Removal of decaying DC offset from fault current by using Kalman filtering theory

[1]Homendra Kumar, [2]Roshni Rahnagdale

[1]PG Scholar, [2]Assistant Professor
[1]Departmaent of electrical Engineering
[1]SSTC (SSGI), Bhilai, India, 491002
[1]hks.2912@gmail.com

***Abstract*— this thesis describes the implementation of Kalman filtering theory for removal of decaying DC offset from fault current. This is a process by which a DC offset can be removed from fault current and can be recovered to its original sinusoidal waveform. Digital filtering and protection algorithms are becoming more complex as the cost of computational equipments continues to decrease. In particular, optimal response digital filters, such as Kalman filters can be implemented on presently available devices. Optimal filters are not yet extensively applied because they appear complex and engineers have not become familiar with their use. This thesis presents the basics of the Kalman filtering technique in power system terminology and illustrates use for removal of decaying DC offsets. Effects of unwanted distortions on power system network current phasor quantity during fault could adversely affect the reliability and discrimination of protective relays. This project is principally concerned with the digital concept based on multistate Kalman filtering approach to minimize such problem. There are a variety of reasons because of that DC offset should be removed from power system network. The main detrimental effects of DC offset in alternating networks are half cycle saturation of transformer core, generation of even harmonics addition to odd harmonics, additional heating in appliances leading to a decrease of the lifetime of transformers and rotating machines, and mal operation of protective relays.**

Key words – **DC offset, relays, Kalman filter.**

I. INTRODUCTION

Removal of DC offset is the process of obtaining the original waveform from the distorted waveform. Removal of DC offset is a field of engineering that studies methods used to recover original waveforms from the distorted waveform which contains DC offsets. Techniques used for removal of DC offset are oriented towards modeling and programming, usually applying various filters to obtain an approximation of the original scene. In this, Kalman filtering theory is used to remove the DC offset from the transmission network. There are variety of reasons that could generates the DC offset in transmission lines, commonly occurring when fault is done in transmission network. Removal of DC offset is necessary for improving relaying, control, improving power quality and security analysis of power system. Fault current not only content steady state component but it also affected by harmonics and decaying DC offset components. DC offset corrupts the information about magnitude of fundamental as well as all type of frequency component. It causes mal operation of the relay. So it is necessary to remove DC offset from secondary of CT, which is provide input signal to the relay. Kalman filter is a standard technique which can remove the DC offset.

The purpose of this paper is to explain Kalman Filtering Theory in power system terminology and to illustrate the application of the Kalman technique to the power system measurements. The concepts of this technique are explained by designing a comparator for the real and imaginary components of the power system voltage and current phasors. This paper summarizes the theory and presents the partial development of digital protection schemes for transmission lines. The schemes are based on a Kalman filtering algorithm that is capable of accurately estimating the post fault voltages and currents. The estimates are used for classification and location. The purpose of this paper is to provide the software necessary for the real time implementation of the estimation process, i.e. Kalman filtering schemes.

II. DECAYING DC OFFSET

During normal operating conditions, the voltage and Current signals are close to pure sine waveforms of nominal Frequency. The expression of fundamental waveform of current is

$$i(t) = Im \sin(wt + \Theta)$$

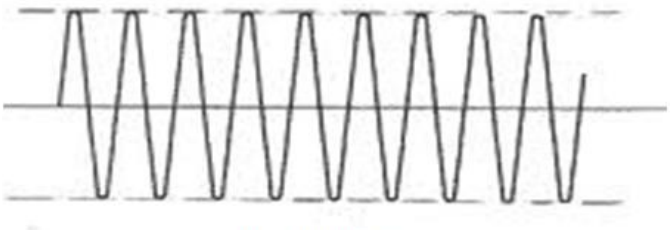


Fig 1, Before fault

When fault occurs in power systems at the instant α, fundamental components are affected by decaying DC offset. Normally current signal only affected by the DC offset. The expression of current with decaying DC offset is

$$i\,(t) = Im*\sin(wt + \alpha - \theta)-Im*\exp(-t/tau)*\sin(\alpha - \theta)$$

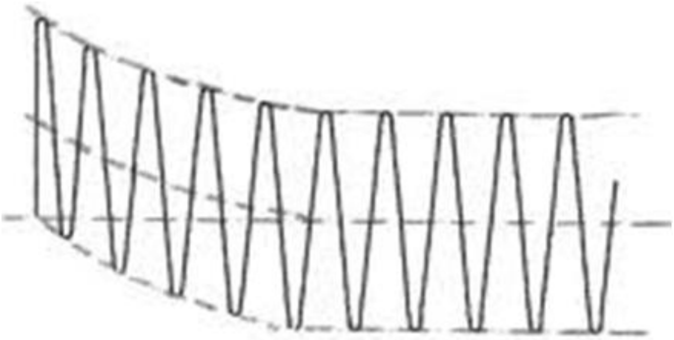


Fig 2, During fault

After fault, followings are the factors which affects the the DC offset:

- Time constant "**tau**"
- Switching instant "**α**",
- Magnitude of dc offset "**Im**"

III. EFFECTS OF DC OFFSET

The main detrimental effects of DC offset in alternating networks are half cycle saturation of transformer core, generation of even harmonics addition to odd harmonics, additional heating in appliances leading to a decrease of the lifetime of transformers and rotating machines, and mal operation of protective relays.

Effect on over current relay

The relay setting is based on steady state calculations. When the protection system of the equipment includes high set instantaneous over-current element that is not immune to the existence of decaying DC component. Relays might have the same setting and have the same current flowing into their terminals but respond to it differently depending on their response to the decaying DC component and this might lead to unsatisfactory protection operation. The general practice to mitigate this problem is to increase the setting of the relay, but this practice reduces the sensitivity of the Protection.

Effect on differential relay

This DC offset can adversely affect the performance of relays. First the pickup level and the operating time can be affected, especially in those relays that do not employ digital filtering techniques to remove the DC component. A second effect is the possibility of CT saturation causing distortion in the current.

Effect on distance relay

The decaying DC offset increases magnitude of current by certain extent. Z calculated =Vm/Im so Z Calculated less as compare to actual value. It means relay sense that fault is near to relay or within operating zone. This effect also called the under reach of the relay.

IV. KALMAN FILTERING THEORY

The Kalman filter keeps track of the estimated state of the system and the variance or uncertainty of the estimate. The estimate is updated using a state transition model and measurements. The Kalman filter, also known as linear quadratic estimation (LQE), is an algorithm that uses a series of measurements observed over time, containing noise (random variations) and other inaccuracies, and produces estimates of unknown variables that tend to be more precise than those based on a single measurement alone. More formally, the Kalman filter operates recursively on streams of noisy input data to produce a statistically optimal estimate of the underlying system state. The filter is named for Rudolf (Rudy) E. Kálmán, one of the primary developers of its theory. The Kalman filter has numerous applications in technology. A common application is for guidance, navigation and control of vehicles, particularly aircraft and spacecraft.

Furthermore, the Kalman filter is a widely applied concept in time series analysis used in fields such as signal processing and econometrics. The algorithm works in a two-step process. In the prediction step, the Kalman filter produces estimates of the current state variables, along with their uncertainties. Once the outcome of the next measurement (necessarily corrupted with some amount of error, including random noise) is observed, these estimates are updated using a weighted average, with more weight being given to estimates with higher certainty. Because of the algorithm's recursive nature, it can run in real time using only the present input measurements and the previously calculated state; no additional past information is required. From a theoretical standpoint, the main assumption of the Kalman filter is that the underlying system is a linear dynamical system and that all error terms and measurements have a Gaussian distribution (often a multivariate Gaussian distribution). Extensions and generalizations to the method have also been developed, such as the extended Kalman filter and the unscented Kalman filter which work on nonlinear systems. The underlying model is a Bayesian model similar to a hidden Markov model but where the state space of the latent variables is continuous and where all latent and observed variables have Gaussian distributions.

Once a fault has occurred, the voltage and current waveforms are severely distorted. Many protection algorithms relay on the fundamental frequency components predetermine, if a fault is in the protected zone, therefore it is necessary to estimate the 50 or 60 Hz components as accurately and quickly as possible. In general, assume that the variables to be estimated have been placed in state variables format and are specified by

$$x(k+1) = Ø(k) + w(k)$$

While the measurement is specified by

$$z(k) = H(k)\, x(k) + v(k)$$

Where,

$x(k)$ = Process state vector
$Ø(k)$ = Matrix relating $x(k)$ to $x(k+1)$
$w(k)$ = uncorrelated white noise sequence
$z(k)$ = vector measurement at time k
$H(k)$ = matrix that gives the noiseless connection between the measurement and $x(k)$
$v(k)$ = uncorrelated white sequence measurement error

Using the measurement at each time k, an estimate of the state variables is determined. This estimate is denoted x(k) The estimate is used to prediction the state variables at time (k+1). This prediction is denoted The measurement and prediction at time (k+1) are used to form a new estimate x(k+1) and from this estimate a new prediction is formed. The complete procedure for Kalman filtering theory is as follows:

1. k=0
2. Enter x(0) and p(0)
3. Compute the Kalman Gain
   $A(k) = P(k)H(k)^t\ (H(k)P(k)H(k)^t + R(k))^{-1}$
4. Determine the estimate
   $x(k) = x(k) + K(k)\ (z(k) – H(k)x(k))$
5. Compute the error covariance matrix:
   $P(k) = (I – K(k)H(k))P(k)$
6. Predict ahead to the next interval:
   $x(k+1) = Ø(k)\ x(k)$
   $P(k) = Ø(k)\ x(k)\ Ø(k)^t + Q(k)$
7. k = k+1
8. Return to step 2

Where

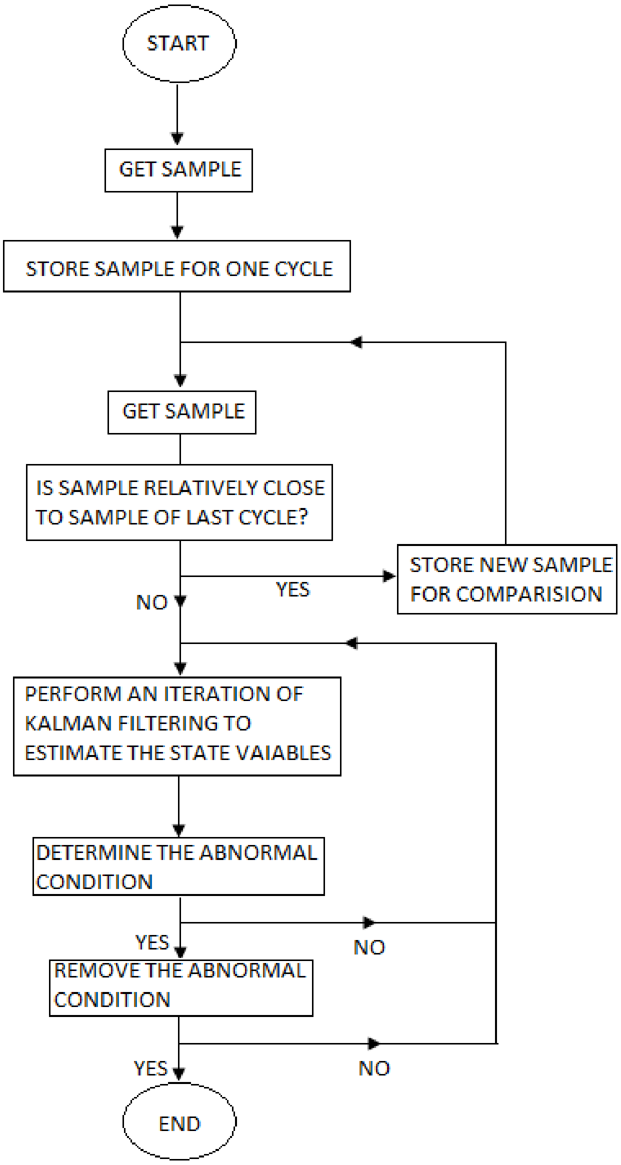
$x(k)$ is the estimated vector at step k,
$Q(k)$ is the covariance matrix for $w(k)$
$R(k)$ is the covariance matrix for $v(k)$
$P(k)$ is the covariance matrix for $x(k)$
I is the identity matrix

The Kalman filtering technique is applied to a state space model of the system. The model includes state transition and output equations. The design of a Kalman filter is based on the statistical properties of the signal that is to be processed. The time varying filter coefficients, called Kalman gains, are calculated to minimize the square of the expected errors between the values of the actual and estimated system states. The Kalman gains can be calculated by solving the following equations.

$$A(k) = P(k)H(k)^t\ (H(k)P(k)H(k)^t + R(k))^{-1}$$
$$P(k) = (I – K(k)H(k))P(k)$$
$$x(k+1) = Ø(k)\ x(k)$$
$$P(k) = Ø(k)\ x(k)\ Ø(k)^t + Q(k)$$

V. COMPLETE ALGORITHM

To qualitatively evaluate the performance of the implementation, a complete protection algorithm will simulated. The algorithm can be divided into the following stages: detection, Kalman filtering, fault type determination, zone computation and fault location. The sequence of events is illustrated by figure.



When the system is first initialized the processors stores the voltage and current samples for one cycle. Each new current and voltage sample is compared with the sample taken one cycle earlier. If there is a difference the system is initiated to begin Kalman filtering process. If there is not a sufficient difference, the new samples are saved for next comparison.

In order to start the Kalman filtering scheme, the initial process vector x(k) must be determined. The initial estimates for the first two components of the voltages and currents are determined by the pre-fault measurement. The third state variable for each of the currents is initially defined as zero.

After the estimate has been calculated, the processor must decide if a fault has occurred and what type of fault has occurred. Based on the relative variations of the phase current, the fault type is determined. Once the fault type is determined, the fault zone is determined. And then Kalman filtering process is begun to initiate.

VI. KALMAN FILTER APPLIED TO PROTECTION

Let there is a DC offset Z(k) in a network after fault has occurred.

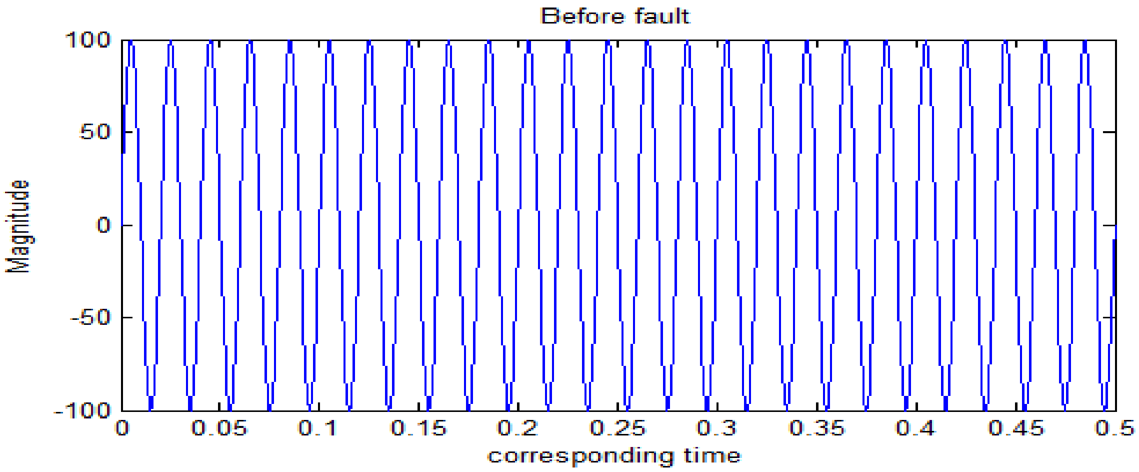
$$Z(k)=E(k)+B(k)$$

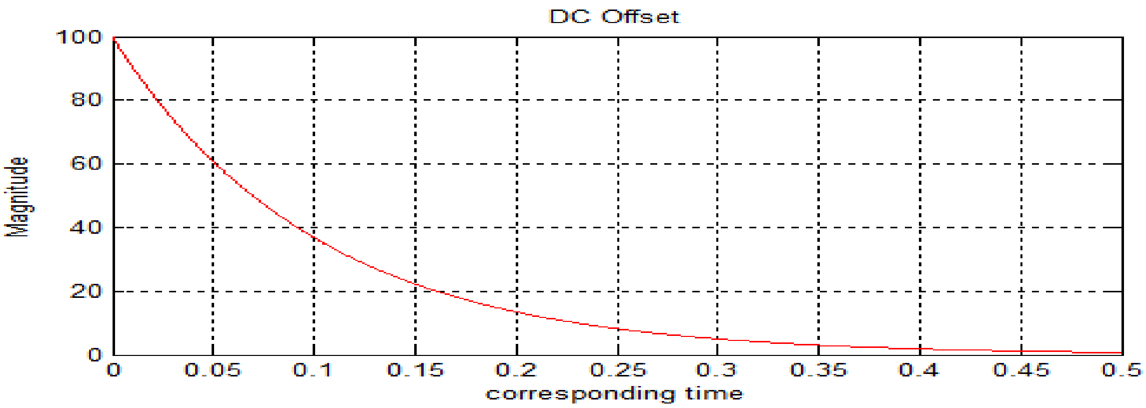
Where,

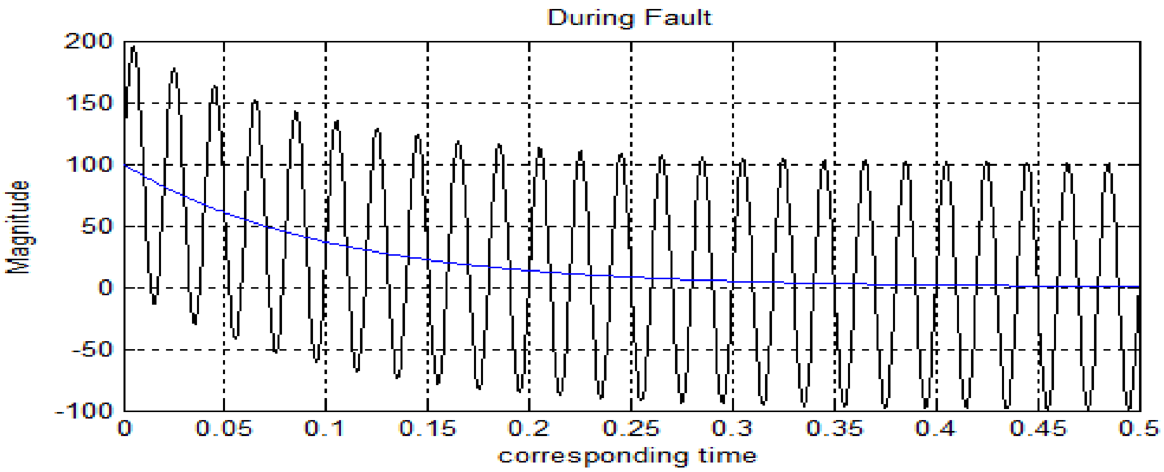
$$E(k)=100.\exp(-t/tau)$$
$$B(k)=100.\sin(wt + Ø)$$

Where

"tau" is the time constant,
w is the frequency, and
Ø is the initial angle at t=0







Now, matrix that gives the noiseless connection between the measurement and x(k) is,

H=[cos(w*k*delta_T) sin(w*k*delta_T) 1]

The covariance matrix is,

R=(1/4)*exp((-delta_T*k)/tau)

Compute the Kalman Gain

A(k) = p0*H’*inv(H*p0*H’+R)

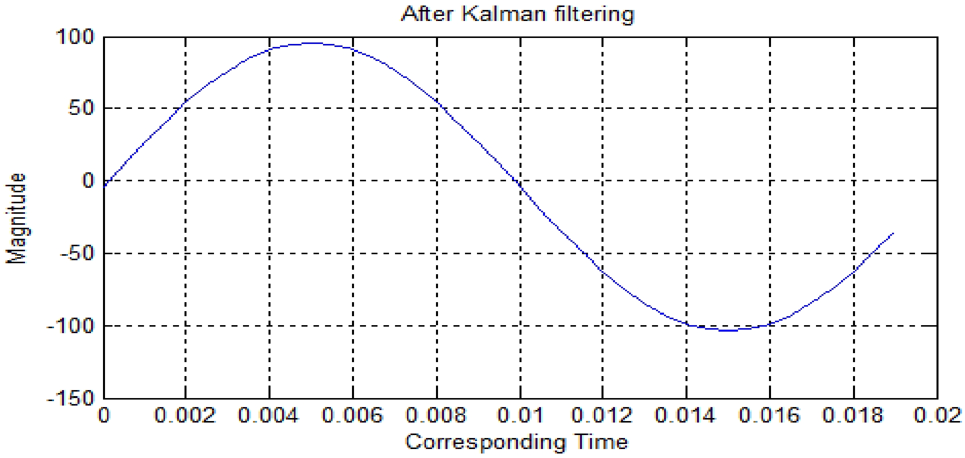
Determine the estimate

x=x+K*(Z(k)-H*x)

Compute the error covariance matrix

p0=(I-K*H)*p0

The above equation and algorithms are the complete process to implement the Kalman filter scheme in power system network when fault is occurred.



VII. CONCLUSION

This paper demonstrates that digital Kalman filtering techniques can be readily applied for removing the harmonics and DC offset present in fault current. A step by step procedure has been presented for applying this method during transients due to faults. Offline calculation of the Kalman gains does significantly reduce the real time computation necessary to implement the filter. For a sinusoidal input, a two state model reaches the correct estimates within two sample periods. However, this model does not provide acceptable results if non-fundamental frequency are presents in the inputs. A properly designed filter, which includes in its model all anticipated frequency components of the post fault signal, responds well, and accurately determines post fault states. The application of statistical methods to the analysis of fault location and post fault voltage and current magnitudes leads to reasonable values for the post fault estimates and for the elements of the initial transition matrix. This procedure is important for obtaining more accurate estimates of the states during transition.

REFERENCES

[1] Nils Hoffmann, and Friedrich Wilhelm Fuchs "Minimal Invasive Equivalent Grid Impedance Estimation in Inductive–Resistive Power Networks Using Extended Kalman Filter" IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 29, NO. 2, FEBRUARY 2014.

[2] João Marcos Kanieski, Rafael Cardoso, Humberto Pinheiro "Kalman Filter-Based Control System for Power Quality Conditioning Devices" IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 60, NO. 11, NOVEMBER 2013.

[3] Ramin Agha Zadeh, Arindam Ghosh and Gerard Ledwich "Combination of Kalman Filter and Least-Error Square Techniques in Power System" IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 25, NO. 4, OCTOBER 2010.

[4] Alberto Pigazo, and Víctor M. Moreno " 3 phase – 3 winding Signal Model for Power System Harmonics and Unbalance Identification Using Kalman Filtering" IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 23, NO. 2, APRIL 2008.

[5] José A. Rosendo Macías, and Antonio Gómez Expósito "Self-Tuning of Kalman Filters for Harmonic Computation" IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 21, NO. 1, JANUARY 2006.

[6] P. K. Dash, A. K. Pradhan, G.Panda "FREQUENCY ESTIMATION OF DISTORTED POWER SYSTEM SIGNALS USING EXTENDED COMPLEX KALMAN FILTER" IEEE Transactions on Power Delivery, Vol. 14, No. 3, July 1999.

[7] G.Gabriel Benmouyal "Removal of DC-offset in current waveforms using digital mimic filtering," *IEEE Trans. Power Delivery*, vol. 10, pp. 621–630, Apr. 1995.

[8] J.L. Pinto de Sa " A new Kalman Filter Approach to Digital Relaying" IEEE transaction on power delivery. Vol. 7, No. 3, July 1992.

[9] Adly A. Girgis, David G. Hart " Implementation and Adaptive Kalman Filtering Algorithms for digital distance protection on a vector signal processor" IEEE transaction on power delivery. Vol. 4, No. 1, January 1989.

[10] Y.V.V.S. Murty, W.J. Smolinski "Design and implementation of a digital differential relay for 3 phase transformer based on Kalman Filtering Theory" IEEE transaction on power delivery. Vol. 3, No. 2, April 1988.

[11] M.S. Sachdev, M.A. Baribeau "A New Algorithm for Digital Impedance Relays," IEEE PAS-98, Vol. 2, No. 4, Dec.1979.