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Algorithms for Synchrophasor Enabled Digital Relay

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Abstract

The differential protection of buses, transformers and generators is a well-established protection principle that emphasizes the importance of synchronized phasor measurements. True differential protection was not possible before the introduction of synchronized phasor measurements. Differential protection is important for series compensated lines and tapped lines. Differential protection involves communication wires or communication band channels. The easy availability of synchronized measurements using Global positioning systems (GPS) technology and the improvement in communication technology makes it possible to consider true differential protection of transmission lines and cables by Synchrophasor Enabled Digital Relay or Phasor Measurement unit (PMU). There is no algorithm which can offer a panacea. Underlying every algorithm is a set of assumptions. The effectiveness of an algorithm depends on how far, in practice, the assumptions on which it is based are close to reality. The behaviour of the measured phasor between the 1PPS (pulse per second) points and the response. To non-steady-state (transient) conditions will vary with the algorithms used.

Keywords

Synchrophasor, Synchrophasor Enabled Digital Relay, Off-nominal Frequency Operation of PMU, Relay Algorithms.

Introduction

Basic phasor measurement units are the sensing devices that capture power system Phasors synchronously over wide geographical areas with high precision by means of global positioning system enabled time-stamping. The data obtained from phasor measurement units form the basis of all monitoring and control actions for wide-area measurement systems, and hence, phasor measurement units are the edifice of a wide-area measurement system. In the conventional communication systems [1]. The network has a hierarchical structure where PMUs initially communicate with their local Phasor Data Concentrator (PDC) [15]. The local PDCs can then forward the aggregated information to the next level PDC and so on.

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The number of hierarchical levels depends on the control Strategy and the placement of the Synchrophasor devices throughout the distribution feeder [3]. Phasor measurement units are emerging as a potential tool for on-line power system state estimation. Incorporation of phasor measurement units to the existing power system's monitoring system is impeded by various physical and economic constraints [4]. Currently, large numbers of PMUs provide real time data to a variety of nodes to support system operation and analysis [15].

Synchrophasor

Synchrophasor (as Per IEEE Std C37.118.1-2011) is defined in [15, 2, 13] The Electric grid continues to expand and as Transmission line are pushed their operating limits. In addition, the ability to effect real-time system cascading outage .phase were used for analyzing A.C quantities assuming A constant frequency .this technology will be called upon the maintain stable operation of the electric power grid of future. The purpose for the standard is to define synchronized phasor measurements in substations so that measurement equipment can be readily interfaced with other systems. Power system measurements are steadily migrating for Analog to digital systems. The phasor diagram for the reference wave, which will be expressed mathematically as:

$$\underset{V}{\rightarrow} = \frac{Vm}{\sqrt{2}} \angle 0 = \frac{Vm}{\sqrt{2}} e^{j0} \qquad (1)$$

Signal with amplitude of Vm and phase angle of φ leading .it can be seen that the phase angle of the measured waveform is given by measuring the occurrence of its peak with respect the rising edge of the 1 pps signal. Synchrophasor combine the concept of Phasor with that of Synchronization in time. The Synchrophasor technology has become possible because of the ability, through GPS, to precisely refer to t = zero instant, all over the power system and all times the concept of phasor is a strictly steady state concept. However, in practice we encounter situation where the amplitude as well phasor angle are continuously varying according to a low- frequency signal. The IEEE standard for Synchrophasor now cover both the steady state and transient condition.

Application of PMU in Power Systems [14]

(1) **State Estimation:** improved computational ability together with synchronized phasor measurement units (PMUs) are deployed to provide globally time synchronized phasor measurements with accuracy of one microseconds for bus voltages and line currents.

(2) **Oscillation Detection and Control:** PMUs could be used as the eye of the power system to detect oscillations early enough before they lead to critical consequences.

(3) **Voltage Stability Monitoring and Control:**The use of synchronized phasor measurements units (PMUs) to improve voltage stability monitoring and control has become very efficient. This is possible through the following applications:

   a) Voltage Instability Load Shedding (VILS)

   b) Wide Area Voltage Stability Monitoring and Control

(4) **Protection of Power Systems:** A number of severe protection problems have been resolved by PMUs (Synchrophasor Enabled relay) .PMUs are effective in improving protection functions, which have relatively slow response time. The latency of remote measurements for such protection functions is not really a significant issue.

Synchrophasor Enabled Digital Relay [1, 2, 4, 5, 6, 7, 8]

The architecture of a Synchrophasor enabled digital relay. It can be seen that it has been evolved from the block diagram of the digital relay fig 1, by adding the GPS clock and a Phasor locked and a phasor locked Oscillator locked to the 1 pps signal given by the GPS clock. The GPS receiver also provides the DSP microprocessor with the time stamp using IRIG-B protocol (Inter Range Instrumentation Group, 'B'). A phasor measurement unit will have very similar organization. To difference between aSynchrophasor enabled digital relay and a PMU just computes the Phasors, time stamps than, assembles the data frames and either store them (record them) or transmits them to a remote entity which may be a phasor data concentrator or a digital computer, whereas a digital protective relay is tasked with taking a trip/restrain decision after computing the Synchrophasor.

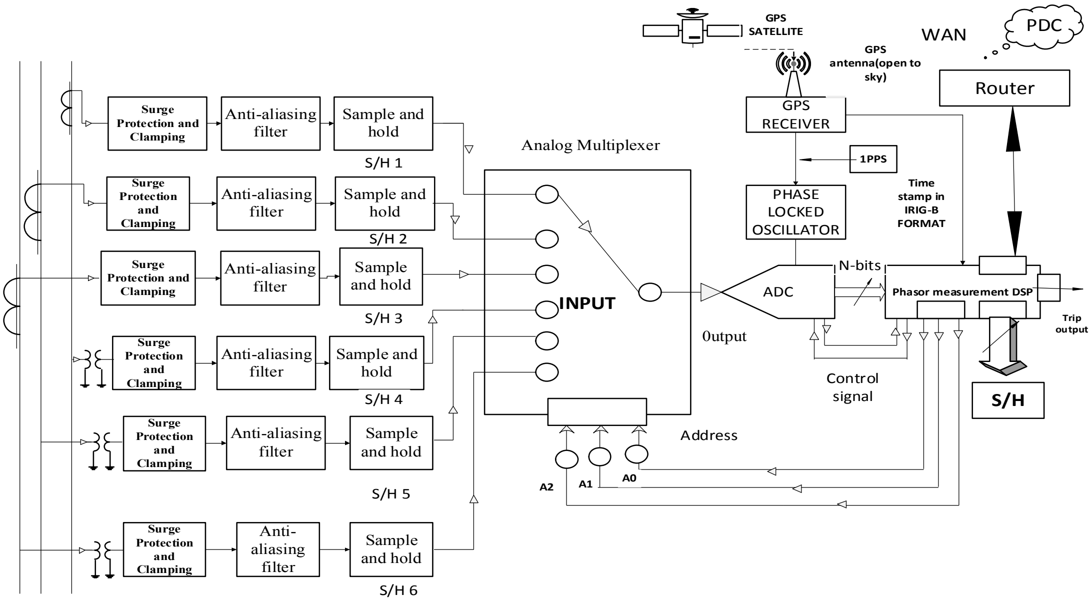

Figure1: Block Diagram of a Synchrophasor Enabled Relay or Phasor Measurement Unit

Off-nominal Frequency Operation of PMU [13]

We need to give careful thought to the effect of sampling frequency on the phasor computation, because in the real life power system the signal frequency is almost never exactly equal to the nominal frequency of 50 Hz. If we lock the sampling frequency to the nominal frequency of 50Hz, as we do in Synchrophasor, we will end up with inaccurate measurement due to the leakage effect. This inaccurate measurement will have to be Corrected or "compensated" by accounting for the actual signal frequency. If we wish to get rid of this error (rather than compensating it) then we will have to lock the sampling to the actual power system frequency by actually measuring it. Thus in both cases extra work, than that indicated by the DFT(Discrete Fourier Transform) algorithm is needed. We keep the sampling frequency locked to factious cosine wave whose positive peak synchronized with 00 hr.: 00min: 00sec on January 1st, 1970.

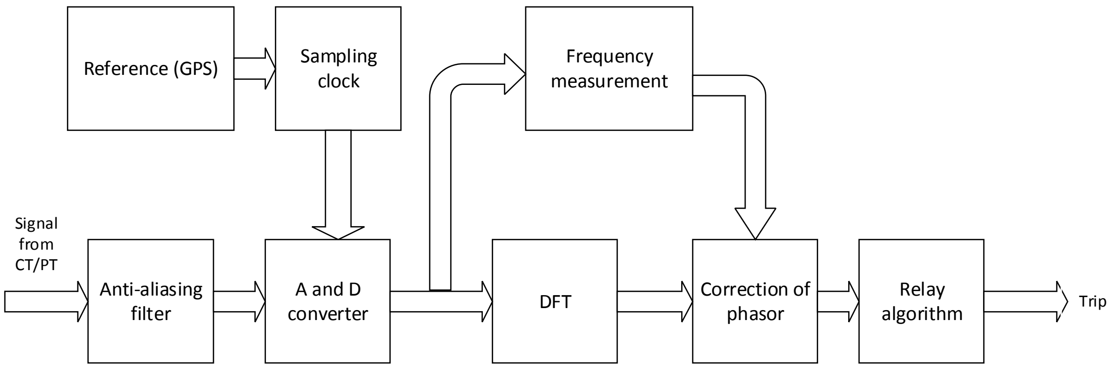

Figure 2: Sampling locked with a fictitious 50 HZ Signal via GPS

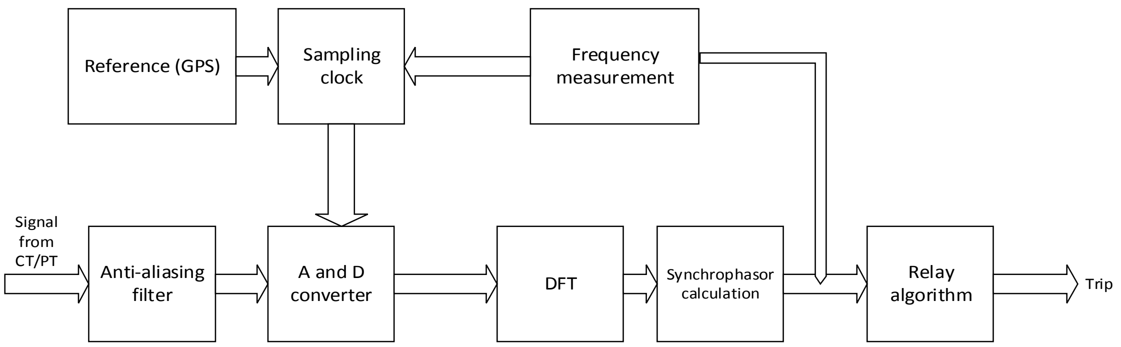

Figure 3: Sampling locked with System frequency.

Relay Algorithms

The algorithms for digital protection of power systems. One may feel awe and wonder at the variety of approaches that the researchers have taken.it seems that the search for algorithmic solution to problems in the area of power system protection is an un-ending one. Inventions and discoveries made in other field like communication, statistics, artificial neural networks, fuzzy logics, genetic algorithm and expected systems have fuelled research in this area.it should note that other method of estimating Phasors have been discussed in literature .However, to best of knowledge, Mann and Morrison, Differential Equation Algorithm, based phasor estimation in this paper work.

Mann and Morrison Method [9]

Even through this algorithm was not the first among algorithms for digital protection, it was the first to get wide publicity. The algorithm protection proposed by M. Ramamoorthy, which was based on Fourier analysis, in the CIGRE Journal can be considered as the first algorithm to be proposed for digital protection of power system.

In this Algorithm, authors model the signal in very simplistic manner. It is assumed that the signal can be represent as a pure sinusoid whose amplitude as well as frequency is constant. Let voltage at the relay location be described by

$$v = V_m \sin(\omega t + \theta_v) \quad (2)$$

And the current by

$$i = I_m \sin(\omega t + \theta_i) \quad (3)$$

The phase angle between the relay voltage and relay current will be given by

$\theta = \theta_v - \theta_i$(4)

We can keep on sliding the window to make a running estimate or rms value of current, rms value voltage, phase angle between voltage and current and hence compute the apparent impedance seen from the relay location. The algorithm appears to be very attractive because of their simplicity. However closer examination reveals that Mann and Morrison method is based on the following assumption Waveform of both the voltage and current consist of undistorted sine waves of fundamental frequency, which is accurately known and is constant.

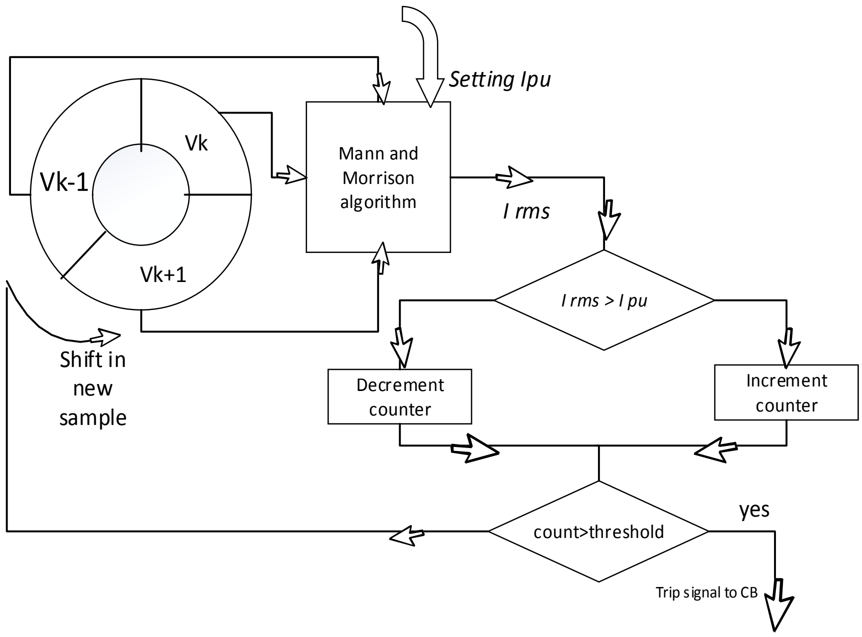

Figure 4: instantaneous OC relay based On Mann and Morrison Algorithm.

Differential Equation Algorithm [10]

In this method, the faulted line is modelled as a lumped series R-L circuit. The distributed natures of the line parameters as well as the shunt capacitance are neglected. Thus, we can relate the voltage and current at the relay location and the resistance and inductance up to the fault location with the help of the differential equation

$$v = i_x R + L\frac{di_y}{dt} \quad (5)$$

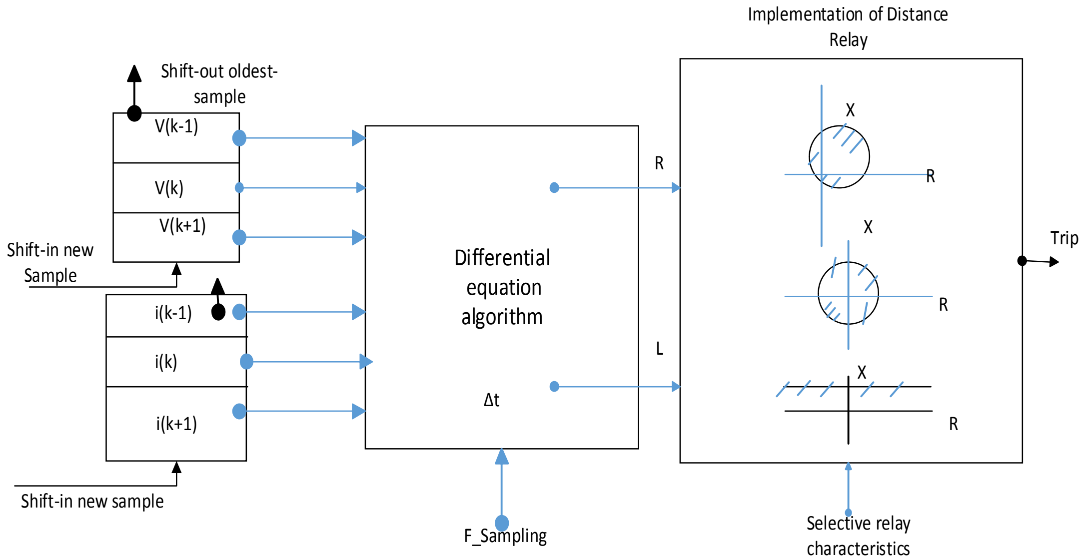

Figure 5: Block –diagram showing inputs to differential equation algorithm and block for implementation of specific distance relay.

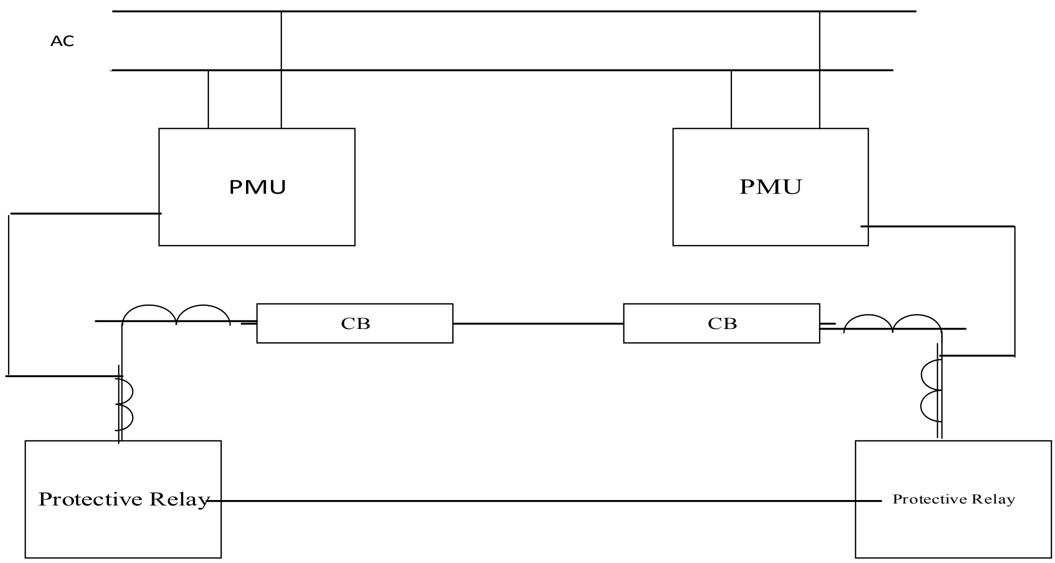

Figure 6: frame work of conventional measurement using reference voltage

Results and Discussions

In this MATLAB script we demonstrate the effect of off-nominal frequency upon the DFT magnitude calculation when the (Discrete Fourier Transform) DFT computation is based on the sampled drawn at multiples of nominal frequency. In this script a 50 Hz, a 45 Hz and 55 Hz signal at 4×5 Hz. Author keep the amplitude of signal constant but change its phase from 0 to 360˚. As expected the 50 HZ signal trace out ellipses. Thus, off-nominal frequency operation of DFT whose sampling is locked to nominal frequency gives rise to error in phasor calculation [12].

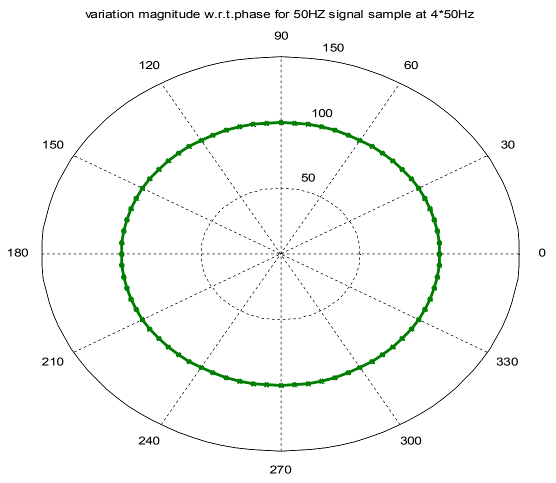

Figure 7: Variation of magnitude w.r.t. phase for 50 Hz signal sampled at 4×50 Hz

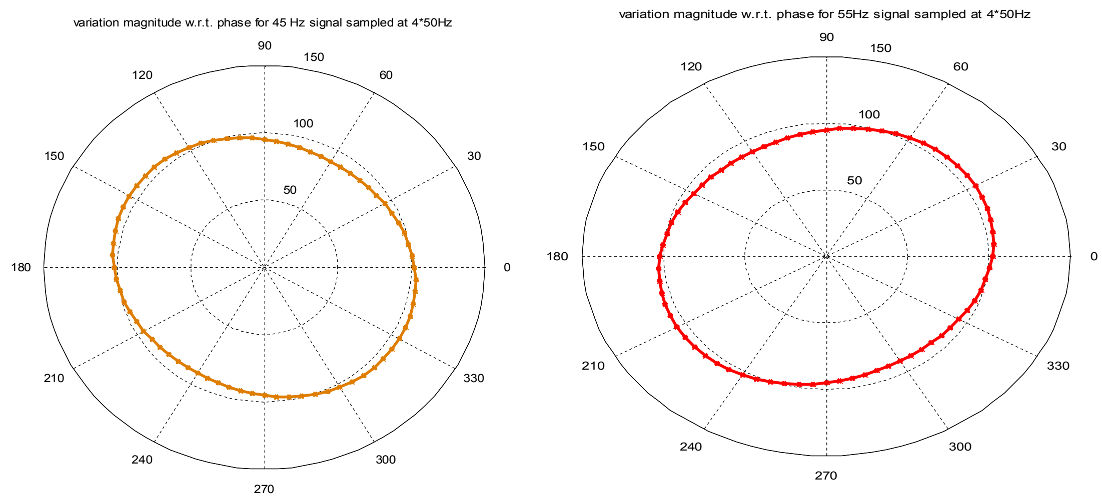

Figure 8: Variation of magnitude w.r.t. phase for 45 Hz and 55 Hz signal sampled at 4×50 Hz

Algorithm based on undistorted signal frequency since wave. Easily get bogged down by the sheer number of algorithm for digital protection which have been proposed in this paper. However, algorithm can be broadly classified into time-domain algorithm and frequency-domain algorithms. For example, the solution of a differential equation is in time domain whereas Fourier algorithm is in frequency domain. For example, if we assume that the signal are undistorted sine waves then can use very simple algorithms such as those of Mann and Morrison's.

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Mann and Morrison Algorithm: Figure 9.1 shown, voltage v, and voltage derivative $\frac{dv}{dt}$, estimated $V_{peak,}$ and estimated phase between voltage and current at relay location.

S. No.	Actual value at relay Location	MATLAB output at relay Location	Percent_Error
(1) Vm	141.4214	140.3572	0.7524
(2) actual_angle	30.0000	29.9664	-0.1120
(3) mean_angle		29.9664	

Table 1: Mathematical results for Mann and Morrison: MATLAB output at relay location.

Computation of one derivative required three sample. Now, we cannot base the trip decision on the signal estimation (which involved only three samples).author have to continuously keep estimating the peak and phase angle and hence the Phasor, in order to be sure about what way the Phasor is really going.

Thus there is error, in both in magnitude and in phase.it can be seen that error in magnitude is only 0.7524% which is less than 0.1% while the error in phase angle is 0.0336°. Thus, Mann and Morrison Algorithm suitable for measurements voltage and phase angle at relay location.

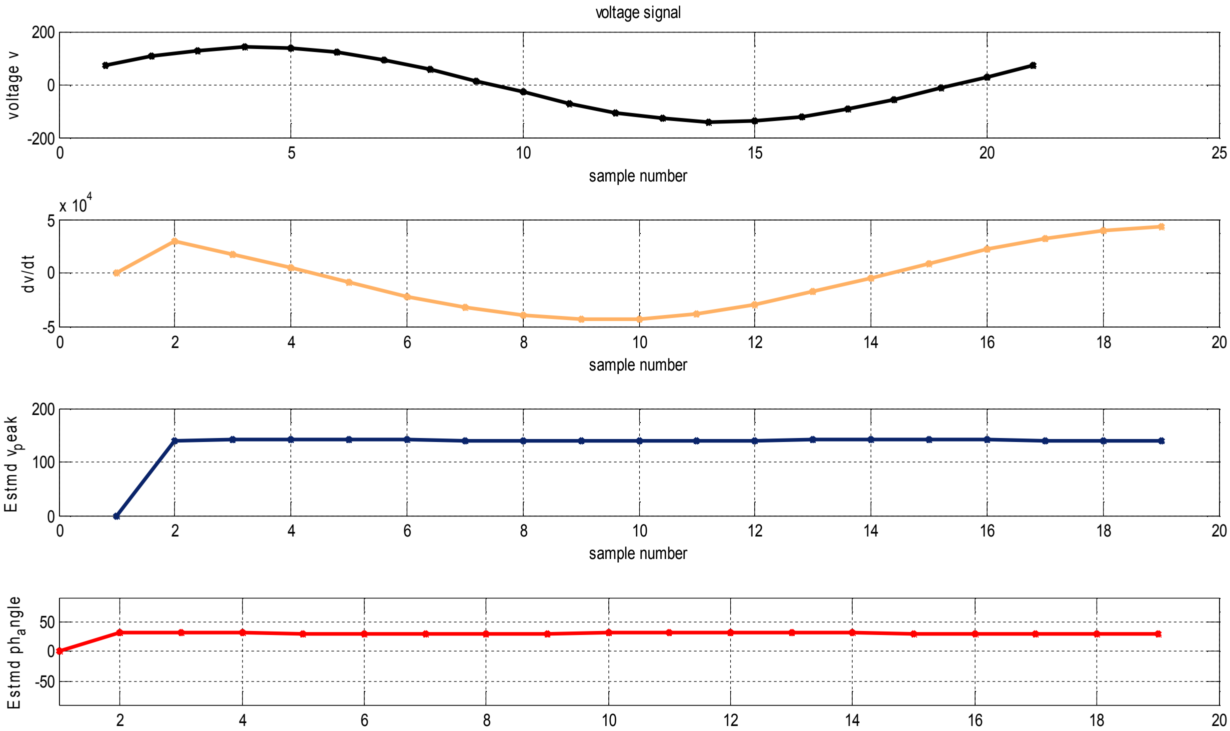

Figure 9.1: voltage v, and voltage derivative $\frac{dv}{dt}$, estimated $V_{peak,}$ and estimated phase between voltage and current at relay location.

Differential Equation Algorithm

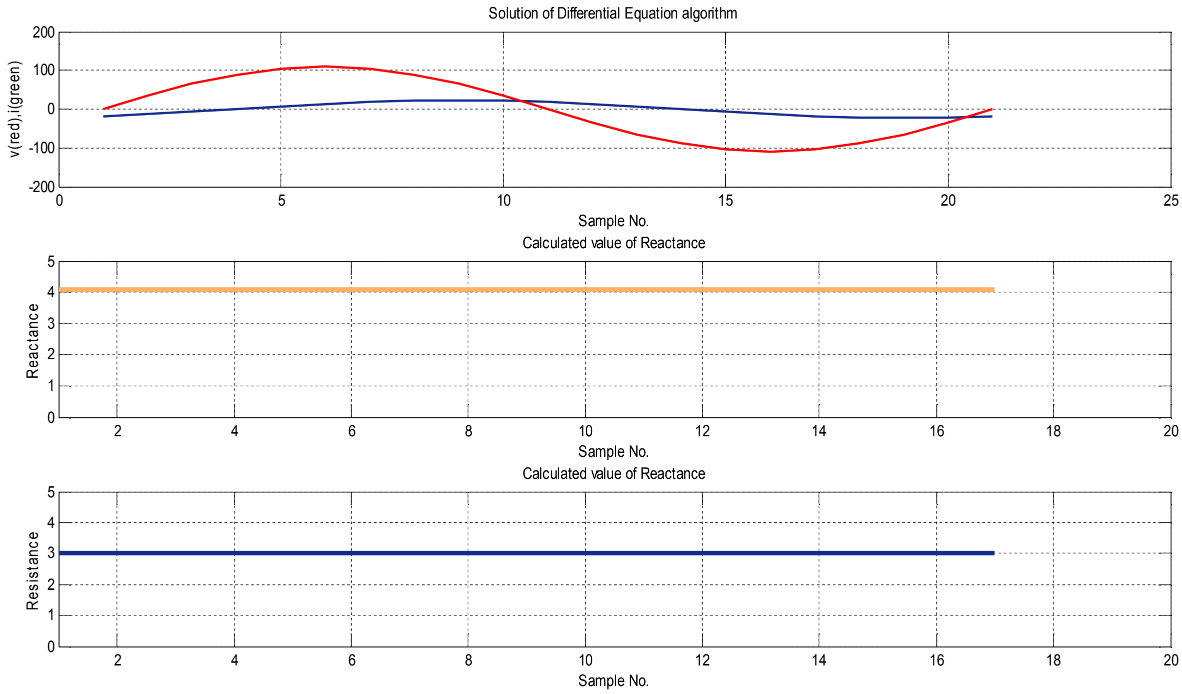

Figure 9.2: shown, voltage, current, reactance and resistance at relay location

S. No.	Actual value at relay Location	MATLAB output at relay Location	Percent_Error_
(1) Reactance	4	3.33436	1.6641
(2) Resistance	3	3	0

Table 2: Mathematical results: MATLAB output at relay location

If faulted line modeled with differential equation Algorithm, Thus there is error, in both Reactance and in Resistance. It can be seen that error Reactance is only 1.6641%. While the error in Resistance is 0%. Thus, differential equation suitable for modelled as a series R-L circuit in relay location.

Conclusion

In this paper, discuss the algorithms for digital protection of power systems. One may feel awe and wonder at the variety of approaches that the researchers have taken. It seems that the search for algorithmic solution to problems in the area of power system protection is an un-ending one. Inventions and discoveries made in other field like communication, statistics, artificial neural networks, fuzzy logics, genetic algorithm and expected systems have fuelled research in this area. It should note that other method of estimating Phasors have been discussed in literature. However, to best of knowledge, Mann and Morrison, Differential Equation Algorithm.

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