A HYBRID RECURSIVE LEAST SQUARE PSO BASED ALGORITHM FOR HARMONIC ESTIMATION

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR

THE DEGREE OF
MASTER OF TECHNOLOGY
IN
ELECTRICAL ENGINEERING

By
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NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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UNDER THE GUIDANCE OF
PROF. P.K. RAY

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CERTIFICATE

*This is to certify that the thesis entitled, "***A HYBRID RECURSIVE LEAST SQUARE PSO BASED ALGORITHM FOR HARMONIC ESTIMATION***" submitted by* **Mahasweta Biswal** *in partial fulfillment of the requirements for the award of Master of Technology Degree in Electrical Engineering with specialization in "***Power electronics & Drives"** *at National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance. To the best of my knowledge, the matter embodied in this Project review report has not been submitted to any other university/ institute for award of any Degree or Diploma.*

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Mahasweta Biswal

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ABSTRACT

The presence of harmonics shapes the performance of a power system. Hence harmonic estimation of paramount importance while considering a power system network. Harmonics is an important parameter for power system control and enhance power system relaying, power quality monitoring, operation and control of electrical equipments. The increase in nonlinear load and time varying device causes periodic distortion of voltage and current waveforms which is not desirable electrical network. Due to this nonlinear load or device, the voltage and current waveform contains sinusoidal component other than the fundamental frequency which is known as the harmonics. Some existing techniques of harmonics estimation are Least Square (LS), Least Mean Square (LMS),Recursive Least Square (RLS), Kalman Filtering (KF), Soft Computing Techniques such as Artificial neural networks (ANN),Least square algorithm, Recursive least square algorithm, Genetic algorithm(GA) ,Particle swarm optimization(PSO) ,Ant colony optimization, Bacterial foraging optimization(BFO), Gravitational search algorithm, Cooker search algorithm ,Water drop algorithm, Bat algorithm etc. Though LMS algorithm has low computational complexity and good tracking ability ,but it provides poor estimation performance due to its poor convergence rate as the adaptation step-size is fixed. In case of RLS suitable initial choice of covariance matrix and gain leading to faster convergence. Initial choice of Weight vector and learning parameter affect the convergence characteristic of estimator. However this algorithm consists more complicated mathematical operations and require more computational resources than LMS algorithms. Though Genetic algorithms are easy to implement and suited well to hybridization, but it has poor convergence than Recursive least square algorithm. Unlike genetic algorithm the particle swarm optimization have not direct combination of genetic materials between the particles during the search. The PSO algorithm employs the social behavior of the particle in the swarm. Hence, it finds the global solution by adjusting the trajectory of each particle towards its own best solution and towards the best particle of the swarm in each generation. The PSO is very popular because of the simplicity of implementation of the algorithm and ability to converge quickly to a acceptable good solution.

The thesis also proposed a hybrid recurvive least square pso based algorithmfor power system harmonics estimation. In this thesis, the proposed hybrid approaches topower system harmonics estimation first optimize the unknown parametersof the regressor of the input power system signal using Particle swarm optimization and then RLS are applied for achieving faster convergence in estimating harmonics of distorted signal.

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Abbreviations

- RLS-Recursive least square algorithm
- PSO-Particle swarm optimization
- LS-Least square
- KF-Kalman filter
- MSE-Mean square error
- BFO-Bacterial foraging optimization
- ANN-Artificial neural network
- GA-Genetic algorithm
- LMS-Least mean square
- UPS-Uninterruptible power supplies
- SNR-Signal to noise ratio
- FFT-Fast fourier transform
- DFT-Discrete fourier transform
- TLS-Total least square
- ANN-Adaptive neural network
- LAV-Least absolute value

Chapter-1

INTRODUCTION

1.1Background

Harmonics in the power system are integer multiples of fundamental power system frequency which are created by nonlinear devices that is static VAR compensators, electric arc furnaces, inverters, DC converters ,AC or DC motor drives and switch-mode power supplies. These harmonics creates disturbance in voltage and current waveform. The deterioration of current and voltage signals in electricalnetworks results in the generation of harmonics. These harmonic signals distribute in the electrical network, hamper the proper operation of electronic device, and promote their degradation. To correctly analyze the components of harmonic in a distorted power signal, accurate harmonics calculation is the prime task in power system environment.This estimation is useful for an efficient design of compensatory filter and for characterization o electrical device at non sinusoidal conditions. Therefore it needed continuously monitoring. Most of the cases harmonics comes from the sources which are dynamics in nature producing time varying amplitudes in generated signal, so it is difficult to estimate the harmonics. Therefore, accurate and fast estimation of phase and amplitude of these frequency components are required.Power electronic devices are very much sensitive to harmonics and they malfunction in presence of harmonics Extensive usage of power electronic devices such as lighting substances, diodes, thyristor rectifiers, uninterruptible power supplies (UPS) etc. introduces more amounts of harmonics to power system. But devices such as computers, UPS's which inject harmonics in power system are more affected as the harmonics content in power system increases. If suitable harmonics estimation and filtering are not undertaken then these devices may inject inter harmonics and sub-harmonics to power system. Harmonic voltages and currents also cause over voltage, saturation of transformer core and increased I^2R losses. The aforesaid adverse affects of harmonic necessitate guidelines to maintain acceptable harmonic labels in the power system.

Hence harmonic is required for estimation of fundamental and other harmonic components.. To provide quality of power , it is essential to know the harmonic parameters that is amplitude and phase. Thus, harmonic estimation is an important task while dealing with power system signals.

1.2A Review on Power System Harmonic Estimation

This portion provides a review on Harmonics Estimation based on Signal Processing ,and Soft Computing techniques such as Fuzzy Logic, Neural Network and Evolutionary Computation.

1.2.1 Recursive Methods

Beides and Heydt [1] estimated phase angles and bus voltage magnitudes of the fundamental and higher harmonics from noisy measurement using Kalman Filter method. This algorithm is also tested with IEEE 14 bus system. These results are helpful in studying the total harmonic distortion over a full cycle. It is also helpful in designing power filter to minimize harmonic

Tao et.al [2] proposed a new algorithm based on M-Estimators for harmonic estimation to overcome the error in estimation in presence of noise in signal. The initial values for harmonic frequencies are acquired using Estimation of Signal Parameters via Rotational Invariance Techniques (ESPIRIT) algorithm to avoid local minima and to improve the convergence rate of optimization.

Kennedy et al [3] proposed Kalman Filtering approach to harmonic analysis in power system. They used three test signals for analyzing power system containing 5th, 7th, 11th and 13th harmonic components for SNR of 40dB with a Gaussian noise of standard deviations 0.01.First test signal consideredwas at normal operating condition, second was due to sudden decrease in frequencyof fundamental componets and third was a fault signal. Both for linear and non-linear models estimation of harmonics has been carried out for the three test signals.

Mandel et.al [4] described Ensemble Kalman Filter (EnKF) a recursive filter for harmonics estimation problem having large number of variables. It is a new version of the Kalman Filter and is an important data assimilation component of ensemble forecasting.

Mori et.al [5] presented a method based on back propagation learning for feed-forward neural network for harmonics prediction. For the effectiveness of the proposed method, it has been applied to the voltage harmonics observed through a computer based measurement system and its performance has been compared with different conventional methods.

P. K. Dash and G. Panda [6] proposed an approach combining both Fourier Linear Combiner and Extended Complex Kalman Filter (ECKF) for power system harmonic estimation. Kalman Filter estimates amplitude and phase when frequency is fixed. However, when frequencies vary, it is unable to retune itself to the frequency changes. Similarly, Fourier Linear Combiner, using single layer neural network able to estimate harmonics at static frequency but during frequency change tracking time becomes much larger and there is more error in estimation.

Jiang et.al [7] presented Least Square method to compute power system harmonic detection and Total Harmonic Distortion. The method has been compared with FFT and Kalman Filter. Simulation and experimental results showed that harmonic component detection scheme using Least Square method has great advantages over other methods because of its less computational cost.

Feilat et.al[8] applied three methods such as Discrete Fourier Transform (DFT), Least Absolute Value (LAV) and Least Square (LS) method to the voltage harmonic estimation of a 3-phase six-pulse converter. In case of ideal noise free data, all the algorithms provides exact estimate of the harmonics for high sampling rate .LS method provides estimates properly for more number of samples in a noisy environment. However, LAV provides a better result for high range of samples.

P K Dash and B Mishra [9] developed a technique based on Fuzzy LMS for estimation of harmonics current and voltage signals in a power system network. They were used fuzzy gain scheduling method for the adjustment of step size which provides noise rejection and faster convergence for tracking fundamental as well as harmonics components from signal.

Dash et al. [10] applied a neural network approach i.e. adaptive by Widow-hoff delta rule for harmonic components estimation in a power system. The error between the actual and desired output is minimized by adjusting the learning parameter α. This method was able to track harmonics and DC components accurately in comparison to Kalman filter based algorithm. This algorithm is suitable for tracking harmonics such as phase angles and with time varying amplitudes due to its adaptive nature.

Dominguez et al. [11] presented the introduction of digital filter for estimation of harmonics components of signal. The main advantage is that same algorithm has been used during pre-fault and post-fault periods. So there is no need to know the time of occurrence of fault. But here the effect of inter and sub-harmonics components. Is not taken into account.

Liu et.al [13] proposed a technique for online tracking of power system harmonicsbased on Wavelet Transform (WT) which utilizes Kalman Filtering. They had estimated the harmonics such as amplitudes and phase angles by solving the scaling functions and the coefficient of wavelet transform. Also they had combined this with Kalman Filtering Technique for developing an online harmonic tracking method.

1.2.2 Soft Computing approaches to Power System Harmonics Estimation

Bettayeb and Qidwai [14] proposed an algorithm for estimation of power system harmonics using Genetic algorithm(GA) hybridizing with Least square algorithm. The proposed algorithm estimates phase of power system signal using GA. After the estimation of phase, amplitude has been estimated using Least Square (LS) algorithm. Signals taken across loadwere applied to this algorithm which is taken from a two-bus three-phase system with a full-wave six-pulse bridge rectifier. Data for voltage taken from an offshore industrial facility was also applied to this proposed algorithm and the algorithm performed well. They showed that there is an improvement of more than 60 % in convergence time of this proposed algorithm compared to the ordinary GA. Convergence time reduces to few seconds by the use of fast machine such as Pentium 300MHz. Therefore online implementation is possible using this algorithm.

Tang et.al [15] proposed a new a technique for estimation of harmonics using particle swarm optimization with passive congregation (PSOPC) to estimate the phases of the harmonics and a least-square (LS) method for amplitude estimation .Signals taken across load from a two bus system were applied to this algorithm .The PSOPC and LS method minimizes the error between the actual signal and estimated signal. The proposed algorithm performed well compared to the conventional GA and DFT schemes under noisy environment. The proposed algorithm estimates inter-harmonics and sub-harmonics more accurately.

Maamar Bettayeb and Uvais Qidwai [16] intoduced a recursive method to estimate the harmonics of power system . Here online estimation of harmonics that is amplitude and phase is possible using several variant of Recursive Least Square (RLS) algorithm. This algorithm is easy to implement for online estimation of harmonics in noisy environment. Here all the estimation error is within 3-4% and maximum deviation is within 9-10%. This algorithm performed well in single frequency estimation as compared to multiple frequency estimation. Because the noise power signal of multiple frequency estimation is larger than the single frequency estimation. Moreover the recursive algorithm gives better results for single frequency signal due to fundamental frequency. Recursive method has simple computation and good convergence properties.

P.K.Ray and B. Subudhi [18] developed a method which uses hybrid Adaline and Bacterial Foraging Approach to estimate the harmonicsof power system. The unknown parameter i.e. Amplitude and phase is estimated by using BFO and this value is taken as the initial weights of Adaline,Then final value of phase and amplitude is estimated from the weights of adaline..

S. Mishra [19] described the foraging behavior of E. Coli bacteria to estimate the harmonic components. The nonlinear part i.e. Phase of each harmonic is estimated by the Fuzzy bacterial foraging scheme andordinary least square method estimates the linear parameters (i.e. amplitudes) .The foraging strategy becomes adaptive by using Takagi-Sugeno scheme. Validation of proposed hybrid method has been accomplished with data collected across the load of a three-phase system with a full-wave six-pulse bridge rectifier at the load bus. It was found that this hybrid method outperformed over DFT.

Seifossadat et.al [20] presented an adaptive neural network based on Genetic Method called GAP (Genetic Adaline Perceptrons) for tracking the harmonics components of current and voltage waveforms in faulted power system. The results were compared with DFT, KF, GA and Adaline methods. It was found that GA has minimum deviation though it is not as fast as other methods like Adaline and GAP. The Adaline is the fastest and GA gives more accuracy.

Lin et.al [21] developed an algorithm based on neural network to estimate both phase and magnitudeup to eleventh harmonics (550 Hz) of a power system in a noise environment. Performance of the proposed method is also tested with the conventional DFT method. It has fast response and high accuracy compared to DFT. It is also tested that there is an improvement in the harmonic detection four times compared to FFT. Experimental results confirmed that proposed ANN model well performed in practice.

Joorabian et.al [22] presented a new algorithm for total harmonics estimation problem into a linear and non-linear problem. Linear Estimator (Least Square (LS)) has been used for amplitude estimation and an adaptive linear combiner "Adaline" which is very fast and simple is used for harmonics phase estimation. There is improvement in convergence and processing time using this algorithm. This algorithm estimates correctly for static, dynamic and fault signal, but estimation using inter and sub harmonic components is not discussed.

Lai et.al [23] applied the Least Square technique with artificial neural networks to harmonic extraction in time varying situations. The proposed method is capable of dealing the measurement of varying frequency, amplitude and any harmonic components present in the power system simultaneously. In this case, there is no restriction about evaluation of the number of harmonic component excepting increasing complexity of neural network as the number of harmonics components is increased.

Lobos et al. [24] developed an algorithm for detectionof harmonics in a power system using Linear Least Square method with singular value decomposition (SVD).The author reconnoitered this method using simulated waveforms as well as current waveforms at the output of a three phase converter which supplies an induction motor load and found that it is very versatile and efficient method for finding the locations of all higher harmonics present in the power system. It is also applicable for estimation of inter-harmonics in a power system.

Kostyla et.al[25] described a technique for estimation of parameters of harmonic signal based on LS and Total Least Square (TLS) optimization criteria. The network model under TLS criteria optimized the estimates assuming the fluctuation of frequency and sampling interval. On higher sampling frequencies, TLS estimates are better than LS estimates.

Yilmatz et.al [26] described parametric spectral estimation technique for harmonics, inter-harmonics and sub-harmonics estimation. Modified Co-variance and Covariance methods were used for estimation of harmonics. He had determined both integer and non-integer multiple harmonics through computer simulations successfully.

Tartan et.al [28] developed a new hybrid algorithm for harmonic estimation.In these hybrid algorithms, phase angles are optimized by an evolutionary computation algorithm and amplitudes are then calculated by Least Squares(LS) Method. In this paper a hybrid algorithm which uses Differential Evolution along with LS Method for the harmonic estimation problem proposed. Here the proposed algorithm is applied in simulations and accuracy - computation time performances are compared with the hybrid algorithm which uses PSOPC.from the obtained results it is seen that the proposed algorithm is more efficient.

Kalaiselvi et.al[40] applied Intelligent Computing techniques for estimation of power system harmonics .The author investigated power electronic equipments in this paper. They estimated the waveforms by using genetic algorithm, hybrid genetic algorithm-least square ,hybrid particle swarm optimization- least square and adaptive neural network (ANN) algotithm.The actual waveform are then compared with the estimated waveforms. It was found that the estimated waveform using ANN method gives more accurate result and the proposed algorithm converges faster.. So ANN algorithm can be used effectively for harmonic estimatiom in on-line applications

1.3 Motivation of the Project work

- Electrical power system environment is polluted by random noise ,harmonics and reactive power disturbance due to sudden mismatch of generation-load and frequent use of nonlinear load in electrical device. It results deviation of fundamental frequency from its standard value and elevates harmonics level in the power system network which is undesirable. It is a difficult task to estimate the harmonics such as amplitude and phase in presence of random noise. Although complex LMS algorithm is used for calculation of power system harmonics. But this algorithm is a batch processing method. Here online estimation is not possible. But in recursive least square algorithm online estimation is possible. Using several variants of recursive least square (RLS) algorithms on-line estimation of harmonic amplitudes and phases is performed. This algorithm has good convergence properties and has simple computational properties. As the samples of the harmonic signals are received, the estimates are updated recursively. It gives accurate estimation and better noise rejection compared to Least square algorithms.

- To exploit benefits of individual algorithms (RLS,PSO) in developing hybrid identification techniques employing both classical and soft computing techniques for estimation of power system harmonics.
- For improvement in quality of power, application of estimation algorithms may be exploited.

1.4Objective of the thesis

The following are the objectives of the Thesis.

- To estimate the harmonics using LMS algorithm is although simple to formulate but having the drawback of poor convergence rate. So we considered RLS algorithm with time varying step size which overcome the above drawback.
- To analyze the RLS algorithms are tested under different signal to noise ratios (SNR) is done to produce good harmonic amplitude and phase estimates.
- To achieve accurate harmonic estimation, attempts have been made to classical techniques such as with soft computing techniques such as PSO.

- This algorithm compare with robust algorithm to estimate the harmonics.
- To validate the proposed estimation algorithms on data obtained from laboratory and industrial setup.

1.5 Thesis Organization

In this thesis, Harmonic estimation by various optimization technique such as RLS and PSO under different SNR are analyses. This thesis contains six chapters.

Chapter-1presents of an introduction of power system harmonics assessment.It also includes a brief literature review on estimation of power system harmonics followed by motivation/objectives. It also provides the thesis organization.

Chapter-2includes causes of harmonics, effect of harmonics and elimination of harmonics. It also describes RLS algorithm for power system harmonic estimation.Simulation results are made by considering signals with different SNR values.

Chapter-3 presents harmonic estimation by Particle swarm optimization. Simulation results of Amplitude and phase of each harmonic are studied.

Chapter-4describes combines RLS-PSO approaches for the estimation power system harmonics .In the previous chapter, only signal processing techniques are described but in this chapter evolutionary Computational technique is hybridized with signal processing technique for harmonic estimation . Unknown parameters are optimized using PSO .Output of PSO is taken as the initial values for RLS . Then amplitude and phase of different harmonics are estimated.

Chapter-5provides comprehensive summary and conclusions of all different estimation approaches for power system harmonics. It focuses on contributions of the thesis and scope for future work.

Chapter-2

Power system Harmonic Estimation Using Recursive Algorithms

2.1 Introduction

In an electric network periodic distortion of current and voltage waveforms is not desirable due to increase in nonlinear load and time varying device. Because of this nonlinear load or device, the voltage and current waveform contains sinusoidal component other than the fundamental frequency which is known as the harmonics. Harmonics are integer multiples of fundamental component frequency. The quality of power factor decreases due to presence of harmonics which results several problem related to power system operation, protection and improvement. The major components of producing harmonics in commercial and industrial power system are the increasing use of nonlinear load like diode and thyristor rectifier, arc furnace, printer and uninterruptible power supplies (UPS) etc. hence it is very much tedious to calculate the harmonics from distorted waveform. Magnitude and phase of fundamental frequency are required for accurate calculation. The most commonly used conventional estimation method is based on the Fast Fourier transform (FFT). However, FFT based algorithm are providing good performance in noise but having a problem of aliasing and spectral effect. In this field, Kalman filtering is one of the robust methods for estimation of magnitude of harmonics but this Kalman filtering fails to track any dynamics changes in measured signal. Hence, Recursive least square algorithm are used here for estimation of harmonics such as Amplitude and phase of voltage and current signal .

2.2Causes, effects and elimination of harmonics

Non-linear loads which draw a non sinusoidal current from a sinusoidal voltage source are the cause of Harmonics . Some of the loads which produce harmonics are electric arc furnaces, , inverters, DC converters, AC or DC motor drives, static VAR compensators and switch-mode power supplies. Harmonics are integer multiples of the inverter operating frequency. Some "interharmonic" currents may also be present at the input or the output of the drive.. Harmonics can occur on the input at the power system frequency plus or minus of that inverter operating frequency. The inverter output can contain harmonics at the rectifier pulse which is multiply the power system frequency plus or minus the inverter operating frequency. The presence of inter harmonics can minimized by proper DC link design.

Effect of Harmonics

High levels of harmonic distortion can cause

- Increased transformer, capacitor, motor or generator heating.
- Misoperation of electronic equipment.
-Incorrect readings on meters.
 -Misoperation of protective relays
-Interference with telephone circuits.
-Decreases the system efficiency .
-Makes the system unstable.

Elimination of harmonics

Harmonics can be eliminated by following ways:-

-The neutral conductor size to be increased.

-The load of delta-wye transformer to be reduced

- The delta-wye transformer to be replaced by a k-factor transformer

- A harmonic filter to be installed at the power source or equipment location

There are also some other methods to elimination of harmonics

Passive filtering Approaches-

Passive Inductor and capacitor (LC) systems are used to eliminate line current harmonics and increases the system P.F.

Active filtering approaches-

Active Power Filter detects the load harmonics and reactive current component and injects a compensating current of same magnitude and opposite in phase into the load.

2.3 Harmonics Estimation Using Recursive least square Algorithms

RLS is a well known recursive estimation techniques to solve the problem of power system harmonics in a noisy environment. Several variants of RLS are using on-line estimation of harmonic amplitudes and phases. As the samples of harmonic signals are received estimates are updated recursively. For which, these algorithms are appropriate for on-line implementation even in polluted power systems. In comparison to the other algorithms such as the least mean squares (LMS), Least square(LS) algorithm this algorithm gives faster convergence. In RLS algorithm, the input signals are considered deterministic, while for the LMS and similar algorithm they are considered stochastic. To improve the performance in the least square algorithm, RLS is applied.

2.3.1 Problem formulation

Let a structure of power system signal with noise to be represented as following manner.

$$Y(t) = A_1 \sin(\omega_0 t + \emptyset_1) + \epsilon(t) \qquad (1)$$

To estimate the signal *y*(*t*), the amplitude(A_1), phase ($\emptyset_1$) can be written in discretized form as

$$Y(k) = A_1 \sin \omega_0 kT\, cos\emptyset_1 + A_1 \cos \omega_0\, kTsin\, \emptyset + \epsilon(k)$$

$$y(k) = [sin\omega_0 kT \quad cos\omega_0 kT][\alpha \quad \beta]^T + \epsilon(k) \qquad (2)$$

Where

$$\alpha = \theta_{11} = A_1 cos\emptyset_1$$

$$\beta = \theta_{21} = A_1 sin\emptyset_1$$

Further notational simplification of can be made by expressing this in regressor form given by

$$Y(k) = H(k)\theta + \epsilon(k) \qquad (3)$$

Where $\epsilon(k)$ is the noise of signal

Using the RLS estimation technique, the parameters can be estimated using the following computing steps.

$$\hat{\theta}\,(k) = \hat{\theta}\,(k-1) + K(k)\epsilon(k) \qquad (4)$$

Where $\hat{\theta}$ (k)=current value of estimate

$\hat{\theta}$ (k−1)= Past value of estimate

K(k)= Kalman Gain

The error in the measurement is given by

$$\epsilon(k) = Y(k) - H(k)^T \hat{\theta}\,(k-1) \qquad (5)$$

The gain K is updated using the following expression

$$K(k) = P(k-1)H(k)[\eta I + H(k)^T P(k-1)H(k)]^{-1} \qquad (6)$$

where $P(k)$ =Error Covariance matrix

and η (0 <η <1)= Forgetting factor

The covariance matrix can be updated using the following updatation law as given by

$$P(k) = [I - K(k)H(k)^T]\,(P(k-1)/\eta \qquad (7)$$

Equations (4) to (7) are initialized at $k = 0$. Initial covariance matrix $P(0)$ is usually chosen to be very large. i.e. $P = \delta I$,

where δ is a large number and I is a square identity matrix.

After getting the final estimate of $\theta = [\alpha \quad \beta]^T$, the fundamental amplitude (A_1)and phase ($\emptyset_1$)can be estimated as given below

$$A_{1=}\sqrt{(A_1 cos\emptyset_1)^2 + (A_1 sin\emptyset_1)^2}$$

$$A_1 = \sqrt{\alpha^1 + \beta^2} \qquad (8)$$

$$tan\emptyset_1 = {}^{\beta}/_{\alpha}$$

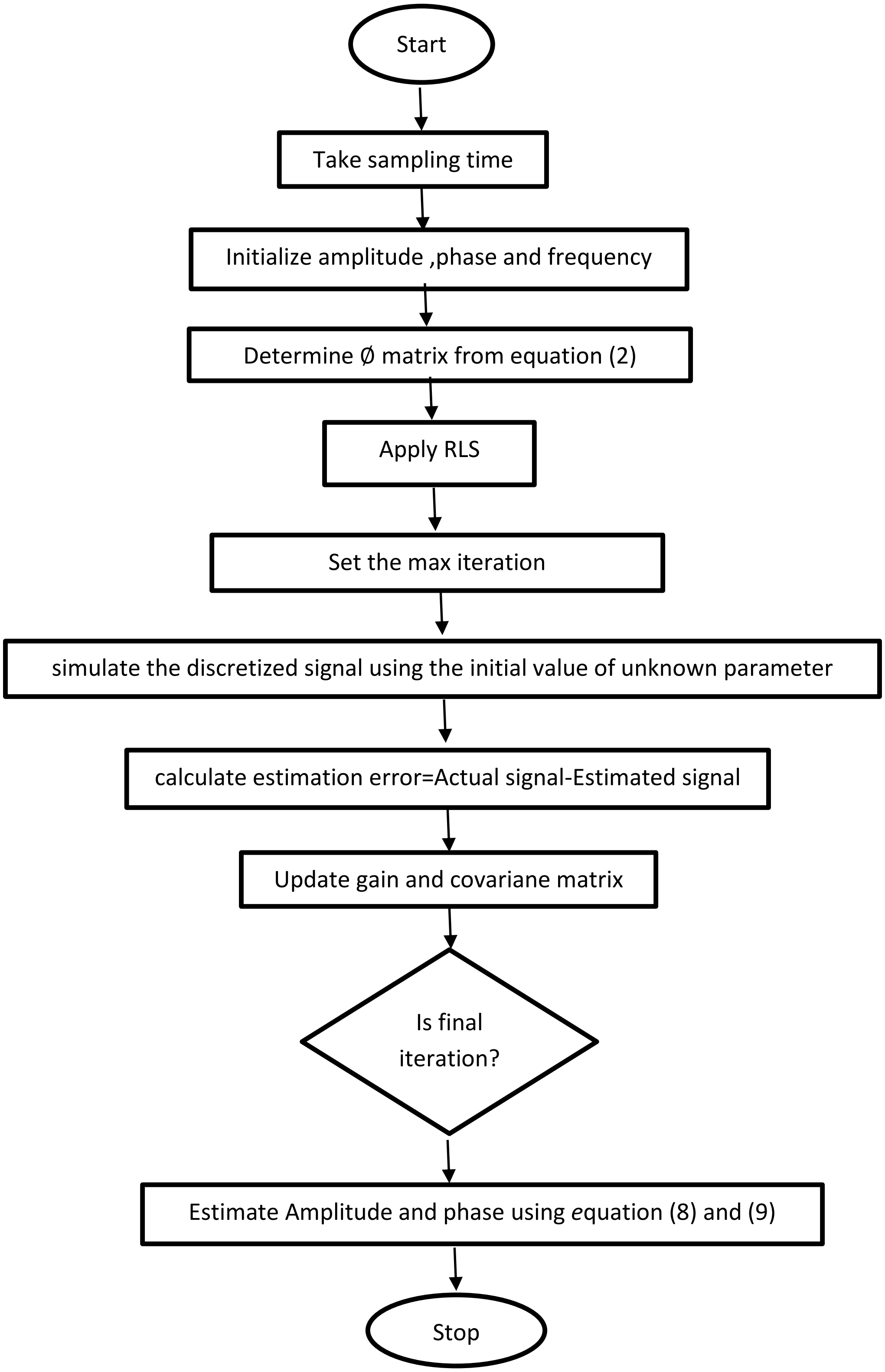
$$\emptyset_1 = tan^{-1}\,{}^{\beta}/_{\alpha} \qquad (9)$$

2.3.2. RLS algorithm

The proposed RLS algorithm can be described as below:

1. Initialize Amplitude, phase, frequency and unknown parameter matrix.
2. Produce a power system signal.
3. Estimate the discredited signal using initial value of unknown parameter.
4. calculate : Estimation error = Actual value - Estimated value.
5. Update covariance matrix and gain.
6. Update unknown parameter.
7. If final iteration is not find out, then go to step 4
8. Estimate the Amplitude and phase of harmonic component.

Fig-2.1 Estimation procedure for Recursive Least square algorithms



2.4 Results and Discussion

Let us consider ω is known fundamental angular frequency of the voltage or current waveforms. The assumed signal structure is used for the basis of the algorithm as followed.

$Y(t) = 1.5\sin(\omega t + 80) + 0.5\sin(3\omega t + 60) + 0.2\sin(5\omega t + 45) + 0.15\sin(7\omega t + 36) + 0.1\sin(11\omega t + 30) + \mu(t)$

Where μ(t) is the noise

The resulting sampled linear model of the system comprising additive noise is given by

$$Y(k) = \theta(k)X(k) + \mu(k)$$

Whereμ(k)= Noisy measurement

$X(k)$ =System structure matrix
θ(k)=vector for amplitude and phases that are to be estimated

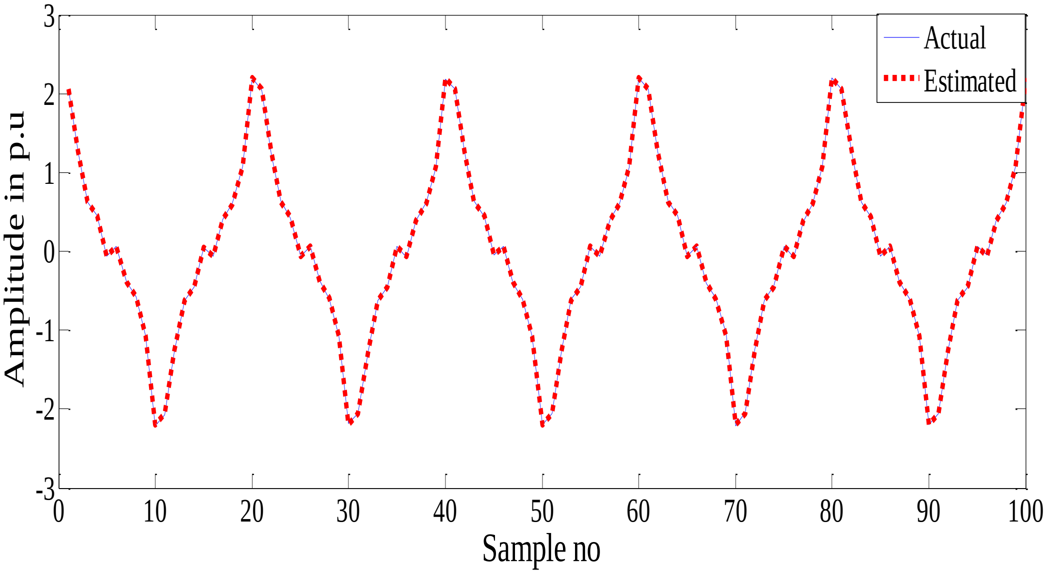


Fig-2.2-Output of actual and estimated signal using RLS algorithm at 40dB

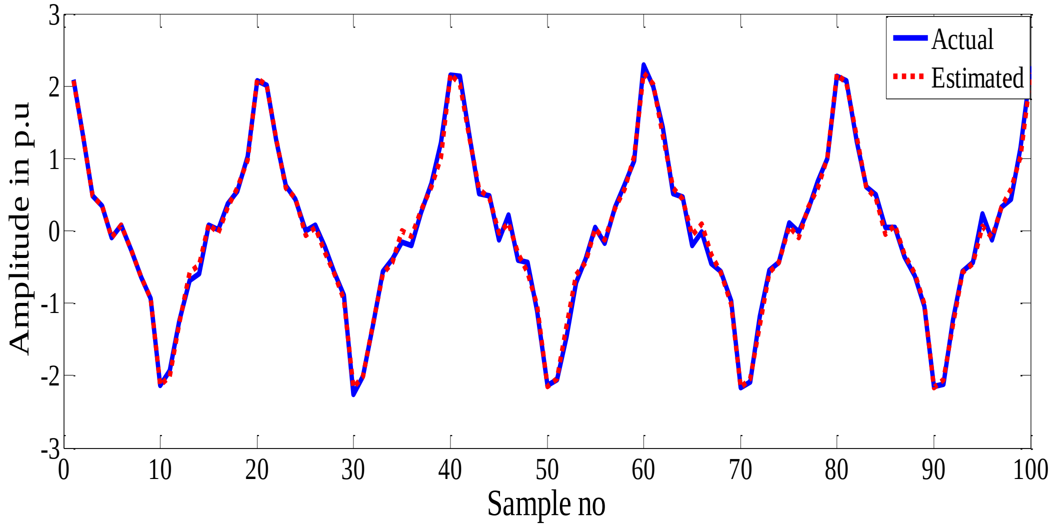


Fig-2.3- Output of actual and estimated signal using RLS algorithm at 20dB

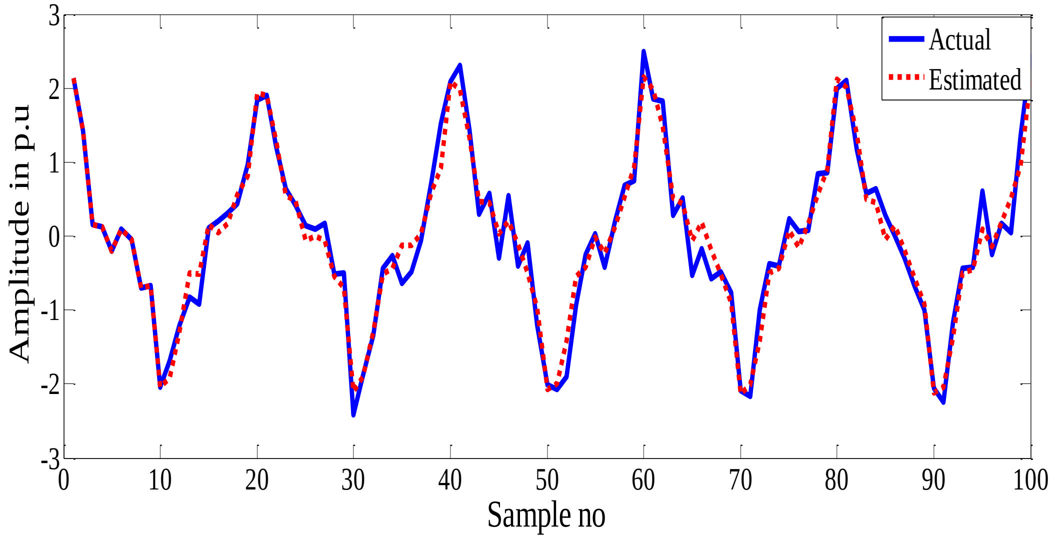


Fig-2.4- Output of actual and estimated signal using RLS algorithm at 10dB

2.5 Comparison of Estimation performances of RLS at different SNRs.

Table 2.1

Parameters used for simulation studies

Parameter	Frequency	Sampling time
Values	**50 Hz**	**0.001**

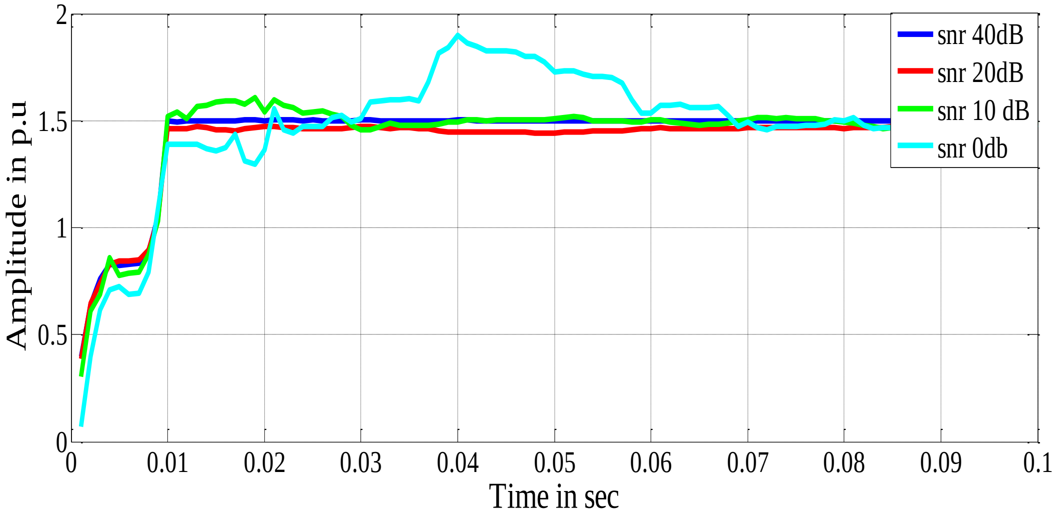


Fig-2.5 Fundamental harmonic estimated amplitude of signal using RLS at 40 dB , 20 dB , 10 dB and 0 dB SNR

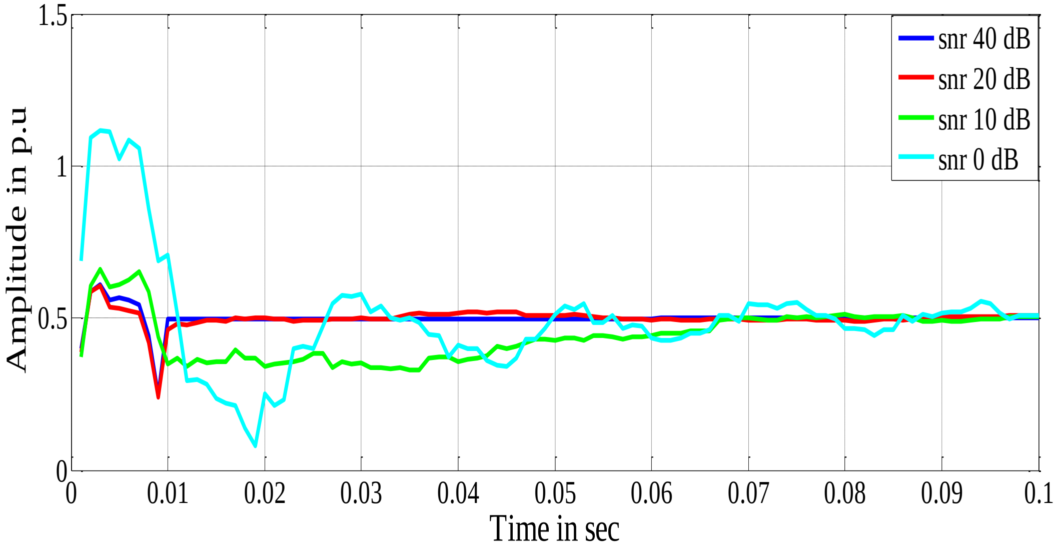


Fig-2. 3rd harmonic estimated amplitude of signal using RLS at 40 dB , 20 dB , 10 dB and 0 dB SNR)

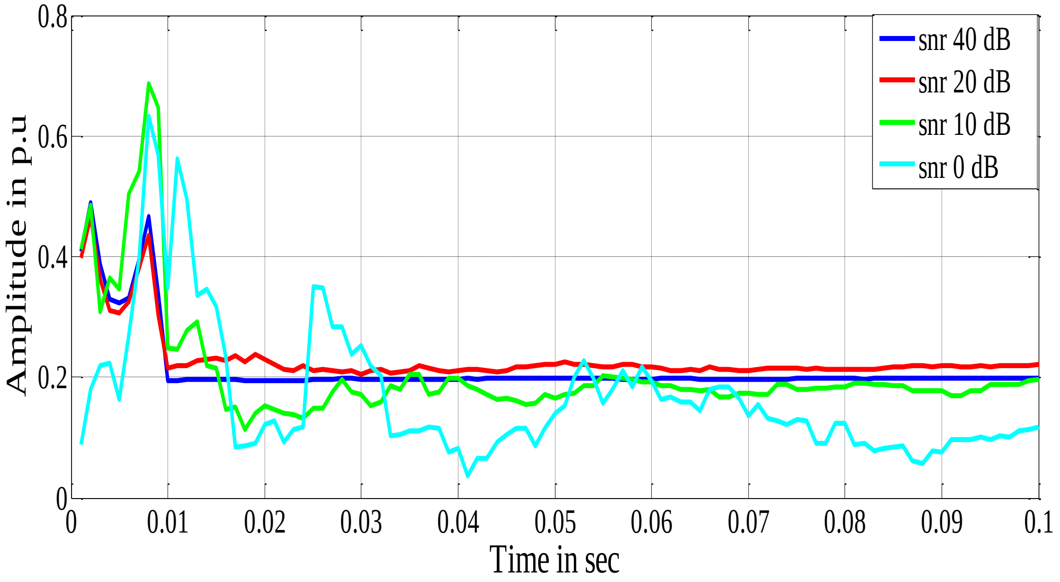


Fig-2.7 5th harmonic estimated amplitude of signal using RLS (40 dB , 20 dB , 10 dB , 0 dB SNR)

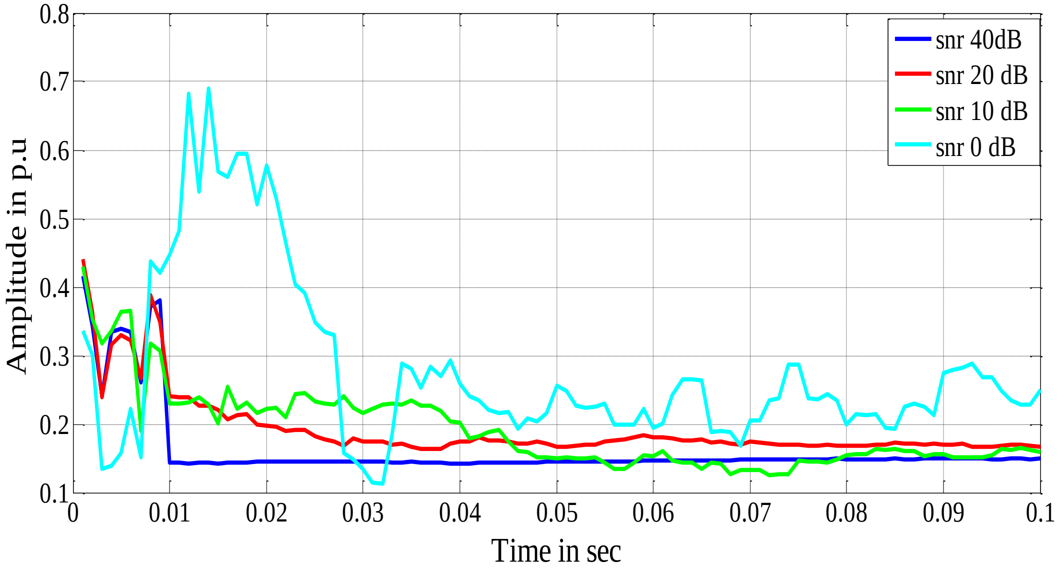


Fig-2.8 7th harmonic estimated amplitude of signal using RLS at 40 dB , 20 dB , 10 dB and 0 dB SNR

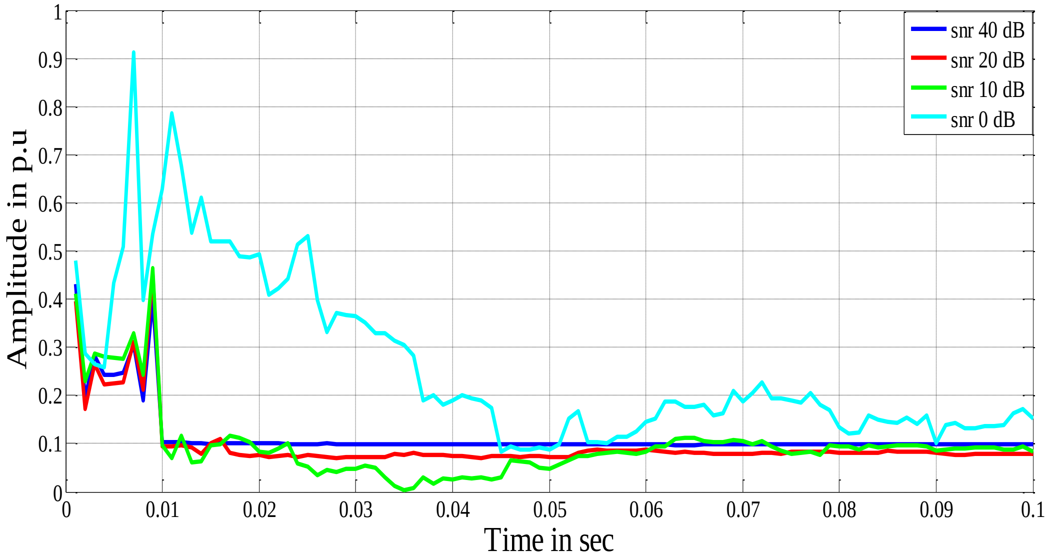


Fig-2.9 11th harmonic estimated amplitude of signal using RLS at 40 dB , 20 dB , 10 dB and 0 dB SNR.

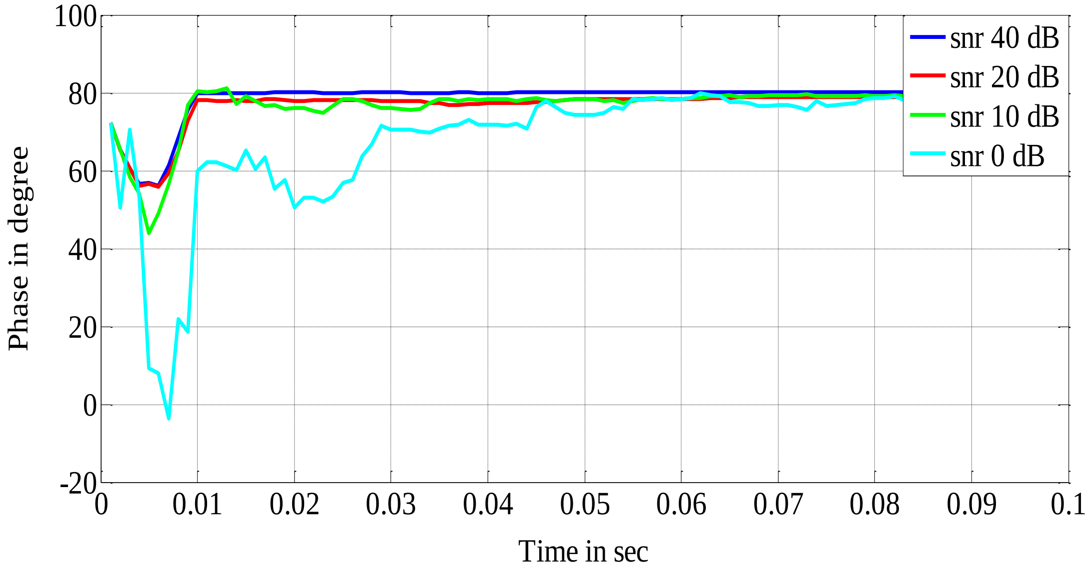


Fig-2.10 Fundamental harmonic estimated phase of signal using RLS at 40 dB , 20 dB , 10 dB and 0 dB SNR

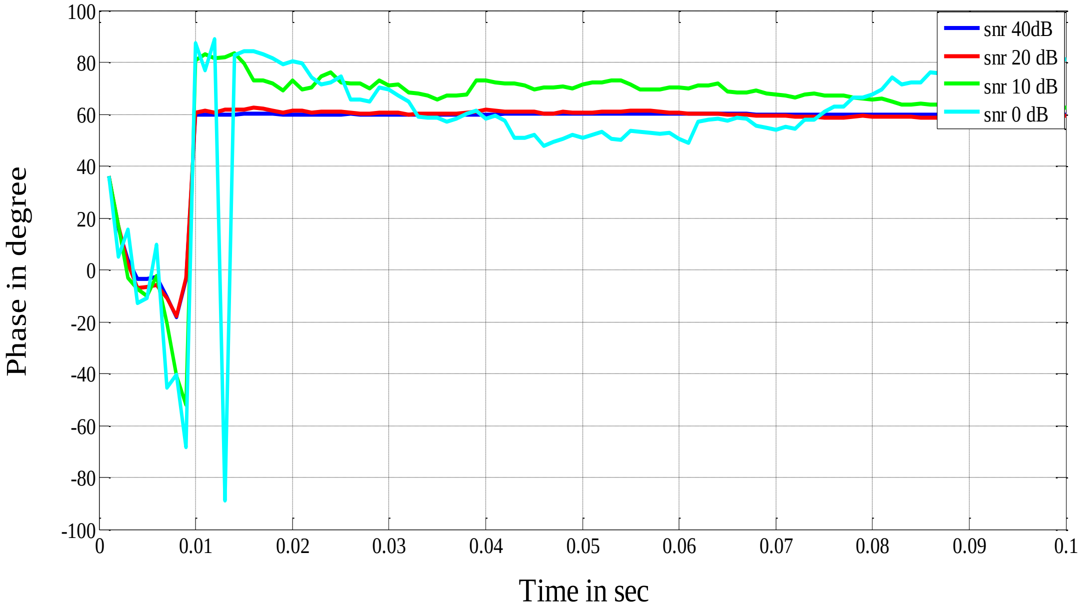


Fig-2.11 3rd harmonic estimated phase of signal using RLS at 40 dB , 20 dB , 10 dB and 0 dB SNR

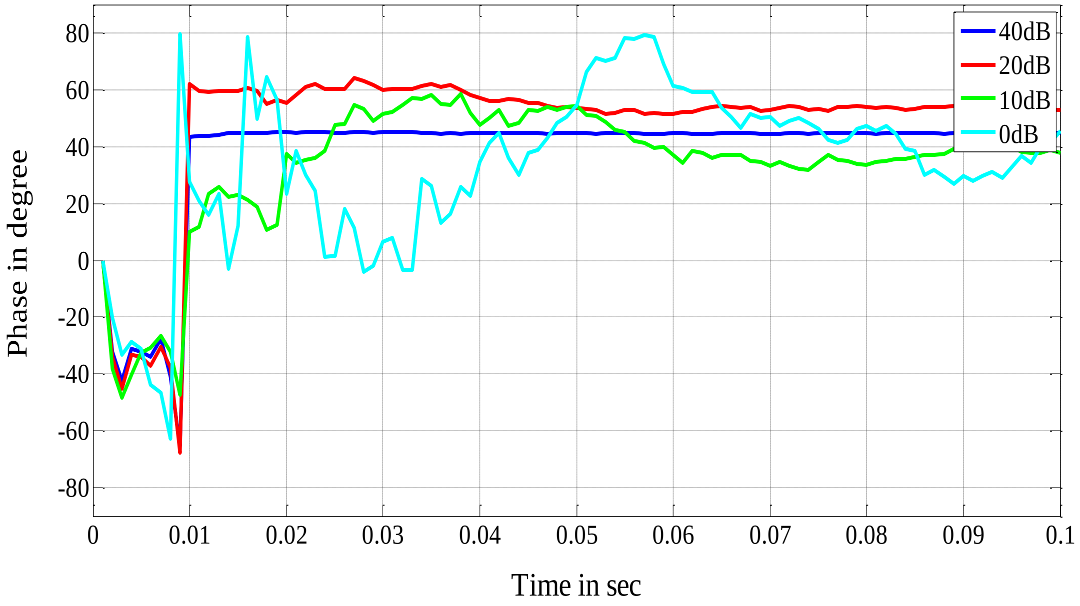


Fig-2.12 5th harmonic estimated phase of signal using RLS at 40 dB , 20 dB , 10 dB and 0 dB SNR

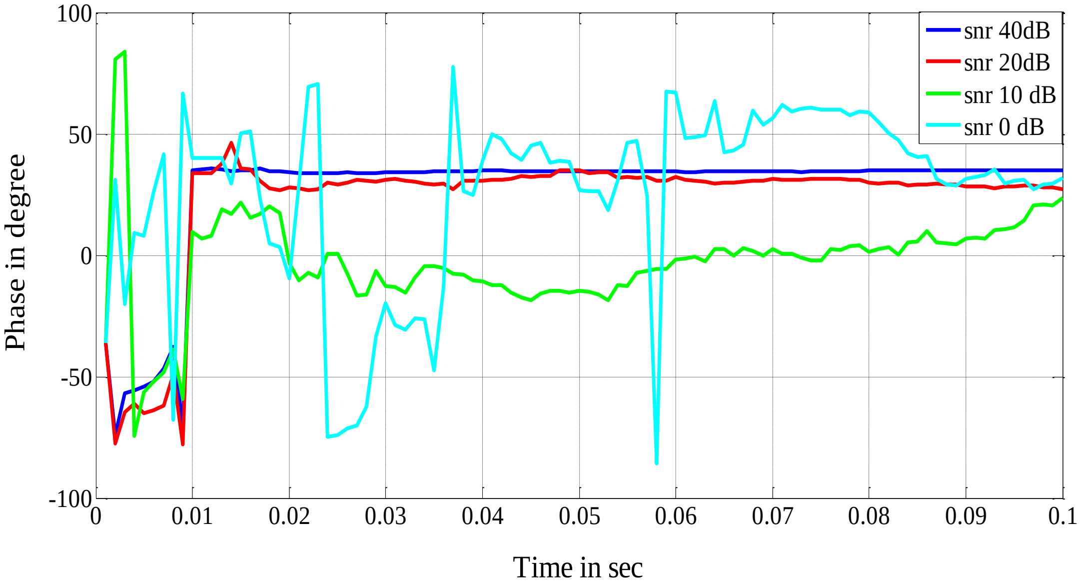


Fig-2.13 7th harmonic estimated phase of signal using RLS at 40 dB , 20 dB , 10 dB and 0 dB SNR

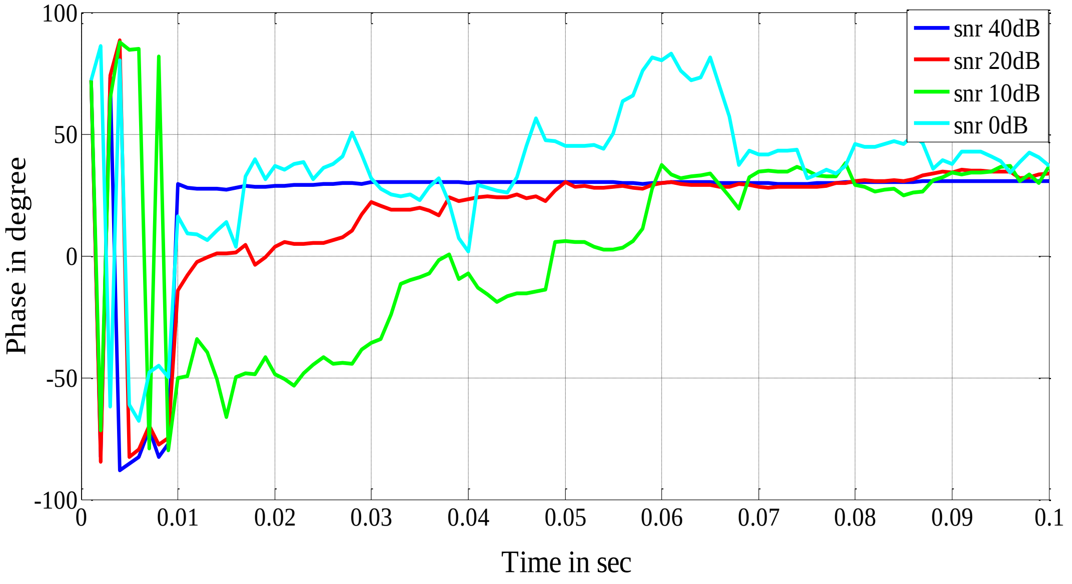


Fig-2.14 11th harmonic estimated phase of signal using RLS at 40 dB , 20 dB , 10 dB and 0 dB SNR

2.6 Summary of the chapter

In this chapter, a new algorithm called Recursive Least square algorithm has been described for accurate calculation of amplitudes and phases of the harmonics contained in a voltage or current waveform. This chapter describes RLS algorithm at different SNRs. Various simulation tests have been done to estimate the harmonics in a power system signal tarnished with noise to analyze the speed of convergence. The proposed algorithm estimates amplitude and phase of the harmonics accurately .The performances of the algorithms for fundamental and other harmonic components are compared for different SNRs that is 0dB,10 dB, 20dB and 40 dB respectively which is shown in Figs. 2.5,2.6,2.7,2.8,2.9,2.10,2.11,2.12,2.13 and 2.14.From the figure it is clear that when the signal to noise ratio goes on increasing, there is more accuracy in the estimation observed. However, initialization of covariance matrix is very important for this algorithms because improper choice may lead to more computational time and more estimation error.

Chapter-3

Power system Harmonic Estimation Using PSO

3.1 Introduction

The PSO algorithm is an algorithm based on population which is stochastic and resolves the complex optimization problem which is nonlinear. In the year 1995, Dr. Kennedy and Dr. Eberhart was first introduced the PSO algorithm. From the social of animals, the fundamental idea of PSO algorithm was first developed . It was based on bird flocking or fish schooling etc. It is based on the concept that when a group of birds searching for food without knowing the best position for them irrespective the individual. if any member can find out a desirable path to go, the rest of the members will follow them according to the nature of the social behavior,. The PSO algorithm is based on to solve optimization problems. In PSO, particle is defined as each member of the population whereas the population is called a swarm. Swarm that is population initialized randomly and move randomly in chosen direction, each particle remains busy in the searching space and reminisces the best previous positions of itself and for its neighbors. The exact position and velocity of particle is decided by the swarm. As long as all particles has not moved, the next step will not start. When the swarm get the solution close to optimum, all other particles moves towards superior and better positions over the searching process. Due to its simpler implementation and easy to converge to a good solution the PSO method is becoming very popular In comparison with other optimization methods, it is faster, cheaper and additional efficient, except a few parameters to adjust be in PSO. For which, PSO is considered as an ideal optimization problem solver in optimization problems. PSO can be used to solve the non-linear, non-convex, continuous, discrete and integer variable type problems.

There are two types of PSO

- Global Best PSO
- Local Best PSO

3.2 Global Best PSO

“The global best PSO (or *gbest* PSO) is a method where the position of each particle is influenced by the best-fit particle in the entire swarm. in this method each individual particle has a current position in search spacex_i , a current velocityv_i, and a personal best position in search space,$p_{best,i}$. The personal best position corresponds to the position in search space where particle i had the smallest value as determined by the objective function$f$, considering a minimization problem. In addition, the position soft the lowest value surrounded by all the personal best$p_{best,i}$ is called the global best position which is contribute byG_{best}.”

Therefore,

$p_{best,i}$ – is personal best position of particle .

G_{best}.- is global best position of particle in the whole swarm.

For gbest PSO method, the velocity of particle i is calculated by

$$\boldsymbol{v_{ij}^{t+1} = v_{ij}^{t} + c1r_{1j}^{t}[p_{best,i}^{t} - x_{ij}^{t}]+c2r_{2j}^{t}[G_{best} - x_{ij}^{t}]}$$

Where

$\boldsymbol{v_{ij}^t}$is the velocity vector of particle i in dimension $j$at time t ;

$\boldsymbol{x_{ij}^t}$is the position vector of particle i in dimension$j$ at time$t$;

$\boldsymbol{p_{best,i}^t}$is the personal best position of particle i in dimension j found from initialization through time t .

$\boldsymbol{G_{best}}$is the global best position of particle i in dimension $j$found from initialization in the course of time t.

$c1$ *and* $c2$ are positive speeding up constants which are used to level the contribution of the cognitive and social apparatus respectively;

$r_{1j}^t$and $r_{2j}^t$are random numbers from uniform allocation at time t.

3.3Local Best PSO

The local best PSO (or *lbest* PSO) method only allows each particle to be inclined by the best-fit particle chosen from its neighborhood, and it reflects a ring social topology . Here this social information exchange within the neighborhood of the particle, denoting local knowledge of the background [25].In this case, the velocity of particle$i$ is calculated by

$$v_{ij}^{t+1} = v_{ij}^t + c1r_{1j}^t[p_{best,i}^t - x_{ij}^t]+c2r_{2j}^t[L_{best,i} - x_{ij}^t]$$

Where

$L_{best,i}$, is the best position that any particle has had in the neighborhood of particle i found from initialization through time t.

Thus in the *gbest* PSO algorithm every particle obtains the information from the best particle in the entire swarm, whereas in the *lbest* PSO algorithm each particle obtain the information from only its instant neighbors in the swarm.

3.4 PSO Parameter

- Swarm size
- Iteration numbers
- Velocity Components
- Acceleration coefficients

3.4.1 Swarm size

The meaning of Swarm size is the size of population which is the number of n particles resides in the swarm. The larger parts of the search space is generated by big swarm which is covered per alternation. If the particles number decrease the number alternation , then a good optimization output is obtained. On the other hand massive amounts of particles accelerate the computational convolution. Hence more time consuming.

3.4.2Iteration numbers

For obtaining a good result, the number of iterations depends on several problem. For small number of iterations the search process may end too early, but for large iterations, it is difficult to compute the result. Also more time is required for computation.

3.4.3 Velocity Components

These very important for updating the velocity of particle. The particle's velocity has three terms.

1. The term $\boldsymbol{v_{ij}^t}$ refers to inertia component which gives a memory of the previous aeronautical direction. This component prevents from altering the direction of the particles and makes easy to get the current direction.
2. The word $\boldsymbol{c1r_{1j}^t[p_{best,i}^t - x_{ij}^t]}$ refers to cognitive component which measures the particles performance comparative performances of past. The best positions of the particle can be achieved by this component. The cognitive component referred to as the longing of the particle.
3. The term $\boldsymbol{c2r_{2j}^t[G_{best} - x_{ij}^t]}$ for *gbest* PSO or for $\boldsymbol{c2r_{2j}^t[L_{best,i} - x_{ij}^t]}$*lbest* PSO refers to social component that determines particles performance compared to a group of particles or neighbors. By the result of this component each particle moves towards the best location which is found by the help of its neighborhood. Particle.

3.4.4Acceleration coefficients

The constants c_1 and c_2, along with the random values r_1 and r_2 known as acceleration coefficients which maintains the stochastic influence of the cognitive and social portion of the particle’s velocity respectively. The term c_1 decides the assurance of a particle of its own while c_2 decides assurance of a particle according to its neighbors.

3.4.5Advantages and Disadvantages of PSO

- It is a derivative-free algorithm .
- The concept of PSO algorithm is very simple
- Very simple calculation is required for PSO algorithm
- Easy to implement.
- Less number of parameters.
- less reliant of a set of primary points

Disadvantages of the PSO algorithm

- Due to the partial optimism, it degrade the regulation of its speed and direction.
- Problems with non-coordinate system (for instance, in the energy field) exit.

3.5Algorithm of PSO

Step-1 The velocity and position of all particle are randomly set to within predefined ranges.

Step-2 At each iteration ,the velocities and positions of all particles are updated according to formula.

$$V_i^{n+1} = \omega^n V_i^n + C_1 * rand_1 * (X_i^{best} - X_i) + C_2 * rand_2 * (X^{best} - X_i)$$

$$X_i^{n+1} = X_i + V_i^{n+1}$$

Where X_i^{best} and X^{best} is the indivisual best and global best positions respectly. n+1 and n denote the current and previous iterations, $rand_1$ and $rand_2$ are random numbers in the range [0,1], C_1 =2 and C_2 =2 are two positive constants and ω^n is the inertial weight in the nth iteration.

Step-3 Update X_i^{best} and X^{best} when conditions are met

$X_i^{best} = X_i$ if f(X_i)>f(X_i^{best})

$X^{best} = X_i$ if f(X_i)>f(X^{best})

Step-4 Repeat steps 2 to 4 till convergence.

3.6 Simulation Results

Particle swarm optimization minimizes the cost function which is the summation of square of error. In this thesis fundamental and other harmonic components are estimated using PSO.

Table 3.1

Parameter for simulation studies

SL.NO	C_1	C_2	ω	V_{max}
1	**2**	**2**	**0.72**	**2**

Table 3.2

Estimated amplitude value

Harmonic	Actual value in p.u	Estimated value in p.u
Fundamental	1.5	1.49
3rd	0.5	0.49
5th	0.2	0.19
7th	0.15	0.148
11th	0.1	0.099

Table 3.3

Estimated phase value

Harmonic	Actual value in degree	Estimated value in degree
Fundamental	80	79.5
3rd	60	59
5th	45	49.5
7th	36	35
11th	30	29.5

3.7 Chapter summery

This chapter concluded that the harmonics contained in a voltage or current waveform of amplitude and phases can perfectly estimate from the new algorithm of PSO. It is an iterative estimation process.

Chapter-4

Harmonics Estimation Using Hybrid Algorithms

4.1 Introduction

Harmonics estimation of power system signals using signal processingTechnique and soft computing technique such as RLS and PSO are discussed in chapter 2 and3To accomplish further improvement in % error in estimation, processing time, performance and decrease in tracking time, hybrid estimation algorithms involving signal processing and soft computing techniques are described in this chapter. In this chapter the estimation of harmonics components of distorted signal in hybrid PSO-RLS approaches is presented. By using these algorithms easily power system can be done by Adaptive tracking of harmonic components .

4.2Hybrid PSO-RLS algorithm for Harmonic estimation

In this hybrid algorithm first unknown parameters are optimized using PSO algorithm. Then the output of PSO algorithm is taken as the initial value of RLS algorithm. Output of RLS is compared with the desired output and the error obtained by comparing with the actual output which is minimized by updating the weight of the RLS. From the final updated value of the RLS, amplitudes and phases of the fundamental and other harmonics components are determined.

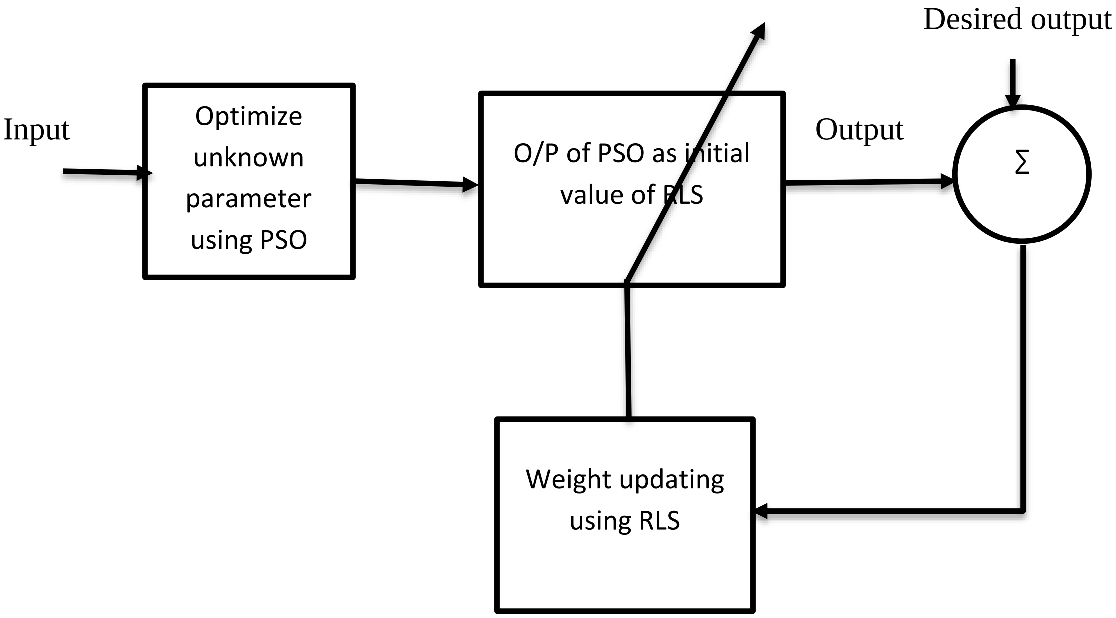


Fig-4 Structure of PSO-RLS estimation scheme.

4.3Simulation Results

Comparison between PSO and PSO-RLS

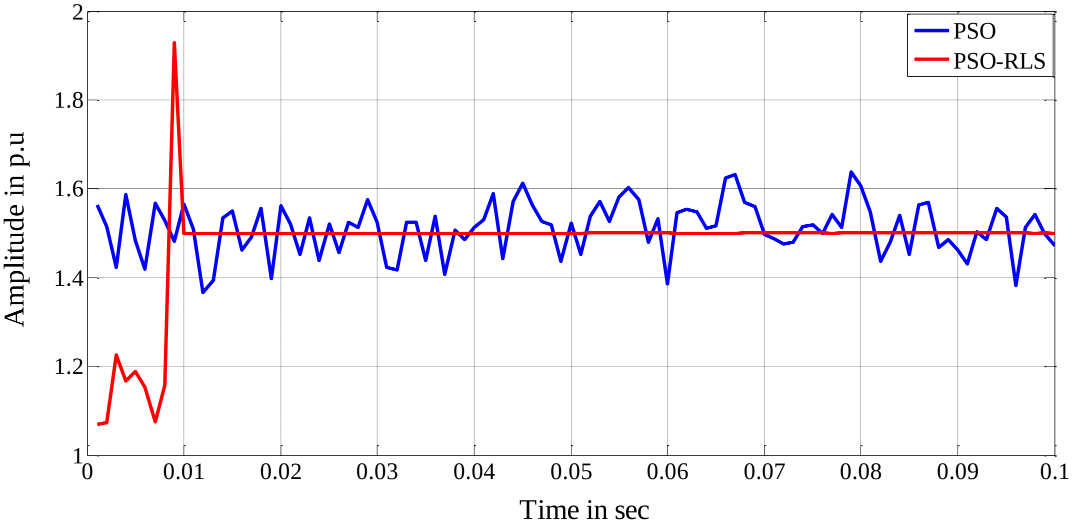


Fig-4.1Estimation of amplitude of fundamental harmonic components of signal Using PSO –RLS (40 dB SNR)

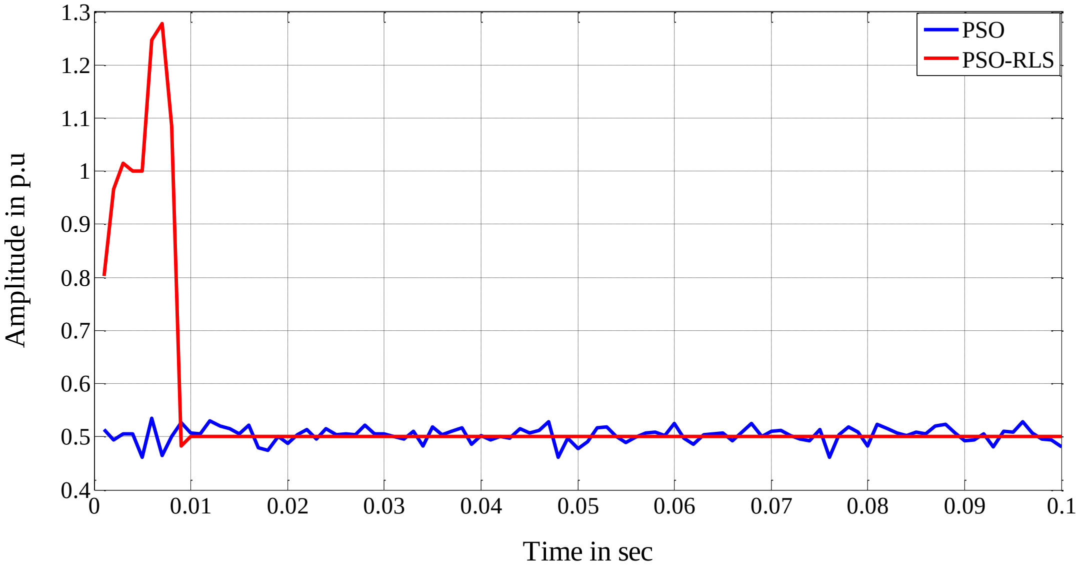


Fig-4.2Estimation of amplitude of 3^{rd}harmonic components of signal

Using PSO- RLS (40 dB SNR).

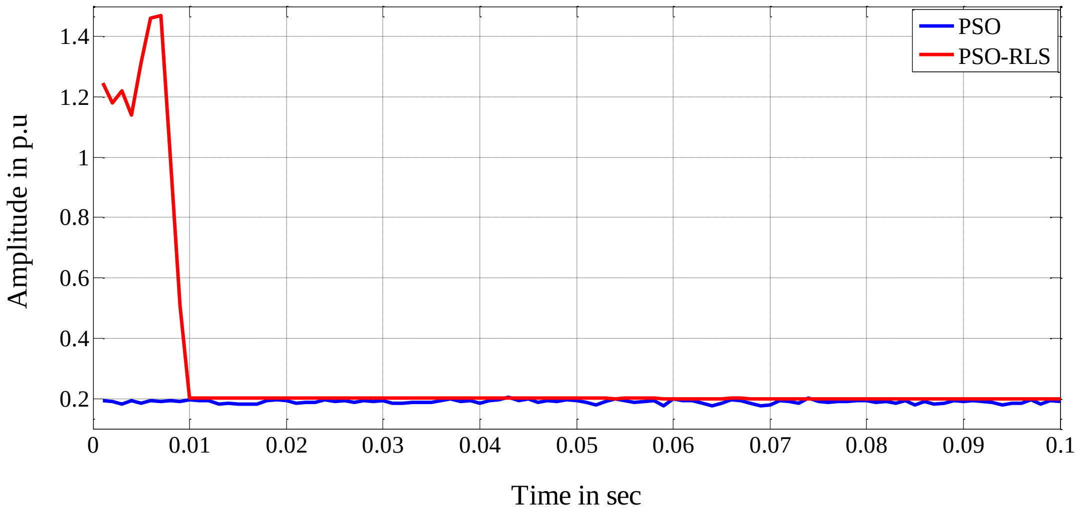


Fig-4.3Estimation of amplitude of 5thharmonic components of signal using PSO-RLS (40 dB SNR).

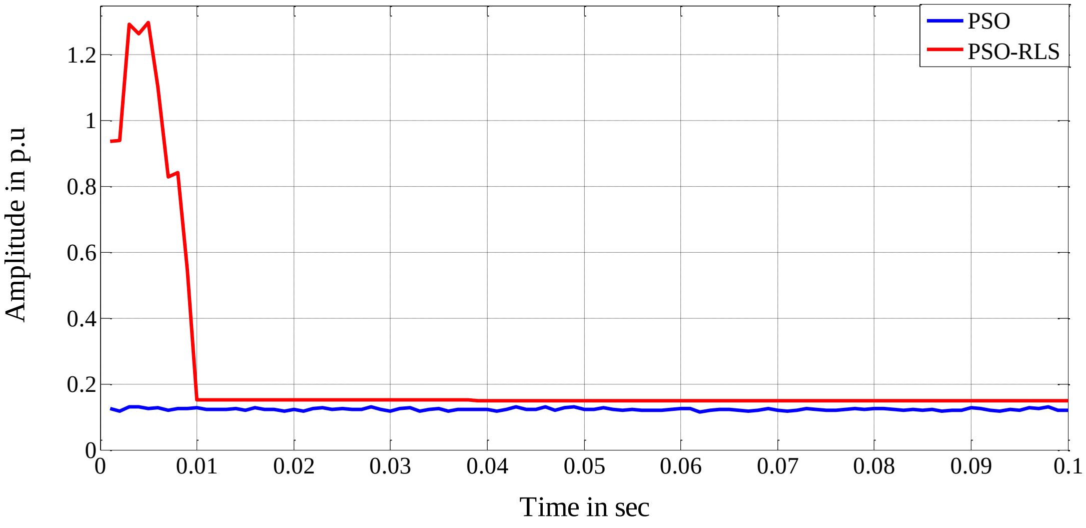


Fig-4.4Estimation of amplitude of 7thharmonic components of signal using PSO-RLS (40 dB SNR).

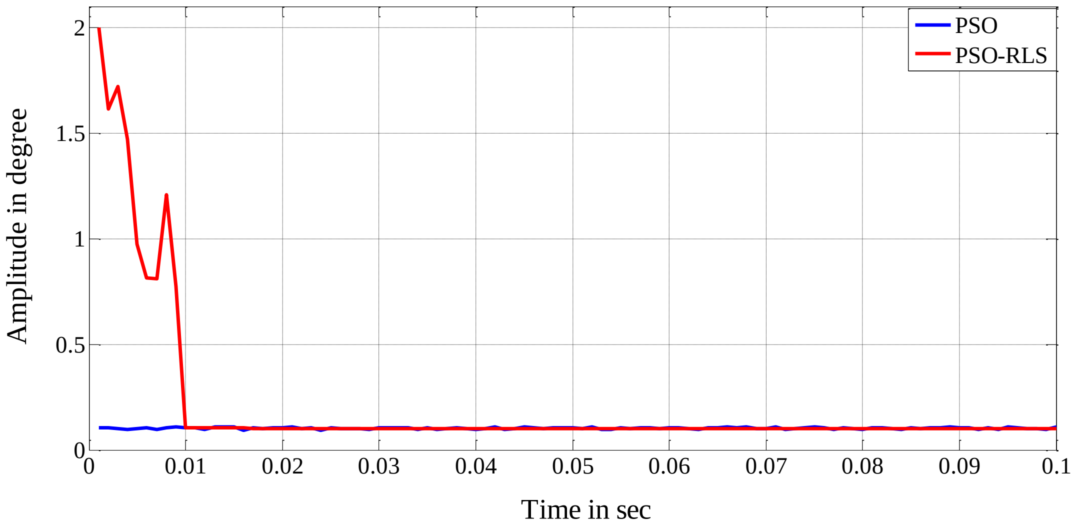


Fig-4.5Estimation of amplitude of 11th harmonic components of signal using PSO-RLS (40 dB SNR).

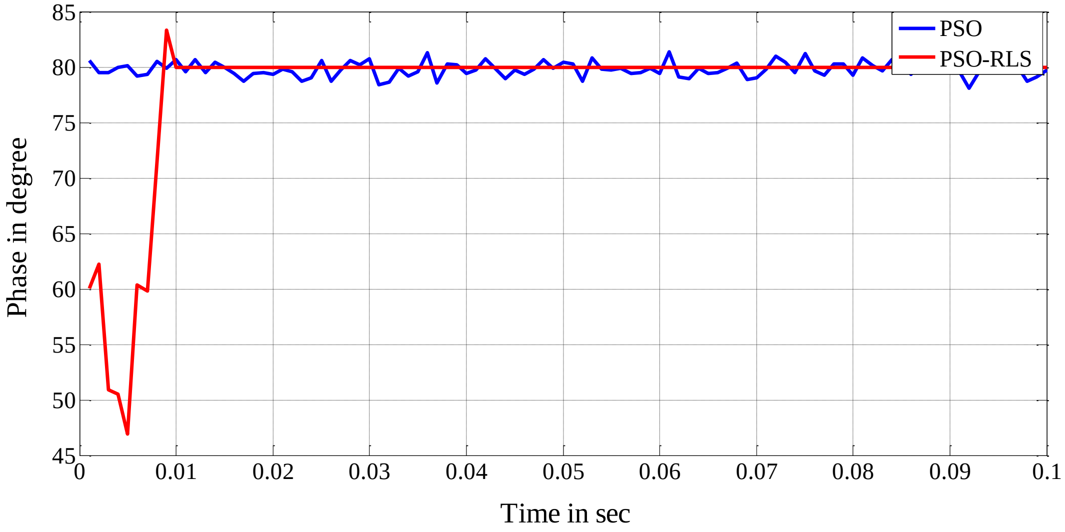


Fig-4.6 Estimation of phase of fundamental harmonic components using PSO-RLS (40 dB SNR).

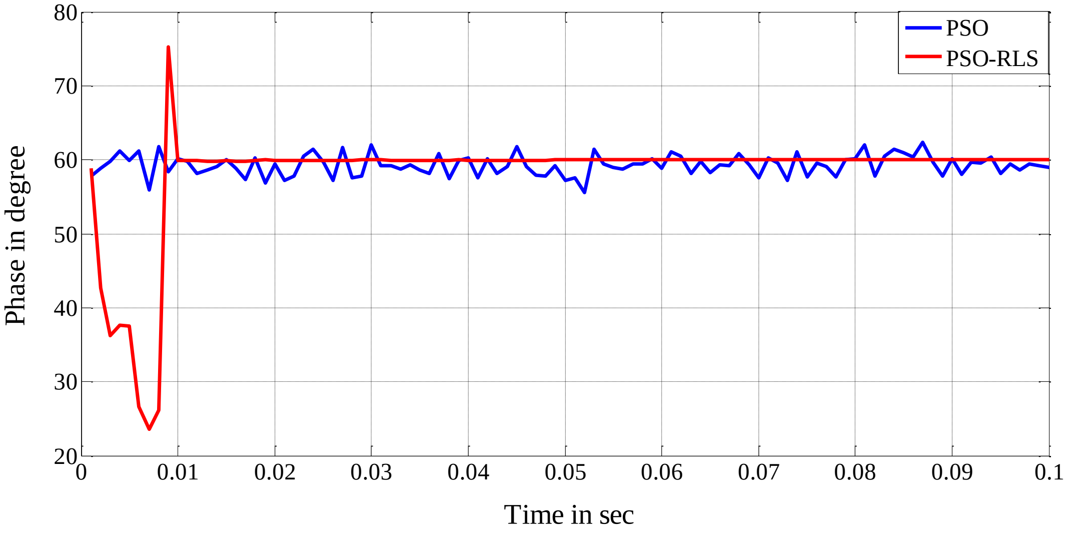


Fig-4.7 Estimation of phase of 3rdharmonic components of signal using PSO-RLS (40 dB SNR).

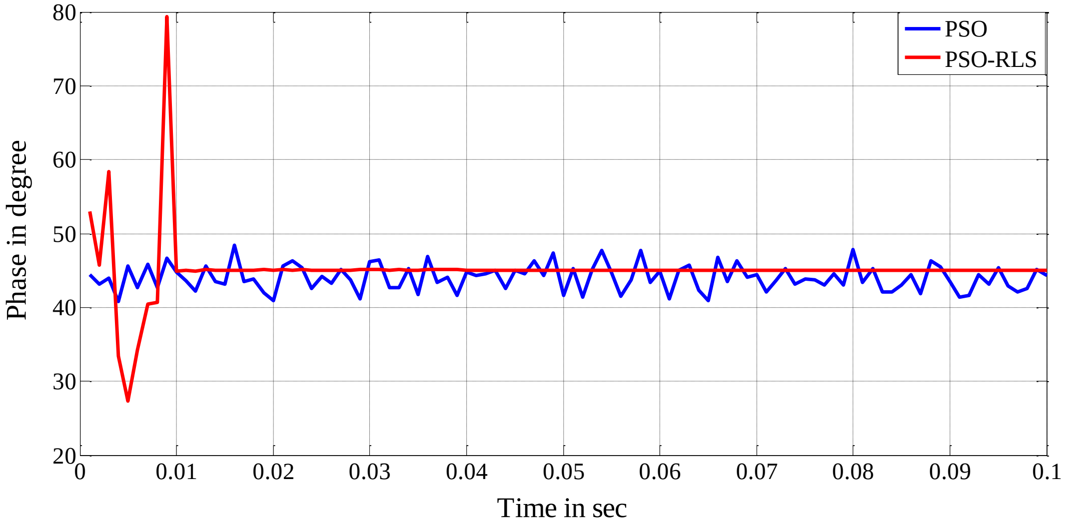


Fig-4.8Estimation of phase of 5thharmonic components of signal using PSO-RLS (40 dB SNR).

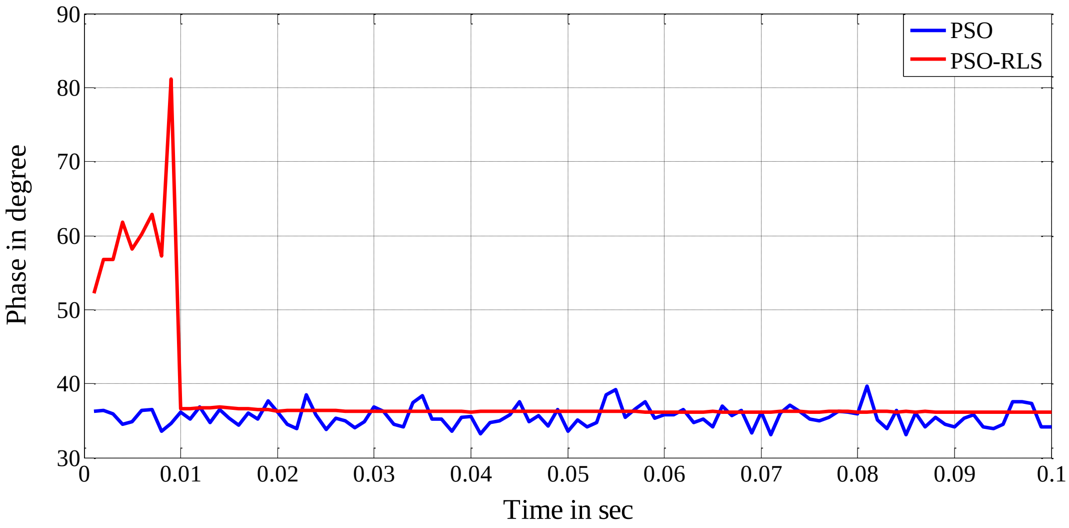


Fig-4.9Estimation of phase of 7th harmonic components of signal
using PSO-RLS (40 dB SNR).

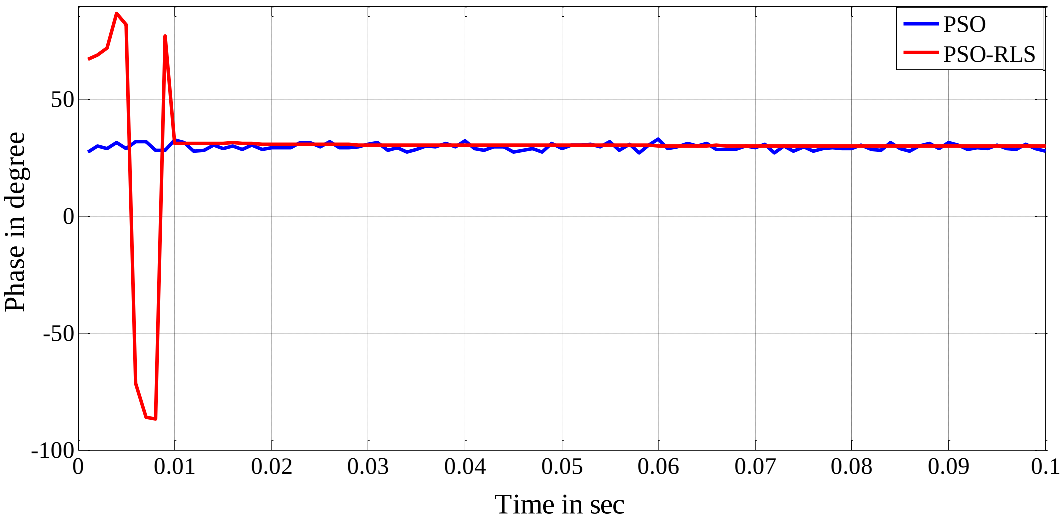


Fig-4.10Estimation of phase of 11th harmonic components of signal
using PSO-RLS (40 dB SNR).

4.4Chapter Summary

In this chapter Figs.4.1,4.2,4.3,4.4,4.5 show a reasonably estimation of amplitude of fundamental and other harmonics components of signal at SNR 40dB by means of both RLS and PSO-RLS algorithms andFigs.4.6,4.7,4.8,4.9,4.10 show a comparative estimation of phases of harmonics components of signal at 40dB SNR. The amplitudes and phases of the fundamental as well as other harmonics components contained in a power system signal consisting noise can exactly estimate with the new algorithm presented in this chapter. As per the algorithm PSO is applied first to estimate the unknown parameters used for determining amplitudes and phases and then RLS algorithm is used to updating the unknown parameter to estimate the final amplitudes and phases of fundamental and other harmonics components. Thus, the new algorithm i.e PSO-RLS with comparison to the other algorithm such as PSO, GA and RLS perform better in each case of estimation.

Chapter-5

Summary and Conclusions

5.1 Conclusions

- One recursive algorithms such as RLS and one soft computing technique such PSO have been functional to power system harmonic estimation. Among this RLS provides sooner convergence.
- For achieving more accuracy in estimation, a new hybrid algorithm PSO-RLS have been applied which gives better result than other two algorithm.

5.2 Future scope of work

- The proposed hybrid algorithm can be experimentally verified by online data which can be generated on laboratory environment.
- BFO algorithm can be implemented for harmonic estimation

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