A Novel Approach for Transmission Line Fault Location using Synchro Phasor Measurement

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Abstract--Now a days the power system structure is growing continuously. So the reliability has become a big task for the protection engineers. This paper presents a fast and accurate fault detection technique which is very much useful for reliable operation of the power systems. To achieve fastness and reliable operation various new technologies have been used but out of all the available equipment the use of phasor measurement unit have brought the reliability index to a significant level. An intelligent approach for fault detection has been used in this paper which adapts for changes in the operation level. It uses synchronized samples of the operation voltages and currents from both the ends of the transmission line to detect, and classify the fault. This technique has been implemented on IEEE 57 bus system and it was found that this method has given better results than the methods proposed earlier. With the use of modern equipment which limits the time of operation for few cycles, the time window can be reduced significantly

Index Terms— PMU application; Fault detection; Power system protection.

I.INTRODUCTION

The fast and accurate fault detection, classification, location algorithms are very much important for maintaining, inspecting and repairing of long transmission line. Several methods for fault location algorithms have been proposed using current and voltage samples, till date. But with the development in PMUs many new techniques have been designed which uses this PMUs in system monitoring, control and protection. Generally to achieve high amount of accuracy in fault analysis these PMUs are meant to be installed at every bus, along with suitable algorithms. Since the cost of each PMU is more they are meant to be placed in optimal locations. When performing system control operations, optimal location of PMU is based on system observability where as in system protection point of this can be achieved using sensitivity factors. Sensitivity factors are generation shift factor (GSF) and line outage distribution factor (LODF).

Generation shift factor is the relative change in power flow on a line between buses 'I' and 'j' due to the change in injection. This factor is a linear estimate of change in power flow with respect change in power at a particular bus. This change in power flow can be calculated using super position theorem. In normal power system loss of generation at a particular bus is assumed to be supplied by the rest of the generators. This compensation is done based on the machine size.

Line outage distribution factor represents the change in line flows when a line is disconnected from a system. After a contingent line is removed because of any reason, the power floe of that line is distributed to the rest of the lines in the system. LODF determines the contribution of each remaining line in the system to adjust the flow of the line which was taken out.

II. PHASOR MEASURING UNIT

The Phasor Measurement Unit (PMU) is a Power System measuring device. It has the capability of measuring the synchronized voltage and current Phasor. Synchronicity among Phasor Measurement Units (PMUs) is achieved by same-time sampling of voltage and current waveforms using a common synchronizing signal from the global positioning satellite (GPS). The ability to calculate synchronized phasor makes the PMU one of the most important measuring devices in the future of power system monitoring and control.

Phasor measuring unit (PMU) uses the GPS transmission to synchronize the sampling clocks so that the calculated phasor would have a common reference. The first pmu was developed in Virginia tech laboratory. PMU provides instantaneous of the state of entire power system by using GPS time pulse as an input to sampling clock. The GPS provides pulses at an accuracy of 1µs, which corresponds to 0.018 degrees for a 50Hz system. The GPS signal with 1pps is used a PLL to create the sampling pulses, which in turn used for sampling analog signals[4].Figure 2 shows the functional representation of phasor measurement unit.

A. Phasor measurement technique

Let a pure sinusoidal waveform can be represented by a unique complex number. This is known as a phasor. Consider a sinusoidal signal

$$X(t) = A_m \cos(wt+\emptyset) \quad (1)$$

The phasor representation of this signal can be represented as

$$X(t) = \frac{X_m}{\sqrt{2}} e^{j\emptyset} = \frac{X_m}{\sqrt{2}}(\cos\emptyset + j\sin\emptyset) \quad (2)$$

The sinusoidal signal and its phasor representation are shown in fig 3. Most commonly the phasor representation of an input signal is determined from the samples taken from the waveform, and by applying the Discrete Fourier Transform (DFT) to calculate the phasor. Since sampled data is used to represent the input signal, it is essential that Anti-aliasing filters must be applied to the signal before data samples are taken.

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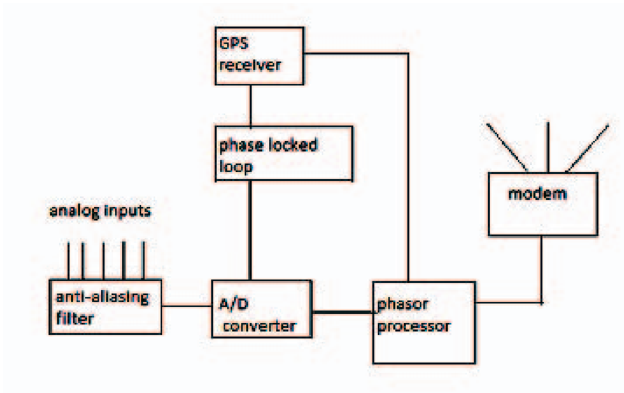


Fig 2: functional block diagram of PMU

Anti-aliasing filter is an analog device limits the bandwidth of the pass band to less than half the data sampling frequency (Nyquist criterion). A digital filter removes unwanted frequency components that may create problems for a particular application. The phasor estimator calculates the phasor representation of the input signal.

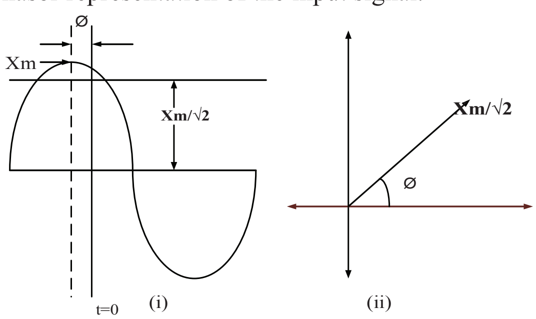


Fig 3: phasor representation of sinusoidal signal (i) sinusoidal signal (ii) Phasor representation

If x_k (k=1, 2, 3…N-1) are the N samples of the input signal taken over one period, then the phasor representation is given by (Phadke and Thorp, 2008)

$$X = \frac{\sqrt{2}}{N}\sum_{k=0}^{N-1} x_k e^{-jk2\pi/N} \quad (3)$$

It is to be noted that for real input signals, the components of the signal at a frequency ‘w’ appear in the DFT at ‘±w’. They are complex conjugates to each other. They can be combined, giving a factor of 2 in front of the summation sign in (3). Thus the peak value of the fundamental frequency is obtained and then converted it to r.m.s value by dividing with 2. The DFT calculation eliminates the harmonics of the input signal. The above mentioned PMU based working is shown in the below shown flow chart.

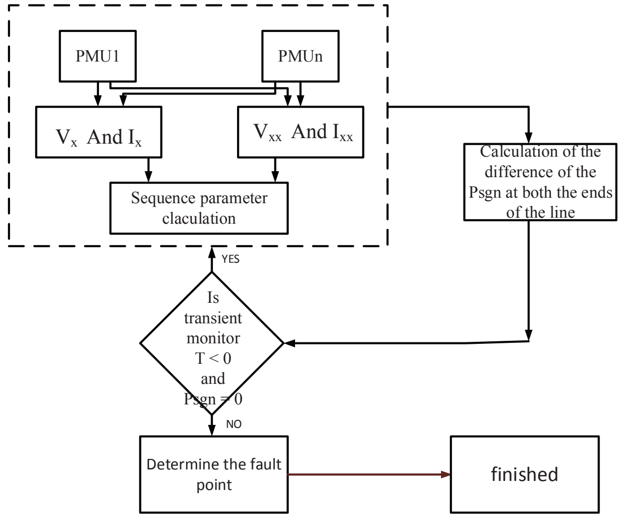


Fig 3: Working of the PMU based technique

B. Method for fault identification and location

To detect weather there it is a faulty condition or not, this method uses the instantaneous power samples obtained from current and voltage samples taken at both the ends of a line. This method is more advantageous compared to the one proposed in [7] as calculating the power at a particular instant doesn’t need any averaging and, thus the samples obtained can be used instantaneously. After the fault identification is over then the method in [17] is used to perform further analysis. This fault distance calculation method used in [17] requires huge amount of data samples whereas the method used for fault detection and classification requires a much lesser number of samples per cycle. A SPLINE interpolation technique [22] used to add extra samples in between two adjacent samples of voltage and current, thus increasing the samples per cycle for input data.

III. FAULT DETECTION PROCESS

This fault detection technique compares the sign (direction) change in the power calculated at two ends of the line using synchronized voltage and synchronized current samples measured at both ends at the same instant of time. In Fig. 1, V_s (t) and I_s (t) are the voltage and currents obtained at the sending end of the line a particular time instant. And let I_r (t) and V_r (t) be the current and voltage shown in Fig.3 are taken as positive.

Let the current and voltage at the sending end of line be

$V_s(t) = V_{sm}\cos(\omega t)$.

$I_s(t) = I_{sm}\cos(\omega t-\varphi_s)$.

Where φ_s be the phase difference between the current and the voltage at the sending end of the transmission line.

$V_r(t) = V_{rm}\cos(\omega t)$.

$I_r(t) = I_{rm}\cos(\omega t-\alpha-\varphi_r)$.

Where φ_r be the phase difference between the current and the voltage at the receiving end of the transmission line and α is the power factor angle between sending end and receiving end of the line.

The instantaneous power at sending end (P_s) of the line and the receiving end (P_r) of the line are

$P_s(t) = V_s(t) * I_s(t)$

$= V_{sm}\cos(\omega t) * I_{sm}\cos(\omega t-\varphi_s)$

$= P_{sm}(\cos 2\omega t + 1)\cos\varphi_s + P_{sm}\sin 2\omega t \sin\varphi_s.$

$P_r(t) = V_r(t) * I_r(t)$

$= V_{rm}\cos(\omega t) * I_{rm}\cos(\omega t-\alpha-\varphi_r)$

$= P_{sm}(\cos 2\omega t-2\alpha + 1)\cos\varphi_r + P_{sm}\sin 2\omega t-2\alpha \sin\varphi_{r.}$

Let us assume that the current direction is –ve before the fault and +ve after the fault has occurred.

For un-faulted case:

$P^{uf}_s = P^{uf}_{sm}((\cos 2\omega t) + 1)\cos\varphi^{uf}_s + P^{uf}_{sm}\sin 2\omega t \sin\varphi^{uf}_s$

$P^{uf}_r = - P^{uf}_{rm}((\cos(2\omega t-2\alpha)) + 1)\cos\varphi^{uf}_r - P^{uf}_{rm}\sin(2\omega t-\alpha)\sin\varphi^{uf}_r$

And the instantaneous powers after the fault has occurred are

$P^f_s = P^f_{sm}((\cos 2\omega t) + 1)\cos\varphi^f_s + P^f_{sm}\sin 2\omega t \sin\varphi^f_s$

$P^{uf}_r = - P^f_{rm}((\cos(2\omega t-2\alpha)) + 1)\cos\varphi^f_r + P^f_{rm}\sin(2\omega t-\alpha)\sin\varphi^f_r$

If the pre-fault and post fault power factors are:

Lagging:

$\varphi^{uf}_s > 0$; $\varphi^{uf}_r > 0$;

$\varphi^f_s > 0$; $\varphi^f_r > 0$; then in pre fault case, $|P^{uf}_s| > 0$ and $|P^{uf}_r| < 0$ and after fault, $|P^{uf}_s| > 0$ and $|P^{uf}_r| > 0$

Leading:

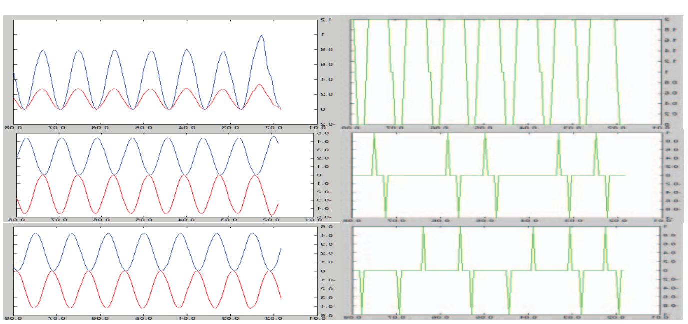
$\varphi^{uf}_s < 0$; $\varphi^{uf}_r < 0$;

$\varphi^f_s > 0$; $\varphi^f_r > 0$; then in pre fault case, $|P^{uf}_s| > 0$ and $|P^{uf}_r| < 0$ and after fault, $|P^{uf}_s| > 0$ and $|P^{uf}_r| > 0$

Thus this special quality when the instantaneous power samples are used helps us to detect and classify the faults without the need of and predetermined threshold value.

This concept can be used to detect the fault and also classify the type of fault as shown below

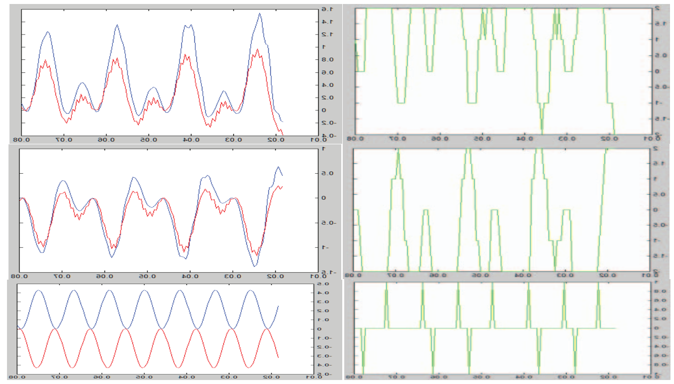
1).Line to ground fault: In the L-G type of fault, the plot shown below, the power at both the ends are shown in 2 (a) – 2 (c). Where in phase R, the fault has occurred and in that, $|P^f_s| > 0$, $|P^f_r| > 0$ where as in the other two cases both are in opposite direction. To show this in more clear form, a signum function is used and sgn (P_s) and sgn(P_r) are calculated and plotted for each phase therefore before fault and after fault cases can be differentiated easily. If sgn (P) = +2 then there is a fault in that case and if its 0 then there is no fault.



2(a) –2 (c) 2(d) –2 (f)

Line to ground fault with fault at phase ag

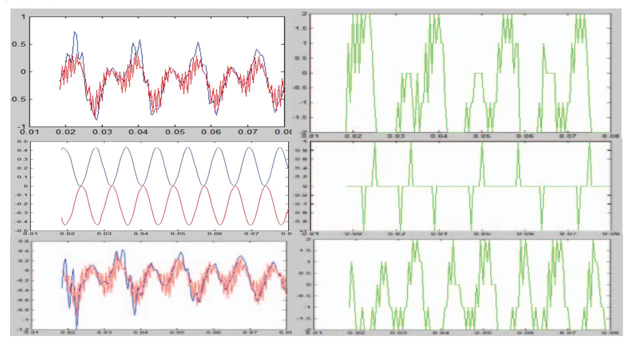
2).Line to line fault: In this L- L fault, phase R and Y are subjected to short circuit case and the corresponding instantaneous powers and their signum are shown in fig 3(a) – 3(c) and 3(d) – 3(f).In this, the powers in phase R and Y change and the power in phase B is same as that of normal operation and thereby from the signum graph we can easily differentiate the faulty phases.



3(a) –3 (c) 3(d) –3 (f)

Line to line to ground fault with fault at phase RYG

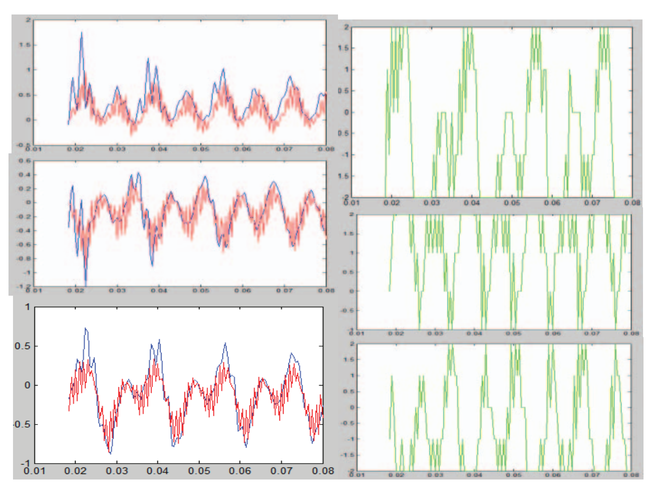
3). Line to line to ground fault: In this L- L-g fault, phase R and Y are grounded and the corresponding instantaneous powers and their signum are shown in fig 4(a) – 4(c) and 4(d) – 4(f).In this case the plots are similar to that of the L-L fault but they can be differentiated from the zero sequence current present in the system.



4(a) –4 (c) 4(d) –4 (f)

Line to line to ground fault with fault atphaseRYG

4) line to line to line to ground fault: in this L L L g fault , all the phases are assumed to be shorted to ground and their corresponding power flows and signum power flows are shown below in fig 5 (a) – 5 (c) and 5 (d) – 5 (c) respectively.



5(a) –5 (c) 5(d) –5 (f)

Line to line to line to ground fault with fault at phase RYBG

5) Load lever change: whenever the load changes abruptly or slowly than the normal might since that as a fault as the current flowing through the line increases and there by generator trip signal. But this comes under mall operation of relay. When this sampling method is used this mall operation of relay is avoided as it takes into consideration the power flows direction on both the ends.

6) Fault on adjacent line : this is a special condition where most of the relay algorithm fail to operate but coming to synchronized sampling method, this difficulty is overcome as the fault on the adjacent line don't affect the relay parameters.

7) Faults on parallel lines: when there are faults on parallel lines, the relay should not sense that case as a fault and this algorithm does that work more effectively there by meeting the desired work.

Fault distance calculation:

The fault-location algorithm is used in this paper with some modifications. Once the line is detected as faulted, an accurate fault location can be identified by this method. In the case of long transmission line (modeled with lumped parameters), the precise equation form for the fault-location equation is given by

$$D = -\frac{\sum_{n=R,Y,B} \sum_{l=1}^{N} pn(l) qn}{-\sum_{n=R,Y,B} \sum_{l=1}^{N} qn(l) * qn(l)}$$

Where

$p_n = v_{nR}(l) - v_{ns}(l) - d \ \Sigma_{n=R,Y,B}\{ \{ r_{np} + \{l_{np}/\Delta t\}\} i_{pR}(k) \{l_{np}/\Delta t\}\} i_{pR}(k-1) \}$

$q_n = d \ \Sigma_{n=R,Y,B}\{ \{ r_{np} + \{l_{np}/\Delta t\}\}\{i_{pR}(k) + i_{ps}(k)\} - \{l_{np}/\Delta t\}\}\{i_{pR}(k-1) + i_{ps}(k-1) \}$

n=R,Y,B is the present sample point; is the time period with respect to the sampling frequency; and subscripts and stand for the values at the sending end and receiving end, respectively.

IV IMPLEMENTATION

The proposed algorithm has been implemented for IEEE 57 bus system and the effectiveness of the algorithm has been tested. Various faults have been simulated for the system changing the fault location value. Changing the fault resistance level two sets of readings are obtained. The corresponding tabular columns are shown below.

Table 1
Low Fault Resistance

Fault type	Fault location	Fault resistance	Actual fault inception time(s)	Detected fault type	Calculated fault inception time(s)		Time to detect (ms)		Calculated fault location	Fault location % error
					Traditional method	New method	Traditional method	New method		
LG	8.28(5%)	0	0.02	LG	0.022	0.021	2	2	9.18	0.89
	33.13(20%)			LG	0.022	0.021	2	3	33.78	0.41
	82.84(50%)			LG	0.022	0.023	2	2	82.7	0.079
	8.28(5%)	20	0.02	LG	0.022	0.019	2	2	18.072	6.12
	33.13(20%)			LG	0.024	0.022	4	3	33.789	0.41
	82.84(50%)			LG	0.022	0.023	2	4	82.69	0.089
	8.28(5%)	100	0.02	LG	0.022	0.027	2	2	7.464	0.51
	33.13(20%)			LG	0.022	0.021	2	3	32.506	0.39
	82.84(50%)			LG	0.022	0.019	2	2	82.984	0.09
LL	8.28(5%)	0	0.02	LL	0.027	0.021	7	5	4.744	2.21
	33.13(20%)			LL	0.023	0.026	3	6	33.258	0.08
	82.84(50%)			LL	0.023	0.025	3	4	83.08	0.15
LLG	8.28(5%)	0	0.02	LLG	0.027	0.021	7	7	11.816	2.21
	33.13(20%)			LLG	0.023	0.028	3	2	33.002	0.08
	82.84(50%)			LLG	0.023	0.039	3	6	83.064	0.14
	8.28(5%)	20	0.02	LLG	0.023	0.034	3	1	9.912	1.02
	33.13(20%)			LLG	0.023	0.031	3	2	33.434	0.19
	82.84(50%)			LLG	0.023	0.025	3	5	82.664	0.11
	8.28(5%)	100	0.02	LLG	0.023	.021	3	4	6.344	1.21
	33.13(20%)			LLG	0.023	0.031	3	8	33.21	0.05
	82.84(50%)			LLG	0.023	0.028	3	6	83.176	0.21
LLL	8.28(5%)	0	0.02	LLL	0.024	0.026	4	3	20.296	7.51
	33.13(20%)			LLL	0.024	0.031	4	2	36.474	2.09
	82.84(50%)			LLL	0.023	0.038	3	2	83.672	0.52
	8.28(5%)	20	0.02	LLL	0.023	0.062	3	4	8.088	0.12
	33.13(20%)			LLL	0.023	0.051	3	5	28.426	2.94
	82.84(50%)			LLL	0.023	0.041	3	2	83.032	0.12
	8.28(5%)	100	0.02	LLL	0.023	0.081	3	3	12.952	2.92
	33.13(20%)			LLL	0.023	0.021	3	6	38.266	3.21
	82.84(50%)			LLL	0.023	0.037	3	2	37.432	9.12

TABLE II
Higher fault resistance value

Fault location	Fault resistance	Actual fault inception time	Calculated fault inception time		Time to detect fault		Calculated fault location	Fault location % error
			Traditional method	New method	Traditional method(ms)	New method(ms)		
8.28(5%)	200	0.02	0.024	0.035	4	4.1	9.096	0.51
33.13(20%)			0.024	0.021	4	3.9	33.514	0.24
82.84(50%)			0..024	0.025	4	3.2	82.984	0.09
8.28(5%)	500	0.02	0.023	0027	3	3.4	7.304	0.61
33.13(20%)			0.024	0.019	4	3.5	32.474	0.41
82.84(50%)			0.024	0.018	4	3.6	82.68	0.1
8.28(5%)	1000	0.02	0.022	0.019	2	4.1	7.192	0.68
33.13(20%)			0.022	0.016	2	2.9	33.69	0.35
82.84(50%)			0.022	0.017	2	1.9	83.144	0.19
8.28(5%)	10000	0.02	0.022	0.021	2	1.5	8.952	0.42
33.13(20%)			0.022	0.019	2	1.8	33.546	0.26
82.84(50%)			0.022	0.015	2	2.1	82.968	0.08

V CONCLUSIONS

The proposed method has located the fault accurately and reliably. An effective and efficient fault analysis method that uses synchronized samples for detecting, classifying and locating transmission-line faults from both ends is proposed. this method has the following advantages

- It locates and classifies faults very precisely using pre and post event samples, it can confirms if the transient is a fault of just a disturbance.
- It works transparently for any type of faults.
- The algorithm is implemented for several cases of faults varying fault distance and fault resistance in a IEEE 57 bus system case, and precise fault classification, and location are calculated.

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