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Performance Evaluation of Modified Least Square Algorithm in Dynamic Events

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ABSTRACT
As the population is increasing rapidly, Energy demands also needs to be fulfilled efficiently, for that supervision and monitoring of power system in various dynamic events have to be done precisely, Such tasks are normally done by Supervisory control and Data Acquisition System(SCADA) and Phasor Measurement Unit(PMU) also. PMU is best among all in terms of accuracy and time delaying as it uses Global Positioning System for synchronization with other PMU's, and strong phasor estimation algorithm with less number of samples giving accurate and real time tracking of power system in normal events as well as dynamic events. This paper evaluates Modified Least square method for various dynamic events as per IEEE standard of synchrophasor measurement. Morever dynamic events taken here are not model based signals, in earlier literatures model based signals were used, that problem is eliminated in this paper.
Keywords - Phasor measurement unit, discrete fourier transform, phasor measurement units, wide area monitoring, smart grids, total vector error, signal to noise ratio.

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I. INTRODUCTION

Phasor measurement units are vital part of any WAM, PMU'S are used to get fundamental phasors from distorted as well pure sinusoidal waves, that means PMU'S are able to give fundamental magnitude, phase, frequency as well as rate of change of frequency from a input signal. The input signal may be distorted from modulation event, frequency ramp event, noise event, and step events also. These all disturbances have been taken into account, and algorithm is tested, as per IEEE **C37.118.1-2011** standards. The phasor estimation based on DFT and least error square algorithm are very old techniques and best suited for pure sinusoidal signal, but for dynamic events, the algorithm fails to get fundamental phasor, for dynamic events DFT and least square algorithms can be used with filters, then it will lead to huge cost requirement, all these demerits made above algorithms unsuitable for estimation of dynamic phasors. In [1], taylor series based algorithm is discussed, the dynamic phasor of an observation data window is imprecised by 2nd order taylor series, algorithm here is models based algorithm but PMU must be capable of estimating phasor for every signal, so it can be unsuitable for some other dynamics. In [2], a phasor estimation technique , with Hilbert transform and convolution is discussed, the algorithm here is little complex and not based on simple procedures. In [3], dynamic phasor estimator based on subspace technique is proposed which is based on large sampling rate and some changes in the subspace-based techniques are taken into account to find the fundamental phasor without anti-aliasing filter to the input signal. In [4], two precise and fast dynamic phasor estimation techniques subjected oscillations and off nominal conditions are discussed, These methods utilizes the signal model under some dynamic conditions, then linearize them using Taylor's coeffcient expansion, and then least square technique is used to find the phasor. Frequency and its rate of change are also calculated using adjacent phasors with minimum complexity.

In [5], phasor estimation algorithm based on conventional Discrete Fourier Transform is discussed, normally DFT gives very good performance for static signals but it is unsuitable for dynamic signals. In [6] phasor estimation algorithm based on taylor series and least square algorithm is discussed which has been implemented and has been tested for pure sinusoidal wave as well some dynamic signals, We have replaced model based signal from some dynamic signals as per IEEE standard of synchrophasor measurement. In [7], a phasor estimation technique based on modified least square algorithm is considered to find the dynamic phasor of a fundamentamental component of frequency with time-changing amplitude. The fault current is supposed to be the mixture of a decaying dc offset, decaying fundamental frequency component and harmonic having constant amplitude. the decaying dc offset exponential function and fundamental frequency component are changed by Taylor series and coefficients. Then, the Least Square method is utilized to find the time constants and magnitudes of decaying components. In [8], DFT is used, a fault current is taken into account as it contains decaying dc component, normally DFT has inaccuracy in phasor estimation. The algorithm can be implemented in four steps- Generation of auxiliary signal by high frequency modulation of fault then DFT of summation of auxiliary signal and fault current is found out. There are some more literatures also[9-11] to estimate phasors for dynamic conditions, There are significant differences among them. The above discussed literatures have many advantages and disadvantages too, all of them have different performances for different test signals. The main problem while implementing the algorithm, the algorithm must have simple procedures for implementations. The above discussed algorithms contains complex and large equations, The paper has following sections- Section II describes modified least square algorithm. Section III describes simulation results for various dynamic signals. Section IV contains conclusion of the work.

II. MODIFIED LEAST SQUARE METHOD

A modified least square technique for time variant signal parameter is used to find the fundamental components of a signal[6]. The test signal is considered to contain decaying dc component and fundamental frequency component, then resolved in terms of 2nd order Taylor coefficients. The modified Least square method having a ridge regression factor is utilized to find Taylor coefficients using that the amplitude, phase, can be accurately evaluated [6].

Let the signal X(n) be written as:

$$X(n) = A_{dc}\exp(-\alpha t) + X_m.\cos\big(nw(n) + \theta(n)\big) + \varepsilon(n) \quad (1)$$

Where, α and A_{dc} are the time constant and time amplitude of decaying dc component, X_m= amplitude of sinusoid,

$w(n)$= angular frequency of sinusoid

$\theta(n)$ = phase of the sinusoid

$w(n) = 2\pi f(n)$

$f(n)$ = signal fundamental frequency

$\varepsilon(n)$ = additive white noise

Now let us express the phase angle as:

$$\varphi(n) = 2\pi f(n)dt + \theta(n) \quad (2)$$

The rate of change of phase angle = frequency so the signal frequency can be expressed as:

$$f = \frac{1}{2\pi}\frac{d}{dt}\big(\varphi(n)\big) = f_0 + \frac{1}{2\pi}\frac{d}{dt}\big(\theta(n)\big) \quad (3)$$

Equation (1) can be expressed as per trigonometric function:

$$X(n) = A_{dc}\exp(-\alpha t) + K_1(n).\cos\big(2\pi f(n)\big) + K_2(n)\sin\big(2\pi f(n)\big)$$

(4)

Where

$K_1 = X_m\cos(\theta(n))$ and $K_2 = X_m\sin(\theta(n))$

$K_1(n)$ and $K_2(n)$ are the coefficients functions that represents the envelope of the steadily changing sinusoid.

From Taylor series expansion the coefficient functions of equation (4) can be written as follows:

$$K_1(n) = Kc_0 + Kc_1 n + Kc_2 n^2 + Kc_3 n^3 \quad (5)$$

$$K_2(n) = Ks_0 + Ks_1 n + Ks_2 n^2 + Ks_3 n^3 \quad (6)$$

Where $Kc_0 = K_1(0)$, $Kc_1 = \frac{dK_1(n)}{dt}$ at n=0, $Kc_2 = \frac{d^2K_1(n)}{dt^2}$ and $Kc_3 = \frac{d^3K_1(n)}{dt^3}$ at n=0

$Ks_0 = K_2(0)$, $Ks_1 = \frac{dK_2(n)}{dt}$ at n=0, $Ks_2 = \frac{d^2K_2(n)}{dt^2}$ and $Ks_3 = \frac{d^3K_2(n)}{dt^3}$ at n=0

Now the DC component of equation (1) can also be expanded as

$$A_{dc}\exp(-\alpha t) = A_{dc}(1 - \alpha t + 0.5\alpha^2 t^2) \quad (7)$$

Using equations (4), (5) and (6), equation (7) is represented in a discrete form as

$$X(n) = A_{dc}(1 - \alpha ndt + 0.5\alpha^2(ndt)^2) + (Kc_0 + Kc_1 ndt + Kc_2(ndt)^2)\cos(2\pi f(n)dt + (Ks_0 + Ks_1 ndt + Ks_2(ndt)^2\sin(2\pi f(n)dt) \quad (8)$$

At $t = t_1$ equation (8) can also be written as

$$X(t_1) = d_0p_0 + d_1p_1 + d_2p_2 + d_3p_3 + d_4p_4 + d_5p_5 + d_6p_6 + d_7p_7 + d_8p_8 \quad (9)$$

Where

$$p_0 = 1, p_1 = t_1, p_2 = t_1^2, p_3 = \cos(2\pi ft_1), p_4 = t_1\cos(2\pi ft_1), p_5 = t_1^2\cos(2\pi ft_1), p_6 = \sin(2\pi ft_1), p_7 = t_1\sin(2\pi ft_1), p_8 = t_1^2\sin(2\pi ft_1)$$

And $d_0 = A_{dc}$, $d_1 = -\alpha A_{dc}$, $d_2 = 0.5\alpha^2 A_{dc}$, $d_3 = Kc_0$, $d_4 = Kc_1$, $d_5 = Kc_2$, $d_6 = Ks_0$, $d_7 = Ks_1$, $d_8 = Ks_2$

So $D = [d_0, d_1, d_2, d_3, d_4, d_5, d_6, d_7]_{9\times 1}$ (10)

Assuming at a specific time interval dt, $t_1 + dt$ and so on till $t_n + ndt$ the signal is sampled, then (9) can be written for each sample and represented in matrix form as:

$$[X]_{9\times 1} = [P]_{n\times 9}[D]_{9\times n} \quad (11)$$

In equation (11), matrix [P] contains elements which are found on the basis of interval of sampling and time references. Matrix [X] has known sampled signal data. In (11), n represents the number of samples and matrix [D] contains 9 variables which are unknown, and are evaluated using the

Least square algorithm which comes with a Ridge regression factor ρ as shown below equation-

$$[D] = ([P]^T[P] + \rho[I])^{-1}.[P]^T[X] \quad (12)$$

Where ρ = small value ranges from 0.05 to 1.

[I] = identity matrix in the form as shown in the below equation

$$[I] = \begin{bmatrix} 1\,0\,0\,0\,0\,0\,0\,0\,0 \\ 0\,1\,0\,0\,0\,0\,0\,0\,0 \\ 0\,0\,1\,0\,0\,0\,0\,0\,0 \\ \dots\dots\dots\dots\dots\dots \dots \\ 0\,0\,0\,0\,0\,0\,0\,0\,1 \end{bmatrix} \quad (13)$$

Now we can find the amplitude and phase angle of the given sinusoid as:

$$X_m = \sqrt{Kc_0^2 + Ks_0^2} \quad (14)$$

$$\theta = \tan^{-1}\left(\frac{Ks_0}{Kc_0}\right) \quad (15)$$

Where

X_m = Estimated amplitude of sinusoid

θ = Estimated phase angle of sinusoid.

To implement modified least square algorithm, MATLAB software is used in Intel (R) Core (TM) 2 duo processor @ 2.00 Hz computer. The performance of modified least square algorithm is tested for dynamic events as per IEEE C37.118.1-2011 standard.

TABLE-1 SPECIFICATIONS USED

Parameter	Notation	Specifications
Signal magnitude	X_m	150 volts
Signal frequency	f	50Hz
Phase angle	θ	0 to 360 Degree
Phase angle sensitivity	K_{am}	0.1
Modulation frequency	f_m	0.2 to 2 Hz
Step change size	K_{xs}	0.1
Phase step size	K_{as}	0.1
Noise	ε	15 db to 50 db SNR
Harmonic	X_3	1.33 % to 5% of fundamental

In this work, the specifications as shown in Table 2 are taken to test modified least square algorithm. The algorithm is able to estimate one phasor per cycle for sampling rate 128 samples/cycle.

III. SIMULATION RESULTS

phasor estimation, the algorithm has been successfully tested under compliance test as per IEEE **C37.118.1-2011** standards[12]. The simulation results shows that the algorithm gives TVE less than 3% for dynamic events and TVE less than 1% for pure sinusoidal waves which satisfied IEEE standard of synchrophasor measurement[12]. The algorithm performance evaluated satisfactorily and TVE for various dynamic events have been plotted with various phase angles as well as various time cycles. The modified least square algorithm is tested for various dynamic signals such as noise event, modulation event, ramp event, step change event etc. as per IEEE standards the simulation results are shown below

1.1 Pure sinusoidal wave

In power system voltage and current can be represented as sinusoidal waveform shown in equation (1) for normal operating condition[2].

$$x(t) = X_m \sin(2\pi ft + \theta) \quad (16)$$

Where X_m is peak magnitude of sine wave, which is taken as 150 volt for test case, f is signal frequency,which is taken as 50 Hz in simulation. θ is the phase angle. PMU'S must be able to detect magnitude and phase angle of pure sine wave efficiently for different phase angles and for different cycles.The performance of any PMU can be estimated by calculating TVE with respect to phase angle change as well for different phasors. The figures shown below can be seen to find TVE at different conditions.

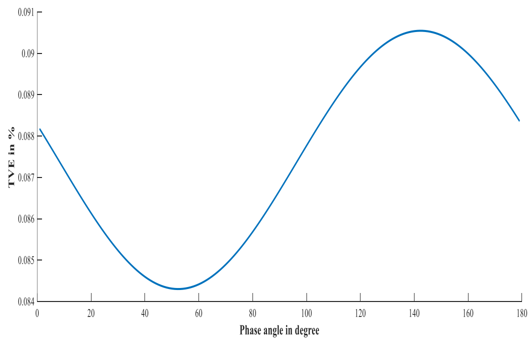

Fig. 1: TVE at different phase angles for pure sine wave.

Fig. 1, shows the TVE with respect to change in phase angle, for pure sine wave. the phase angle is varied here from 0° to 180°, As we can see the TDPE is performing well and in all the cases TVE is less than 1% as per the requirement of IEEE standard for synchrophasor measurement[12].

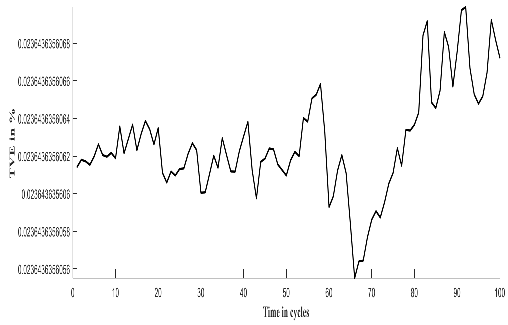

Fig. 2: TVE at time cycles of pure sine wave.

Fig. 2 shows the TVE with respect to time in cycles, it can be seen here, TVE remains less than 0.025 % which is good as per requirements of IEEE standards.

1.2 Modulation event

There are various abnormal conditions in power system because of that there is some undesirable change in fundamental magnitude and phase of sinusoidal wave. Power swings in power systems is one the major abnormality. These power swings are caused due to generator outages, switching of lines, use of lumped load and also overloaded tie lines, these all changes in power system causes oscillations in machine rotor angles in power swing. These power swings can be modeled as modulated sine wave and it causes abnormal change in magnitude and phase of the pure sine wave[2].

The modulated sine wave can be represented as equation

$$x(t) = X_m\big(1 + K_{xm}\sin(2\pi f_m t + \theta)\big)\sin(2\pi ft + K_{am}\sin(2\pi f_m t) + \theta) \quad (17)$$

Where X_m is peak magnitude of sine wave , f is signal frequency and θ is the phase angle, K_{xm} modulated amplitude, f_m is modulation frequency, K_{am} phase sensitivity.

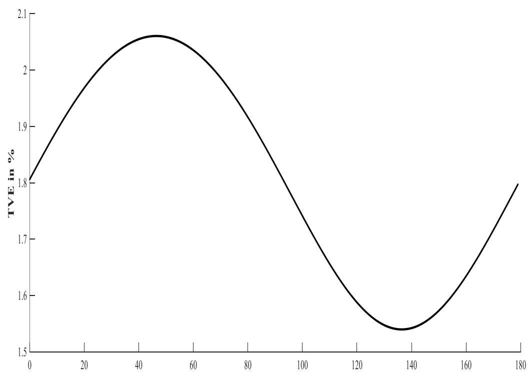

Fig.3: TVE at different phase angles for modulation event.

Fig.3, shows TVE with respect to phase angle variation, the modulation frequency is 2 Hz, as it can be seen that there is maximum TVE of 2.1 %. Here also proposed algorithm is meeting IEEE standard for synchrophasor measurement[21].

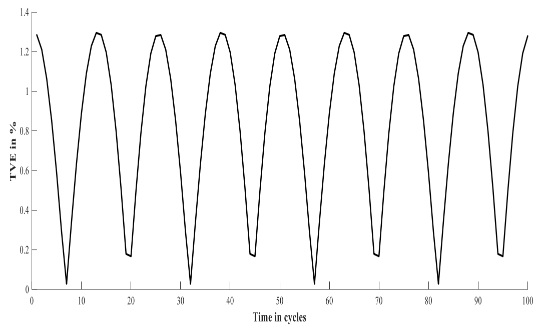

Fig.4: TVE with modulation event.

Fig.4, shows TVE with respect to estimated phasor estimated by TDPE for modulation frequency of 2 Hz, in power system modulation frequency varies from 0.2 Hz to 2 Hz, maximum TVE is just 1.3 %.

1.3 Noise event

The use of capacitor banks as well as some capacitive loads causes noise in power system, also while receiving signals in PMU may cause pure sine wave to get distorted hence the algorithm is also tested for noise event for different Signal to Noise ratios e.g. 25 db, 15 db and 50 db[2].

$$x(t) = X_m\sin(2\pi ft + \theta) + \varepsilon \quad (18)$$

Equation (18) represents sine wave distorted with white Gaussian noise, where X_m is peak magnitude of sine wave , f is signal frequency and θ is the phase angle, and ε is white Gaussian noise.

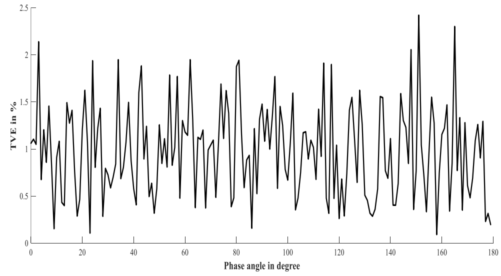

Fig. 5: TVE vs phase angle for noise event.

Fig. 5, shows TVE variation with respect to phase angle in degree. the maximum TVE can be seen as 2.9 %. 50 db noise level.

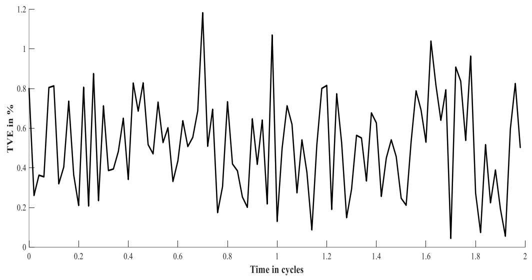

Fig.6: TVE with noise event.

Fig. 6 shows TVE with noise event for various time cycles, maximum TVE here is 1.2 % for 50 db noise level.

1.4 Frequency ramp rate event

In power system to meet the load demands the generating power has be adjusted, load demand is not constant in power system it changes time to time, hence to meet all these automatic generation control adjusts the speed of generators, due to that there is sudden increase and decrease in frequency of power system. This phenomenon can be represented as sinusoidal wave with ramp event and it can be mathematically shown as[2]:

$$x(t) = X_m \sin(2\pi f t + \pi R_f t^2 + \theta) \quad (19)$$

where X_m is peak magnitude of sine wave , f is signal frequency and θ is the phase angle, and R_f is ramp constant.

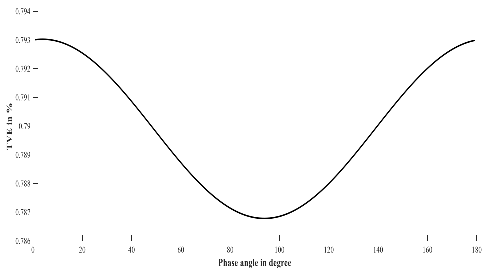

Fig.7: TVE with +1 Hz frequency ramp event.

Fig. 7 shows TVE with +1 Hz ramp event for various phase angles, maximum TVE here is 0.79%.

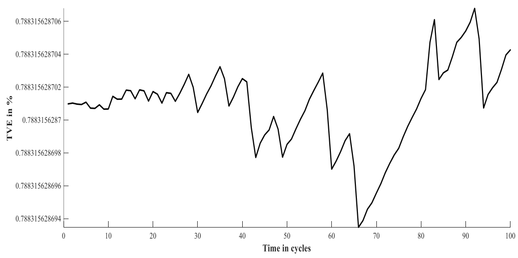

Fig.8: TVE with +1 Hz frequency ramp event.

Fig. 8 shows TVE with +1 Hz ramp event for various time cycles, maximum TVE here is 0.79%.

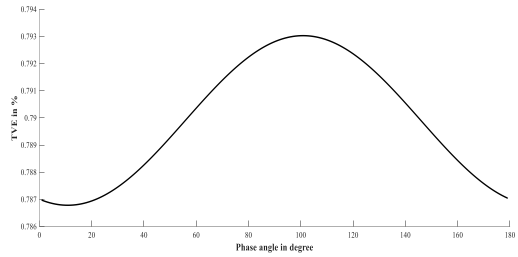

Fig.9: TVE with -1 Hz frequency ramp event.

Fig. 9 shows TVE with -1 Hz ramp event for various phase angles, maximum TVE here is 0.8%.

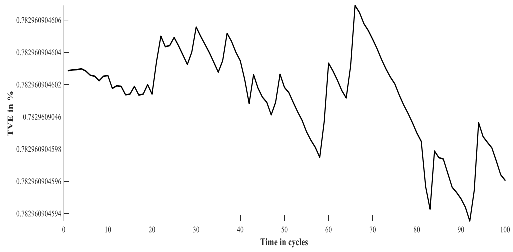

Fig.10: TVE with -1 Hz frequency ramp event.

Fig.10 shows TVE with -1 Hz ramp event for various time cycles, maximum TVE here is 0.79%.

1.5 Step change event:

In power system due to lightening surges and also switching phenomenon the transients occurs, these transients occurs for some cycles and after that it can be cleared also, step wave in power system is the best way to represents these surges[2].
Mathematically sine wave with step event can be represented as:

$$x(t) = X_m\left(1 + K_{xs}U_1(t)\right)\sin(2\pi f t + K_{as}U_1(t) + \theta) \quad (20)$$

where X_m is peak magnitude of sine wave , f is signal frequency and θ is the phase angle, K_{xs}=amplitude step size, K_{as}=phase step size

$$U_1(t) = \begin{cases} 0 \text{ if } t < t_1 \\ 1 \text{ if } t > t_2 \end{cases} \quad (21)$$

t_1 = step change occurance time,

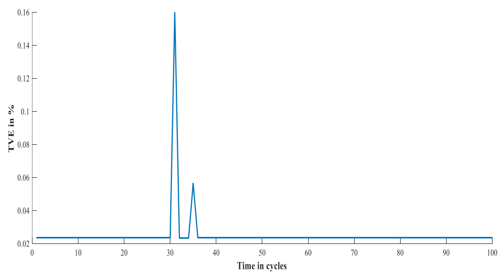

Fig. 11: TVE with step event.

Fig. 11 shows TVE with step change event for various time cycles, step change occurs from 30th to 35th time cycle. Maximum TVE remains less than 0.16 % during step change event, which satisfies IEEE standard of synchrophasor measurement [12].

1.6 For sinusoidal wave with harmonic event:

The fundamental signal containing odd harmonics from 3rd to 21st is considered here, it can be represented as[2]:

$$x(t) = X_m \sin(2\pi ft + \theta) + \sum_{k=3}^{21} X_k \sin(2\pi kft + \theta) \quad (22)$$

where X_m is peak magnitude of sine wave , f is signal frequency and θ is the phase angle, k= harmonic order X_k is magnitude of harmonic, which varies with order of harmonics, In this paper harmonic level of second component is taken from 1.33% to 5% and TVE is plotted with phase angle as well as estimated phasor.

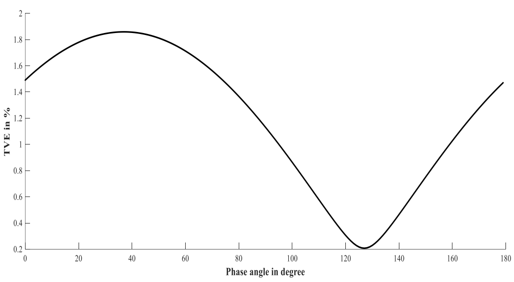

Fig. 12: TVE with harmonic event.

Fig. 12 shows TVE with harmonic event for different phase angles. TVE remains less than 2% satisfying IEEE standard of synchrophasor measurement[12].

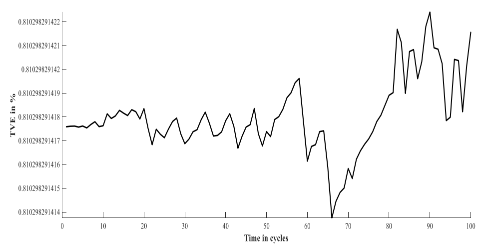

Fig. 13: TVE with harmonic event.

Fig.(13), represents TVE with respect to various time cycles for harmonic event at 20 degree phase angle and 5 % of harmonic level, TVE remains less than 0.81%.

IV. CONCLUSION

This paper evaluates modified least square algorithm for dynamic phasor estimation, the algorithm has been successfully tested under compliance test as per IEEE **C37.118.1-2011** standards[12]. The simulation results shows that the algorithm gives TVE less than 3% for dynamic events and TVE less than 1% for pure sinusoidal waves which satisfied IEEE standard of synchrophasor measurement[12]. The algorithm performance evaluated satisfactorily and TVE for various dynamic events have been plotted with various phase angles as well as various time cycles.

REFERENCES

[1]. Tianshu Bi, Hao Liu, Qian Feng, Cheng Qian, and Yilu Liu, “Dynamic Phasor Model-Based Synchrophasor Estimation Algorithm for M-Class PMU,” IEEE Transactions on power delivery,vol.30, no. 3, june 2015

[2]. Shaik Affijulla , Praveen Tripathy, ”Development of Phasor Estimation algorithm for P –class PMU suitable in Protection Applications”, IEEE Transactions on Smart Grid, vol.9, no.2, pp, 4-6, 2016.

[3]. P. Banerjee, and S. C. Srivastava, “A Subspace-Based Dynamic Phasor Estimator for Synchrophasor Application,” IEEE Transactions on instrumentation and measurement,vol 61, no. 9, september 2012.

[4]. Sadegh Vejdan, and Majid Sanaye-Pasand, Om P. Malik, “Accurate Dynamic Phasor Estimation Based on the Signal Model Under Off-Nominal Frequency and Oscillations, ” IEEE Transactions on Smart Grid, vol. 8, no. 2, march 2017

[5]. J. C. Gu and S. L. Yu, ”Removal of DC Offset in Current and Voltage Signals Using a Novel Fourier Filter Algorithm,” IEEE Trans. Power Del., vol. 15, no. 1, pp. 73-79, Jan. 2000.

[6]. Sarita Nanda, P. K. Dash and S. S. Pujari, “An adaptive signal parameter Estimation Technique using Quadratic polynomial signal model and least square Techniques,” IEEE power communication and information technology conference, (PCITC 2015).

[7]. Dong-Gyu Lee, Sang-Hee Kang, and Soon-Ryul Nam,” Modified Dynamic Phasor Estimation Algorithm for the Transient Signals of Distributed Generators,” IEEE Transactions on Smart Grid, vol. 4, no. 1, pp. 419-424, March 2013.

[8]. Babak Jafarpisheh, Seyed M. Madani , and S. Mohammad Shahrtash, “A New DFT-Based Phasor Estimation Algorithm Using High-Frequency Modulation,” IEEE Transactions on Power Delivery, vol. 32, no. 6, pp. 2416-2423, Dec. 2017.

[9]. J A de la O Serna, “Dynamic phasor estimates for power system oscillations,” IEEE Transactions on Instrumentation and

Measurement,vol. 56, no. 5, pp. 1648-1657, Oct. 2007.

[10]. W Premerlani, B Kasztenny and M Adamiak, "Development and implementation of a synchrophasor estimator capable of measurements under dynamic conditions," IEEE Transactions on Power Delivery, vol.23, no. 1, pp. 109-123, Jan. 2008.

[11]. A G Phadke and B Kasztenny, "Synchronized phasor and frequency measurement under transient conditions," IEEE Transactions on Power Delivery, vol. 24, no. 1, pp. 89-95, Jan. 2009.

[12]. IEEE Standard for Synchrophasor Measurements for Power Systems, IEEE Std. C37.118.1-2011, Dec. 2011.

[13]. Andrzej Borys, "On Using Tensors in the Areas of Circuit Theory,Signal Processing, and Telecommunications," in the IEEE conference on Signal Processing: Algorithms, Architectures, Arrangements, and Applications (SPA), 20-22nd September 2017, Poznan, Poland

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