Power System Frequency Estimation using Least Mean Square Filter based Algorithm

Bibhu Prasad Ganthia, Rosalin Pradhan, Priya Pritam Panda, Subrat Kumar Barik

Abstract: *In the field of electrical power sector frequency as a parameter plays an important role. The value of frequency is not constant, varies according to the load conditions. The power system functionalities like operation, monitoring and controlling of electric device are having lots of contribution to it. So it is required to measure the accurate value of this slowly varying frequency. The total power generated by generating stations is equal to the power consumed and losses under steady state conditions. Due to sudden mismatch in the appearance of generation and load can deviate the frequency from its nominal value. Frequency is an important parameter which influences functions of different relays. This study was performed to calculate the frequency of voltage or current signal in the presence of noise and distortion. In this paper Least Mean Square (LMS) Filter is studied and its frequency estimations are discussed.*

Index Terms: *Adaptive Filters, LMS, RLS, DFT, Frequency Estimation.*

I. INTRODUCTION

In a power system, the conventional techniques of phasor estimation which is based on the constant frequency modeling are affected mostly due to the dynamic variation of the frequency. Further the change in reactance component which results from the nominal value of the system frequency affects the functionality of different relays. Therefore, the frequency plays an important role in relaying, monitoring and operation and controlling of electrical devices using digital techniques.

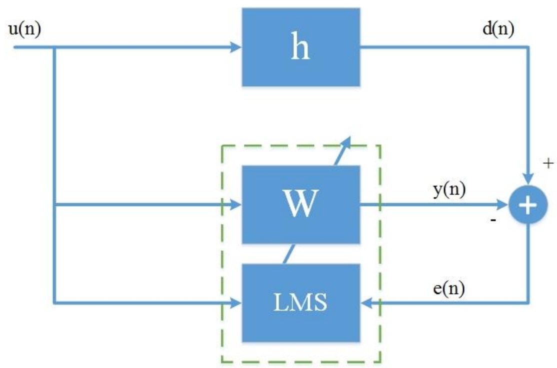

Fig.1. LMS filter with Signaling

Revised Manuscript Received on September 03, 2019

Bibhu Prasad Ganthia, PhD Research Scholar, School of Electrical Engineering, KIIT University, Bhubaneswar, Odisha, India.

Rosalin Pradhan, Assistant Professor, Department of Electrical Engineering, IGIT, Sarang, Dhenkanal, Odisha, India.

Priya Pritam Panda, Assistant Professor, Department of Electrical Engineering, IGIT, Sarang, Dhenkanal, Odisha, India.

Dr. Subrat Kumar Barik, Associate Professor, School of Electrical Engineering, KIIT University, Bhubaneswar, Odisha, India.

By considering the purely sinusoidal voltage waveform, the system frequency is indicated by the time difference between two zero crossings. However, in general, the distorted forms of measured signals are available therefore numbers of techniques are there for the power system frequency estimation. In this paper Least Mean Square (LMS) filtering technique is used for the study of frequency estimation. In figure 1 the use of least mean square filter is used at signaling purposes.

II. MODELLING OF POWER SYSTEM

In power system with no loss performance is considered for estimation. So for a better power quality it is significant to have a purely sinusoidal voltage or current signal. But in practical poor power quality results due to over voltage, under voltage, change in frequency, harmonics and generation-load mismatches. Therefore it is required to estimate the frequency accurately without any delay for the better power quality even in the presence of disturbances. To find the frequency of a pure sinusoidal voltage waveform there are some basic methods such as zero crossing detection and number of cycles calculation within a time interval are available. Discrete Fourier transform (DFT), Kalman filtering, least square error, and iterative techniques are some of the other well-known techniques in this area. In this chapter Adaptive Filters has been implemented for frequency estimation. A power system voltage or current in discrete time signal can be expressed in the form of

$$y_k = A\cos(k\omega T_s + \phi) + e_k \qquad (2.1)$$

Where,

y_k = instantaneous value of signal
A = Amplitude
k = Sampling instant
T_s = Time of sampling
ω = angular frequency
ϕ = phase
e_k = Additive noise

Eq.(2.1) can be written as

$$y_k = \hat{y}_k + e_k \qquad (2.2)$$

Where, $\hat{y}_k$ is the estimated signal.

It is known that the samples of this sinusoidal signal should satisfy the following relationship.

$$\hat{y}_k - 2\cos\omega T_s \hat{y}_{k-1} + \hat{y}_{k-2} = 0 \qquad (2.3)$$

Now, the problem is to find out the value of ω from the above equation (2.3).

III. ADAPTIVE FILTER

An Adaptive filter is a linear filter which has a transfer function that is controlled by variable parameters and those parameters are adjusted by an optimization algorithm. The adaptive filters are digital filters for the complexity in the algorithm.

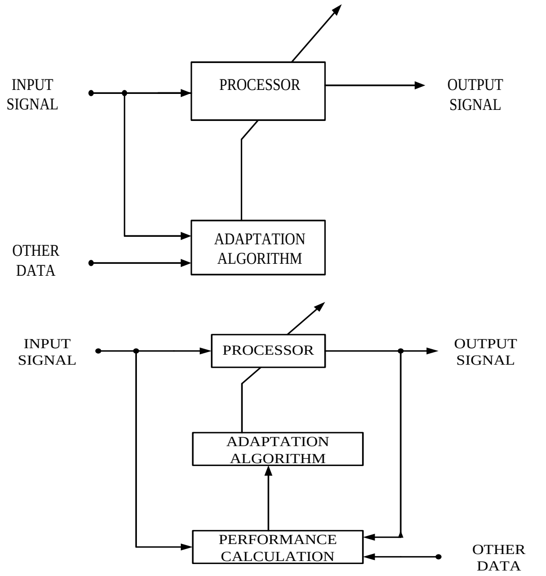

Fig.2. Open Loop Adaptive Filter Structure and Closed Loop Adaptive Filter Structure

IV. LEAST MEAN SQUARES (LMS) FILTER

LMS (Least Mean Square) algorithms are the set of adaptive filters used to imitate a desired filter by finding the co-efficient of filters which are related in producing error signals of the least mean squares. The algorithm starts by taking weights as zero(in most cases) and for each step the weights are updated by finding the mean square error. It acts as a Low-Pass filter.

The least-mean-square (LMS) algorithm consists of two basic processes:

1. A filtering process that includes (a) Evaluation of transversal filter output which is generated by tap inputs, and (b) Error estimation from the comparison between this output with desired output.

2. An adaptive process that includes automatic adjustment of the tap weights in accordance with the estimated error.

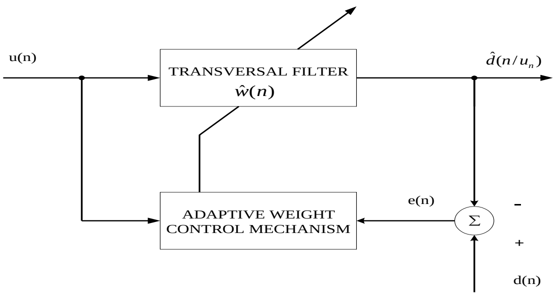

Fig.3. LMS Filter Structure

A. LMS Adaptation Algorithm

$$\nabla J(n) = -2p + 2Rw(n) \qquad (2.4)$$

Where, R = correlation matrix

p = cross-correlation matrix

w(n) = weight of the system

J(n) = mean square error

$\nabla J(n)$ = gradient vector

$$\hat{R}(n) = u(n)u^H(n) \qquad (2.5)$$

Where, u(n) = input signal of the system

$u^H(n)$ = Hessian matrix of u(n)

$$\hat{p}(n) = u(n)\, d^*(n) \qquad (2.6)$$

Where, $d^*(n)$ = desired response of the signal

V. COMPLEX LMS BASED FREQUENCY ESTIMATION ALGORITHM

In power system the three phase voltage signal can be expressed in discretized form as

$$V_{a_k} = V_m \cos(\omega k\,\Delta T + \emptyset) + \epsilon_{a_k} \qquad (2.7)$$

$$V_{b_k} = V_m \cos\left(\omega k\,\Delta T + \emptyset - \frac{2\pi}{3}\right) + \epsilon_{b_k} \qquad (2.8)$$

$$V_{c_k} = V_m \cos\left(\omega k \Delta T + \emptyset + \frac{2\pi}{3}\right) + \epsilon_{c_k} \qquad (2.9)$$

Where V_m is peak value of the voltage signal, ϵ_k is the noise component, ΔT is the sampling time, k is the sampling instant, $\emptyset$ is the phase of the signal, and ω is the angular frequency ($\omega = 2\pi f$, with f being the system frequency) [1]. The complex form of signal originated from the three-phase voltages is obtained by $\alpha\beta$ transform written as follows

$$\begin{bmatrix} V_{\alpha_k} \\ V_{\beta_k} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} [V_{a_k} \quad V_{b_k} \quad V_{c_k}]^T \qquad (2.10)$$

A complex voltage V_k can be obtained from above as

$$V_k = V_{\alpha_k} + jV_{\beta_k} \qquad (2.11)$$

Where A is amplitude of the complex signal V_k, and ξ_k is its noise component and $\hat{V}_k = Ae^{j(\omega k\Delta T + \emptyset)}$.

VI. RESULTS AND DISCUSSION

This chapter discusses the MATLAB/Programming software implementation of LMS filter for system identification and frequency estimation.

A. LMS Filter for System Identification

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

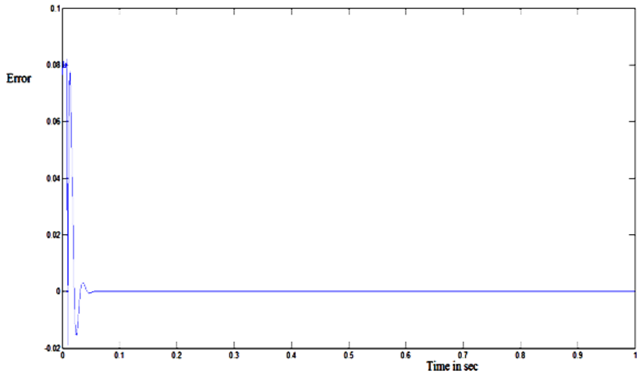

Fig.4. Error waveform of LMS Filter for System identification

For system identification the input x(n) was given as $x = \sin(2\pi ft)$ and the desired input d(n) was given as $d = \cos(2\pi ft)$. Where f is the frequency (50Hz). Here the LMS filter identified the system after 0.06 Sec.

B. Complex LMS Filter for Frequency Estimation

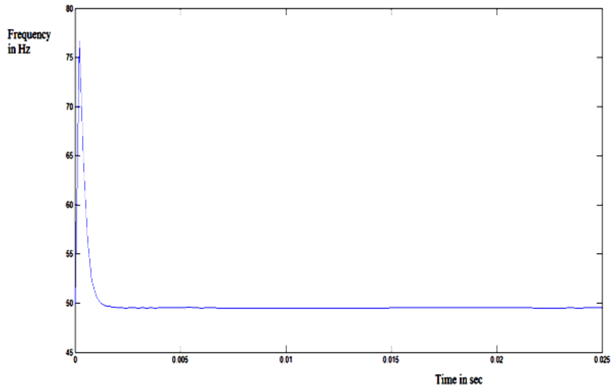

Fig.5. Approximation analysis of 49.5 Hz frequency initialized at 50 Hz by LMS

- At t=0.00198 sec the LMS Filter tracked the Frequency.

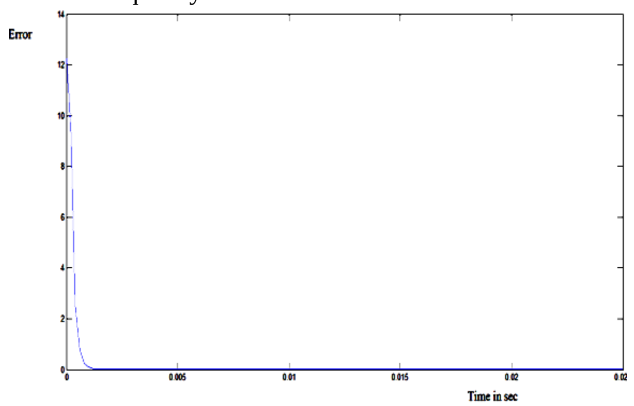

Fig.6. Error waveform of LMS Filter for the estimation of frequency 49.5 Hz

- For estimating the frequency 49.5 Hz using the LMS Filter the error becomes zero after 0.0013sec.

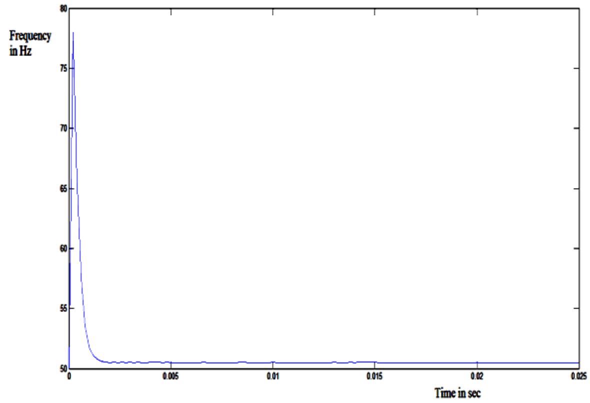

Fig.7. Approximation analysis of 50.5 Hz frequency initialized at 50 Hz by LMS

- At t=0.0016 sec the RLS Filter tracked the Frequency.

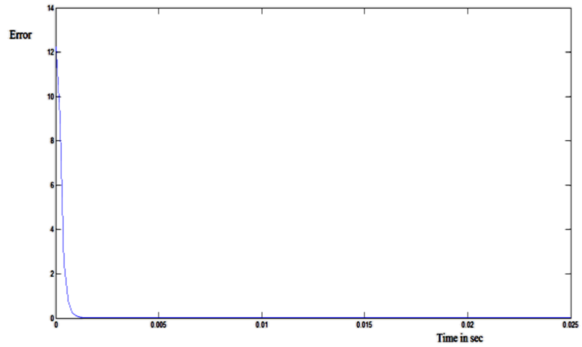

Fig.8. Error waveform of LMS Filter for estimating of frequency 50.5 Hz

- For estimating the frequency 50.5 Hz using the LMS Filter the error becomes zero after 0.0015sec.

C.For System Identification

An algorithm is applied to identify the signal. The systems are identified for LMS Filters with a sampling rate of 1kHz in MATLAB. The influencing parameters of the algorithm are $\mu = 0.05, P_{initial} = 0, \lambda = 0.97,\ \gamma = 0.01, and\ \rho = 0.99$.
For LMS Filters two signals are given to the Filters. They are input signal i.e. $x = \sin(2\pi ft)$ and the desired signal i.e. $d = \cos(2\pi ft)$. Here f is the frequency and the value of the frequency is 50 Hz.
Here the LMS Filter identified the desired signal after 0.06 sec.
D. For Frequency Estimation
Frequency Estimation for LMS Filter

Table.1. Estimation of frequency for LMS Filter

Frequency in Hz	**Time in sec. when the frequency is tracked**	**Time in sec. when the error becomes zero**
49.5	0.00198	0.0013
50.5	0.0016	0.0015

The 49.5 Hz fundamental frequency has a signal-to-noise ratio (SNR) of 30 dB is employed to the filter which is initialized at 50 Hz and the corresponding graph is plotted in Fig.4. It is seen that after 0.00198sec the LMS Filter detects the frequency. Here the error becomes zero after 0.0013 sec. Again the 50.5 Hz fundamental frequency of 30dB signal-to-noise ratio (SNR) is employed to the filter which is initialized at 50 Hz and the graph is plotted in Fig.6. It is seen after 0.0016sec the LMS Filter detects the frequency. Here the error becomes zero after 0.0015 sec.

VII. CONCLUSION

Based on studies which are conducted in this project, the following conclusions may be derived from the above algorithm for frequency estimation. For the power system frequency estimation the least square method is the simplest one. This algorithm gives good accuracy and convergence speed. The frequency of the signal can be estimated from this least square algorithm by minimizing the squared error between the actual signal and assumed model signal. The formulation of this LMS based approach is very simple by the use of the sampled values voltage signals. The frequency estimation done here by using the distorted signals of single phase voltage waveform. The results obtained from the simulation are accurate and the estimation speed is also less even in the presence of noise. By considering different aspects the LMS based frequency estimation approach gives better rate of convergence and efficiency.

REFERENCES

1. Y. Xia, L. Qiao, Q. Yang, W. Pei and D. P. Mandic, "Widely linear adaptive frequency estimation for unbalanced three-phase power systems with multiple noisy measurements," *2017 22nd International Conference on Digital Signal Processing (DSP)*, London, 2017, pp. 1-5.
2. T. R. F. Mendonça, M. F. Pinto and C. A. Duque, "Least squares optimization of zero crossing technique for frequency estimation of power system grid distorted sinusoidal signals," *2014 11th IEEE/IAS International Conference on Industry Applications*, Juiz de Fora, 2014, pp. 1-6.
3. Bibhu Prasad Ganthia, Aditi Abhisikta, Deepanwita Pradhan, Anwes Pradhan, A Variable Structured TCSC Controller for Power System Stability Enhancement, Materials Today: Proceedings, Volume 5, Issue 1, Part 1, 2018, Pages 665-672, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2017.11.131.
4. H. M. M. Alhaj, N. M. Nor, V. S. Asirvadam and M. F. Abdullah, "Power system fundamental frequency estimation using variable step size NLMS," *2013 IEEE International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA)*, Kuala Lumpur, 2013, pp. 1-6.
5. Bibhu Prasad Ganthia, Prashanta Kumar Rana, Tapas Patra, Rosalin Pradhan, Rajashree Sahu, Design and Analysis of Gravitational Search Algorithm Based TCSC Controller in Power System, Materials Today: Proceedings,Volume 5, Issue 1, Part 1,2018, Pages 841-847, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2017.11.155.
6. L. Yunlu, W. Dazhi, H. Wei and L. Zhen, "A novel predictive control for active power filter using a variable-step LMS algorithm," *The 27th Chinese Control and Decision Conference (2015 CCDC)*, Qingdao, 2015, pp. 4688-4692.
7. R. W. Wies, J. W. Pierre and D. J. Trudnowski, "Use of least mean squares (LMS) adaptive filtering technique for estimating low-frequency electromechanical modes in power systems," *IEEE Power Engineering Society General Meeting, 2004.*, Denver, CO, 2004, pp. 1863-1870 Vol.2.
8. J. C. M. Bermudez and N. J. Bershad, "Time-varying system identification using the quantized LMS algorithm," *38th Midwest Symposium on Circuits and Systems. Proceedings*, Rio de Janeiro, Brazil, 1995, pp. 247-250 vol.1.
9. P. A. C. Lopes, G. Tavares and J. B. Gerald, "A New Type of Normalized LMS Algorithm Based on the Kalman Filter," *2007 IEEE International Conference on Acoustics, Speech and Signal Processing - ICASSP '07*, Honolulu, HI, 2007, pp. III-1345-III-1348.
10. B. P. Ganthia, R. Pradhan, S. Das and S. Ganthia, "Analytical study of MPPT based PV system using fuzzy logic controller," *2017 International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS)*, Chennai, 2017, pp. 3266-3269.
11. Junmin Zhang and Kaipei Liu, "Harmonic detection for three-phase circuit based on the improved analog LMS algorithm," *2008 International Conference on Electrical Machines and Systems*, Wuhan, 2008, pp. 3978-3982.
12. Ganthia B.P., Pritam A., Rout K., Singhsamant S., Mohanty J. (2018) Study of AGC in Two-Area Hydro-thermal Power System. In: Garg A., Bhoi A., Sanjeevikumar P., Kamani K. (eds) Advances in Power Systems and Energy Management. Lecture Notes in Electrical Engineering, vol 436. Springer, Singapore
13. A.K. Pradhan, A. Routray and A. Basak, "Power System Frequency Estimation using Least Mean Square Technique" IEEE Transactions on Power Delivery, Vol.20, No.3, PP.: 1812-1816, July 2005.
14. Vullings, B.D. Vries and J.W.M. Bergmans "An Adaptive Kalman Filter for ECG Signal Enhancement" IEEE Transactions on Biomedical Engineering, Vol.58, No.4, PP.: 1094-1103, April 2011.

AUTHORS PROFILE

Bibhu Prasad Ganthia is currently working as Assistant Professor in the Department of Electrical Engineering at Indira Gandhi Institute of Technology, Sarang, Odisha, India. He has received his Master's degree in the year 2016 from IGIT, Sarang in Power Electronics & Drives specialization and pursuing his Ph.D at Kalinga Institute of Industrial Technology, Deemed to be University, Bhubaneswar, Odisha, India. He has both teaching as well as industrial experience in his profession. In the short duration he has published 27 journal, book chapters and conference papers in reputed publishers like IEEE, Elsevier and Springer etc. with editor of 3 Scopus index journals and reviewer of many journal and conferences like BEEI, Indonesia, MDPI Journal, IASTER, The Institute of Engineers, Springer etc. He is also the member of national and international scientific associations such as IAENG, SESI, ISRD, IFERP, BEIESP, SCIEI and NSPE and many more. He has software proficiency in MATLAB, ANSYS, LabView, DSpace and VLSI designing. He has got Certificate of Merit for excellence in Mater degree from BPUT, Rourkela, Odisha. He is awarded as "Best Ed Tech Teacher of the Year" by Indian Education Award 2019 sponsored by Techpro Labz and IIT Patna. Moreover he is awarded as "Young Teacher Award" by International School Award 2019, India. He owned Best Researcher Award and Young Researcher Award from DFIRF and Vedant Academics Bangkok Awards in the year 2019 respectively. He has also awarded Innovative Researcher of the Year in renewable energy for the year 2019 by Research Under Literal Access and World Research Council. His Ph.D research is on meta-heuristic artificial neural network optimization, control, protection of wind energy conversion system Hardware-In-Loop in Real Time System.

Rosalin Pradhan is currently working as Assistant Professor in the Department of Electrical Engineering at Indira Gandhi Institute of Technology, Sarang, Odisha, India. He has received his Master's degree in the year 2013 from VSSUT, Burla, Odisha in the specialization of Power System Engineering. She has completed her graduation (B.Tech) CEB, Bhubaneswar in the year of 2011 in

Electrical Engineering. She has six years of teaching experience and published paper in reputed journals and conferences like IEEE, Elsevier Proceedings. Her areas of interest are Power System, Renewable Energy and Smart Grid.

Priya Pritam Panda is graduated (B.E) from Hindustan University, Chennai in 2014 in Electrical and Electronics engineering. He perused Master degree (M.Tech) from Indian Institute of Technology Guwahati in the year 2018 with Radio frequency and photonics specialization. Now working as Assistant Professor in department of Electrical Engineering, Indira Gandhi Institute of Technology, Sarang, Odisha. He has teaching experience of more than three year. He was awarded by IEEE, Madras section sight for developing low cost solar lamp from waste material. He has done research in vibration analysis of single later grapheme plate in his master course. His area of interest is high frequency study, engineering optics, renewable energy, Internet of Thing and micro grid. His software proficiency includes MATLAB, Multisim, CAD, Optispice, OptiWave and Comsol Multiphysics..

Dr. Subrat Kumar Barik working as associate professor in school of electrical engineering at Kalinga Institute of Industrial Technology, Deemed to be University, Bhubaneswar, Odisha India. Dr. Barik has thirteen years of experience in teaching in undergraduate and postgraduate level. He has also an excellent research career in the area of Solar Photovoltaic Grid Integrated System. He has a number of research publications in SCI, Scopus indexed journals and international conferences. He graduated from the VSSUT, Burla in Electrical Engineering discipline and received his PhD from SOA University.