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KF Filter Algorithm in Multilevel Inverter for Harmonics Reduction

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Abstract

This Paper approaches the showing and modernization of PV based 13-level multilevel inverter with less number of switches using Kalman filter. The current multilevel inverter contains the number of switches and voltage sources. A multilevel level inverter is a be understandable among the most gainful power converters for high power application and present day applications with reduced tune. Multilevel level inverter not simply fulfills high power output waveform and besides used as a piece of economical power sources using photovoltaic. The controller gives actual way day and age to switches through driver circuit using PWM methodology A Kalman Filter (KF) is introduced to improve the Performance and reliability of the inverter. The execution assessment of proposed multilevel inverter is checked using MATLAB/Simulink and prototype model implemented. This is the outstanding among other technique appeared differently in relation to all other existing systems.. The proposed LET-KF algorithm is compared with conventional KF based algorithms like KF, Ensemble Kalman Filter (En-KF) algorithms for harmonic estimation with the random noise values 0.001, 0.05 and 0.1.

***Keywords**: - KF Filter, multilevel inverter, Harmonics, power quality*

1. Introduction

A novel strategy by the multilevel examination (MLA) to gauge the organization rate of electric burdens regarding estimated add up to current waveform by moving forward the execution of a past estimation plot proposed by the creators. The proposed MLA makes it conceivable to break down the electric load piece rate (LCR), which demonstrates the bits of a few ordinary burdens associated with a solitary purpose of normal coupling (PCC), with the parcel of a few levels. At that point, the Kalman-channel (KF) calculation is connected to explain the estimation issue of LCR in light of detailing with current waveforms in each level. The viability of MLA in light of the KF in rehearse is confirmed by the exploratory execution based on the model's setup in research center. It comprises of a 3-kW photovoltaic framework associated inverter, which adds to a little mutilation in voltage at PCC, and down to earth nonlinear burdens associated to PCC. Likewise, the symphonious current-infusion show based time-area reproductions are completed to demonstrate the capability of the proposed technique under different conditions is expressed in [1].

In this discussion likewise introduces the investigation for the terminal voltage over the PV cluster and the normal mode voltage of the inverter in light of the exchanging capacity. Utilizing the given investigation, the impact of the PWM system can be examined, as it straightforwardly interfaces the exchanging capacity with the normal mode voltage and spillage current. Likewise, the proposed PWM system requires lessened number of transporter waves contrasted with the ordinary sinusoidal heartbeat width tweak strategy for the given CMLI as discussed in [2].

The survey manages the development of a 14-state demonstrate, and the criticism control circle to acquire sufficient shut circle reaction. Reenactments show a decent execution of the controller, with a add up to symphonious current twisting (THD) underneath 1%. Trial comes about affirm reproductions, and delineate the right activity of the Kalman onlooker to assess the twisted framework voltage (THD 3%). The onlooker just uses the inverter current estimation as expressed in [3].

Another calculation for nonpartisan point voltage irregularity estimation in DC connection of the three-level (3L) nonpartisan point clipped (NPC) voltage source inverter (VSI) is proposed. Utilization of the proposed calculation does not require any extra sensors. Proposed calculation can be utilized for sensor less task without voltage sensor at the nonpartisan point and can be utilized additionally for the voltage sensor demonstrative purposes by examination of the assessed is discussed in [4].

Investigates the useful use of the Kalman channel to the examination of consonant levels in control frameworks. The benefits and constraints of various conceivable executions are examined and the impact of basic recurrence variety is inspected. The tuning of the Kalman channel for wanted dynamic reaction is talked about and a versatile tuning calculation inferred for the enhanced meeting of nonlinear models. The viability of the subsequent plans are tried under an assortment of ordinary power framework working conditions is discussed in [5].

To address these issues, this paper develops a robust Generalized Maximum likelihood Unscented Kalman Filter (GM-UKF). The statistical linearization approach is presented to derive a compact batch mode regression form by processing the predicted state vector and the received measurements simultaneously is expressed in [6].

The proposed GMIEKF dynamic state estimator can track framework homeless people in a speedier and more solid route than the traditional broadened Kalman channel (EKF) and the unscented Kalman channel (UKF) because of its bunch mode relapse shape and its heartiness to development and perception anomalies, even in position of use. Development anomalies might be caused by hasty clamor in the dynamic state demonstrate while perception anomalies might be expected to extensive inclinations, digital assaults, or transitory loss of correspondence connections of PMUs.[7].

developed by the authors and is characterized by differ numbers of state variables, depending on the number of terms taken from a Taylor series expansion. The proposed filter is tested when the measurements set is contaminated by noise. The effects of the sampling rate, data-window size and number of terms taken from the Taylor series expansion are investigated was discussed in [8].

Procedure is computationally proficient thought about to ordinary Kalman sifting prompting less computational cost what's more, equipment prerequisite. It is seen from both reproduction what's more, test examines that the proposed group Kalman channel (KF) way to deal with estimation of sounds, inter harmonics, what's more, sub harmonics in a twisted power framework flag shows predominant estimation execution as far as following time and precision when contrasted with exhibitions of a portion of the current strategies, for example, recursive slightest square, recursive minimum mean square, and KF calculations.[9].

Great measurable proficiency under the Gaussian conveyance suspicion of the procedure and the perception commotion is accomplished on account of the utilization of the Huber cost work, which is limited by means of the iteratively reweighted slightest squares calculation. The asymptotic covariance lattice of the state estimation blunder vector is inferred by means of the covariance framework of the aggregate impact capacity of the GM-estimator. Recreations completed on the IEEE 39-transport test framework uncover that our hearty expanded Kalman channel displays great following capacities under Gaussian process and perception commotion while smothering perception exceptions is discussed in [10].

The control is accomplished by adjusting the rectifier de current or control and the inverter de voltage Coordinated dynamic and responsive power tweak is proficient by Linear Quadratic (LQ) control configuration Improved execution is acknowledged by using receptive power coupling amongst de and air conditioning systems to adjust de and air conditioning dynamic power For the exhibition framework,

control adjustment with composed voltage regulation is appeared to be around ten times more successful than control regulation alone Control connections between electromechanical methods of oscillation are dispensed with by Kalman sifting[11]

the utilization of K h a n channel estimation procedures to an operational 500 MW oil-terminated kettle/turbine unit. In regular with most physical procedures, the plant contains nonlinearities, obscure or inadequately characterized factors, and inclination unsettling influences.[12]

heguage information of wind and sun based irradiance may contain predisposition blunder and does not give the genuine power accessible from wind and photovoltaic producing frameworks. This investigation proposes a technique in view of discrete Kalman channel (DKF) to dispense with the inclination blunder display in the guage information so obvious energy of wind and photovoltaic frameworks could be anticipated.[13].

2. Multilevel inverter

Concept of this inverter is based on linking H-bridge inverters in series to get a sinusoidal output voltage. Symmetric cascaded multi-level inverter is one in which the H- bridge units are fed by equal voltage sources. Hence, all units produce similar output voltage steps. Output voltage is the sum of the voltages that are generated by each cell. One of the advantages of this type of multi-level inverter is that it needs lesser number of components compared with the diode clamped or the brief capacitor type. It leads to lesser price and weight of the inverter as shown in the fig.1.

Cascaded multi level inverter requires least number of components. Its dominant advantage is flexible circuit layout and outstanding availability due to their component redundancy. Owing to these features, the cascaded multi level inverter has been recognized. The formation and switching patterns of the symmetric cascaded multilevel inverter with equal DC sources are discussed in this chapter

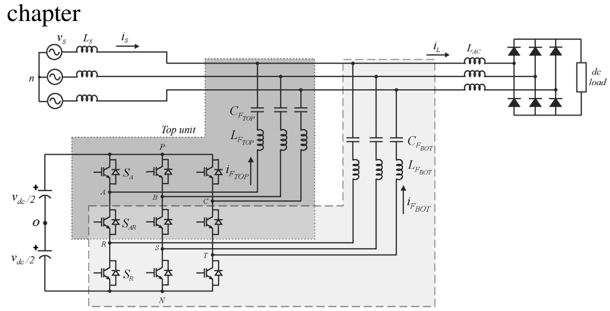

Fig.1.Multilevel inverter

2. KF ALGORITHM

Several variants of KF algorithms, which are applied for harmonic estimation problems, are discussed in this section. The detail procedure of the LET-KF algorithm for Harmonic Estimation is also reported in this part.

(a) Kalman Filter

In this algorithm X is the vector of unknown parameter taken and updates the weights as KF algorithm is applied in Eq. (1). The KF is discussed in this section is referred from [9, 18].

$$G(k) = P(k/k-1)H(k)^T\left(H(k)P\left({}^{k}/_{k}-1\right)H(k)^T + Q\right)^{-1} \quad (1)$$

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Where k is the Kalman gain, H is the observation matrix, Q is the noise covariance of the signal. P=SI is covariance matrix, where S is the large number and I is the square identity matrix.

The covariance matrix is related with Kalman gain as give in the following estimation.

$$P(k/k-1) = P(k/k-1) - G(k)H(k)P(k/k-1) \quad (2)$$

Here the updated estimated state vector is related with earlier state vector as follows

$$\hat{X}(k/k) = \hat{X}(k/k-1) + G(k)(y(k) - H(k)\hat{X}(k/k-1)) \quad (3)$$

After updating the weight vector, amplitude, phases of the fundamental and n[th] harmonic parameters are found out using the above equations.

(b) Ensemble Kalman Filter (En-KF)

The En-KF method is a Monte Carlo approximation method of the Kalman Filter, which let alone evolving the covariance matrix of the Probability Density Function (PDF) of the state vector, X. In this case, the distribution is represented by a sample, which is called an ensemble.

$$X = [x_1, x_2, \ldots . x_N] \quad (4)$$

Where X is a $n \times N$ matrix, whose columns are the ensemble members, and it is called the prior distribution. As every En-KF step ties ensemble members together so they are not independent. Signal data y (t) is arranged as $m \times N$ matrix.

So the vector of unknown parameter/Ensemble as in Eq. (5) and (6)

$$X(k) = [X_1(k)X_1(k) \ldots X_{2N-1}(k)X_{2N} \ldots X_{2N+2}(k)]^T \quad (5)$$

$$X(k) = [A_1\cos(\phi_1)\, A_1\sin(\phi_1) \ldots A_n\cos(\phi_n)\, A_n\sin(\phi_n)]\ A_{dc}A_{dc}\alpha_{dc}]^T \quad \backslash \quad (6)$$

The ensemble mean and covariance are

$$E(X) = \frac{1}{Q} = \sum_{k=1}^{Q} X(k) \quad (7)$$

$$C = \frac{GG^T}{Q-1} \quad (8)$$

$$G = X - E(X) \quad (9)$$

The updated the ensemble is given then

$$\hat{X} = X + CH^T(HCH^T + R)^{-1}(y - HX) (10)$$

Columns of X represents a sample from the prior probability distribution and columns of $\hat{X}$ will form a sample posterior probability distribution. The En-KF is now obtained by replacing the state covariance P in Kalman gain matrix $K = PH^T(HPH^T + R)^{-1}$ by the sample covariance, C computed from the ensemble members. R is a covariance matrix, which is a ways positive semi definite and usually positive definite, so the inverse of the above exists. Using Eq. (7)-(9)) obtain the amplitudes, phases of the fundamental and n[th] harmonics parameters.

(c) Background theory of LET-KF algorithm

The background theory discussed in this section about LET-KF is taken from [21-23]. The main features of LET-KF method are well known for its more efficiency and accuracy and also less multiplicative operations that reduce rounding errors. This method is very less expanse, because of the reduction of storage of large matrices that include Kalman gain matrix (k_e).To describe the proposed LET-KF algorithm, consider the ensemble size to be N and represented by the local forecasted ensemble members by$x_i^f, i = 1,2, \ldots \ldots, N$, each of which length n.

$$x_i^f = [x_1^f, x_2^f, \ldots \ldots, x_N^f] \quad (11)$$

The forecasted ensemble mean is given by

$$\overline{x^f} = \frac{1}{N}\sum_{i=1}^{N} x_i^f \quad (12)$$

$n * N$Forecasted ensemble matrix is also defined by

$$x^f = \frac{1}{\sqrt{N-1}}(x_1^f, x_2^f \ldots \ldots x_N^f) \quad (13)$$

Whereas the forecasted ensemble perturbation matrix is defined by

$$X'^f = \frac{1}{\sqrt{N-1}}(x_1^f - \overline{x^f}, x_2^f - \overline{x^f}, \ldots \ldots, x_N^f - \widehat{x^f} \quad (14)$$

The Eigen value decomposition is used on a matrix of measured, real data, the inverse may be less valid when all Eigen values are used unmodified. This is because as Eigen values become relatively small. Their contribution to the inverse is very large. Those near Zero or at the noise of the measurement system will have undue influence and could hamper solutions using the inverse. Eigen value decomposition with avoid the problems, the scaled and forecasted observation ensemble of the perturbation matrix can be introduced asy_i^fwhich can be replaced by

$$y_i^f = h(x_i^f) \quad (15)$$

Linear observation operator h = H is considered then the mean of this ensemble is and the $\overline{y^f} = H\overline{x^f}$ensemble perturbations are replaced by

$$y_i^f = H(x_i^f) - \overline{H(x^f)} = H(x_i^f) - H(\overline{x^f}) = H(x_i^f - \bar{x}^f) \quad (16)$$

After, updating the vector of unknown parameters using the LET-KF algorithm, amplitudes and phases of the fundamental and n[th] harmonic parameters can be computed using the following expression (14)-(16):

$$\upsilon_n = \sqrt{X'^{f^2}_{2N} + X'^{f^{2N}}_{2N+2}} \quad (17)$$

$$\phi_n = \tan^{-1}\frac{X'^{f}_{2N}}{X'^{f^{2N}}_{2N-1}} \quad (18)$$

$$\upsilon_{dc} = X'^{f}_{2N+1} \quad (19)$$

$$\alpha_{dc} = \left(\frac{X'^{f}_{2N+2}}{X'^{f}_{2N+1}}\right) \quad (20)$$

3. Simulation results and discussion

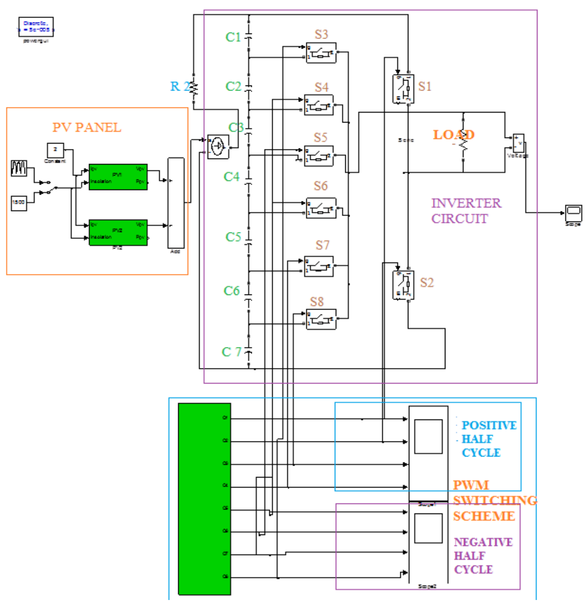

Fig.2.**Simulation of MLI with kalman filter algorithm**

The s-type PV based 13 level symmetric multilevel inverter as shown in the fig .2. The proposed topology has 8 switch where as conventional topologies has 10 switches, and hence Thermal stress and operating time of this circuit better than the conventional systems. This system uses basic pulse width modulation as a switching the switches

To assess the execution of the proposed LET-KF calculation for evaluating the music amplitudes an d stages for consonant, sub-music and bury music, a discrete flag having a principal recurrence off_1=50 H , third symphonious frequencyf_3=150 Hz, fifth conso nant recurrence f_5=250 Hz, seventh symphonious fre quencyf_7=350 Hzandeleventhharmonics frequencyf_11 =550 Hz is created utilizing MATLAB. The stationary power flag comprising of first, third, fifth, seventh, e leventh request of sounds is given in Eq. (17). This s ort of flag is ordinarily present in modern load includ ing power electronic gadgets and circular segment hea ters.

x_t = 1.5sin (2πf1t+800) + 0.5sin (2πf3t+600) + 0. 2sin (2πf5t+450) + 0.15sin (2πf7t+360) + 0.1sin (2πf1 1t+300) + μn (21)

Fig. 3, 4 and 5 speaks to the abundance and stage estimation plot of the symphonious flag containing pri ncipal consonant with various irregular commotion i.e. is 0.01 arbitrary, 0.05 irregular, 0.1 irregular. 0.01 Ran dom esteem created the less clamor and furthermore d elivered better effectiveness, exactness to the 0.05, an d 0.1 arbitrary commotions. This three arbitrary comm otions utilized then correlation between the sub – mus ic, central, Inter – music, dynamic sounds, 3rd,5th,7th, 11th music.

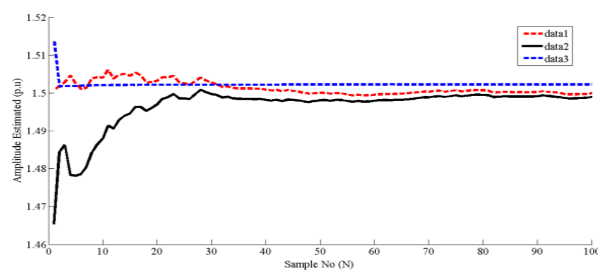

Fig.3. Amplitude estimated Vs Sample No Plot of the Fundamental Harmonic signal using KF, LET-KF& En-KF algorithms.

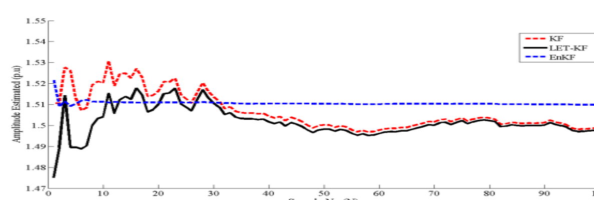

Fig.4. Amplitude Estimation Vs Sample No Plot of the Fundamental Harmonic signal using KF, LET-KF&En-KF algorithms.

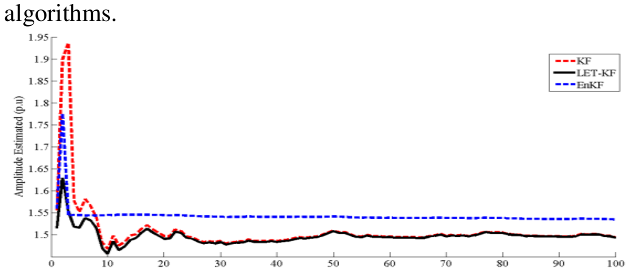

Fig.5. Amplitude Estimated vs Sample No Plot of the Fundamental Harmonic signal using KF, LET-KF &EnKF

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algorithms.

In fig.1 we use the 0.01 Random, in fig.6 we use the 0.05 Random and in fig.3 we use 0.1Random noise.

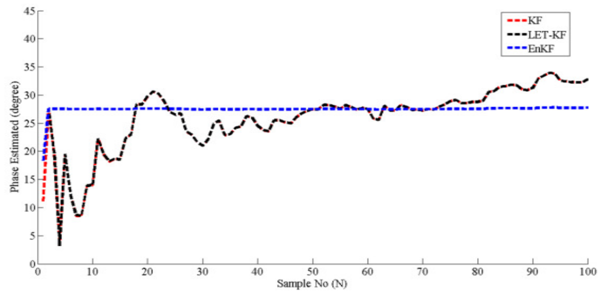

Fig.6. Phase Estimated Vs Sample No Plot of the Eleventh Harmonic

The proposed LET-KF calculation is connected and after that adequacy and stage are assessed. Fig.7. speaks to the plentifulness of estimation plot alongside real flag of the sub consonant flag in nearness with Irregular clamor acquired with LET-KF calculation

Fig.6. represents the amplitude of estimation plot along with actual signal of the sub harmonic signal in presence with Random noise obtained with LET-KF algorithm. It is found that the estimation error achieved with the proposed algorithm for the sub harmonic signal is very much reduced and almost matches with the actual signal.

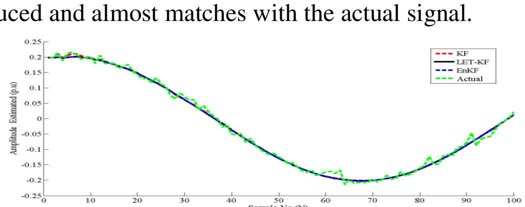

Fig.7. Amplitude Estimated Vs Sample No Plot of the Sub Harmonic signal using KF, LET-KF&En-KF algorithms.

Next the performance of the algorithm is study on inter – harmonic as given by (44) and generated in MATLAB. The signal considered for testing is of two different frequencies at,

$$f_{inter-1} = 130Hz \;\; and \;\; f_{inter-2} = 180Hz$$

$$x(t) = 0.1\sin(2\pi f_{inter-1} + 65^0) + \mu_n$$

$$x(t) = 0.15\sin(2\pi f_{inter-2} + 10^0) + \mu_n (44) \text{ load}$$

The Total Harmonic Distortion (THD) of the proposed inverter RL stack broke down from FFT investigation as shown in the figure.8. The above investigation demonstrates the size Vs Harmonic request shape that we watched that THD is 4.20 % which is not exactly the IEEE standard

Table 1, 2 demonstrates the near execution of KF, EnKF and proposed LET-KF calculation for evaluating consonant parameters for crucial, third, fifth, seventh and eleventh request music alongside sub and bury music comparing to the arbitrary commotions 0.01, 0.05 and 0.1. The assessed esteems acquired with every one of the three calculations for every one of adequacy and stage is accounted for with their computational time too. It is obvious from the tables 1, 2 and 3 that the execution of proposed LET-KF calculation is superior to any of the other two calculations as far as precision.

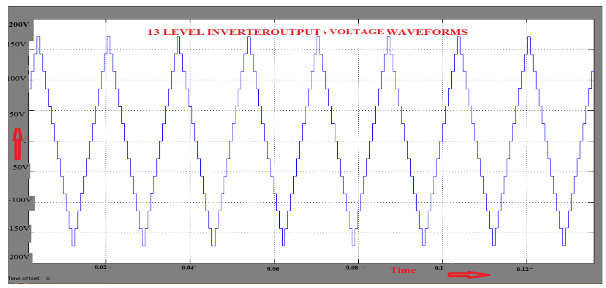

Fig.8. **Output voltage waveform of Multilevel inverter**

The simulation of PV based S-type multilevel inverter produced 13 level stepped waveforms (Vdc,Vdc,/2,Vdc/3,Vdc/4, Vdc/5, Vdc/6,0, -Vdc,- Vdc/2,-Vdc/3,-Vdc/4, -Vdc/5, -Vdc/6) are obtained in the proposed inverter as shown in the figure 8.This results indicates a reduced Total Harmonic Distortion as expressed in Fig.9&10.

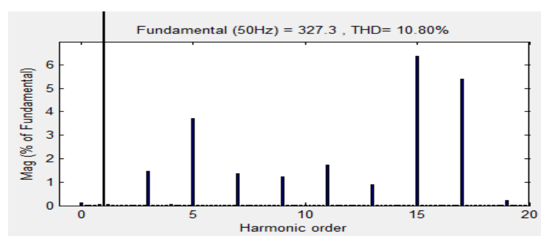

Fig.9. **THD Analysis of Proposed inverter Without kalman filter**

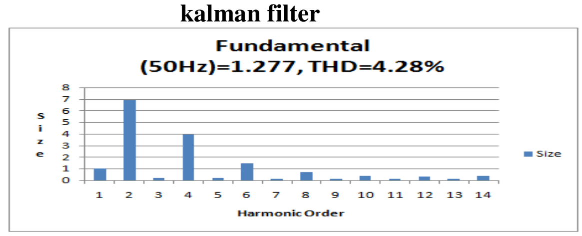

Fig.10. **THD Analysis of proposed inverter using KF, algorithms**

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Table 1-Performance of KF, En-KF and proposed LET-KF algorithm for harmonic parameter estimation including sub and inter harmonics, with 0.01 random values.

Algorithm	Parameters	Sub	Fund	3^{rd}	Inter-1	Inter-2	5^{th}	7^{th}	11th
Actual	Frequency	0.1	0.75	0.25	0.05	0.075	0.1	0.075	0.05
	Amp (V)	37.5	40	30	32.5	5	22.5	18	15
	Phase(deg)	0.101	0.75	0.2505	0.04995	0.07625	0.10145	0.07415	0.04945
KF	Amp (V)	-0.0015	-0.0005	-0.00015	0.000575	0.001	-0.0014	0.0008295	0.00145
	Error (%)	37.40175	39.95	29.85	32.1875	4.29495	22.3995	17.76625	15.2692
	Phase	0.45	-0.055	0.1	0.49225	0.70505	0.031	0.23375	-0.2692
	Error (%)	0.10355	0.75115	0.2554	0.05105	0.0745	0.10105	0.0762	0.05115
En-KF	Amp (V)	-0.005	-0.001	-0.0005	-0.00665	-0.00075	-0.00115	-0.00119	-0.00115
	Error (%)	36.5505	40.125	30.285	33.7251	5.73135	22.785	18.26255	14.735
	Phase	3.7	-0.05	-0.35	7.8855	-0.73135	-0.4	-0.26255	0.26315
	Error (%)	0.10095	0.7495	0.25035	0.04995	0.0762	0.10135	0.07415	0.0494
LET-KF	Amp (V)	-0.002	0.0005285	-0.001	0.000606	-0.00065	-0.00135	0.0008745	0.0005805
	Error (%)	37.3955	39.85	29.825	32.18655	4.2981	22.396	17.7672	1.7706
	Phase	0.25	0.1	0.15	0.4944	0.7019	0.031	0.2328	-0.2706
	Error (%)	0.1	0.75	0.25	0.05	0.075	0.1	0.075	0.05

Table 2- Performance of KF, En-KF and proposed LET-KF algorithm for harmonic Parameters estimation including sub and inter harmonics with 0.05 random values.

Algorithm	Parameters	Sub	Fund	3rd	Inter-1	Inter-2	5^{th}	7th	11^{th}
Actual	Frequency	20	50	150	130	180	250	350	550
	Amp (V)	0.1	0.75	0.25	0.05	0.075	0.1	0.075	0.05
	Phase(deg)	37.5	40	30	32.5	5	22.5	18	15
KF	Amp (V)	0.10225	0.7499	0.25255	0.04985	0.08175	0.10715	0.0709	0.0473
	Error (%)	-0.006	0.00005	0.002515	0.00015	-0.00675	-.007115	0.004095	0.00275
	Phase	37.77725	39.9125	30.44635	30.9394	1.70465	22.465	16.77715	16.40785
	Error (%)	-0.275	-0.028	-0.18	1.5595	4	0.03441	1.2235	-1.4075
En-KF	Amp (V)	0.10605	0.755	0.255	0.05535	0.0796	0.10535	0.0803	0.05525
	Error (%)	-0.00225	-0.00055	-0.00485	-0.00535	-0.002	-0.005	-0.006	-0.006
	Phase	37.62735	38.895	30.08395	33.51295	6.07045	24.1	18.71905	13.8739
	Error (%)	0.125	0.085	-0.5	-1.01295	-2.5	-1.8	-0.0053	1.25
LET-KF	Amp (V)	0.1022	0.7499	0.2524	0.0498	0.0817	0.1071	0.07085	0.04725
	Error (%)	-0.0022	0.0006	-.002365	0.00018	-0.0066	0.00702	0.0042	0.00285
	Phase	37.77085	39.9015	30.0854	30.9375	1.70795	22.465	16.7783	16.409
	Error (%)	-0.2695	-0.025	-0.177	1.5625	3.98	0.03437	0.004135	-1.40865

5. Conclusion

At introduce we can watch impressive enthusiasm for present day, viable techniques and frameworks which diminish level of distortions of voltages in beneficiaries of electric vitality. These are converters controlled normally with utilization of diverse techniques for PWM tweak. It gives opportunity of maximal use of exchange band, restricted via transporter recurrence of PWM balance, with safeguarding of irreplaceable edge of dependability of the shut framework.

The proposed system has reduced Total harmonic distortion as 4.28 , where as conventional system has 10.80

Another variation of KF and LET-KF is connected out of the blue for the estimation of abundancy and period of a period differing basic flag, its sounds, sub music and entomb music degenerate with irregular commotion. The symphonious parameters are assessed utilizing the proposed Given KF and other two variations of Kalman A chance to channel, i.e. KF and En-KFalgorithms, for assessing their similar execution with the irregular commotion esteems 0.001, 0.05 and 0.1. Among these three clamors, 0.01 arbitrary commotion results will give superior to other two commotions. Since the stage deviation and sufficiency deviation less in 0.01 irregular commotion. The execution comes about acquired with all the three calculations uncovers that the proposed LET-KF calculation is the best among all the three calculations regarding exactness in evaluating symphonious, sub-consonant, entomb sounds. It is additionally more affordable, as it doesn't require the putting away of substantial Kalman pick up frameworks like in the other

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KF based techniques

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