Investigation on Harmonic Parameter Estimation and Power Quality Improvement in a Distribution Network

Research Plan for
Doctor of Philosophy
in
Electrical and Electronics Engineering

by
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1. Introduction-

Recent years have witnessed a thrust towards the extensive use of nonlinear power electronic devices in the electrical energy systems thereby deteriorating power quality. Because of this, power quality (PQ) analysis and its improvement has become a major concern for power engineers and researchers. Harmonics are the primary cause for poor power quality of the distribution system. The non linear loads like converters and solid state drives that employ high speed semiconductor power switches are the main sources of harmonics in the distorted power system signal. Estimation of magnitude and phase of these harmful harmonic interferences is necessary for the analysis and design of modern sophisticated equipments. The need for the effective elimination of such unwanted frequency components becomes essential for power system planning, analysis, and operation.

The most commonly used classical techniques for estimation of harmonics is Fast Fourier Transformation (FFT) of the signal. However, in applying FFT, the phenomena of aliasing, leakage and picket-fence effect may lead to inaccurate estimation. To overcome these drawbacks, least square (LS) and Recursive Least Square (RLS) algorithms have been commonly applied. But these algorithms are generally used for frequency estimation and not to be so effective for amplitude and phase estimation. However, Kalman Filter (KF) is a robust algorithm for estimating the amplitude and phase of sinusoids of known frequencies embedded in an unknown measurement noise. But this algorithm fails to track any dynamic changes of signal such as sudden changes in amplitude, phase or frequency of distorted signal. To overcome these problems associated in the above mentioned techniques, adaptive linear neural network (ADALINE) structure for estimation of harmonics is proposed. In ADALINE network, generally weights are updated online by using LMS, RLS and KF recursive algorithms.

In the past, the passive power filters were often used to compensate the harmonic distortion in the distribution system. The use of passive power filters are not preferred as they are bulky, derate itself with age and may cause resonance with series impedance. This has motivated the introduction of Active Power Filter (APF) for power quality improvement in distribution network. The APF has many advantages over a passive power filter. The APF can be smaller, cheaper, more versatile and less prone to failure than its passive counterpart.

The active power filter which is developed to overcome the shortcomings of the passive filter consists of a voltage/current source inverter, a DC-link storage capacitor and an output
filter. The basic principle of APF is to utilize power electronics technologies to produce current components that cancel the harmonic currents produced because of the nonlinear loads applied in distribution network. As a solution to this situation, the different topologies of active power filters have been developed based on application and its simplicity in structure. The harmonics filtering task employing hybrid active power filter is divided into these two filters. The APF cancels the higher order harmonics, while the passive filters cancels the lower order harmonics. The main objective in the development of HAPF is to reduce the cost and the rating of an active filter by using a passive filter that filters the dominant harmonics caused by non-linear loads and supplies reactive power requirements.

Generation of reference signals either in terms of voltages or currents is an important part of APF control. Control strategies in frequency-domain are discrete Fourier transform (DFT), Fast Fourier Transformation (FFT), Kalman Filter (KF), wavelet transform, etc. The frequency domain methods require large memory, computation power and the results provided during the transient condition may be imprecise. In order to overcome these limitations, time-domain approach such as d-q transformation, p-q transformation, symmetrical components transformation, etc are based on the measurements and transformation of three-phase quantities. However, these three-phase to two-phase transformation methods, fails to work effectively under distorted voltage condition. Recent study has proposed ADALINE-based approach to extract the fundamental sinusoid from a distorted load current waveform, which is a simple and fast method of current extraction.

2. Literature review-

Current pollution of electrical networks has become a major power quality problem in recent years. This is mainly due to the increasing use of nonlinear loads; especially power electronics converters in power systems. This has necessitated worldwide interest in harmonic studies, including harmonic estimation, elimination and a variety of related areas.

A Review on Harmonics Estimation-

Harmonics are a mathematical way of describing distortion in voltage or current waveform. The term harmonic refers to a component of a waveform occurs at an integer multiple of the fundamental frequency. Estimation of the harmonic components in a power system is a standard procedure of the assessment of quality delivered power. Several methods such as
discrete Fourier transforms, least square error technique, Kalman filtering, adaptive notch filters etc; has been used for harmonic estimation of distorted signals in power system. Some of the methods used for harmonics estimation purposes are described here.

Fast Fourier transform (FFT) is an efficient method for harmonics estimation and it produces reasonable results for a large class of signal processes [1]. Though it has some advantages but still there are several performance limitations of this approach.

Ref [2, 3] proposed several variants of Recursive Least Square (LS) algorithm for estimation of power system Harmonics. They have used a noisy harmonic signal from an AC bus of a six-pulse Rectifier as a test signal and applied various RLS algorithms to signals having different SNR values.

A. Pradhan et al; [4] and Pravat Ray et al; [5] proposed the power system frequency estimation using LMS and VLLMS algorithms respectively. The three-phase voltages are converted to a complex form for processing by the proposed algorithm. To enhance the convergence characteristic of the complex form of the LMS algorithm, a variable adaptation step-size is incorporate. In VLLMS approach uses a variable leaky adjustment technique to avoid drifting of the weights involved in the estimation mechanism.

In kalman filter [6] individual harmonics injection source is treated as a random state variable. Error covariance analysis of harmonic injection source is treated as a random state variable. Based on this optimal arrangement, the kalman filter was able to estimate and track each harmonic injection in power system. Kalman Filter estimates amplitude and phase when frequency is fixed.

Mandel [7] and Ray Pravat [8], suggested Ensemble Kaman 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. This ref. described the derivation and practical implementation of the basic Version of EnKF. Qidwai and Betayeb et al; [9] use Genetic algorithm (GA), for this purpose. But GA suffers from larger time requirement for convergence when estimating multiple frequency components.

Dash et al. [10] presented an ADALINE structure for estimation of harmonic components of a power system. The learning parameters in the proposed neural estimation algorithm are adjusted to force the error between the actual and desired outputs to satisfy a stable difference.

Joorabian et.al. [11] and Sarkar [12] described decomposition of 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 harmonic components is not discussed.

Hybrid estimation algorithms such as KF-ADALINE, RLS-ADALINE and ADALINE-BFO, for estimation of power system frequency and harmonics are presented in [13]. ADALINE based algorithms achieving faster convergence in estimating the frequency and harmonics of distorted signal.

**A Review on Harmonics Elimination**

The effect of Harmonics due to linear and non-linear load in power system was not a major issue in the last 40 years, however, in the recent year the number of harmonic producing devices is increasing rapidly from low-voltage to high voltage application. Which increases the generating capacity of harmonics, the increased severity of harmonics pollution in power network has attracted the attention of many researchers to develop different types of device to mitigate the harmonics and enhance the power quality. A progressive development of various devices and control algorithm used for Harmonics elimination in power system to enhance the power quality discussed in this section.

Ref [14] and [15] presented a comprehensive review of active filter configurations, control strategies, selection of components, other related economic and technical considerations, and their selection for specific applications.

The most important configuration widely used in active filtering applications for current harmonic reduction and power factor improvement is the shunt active power filter (SAPF) [16-22]. A SAPF consists of a controllable voltage or current source inverter. The voltage source inverter (VSI) based SAPF is the most commonly used type, due to its well known topology and straight forward installation procedure. SAPF acts as harmonic current source which injects an anti-phase but equal magnitude of the harmonic and reactive current as that of nonlinear load. As a result components of harmonic currents contained in the load current are cancelled and the source current remains sinusoidal and in phase with the respective phase to neutral voltage. Two separate loops are considered to control the APF. Current control loops is used to separate the
harmonics components from sensed load currents with fast dynamics, and voltage control loop is considered to maintain the DC-Link capacitor voltage and minimize the system loses.

Victor Corasaniti et al; [23] and Srianthumrong et al; [24] proposed new control algorithm for medium-voltage three-phase shunt HAPF to eliminate harmonics, correct supply power-factor, and balance the nonlinear unbalanced loads. HAPF is formed with the connection of a low-rate APF in series with one or several passive filters is gaining attention. That type of combination allows significantly reducing the rating of APF [25-27]. These A seventh order low cost passive filter is used to eliminate seventh order harmonic. No additional switching ripple filters is required for the hybrid filter because its LC circuit accomplishes the filtering of the switching ripples.

S. Rechka et al; [28], L. Asiminoaei et al; [29] and D. Chen et al; [30] proposed two major approaches that have emerged for the harmonic detection namely, time domain and the frequency domain methods. The frequency domain methods include, Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT), Recursive Discrete Fourier Transform (RDFT), kalman filter, and wavelet transform based methods. The frequency domain methods require large memory, computation power and the results provided during the transient condition may be imprecise. On the other hand, the time domain methods require fewer calculations and are widely followed for computing the reference current. The two mostly used time domain methods are synchronous reference (d-q-0) theory and instantaneous real-reactive power (p-q) theory. But, these three-phase to two-phase transformation methods, fails to work properly under distorted voltage condition. R. Pereira [31], Q. Wang [32], M. Cirrincione [33] and B. Singh [34], have proposed ADALINE-based approach to extract harmonics from a distorted load current waveform, which is a simple and fast method of current extraction. This control provides a very precise solution to get the reference current even under unbalanced conditions of supply voltages. This procedure significantly reduces the real-time computation burden.

3. Objective of the research work-

- To describe importance of power quality with regard to harmonics, understanding the impact of non-linear loads on power system and need for harmonic estimation and elimination.
• To estimate the harmonics magnitude and phase using combined ADALINE-recursive algorithm.
• To compare the proposed estimation algorithms with conventional algorithms.
• To validate the proposed estimation algorithms on data obtained from laboratory and industrial setup.
• To develop mathematical modeling of proposed active power filter connected in a distribution network.
• To simulate and analyze the proposed system using MATLAB/SIMULINK platform.
• To develop a harmonic filtering strategy that reduces the switching frequency requirements of the APF system.
• To regulate the DC-Link capacitor voltage at a fixed reference level without any external power supply.
• To develop new hybrid control technique based active power filter for harmonic elimination and reactive power compensation in a distribution network.
• To develop a laboratory prototype model for validation of proposed controller employed.
• To exploit the efficacies of the developed estimation algorithms for designing control performance of APF.
• Additional goal is to create self-adjustable controller that will adapt for load changes.

4. Research Methodology-

• Extensive literature survey
  The analysis starts with a literature studies which are related to the research work. A completed studies and investigations were carried out on the characteristic of nonlinear loads, voltage and current distortion, total harmonic distortion, power factor, active power and reactive power. In the literature survey, various topologies have been evaluated which might be able to fulfill the design specifications. Based on the literature survey, topology of active filter along with control techniques can be proposed in this work.

• Development of robust hybrid algorithm
  Both time domain and frequency domain control strategy for APF/HAPF will be developed. A new combined ADALINE-based recursive algorithm for calculation of
reference signal fed to proposed controller based active will be developed. That proposed algorithms will be compare with existing algorithm, to verify the effectiveness.

- **Performance verification**
  
  In measuring power factor, harmonics in term of Total Harmonic Distortion (THD) and power ratings of different nonlinear loads, MATLAB software was used. After collecting the data and identifying the problems associated with diode bridge rectifier, an APF/HAPF circuit has been designed in order to achieve unity power factor.

- **Development of laboratory prototype model**
  
  Finally a laboratory prototype is build up, and experimental results are obtained by conducting various tests.

### 5. Time Schedule for Ph D thesis work

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<th>Task</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; Sem (Jan-June) 2014</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; Sem (July-Dec) 2014</th>
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<td>Development of hybrid algorithms for harmonic identification and detection</td>
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6. References