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Power System Harmonics Estimation Techniques: A Review

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Abstract

Power Semiconductor Devices have been more important in power systems during the last several decades. Flexibility in AC transmission is a new trend in the power system industry. Transmission and distribution quality are harmed by the use of Fact devices and non-linear loads in the distribution sector, resulting in harmonic production. These harmonics may have a devastating effect on the system if necessary precautions are not followed. Measurement of power harmonics components is critical to the design of a filter that reduces harmonics.

This study outlines a step-by-step process for measuring the harmonic content of power system signals, beginning with a traditional technique and progressing to a soft computing approach. Real-time analytic methods are the focus of this course. The researchers in this field may benefit from this review study.

Index Terms: Fast Fourier Transform (FFT), Least Squares, and Harmonic Estimation (LS). RLS, VLLMS, KF, NTA, IRNTA, BFO, NN, Adaptive Linear Neural Network (Adalkine)

I. INTRODUCTION

A consistent magnitude and frequency sine wave voltage and current is anticipated throughout the transmission and distribution sectors of the power system. The AC power system is distorted by power semiconductor devices in all sectors, resulting in a voltage and current waveform that diverges from its original waveform and reflects as an integer multiple of fundamental frequency. This sinusoidal waveform has varying magnitudes and phases. Harmonic frequencies are produced by multiplying this frequency by the fundamental. In the transmission and distribution sector, harmonics levels have increased due to the massive expansion of power semiconductor components. Harmonics are mostly produced as a result of the utilisation of nonlinear loads. Additionally, the need for power converters in drives and uninterruptible power supply (UPS) for backup in different systems contributes to these harmonics. Harmonics may have a number of negative effects on the operation and control of the electrical system, as well as relaying issues (faulty relays).

In order to improve power system efficiency, the heating impact of the load current is taken into account. This reduces the life lifetime of power system machinery. Disruption of current waveform signals poses a greater risk to the power grid. Interharmonics and subharmonics are introduced into the system if suitable filtering is not implemented[1-2].

Power Generation

Figure 1: Power System Harmonics Estimation Issues

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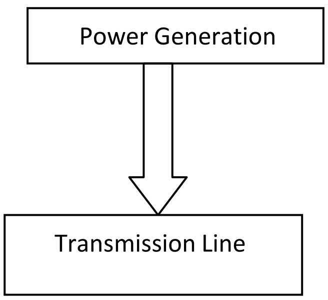

Precision and accuracy are critical to designing and developing an efficient filter for mitigating harmonics in the distorted power system current/voltage signal. As the power system signal evolves, the estimate approach is designed to deliver the best results in the presence of noise, inter and subharmonics, dynamic changes in the signal etc. An precise estimate technique is thus being developed for the harmonics of distorted voltage/current signals in order to get their magnitude and phase.

Everything else is laid out as follows. Progressive reviews of conventional and soft computing approaches are discussed in Sections II and III. Section IV presents a comparison of the outcomes for the two scenarios, and Section V summarises the findings.

The conventional approach to the HARMONICS ESTIMATION problem.

Let's imagine a signal that includes basic components, harmonic components, noise, and so on. This is a real-time signal representation. Equations are used to express the wave shape numerically. 1. Various approaches for estimating harmonic amplitude and phase are given and reviewed.

DC's Declining State Component that provides a pulsating waveform that is in tune with the harmonics.

The total harmonics estimate issue may be broken down into a linear and non-linear problem [9]. An adaptive linear combiner "Adaline" has been utilised for harmonic phase estimation, which is highly fast and has been used for amplitude estimation.

Combine artificial neural networks with the Least Squares method to extract harmonics in time-varying settings.

Adc exp(dct) - y(t) = An sin(nt - nn) - Adc (t)

n⍰1The order of harmonics is N. n n2f0; (1)

[10] is on display. The frequency, amplitude, and harmonic components of the signal may all be measured concurrently using this approach.

"t" stands for time; "f" stands for fundamental frequency;

In the dc decay equation, the decaying term is given by adc exp(t).

Many strategies have been used to analyse harmonics, according to the review [1-2]. Because of its speed, the Fast Fourier Transform (FFT) is one of the most extensively utilised of these methods. An efficient approach for estimating harmonics, the Fast Fourier transform (FFT) [1-2], is a good fit for a wide range of signal processing. Even while this strategy has several benefits, there are still some performance drawbacks associated with it. The frequency resolution constraint, which takes into account the spectral responses of two or more signals, is the most obvious. As a result of their presence, it is essential to build better tools in order to minimise any potential technological problems. The second constraint is the spectral domain leakage caused by data windowing. It is difficult to interpret short data records because many detected processes are short in duration and have short time-varying spectra. Many additional spectrum estimating techniques have been presented in the past few decades [3-5] to ease the constraints of the FFT methodology. new approaches' advantages are heavily dependent on the Signal-to-Noise Ratio (SNR).

Other techniques include the Kalman Filter (KF) [5- 6], in which the harmonic injection error covariance analysis and the individual harmonic injection source are considered as random state variables.. Metering sites in power systems may be determined using these two factors. The KF was able to monitor and evaluate each harmonic injection in the power system using this ideal design [6]. In cases when the frequency is known, KF may be used to calculate amplitude and phase. Frequencies are impossible to alter, therefore it cannot retune itself. A single-layer neutral network-based Fourier Linear Combiner can estimate harmonics at fixed frequencies, but the tracking time is substantially longer and there is a greater amount of inaccuracy when the frequency changes. A method [7] that solves the aforementioned issue by combining the Fourier Linear Combiner with the Extended Complex Kaman Filter (ECKF).

Even when higher harmonics are present, STDFT demonstrates a fairly uniform convergence within a period to the harmonic's appropriate value, despite the existence of higher harmonics in the data set. The problem, though, is that it can't handle the presence the system of power Other than the rising complexity of the neural network with a rise in the number of harmonic components, there are no restrictions on the evaluation of harmonic component number. For the estimate of harmonics in a feed-forward neural network, Mori et al. [9] used an approach based on back propagation learning. A computer-based measuring system was used to observe voltage harmonics, and the suggested method's performance was compared to that of many other standard approaches. [10] has created a technique to predict the size and phase of a power system's eleventh harmonics (550 Hz) using a neural network. To determine the model parameters, they employed a noise-based technique. It is also shown that the neural technique outperforms a traditional DFT method in terms of estimation performance. When compared to DFT, NN techniques have a much faster reaction time, as well as a much higher level of accuracy. As samples of harmonic signals [12] are received within the specified time period, estimations of fundamental and harmonic amplitude and phase angle are updated recursively using the RLS method. To estimate harmonics using Recursive Least Square (RLS) and Extended Least Square (ELS), amplitude and phase are first estimated, then frequency. Using the covariance matrix makes them easy and beautiful. To get an accurate estimate of power system characteristics, the use of a covariance matrix is essential.

As a result, a nonlinear state estimation approach based on ensemble Kalman filtering employing one framework and at the same time employed for estimation is computationally efficient compared to standard Kalman filtering. Existing HSE approaches are ineffective if there are just a few harmonic metres accessible, owing to observability issues. For the measurements, a novel system-wide harmonic state estimator [15] is used, which uses fewer metres than previously known state variables to accurately detect harmonic sources. The identification of harmonics, inter-harmonics,

and sub-harmonics in power system signals requires the use of parametric spectral estimating techniques such as Yule Walker, Burg, Covariance, and Modified Covariance [16]. Estimates of the covariance between the state and measurement noise
displayed in the operational input–output data matrixes [17] when the state or parameter estimation is performed using the EKF. Using M-Estimators for harmonic estimating, a new method has been presented to address the limitations of the MLE. Harmonics with variable amplitudes may be tracked using Kalman filtering theory without an integer number of samples in an integer number of cycles [19]. Variable Leaky Least Squares algorithm[20] employing leak adjustment approach to prevent drifting of parameters is provided and processed in arduino due microcontroller, which also supports its superiority.

Approach to Harmonic Estimation Problem I: Soft Computing

Soft computing is a relatively new idea, and its use in system analysis is still in its infancy. Power system harmonic estimates may be improved by using "soft" computing approaches, which are more tolerant of imperfection and partial truth than standard "hard" computing methods. There are several major fields of "soft computing," including "artificial neural networks," "fuzzy logic," "genetic algorithms," and "bounded form optimization."

Despite the fact that Evolutionary Computation and Neural Network methods may be used to estimate harmonics, there is still room for improvement by including a number of other traditional techniques into the equation. It has recently been created a variety of hybrid algorithms for estimating harmonics in a power system, such as Genetic Algorithm-Least Square (GA-LS), Particle Swarm Optimization-Least Square, and Adaptive Neural Network (ANN) [11]. monitoring the harmonic components of current and voltage waveforms [21] in a damaged power system using a GAP (Genetic Adaline Perceptrons)-based adaptive neural network.

The solution to the optimization issue relies on neural network concepts [22] and a signal processing strategy that have both been independently confirmed. Analog neuron-like adaptive processor designs are shown. It is now possible to estimate harmonic components using an algorithm inspired by the E. coli bacteria's foraging activity in human intestines [23]. To hasten convergence, the fundamental foraging method is made adaptable using a Takagi-Sugeno fuzzy scheme that takes into account the operating conditions. evolutionary strategies (ES), a branch of evolutionary algorithms, are used in a novel way to predict harmonic distortions in an electrical power system [24]. RLS and BFO have been developed for the precise measurement of harmonics[25] in distorted power system signals. The fundamentals of foraging are establishedRLS, which successively updates the signal's unknown parameters, is used to make the system adaptable. Accurate estimate of distinct harmonics components of a distorted power system signal is achieved by combining two computational intelligence approaches [26] such as artificial neural network and evolutionary computing techniques handling of local minima. Linear Neural Networks (Adaline) on the basis of starting weights[27] from BFO. The new algorithm's performance is compared

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to that of BFO. It is possible to increase the accuracy of harmonics estimate by using Kalman filter-modified genetic algorithm, and Kalman filter-bacterial foraging optimisation (KF-BFO).[28] The technique shows a significant improvement in both solution convergence and processing time. Conventional least square (LMS) technique for harmonic parameter estimation is claimed to have a slower convergence rate than an adaptive linear neural network and variable leaky least square (ADALINE-VLLMS) approach [29]. By feeding the neural network just half-cycle samples of distorted waveforms, an alternative technique based on the neural network methodology has shown good results for rapid and exact harmonic identification [30]. Sensitivity analyses are carried out to identify the most important aspects influencing the suggested model's performance efficiency in order to achieve the lowest mistakes in testing patterns. Simulation and experiments have shown the feasibility of a hybrid genetic algorithm that incorporates ANN methods [31]. A nonlinear phase and amplitude estimation issue is a harmonic estimation problem. Iterating between linear least squares amplitude estimation and nonlinear GA-based phase estimation, a structure is constructed with the use of genetic algorithms (GAs) [32]. This approach shows improvements in solution convergence and processing speed.

Using the fuzzy gain scheduling approach to change the step size for quicker convergence and noise rejection, a new technique based on Fuzzy LMS for the estimation of harmonic voltage and current signals in power networks was developed and successfully tested using real-time analysis[33]. It is impossible to effectively monitor power systems using traditional FFT based on fixed measurement windows when there is any frequency drift in the signal. However, one of the successful solutions for the aforementioned goal is the use of the Least Square approach with ANN to harmonics extraction in time changing situations. Any harmonic components in the power system may be detected using this approach since it can concurrently monitor frequency, amplitude, and harmonic components at different frequencies.

An improved estimation approach dubbed ADALINE [35] is used to estimate harmonic components in a power system synthetic signal using an adaptively interpreted linear Neuron. It is necessary to alter the learning parameter in order to maintain a sufficient difference between the actual and expected values in order to meet the error equation's requirement.

I.COMPARATIVE ANALYSIS OF CONVENTIONAL AND SOFT COMPUTING TECHNIQUE

After a rigorous review of all the paper related to power system harmonics estimation by different technique A comparative analysis is done by considering the following parameter. Conventional soft computing and Combination of Conventional and soft computing Table is formed from the references.

TABLE I

ESTIMATION PERFORMANCE OF SIGANAL PROCESSING, SOFT COMPUTING AND COMBINATION OF BOTH

Methods	Param-	Fund-	3rd	5th	7th	11th
Actual (Synthetic signal)	f(Hz)	50	150	250	350	550
	A (V)	1.5	0.5	0.2	0.15	0.1
	φ(°)	80	60	45	36	30
	A (V)	1.232	0.3126	0.1206	0.1323	0.0448

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RLS	Deviat-ion (%)	1.030	2.8506	14.382	2.3683	5.3872
	φ(°)	78.31	57.61	43.27	31.267	22.4[illegible]
	Deviat-ion (°)	0.460	0.4001	1.0881	1.261	3.8612
GA	A (V)	1.345	0.4562	0.1532	0.1423	0.0845
	Deviat-ion (%)	1.010	2.8438	12.982	2.4598	5.17[illegible]
	φ(°)	79.32	58.62	43.86	32.826	24.600
	Deviat-ion (°)	0.570	0.3002	2.0985	1.646	4.6993
RLS-GA	A (V)	**1.493**	**0.4973**	**0.1931**	**0.1499**	**0.0986**
	Deviat-ion (%)	1.030	2.9507	14.682	2.3597	6.2761
	φ(°)	**80.01**	**59.99**	**44.81**	**35.987**	**29.900**
	Deviat-ion (°)	0.60	0.3006	1.0657	1.139	3.892

II. CONCLUSION

From a signal processing method to a soft computing approach, this study gives a progressive evaluation of power system harmonics estimate technique. The most recent publications in this field are listed below. All the citations are included in a table in this document. Using the table, one can quickly see how accurate the estimate of amplitude and phase is to that of the harmonics in the case of combined method. Through modelling, testing, and real-time analysis, several studies have shown the usefulness of the combined approach methodologies. Because of these positive findings, it is advisable to use both a conventional and an adaptive computing strategy for the estimate of power system data.

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