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A Review on Estimation Technique Applied to Power System Frequency

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Abstract—*Estimation of Power system Frequency and Harmonics has now become a mature technology for Power quality related Problem. This paper presents a comprehensive review of Frequency estimation in power system by various methods starting from Signal Processing to soft computing. It is aimed at providing a broad perspective on the status of Frequency Estimation technology to researchers and application engineers dealing with power quality issues. A list of more than 100 papers research publications on the subject is also appended for a quick reference.*

Keywords: *Estimation, KF, FFT, NTA, IRNTA, LMS, VLLMS ,Power Quality.*

1. INTRODUCTION

Frequency is one of the most important and sensitive parameter in power system. Any variation in power system is eventually reflected the change in frequency. A change in frequency leads to change in system reactance and the operation of several relays such as reactance relay is affected. Frequency is a measure of mismatch between power generation and load demand. If load demand is greater than power generation under frequency situation arises and if generation is greater than load demand over frequency situation arises, in either case change in frequency poses a threat to efficiency, safety of entire system and increase in chances of system collapse, thus frequency is an integral part of power system protection, power quality monitoring, and operation and control of devices using digital technology. Hence the accurate estimation and tracking of system frequency is of utmost important.

The rapid growth of Signal processing Techniques and soft computing techniques make modern frequency measurement flexible and a variety of techniques have been developed in the recent years for the same purpose.

This paper is organized as follows Section 2 Describes the Various frequency estimation Techniques followed by Introduction in Section1,Section 3 Presents the conclusions of the Paper and in the last section a Complete Reference for the Frequency estimation technique is presented. .Some of the best techniques for frequency estimation are described in this chapter.

2. REVIEW OF THE PROPOSED WORK

This Section presents a progressive review on power system Frequency estimation, Power System Frequency based on signal processing approach such as Recursive Least square (RLS), Extended Least Square(ELS), Kalman filtering(KF), Least Mean square (LMS) etc to soft computing approach such as Fuzzy logic, neural network ,Genetic algorithm and Evolutionary Computation etc.

Frequency or the period of a signal can be measured by Zero crossing detection [1], when measuring the frequency of a signal, cycles of a reference signal is measured over one or more time periods, however Multiple periods of measurement helps to reduce errors caused by phase noise. Accurate measurement can be achieved by this method at the expense of slow measurement rates. Zero crossing detection method or its modification using curve fitting of voltage samples is the simplest approach for frequency estimation [2] but the estimation accuracy gradually decreases when high contents of harmonics are associated with the signal,

Duric, M.B et al; [3] proposed a new approach to the design of a digital algorithm for network frequency estimation. Derivation of the proposed algorithm is based on Fourier and zero crossing technique. Fourier method is used as digital filter and zero crossing technique is applied to the cosine and sine components of the original signal which can be corrupted by higher harmonics. Discrete Fourier Transform (DFT) is used by many researchers for frequency estimation of a signal, The conventional DFT shows excellent performance when the signals contains fundamental and integer harmonics component [4]. presence of decaying dc component in a signal and the implicit data window in DFT, introduce fairly large errors in the estimation when frequency deviates from the nominal value.[5] To improve the performance of DFT, some approaches has been mentioned by some authors [6-8] like feedback loop by turning the sampling interval, adjusting the data window length, changing the nominal frequency used in

DFT iteratively, correcting the gains of orthogonal filter and tuning the weighted factor recursively respectively. Theoretically the decaying component can be completely removed from the original waveform once its parameter can be obtained. Some of the authors added some samples to calculate the parameter of the decaying component based on this idea. The effect of DC components by DFT is eliminated by using the outputs of even-sample set and odd-sample set. Some authors estimate the parameter of the DC of decaying component by using the phase-angle difference between voltage and current.

Fast Fourier Transform (FFT) is one of the conventional methods for frequency estimation and it is based on a Fourier series model of the data and the data are composition of harmonic signals. This analysis is computationally efficient and produces reasonable results for a large class of signal process [9]. Though this method possess this type of advantage it has associated with some disadvantage like frequency resolution,i.e the ability to distinguish the spectral responses of two or more signals and irregular windowing of data that occurs at the time of processing with FFT. Windowing manifests itself as leakage in the spectral domain-energy in the main lobe of spectral responses that are present [10-11].

Sidhu et al; [12] proposed a revised digital algorithm called Smart Discrete Fourier Transforms to estimate the frequency of a sinusoidal signal with harmonics in real time. This algorithm smartly avoids the errors which are coming due to the deviation of frequency from nominal frequency and always associated with all the advantages of DFT [4], although this approach is suitable for measurement of frequency over a wide-range, the on-line application requires a trade-off between the accuracy and computational complexity.

T.Lobes et al; [13] Proposed Prony estimation technique along with Discrete Fourier Transform (DFT) which is a static state algorithm for power system frequency estimation with a variable data window to eliminate the noise and harmonics associated with a signal. Least square algorithm along with orthogonal FIR digital filter presented by the same author [13] for measurement of frequency in the operating condition of a power system.This algorithm is capable of producing a correct and noise free estimate for near nominal, nominal and off nominal in very short duration.

Jin Kwon Hwang et al; [14] presented a Novel-DFT based frequency estimation technique by introducing three digital filter to reduce the frequency error developed by noise and leakage effect of the negative fundamental frequency in a single phase signal analyzed by DFT based algorithm[4]. Tomas Radil et al; [15] proposed one algorithm based on leakage compensation by best fitting a theoretical spectrum of a rectangular windowed single-tone signal on the spectrum of the analyzed signal for the accurate estimation of the signal's frequency. The proposed algorithm is several times faster than the multi harmonic sine fitting algorithm. The proposed algorithm is suitable for monitoring frequency in power systems. It can also be applied in other areas, particularly when the accurate estimates of the signal's amplitude and phase are required.

Arghya Sarkar, [16] proposed a novel digital signal processing algorithm for online estimation of the fundamental frequency of the distorted power system signals. The basic algorithm relies on the development of an efficient variance reduction algorithm and design of a new stable band pass infinite impulse response (IIR), second-degree digital integrator (SDDI) with reduced approximation error. Compared with the well-established technique such as the enhanced-phase-locked-loop (EPLL) system, the proposed algorithm provides higher degree of immunity and insensitivity to harmonics and noise and faster response during step frequency change.

Karimi.H et al; [17] presented A method for estimation of power frequency and its rate of change, the proposed scheme accommodates the inherent nonlinearity of the frequency estimation problem by providing a fast and accurate estimation of the frequency when its deviation from the nominal value is incremental or large. The estimator is based on a newly developed quadrature phase-locked loop concept.

The dominant frequency component of a input signal and its frequency estimation is proposed by P.J moore [18] on introducing a phase-locked loop (PLL) system. The mechanism of the proposed PLL [18] is based on estimating in-phase and quadrature-phase amplitudes of the desired signal. Mohsen Mojiri et al; [19] proposed an Adaptive Notch Filter (ANF) which can be employed and furnished with pre- and post-filters to devise a method for estimation of power system frequency and its rate of change They discussed the adjustment of the ANF parameters and the design of pre- and post-filtering stages. The dynamic responses of the proposed method with regard to step, ramp, and oscillatory changes of frequency are faster than those of the PLL-based method. The structural simplicity of the proposed estimator renders it suitable for digital implementation both in hardware and software environments.

Wu Jiekanget al; [20] proposed a high-accuracy, wide-range frequency estimation method based on the principle of numerical differentiation. The fundamental frequency of non-sinusoidal signal voltage and current of a power system can be estimated with a structure similar to the basic parameter estimator, the estimator is simple in design and implementation and it is very effective for tracking the real-time frequency of the power system.

YiliXial et al; [21] proposed a novel technique for online estimation of the fundamental frequency of unbalanced three-phase power systems based on Clarke's transformation and widely linear complex domain modeling, the proposed method makes use of the full second-order information within three-phase signals, thus promising enhanced and robust frequency estimation. The proposed method is also less sensitive to the variations of the three-phase voltage amplitudes over time and in the presence of higher order harmonics.

Least Mean Square (LMS) [22] algorithm is adopted where the formulated structure looks very simple and it has been observed that this algorithm is found to be accurate under various systems changing condition to estimate correct measure of frequency. Pradhan et al; [23] proposed a Least Mean Square algorithm in complex form to estimate the frequency of a power system. This estimation of frequency is verified in the presence of noise, with frequency jump and data collected from real time system. The presence of 3rd harmonic in the signal does not affect the performance of the algorithm as the 3rd harmonic component is eliminated during Clarks transform. But the presence of 5th harmonic component affects the performance of the algorithm, so a Butterworth Filter used for pre filtering shows the correctness of the estimation with less error.

A Variable Step Size LMS (VSSLMS) has been proposed [24] to get more accurate and better convergence in estimation over conventional LMS algorithm. Disturbances exist in a signal do not affect the estimation performance using VSSLMS algorithm. Step size of this algorithm is adjusted by autocorrelation of square of time averaging estimate error and previous error. The auto-correlation error is a good measure of the proximity to the optimum and it rejects the effect of uncorrelated noise sequence in the step size update. However, this VSSLMS provides faster convergence at early stages of adaptation while there is little deviation in the later stage.

The conventional LMS technique based on adaptive linear filtering possesses the advantage of simplicity in its underlying structure. However, it suffers from the problem of poor convergence rate if the step size for adaptation is fixed [25] This step size, in general depends inversely on input power, i.e, it takes more time to learn about its input when step size is small and vice versa. Time-varying step size is usually employed to overcome this poor convergence problem. If the LMS of the error is only considered as the cost function to be minimized, with respect to the dynamic variation the linear weights of the filter may go unbounded or take longer time to respond because of the stalling effect [26]. In order to avoid the drifting of weight involved in the estimation mechanism, B.Subudhi et.al proposed a variable leak adjustment technique in which a variable adaptation step size is incorporated to attain faster convergence. To enhance the convergence characteristics and to reduce the error of the LMS algorithm in power system frequency estimation Ray proposed Extended Least square [27]

Soliman Abdel-Hady [28] proposed a new application for linear Kalman Filter algorithm for power system frequency estimation. The filter uses the digitized samples of the three-phase voltages or current waveform signals. These three phases are transformed into two phases, using the well-known αβ –transformation matrix. Having obtained the signal of the two new phases, a complex phasor is constructed using the new two-phase voltages. Kalman filter is then applied to extract the frequency and phase angle of the fundamental component of the complex phasor.

An approach based on Recursive Least Square (RLS) Algorithm applied to frequency estimation of the instantaneous power system [29] the Three-phase voltage signal is transformed to a complex form which is easy to be handled by the proposed approach. The RLS Algorithm is more suitable for online frequency estimation due to its rapid convergence rate. This algorithm recursively finds the coefficients that minimize a weighted linear least squares cost function related to the input signals. When compared with other algorithms, the RLS algorithm exhibits the feature of rapid convergence rate. However, this benefit comes at the cost of high computational complexity.

Adaptive LMS algorithm-based adaptive filters are used to estimate the discrete Fourier coefficients of sine and cosine terms of noisy sinusoidal signals, whose frequencies are known a priori. The standard RLS technique is used by many researchers but it is computationally complex. Using approximations, a new recursive Gauss–Newton adaptive filter is proposed by Das [30] to estimate fundamental and harmonic phasors of power system voltages or currents and their variations because of sudden disturbances take place in a power system. Further, the filter possesses computational simplicity of the normal gradient technique and has the speed of convergence of the Newton method.

A. Pradhan et al, [23] Presents an arc cosine function – free technique for frequency estimation to reduce the burden of computation with little decline in frequency estimation accuracy. A leak factor updatation algorithm has been proposed for variable leakage factor in VLLMS [24]. This leak adaptation in the proposed VLLMS has the advantage of using measurable signals in the system to perform the adjustment of the leak factor.

Recently Soft Computing (SC) techniques are receiving more attention as optimization techniques for many industrial applications. It is an evolving collection of methodologies, which aims to exploit tolerance for imprecision, uncertainty and partial truth to achieve robustness, tractability, and low cost. SC provides an attractive opportunity to represent the ambiguity in human thinking with real life uncertainty. Fuzzy logic (FL), Neural Networks (NN) and Evolutionary Computation (EC) are the core methodologies of soft computing; it can solve problems that have not been able to be solved by traditional analytic methods. In addition, SC yields rich knowledge representation (symbol and pattern), flexible knowledge acquisition (by machine learning from data and by interviewing experts) and flexible knowledge processing (inference by interfacing between symbolic and pattern knowledge), which enable intelligent systems to be constructed at low cost and high machine intelligence quotient (HMIQ).

This section describes some of the recent developed soft computing methods applied for frequency estimation in power system signal.

Neural Network and Genetic Algorithm (GA) have been used in [31], for estimation of power system frequency. In this proposed algorithm, the learning of weights of NN was carried out by GA. Authors have compared the performance of this proposed technique with the conventional error back propagation and LMS algorithm. But they found that the proposed algorithm outperforms over the other two. They have judged the performance using simulation only and also observed that though the algorithm gives better performance still it suffers from problem in training of the network.

M. Gupta et al; [32], proposed a faster training algorithm for estimation purposes. The author first applied only Gradient Descent (GD) algorithm separately for the estimation of frequency and observed that it has the disadvantages of getting stuck in local minima. Then applied PSO separately and observed that the square of the error fluctuates randomly and it may take much iteration to converge. To avail the advantages of both the technique, a hybrid algorithm has been proposed by the same author in the same work to estimate the power quality parameter estimation. In those new hybrid algorithm chances of getting stuck in the valley of local minima becomes almost nil. Simulated results prove the superiority of the proposed hybrid algorithm (combination of GD& PSO) in terms of lesser number of iterations to converge.

A. Sundarrajan [33], proposed Evolutionary Algorithms (EA) like, Enhanced Particle Swarm Optimization (EPSO), Multi Objective Particle Swarm Optimization (MOPSO) and Stochastic Particle Swarm Optimization (SPSO) to overcome the premature convergence problem in a standard PSO. These algorithms reduce transient oscillations and also increase the computational efficiency for frequency estimation,

P. K. Ray et al; [34], proposed RLS-Adaline and KF-Adaline algorithms for power system frequency estimation approaches, the weights of the Adaline are updated using RLS/KF algorithms. Frequency of power system signal is estimated from final updated weights of the Adaline. Neural estimator was found to be an effective estimator [35]. It consists of an adaptive perception of neuron called Adaline. Since KF and RLS both are recursive in nature, online estimation is possible and KF can be used for both filtering and estimation, KF and RLS algorithms have been employed in the proposed hybrid algorithm for updating the weight in Adaline. Both RLS-Adaline and KF-Adaline estimators' track the power system signal in different cases such as signal corrupted with noise, in presence of harmonics and in presence of sub harmonics and inter harmonics. Evolutionary Computation technique [36] is a population based search algorithm; it works with a population of strings that represent different potential solutions. It enhances its search capability and the optima can be located more quickly when applied to complex optimization problems. An EC technique called Bacterial Foraging Optimization (BFO) is developed and it is combined with RLS and Adaline [38] to power system frequency estimation. BFO is one of the recent bio-inspired computing used by many researchers in different areas of optimization.

Four new hybrid algorithms such as RLS-Adaline, KF-Adaline, RLS-BFO and Adaline-BFO [39] are presented. The performances of the first two proposed hybrid algorithms i.e RLS-Adaline and KF-Adaline are dependent on the initial choice of weight vector W and Covariance matrix P. By using an optimal choice of weight vector, faster convergence to the true value of signal parameter can be achieved. After the optimization of the weight vector, online tracking of frequency of signal can be carried out. Both the algorithms track the frequency of signal at different level of noises and different signal changing conditions but the performance of tracking using KF-Adaline is better than RLS-Adaline.

Fuzzy linear regression is proposed in [40] for frequency and harmonics evaluation in a power network, which used digitized voltage signals as fuzzy numbers for estimation of frequency and harmonics components of voltage signal. Sampling frequency effects, data window size and degree of fuzziness on the estimated parameters has been investigated and presented.

The frequency and the rate of frequency change are estimated by the non recursive Newton-type algorithm [40, 43] using generator swing equation, the recursive algorithm form is improved with a strategy of sequential tuning of the forgetting factor. By this, the algorithm convergence and accuracy are significantly improved.

3. CONCLUSIONS

This Paper provides a brief back ground on the area of research of frequency estimation and the techniques used to measure the frequency in a power system signal and also techniques used to measure the frequency in different situation that arises in a power system such as change in Amplitude, Phase, In Presence of Harmonics and Inter Harmonics etc.

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