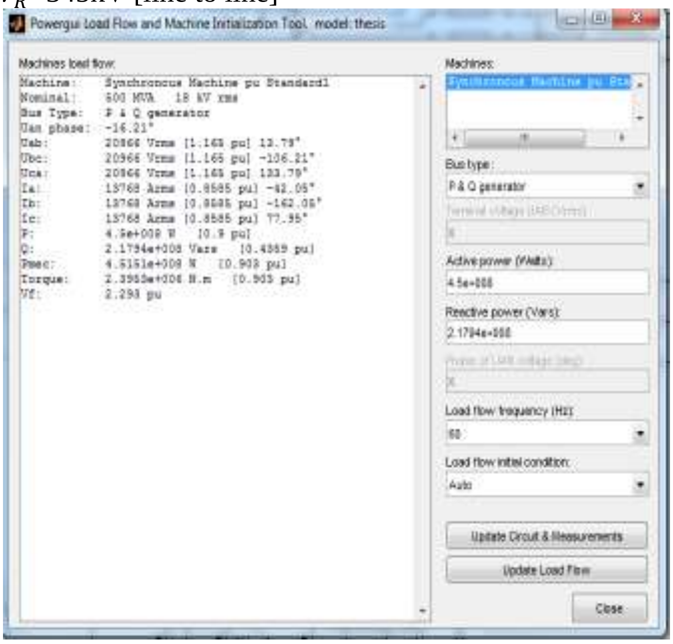


Here, 500MVA, 18 kV generator is connected with infinite bus via step up transformer of 18/345kV and transmission line of 100km having parameters,

R_0= 0.3479 Ω/km
L_0= 1.370e-3 H/km
C_0= 2.8e-8 F/km
R_1= 0.0321 Ω/km
L_1= 0.4730e-3 H/km
C_1= 3.8e-8 F/km

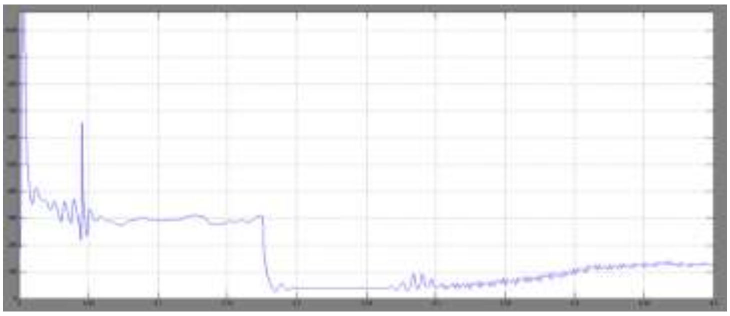
Both ends of the line are replaced by Thevenin's equivalent impedance with an angle different than that of the line impedance

Sending end:
Z_0= 2.738 + j10.000 [Ω]
Z_1= 0.238 + j5.7312 [Ω]
V_S=345kV [line to line]
Receiving end:
Z_0= 0.833 + j5.118 [Ω]
Z_1= 0.238 + j6.190 [Ω]
V_R=345kV [line to line]

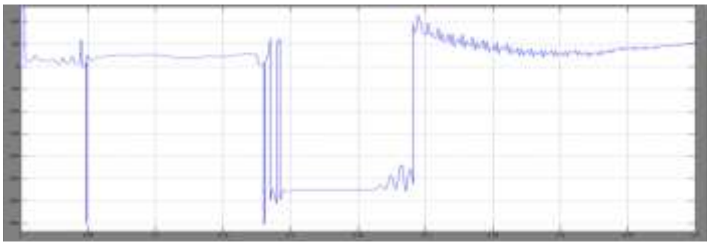


3.1 RESULTS

Case 1: External fault

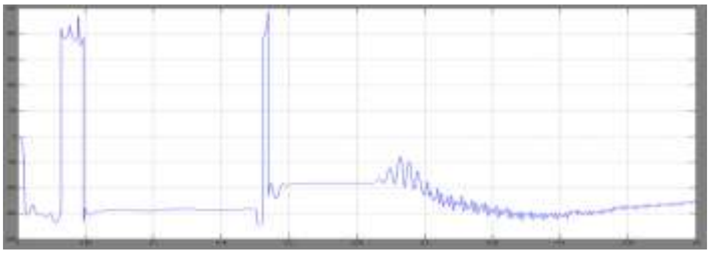


Sending end impedance for type LL fault (External fault)

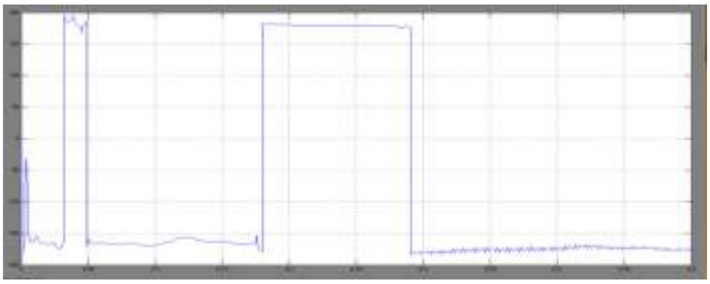


Phase angle of sending end impedance for type LL fault (External fault)

Receiving end impedance for type LL fault (External fault)

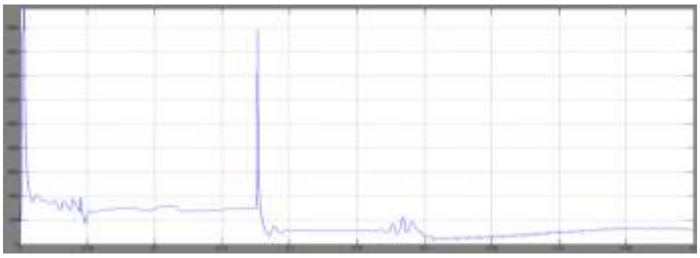


Phase angle of receiving end impedance for type LL fault (External fault)

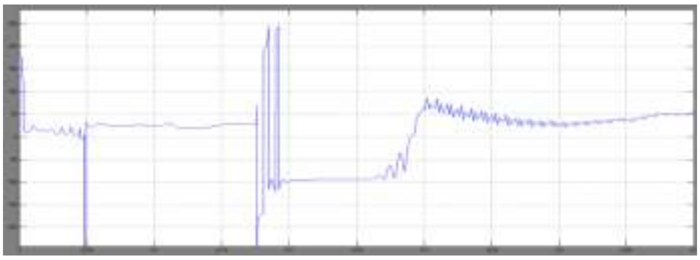


Phase angle difference of negative sequence current at sending end and negative sequence current at receiving end for type LL fault (External fault)

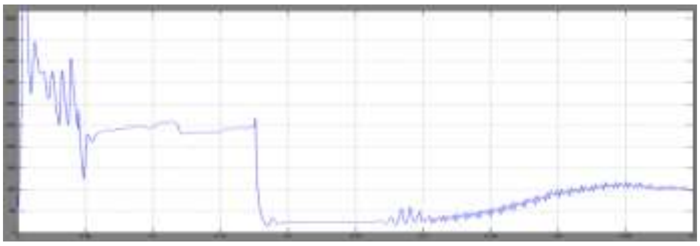
Case 2: Internal fault



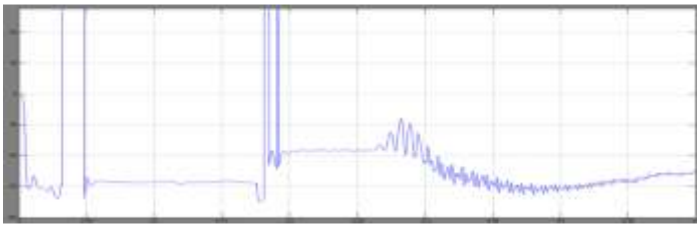
Sending end impedance for LL type fault (Internal fault)



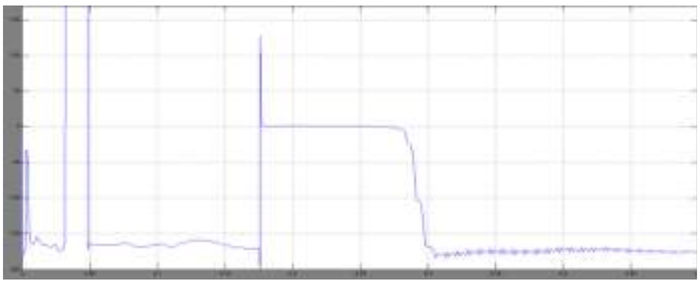
Phase angle of sending end impedance for LL type fault (Internal fault)



Receiving end impedance for type LL fault (Internal fault)



Phase angle of receiving end impedance for type LL fault (Internal fault)



Phase angle difference of negative sequence current at sending end and negative sequence current at receiving end for type LL fault (Internal fault)

3.2 CONCLUSION

By studying simulated waveforms, for different values of fault resistance simulated results are same. Values of internal fault for near the bus and at the middle of bus are also same because both are in forward direction for sending end relay. Values of receiving end relay for all the 3 cases will be same because fault is in reverse direction for this relay.

180° difference in phase angle impedance of negative sequence impedance for external fault and internal fault i.e. fault for forward direction and reverse direction of sending end relay.

Similarly 180° difference in phase angle difference of Negative sequence current at sending end and negative sequence current at receiving end.

Directional decision can be take on the basis of phase angle of negative sequence impedance and phase angle difference of Negative sequence current at sending end and negative sequence current at receiving end as there is 180° phase angle difference for forward and reverse fault.

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BIOGRAPHY

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