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A Review on Power Quality Analysis, Techniques, Methods and Controlling

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ABSTRACT: The emergence of power quality (PQ) issues has recently increased because of the increased use of power electronic equipment, which results in a deviation of voltage and current waveforms. The PQ monitoring is covered by two main subjects: the development of PQ indices to quantify the power supply quality and the electrical disturbances detection such as harmonics, sags, swells, flicker etc., which allows knowing the conditions of the electric power systems. In this study a review of techniques and methodologies developed for PQ analysis and power quality controlling techniques are presented in order to improve the system performance.

KEYWORDS: Flicker, Harmonics, Power Quality, Power Quality Monitoring, Voltage sag, Voltage swell.

I. INTRODUCTION

The improvement of techniques and methodologies focused on the diagnosis of power quality (PQ) has taken great interest nowadays owing to the sensitivity of modern equipment and a host of problems originated by electrical systems in the presence of unregulated framework and energy supply, which does not meet appropriate stipulations [1].Also, the growth of non-linear loads and electronic devices that are source of disturbances in voltage and current signals [2]. Due to the fact that these problems directly affect consumers in production times and costs, nowadays there is a demand by industry for continuous monitoring power systems. Power quality indices (PQI) are the basis of PQ standards for illustrating the negative impact of electrical disturbances [3–5]: power frequency deviation, supply voltage variations, flickers, transient voltages, and harmonics and so on. Both traditional indices [peak values, crest factor, total harmonic distortion (THD), power factor and so on] and new proposed indices in the literature (normalized instantaneous distortion energy ratio, instantaneous frequency, burst indices and so on) are mostly obtained from the signal frequency spectrum and Parseval's theorem [6].The standards refer to methods in the frequency domain for providing a tolerance in the used algorithms such as fast Fourier transform (FFT), Goertzel algorithm, chirp Z transform, Welch algorithm, zoom FFT, amidst others, which have been widely used for electrical-parameter monitoring [7, 8]. However, sometimes the information provided by the standards is insufficient as shown in [9].

It also displays study cases in which standards are also insufficient. Moreover, in [10] some problems that are not resolved by the standards are described. One of the main limitations of FFT-derived techniques [11] is that they use stationary signals; hence, their use is not suitable for detecting transient or short spikes in the signal. To overcome this problem, multiple studies propose new PQI for transient signals using time–frequency algorithms allowing the energy estimation of harmonic components, such as the short-time Fourier transform (STFT), wavelet transform (WT), Kalman filters (KF) etc. This paper presents a review of the techniques and methodologies developed for PQ analysis in transmission and distribution systems. In Section II, the signal analysis of PQ indices are presented. Afterwards in Section III, the frequently used techniques for signal analysis are described. Then in section IV various PQ controlling techniques are presented. Finally, in Section V, some conclusions are made.

II. SIGNAL ANALYSIS IN POWER SYSTEMS

Power systems are generally classified in generation, transmission and distribution; the scope of this work just covers the last two. An important aspect studied in transmission systems is transient oscillations, which may result from the loss of major transmission and generation resources and may also be complicated by control actions, switching events and changes in system topology and operating conditions [15]. Accordingly, it is necessary to monitor the

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oscillating modes' parameters through measurements in real time that arise after a system disruption. Fortunately, over the last few years there has been a growing deployment of system-wide measurement activities through wide-area measurement systems that collect data using phasor measurement units from different locations, synchronizing time through global positioning systems. These data comprise measurements of voltage magnitudes and angles, current magnitudes and angles, active and reactive power and system frequency gathered at a high sampling rate [16]. A review of the methods used for estimation of oscillations characteristics in power systems has been carried out in [17]; such work includes techniques like Prony analysis (PA), KF, matrix pencil, Hankel analysis and so on. Likewise, it presents combination of techniques like the Hilbert–Huang transform [18], which improve both the masking technique and the computation of Hilbert transform.

III. TECHNIQUES USED IN SIGNAL ANALYSIS

The most used techniques for non-stationary signal analysis are short time Fourier transform, WT, filter bank, Gabor transform (GT), S-transform (ST), PA, KF, Cohen class and parametric methods. These algorithms allow obtaining information in time and frequency domain. The best-known technique for frequency-domain analysis is the Fourier transform (FT). However, it just works well for the infinite time case of a stationary signal and it is unable to resolve any temporary information associated with fluctuations. To resolve this, the STFT divides the signal into small segments, where these signal segments can be assumed to be stationary [12]. The STFT works well provided that the window is short enough compared to the fluctuation rate. High rates of fluctuation can lead to significant errors [19]. The FT correlates the signal with sine and cosine functions. Similarly, for transient signals, in [20], a portion of the time-domain signal is compared at each time with the damped sinusoidal functions of a redundant dictionary.

Nowadays, WT is the most popular technique employed to obtain characteristic in time–frequency domain. Many kinds of mother wavelet have been proposed including complex wavelet [21]. Other works use the combination of WT and FFT for obtaining certain characteristics of the signal under analysis [22–25]. In 1988, Mallat established a new arithmetic of the WT based on multi-resolved analysis (MRA) [26]. The signal being analyzed is first decomposed into distinct representations: one rich in high frequencies and the other in low frequencies, by processing the signal through high- and low-pass filters. This process is repeated as the signal is filtered at succeeding levels of detail; the filtering is accompanied by a down-sampling operator, which reduces the amount of information passed to subsequent levels [27]. This type of methodology MRA is widely used in various non-stationary signal analyses for different electrical problems such as rotating machines [28]. Sometimes a filter is applied to remove the fundamental frequency component so that the remaining signal, attributed to disturbance events, can be analyzed [29, 30] use this methodology to detect PQ disturbance and evaluate PQI.
Similar to the MRA, band-pass filters will be able to extract the high-frequency signals representing sudden changes in power systems as: transients caused by power system faults or power system switching operations, as well as the rapid rises or falls of the system voltage [13, 31]. On the other hand, low-pass filters can extract slower signals, such as steady state distortions like power system harmonics [32]. Therefore an appropriate combination of several band pass filters will be able to obtain the necessary information to identify the PQ problems. To illustrate the general concept of a filter bank, the diagram in Fig. 1 shows a block diagram, where the signal under analysis x(t) is divided into frequency bands. These bands are determined by the coefficients of each filter for being evaluated afterwards. Another kind of filter is a complex band pass filter presented in [14, 33–35], which can correctly extract the phasor of the fundamental component and symmetrical components in voltage or current waveforms and then accurately estimate their instantaneous amplitude, phase angle and frequency, even encountering various power disturbances.

Different strategies have been proposed in the literature with respect to the phase detector strategy [36]. Some of the methods for generating harmonic references require phase locked loop (PLL) or frequency estimators to identify the specific harmonic frequency before the corresponding reference is generated [37]. They are also capable of evaluating frequency in the presence of transient disturbances. Thus, they can be applied to both synchronous sampling in instrument applications and synchronisation to the power frequency [38]. GT is effective in monitoring the frequency variation of a signal as time varies. For those time intervals where the function changes rapidly, the method can zoom in on the area of interest for better visualization of signal characteristics [39].

Other work [40] presents the Gabor–Wigner transform which combines the GT with the Wigner distribution function. This method improves the time and frequency resolutions at the same time, and covers the cross-term problem

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of WDT and the low clarity of GT. In addition, it is shown that the window width is critical for time–frequency analysis. The ST is an extension to the GT and WT. Several studies have used ST for the analysis of power systems [41–51] because the method allows location in time; real and imaginary components of the spectrum. Some methods based on the non-stationary model of a power disturbance waveform that consider the fundamental frequency as a variable, have been proposed. A variety of non-linear curve fitting and unconstrained optimization tools were further employed to realize both high accuracy and fast convergence of the amplitude and frequency estimations. In [23], the curve-fitting technique is used to estimate sudden voltage step changes. Curve-fitting methods include the Kalman filtering, the recursive least squares algorithm, the non-recursive Newton-type algorithm, the recursive Newton-type algorithm and artificial neural networks (ANNs) [34]. PA identifies the amplitudes, damping factors, frequencies and phases contained inside the observed signal. This method is used to supervise power system transient harmonics, or time-varying harmonics. [37], calculates PQI in the presence of non-stationary disturbance [52], detect power oscillations [53] and so on. KF are useful tools for many power system applications; for example, real-time tracking of harmonics, estimation of voltage and current parameters in power system protection and estimating the parameters of transients [13]. When the underlying system model is non-linear, it is required to extend the KF through a linearization procedure known as extended Kalman filter (EKF). EKF is used to accurately track the change in amplitude, frequency, phase and harmonic content of the distorted signal [41]. Other methodology [54] presents a hybrid approach for tracking the amplitude, phase, frequency and harmonic content of PQ disturbance signals occurring in power networks using an unscented Kalman filter.

Cohen class defines different types of time–frequency distributions (TFD). Different types of TFD with special properties have been proposed for improving the time– frequency resolution in the analyzer of PQ; some examples are the spectrogram, Wigner–Ville distribution [19, 55], Choi–Williams distribution and reduced interference distribution [52]. In [56], the importance of the choice of kernels that determines the properties of various TFD suitable for PQ analysis is discussed.

Parametric methods offer high frequency and time resolution; these methods have also been proposed to analyze non-stationary waveforms in power systems using signal models and furnish a time frequency representation of a waveform and providing the time variations of spectral component parameters [52]. Parametric methods estimating the parameters of the models through linear-prediction techniques, singular value decomposition, Burg algorithm, the Marple algorithm and so on [37], which require high computational resources and processing time.

IV. CONTROL TECHNIQUES

The major power quality problems in the power system are voltage sag, swell, harmonics, flicker, etc. There are several techniques available to monitor these problems as discussed in Section III. The control of monitored disturbances improves the system performance. There are several methods/techniques used to mitigate those problems as discussed below.

A. VOLTAGE SAG & SWELL MITIGATION TECHNIQUES

One of the important issues in power system is voltage sag. Dynamic Voltage Restorer (DVR), a custom power device mitigates the sag, swell and maintains the load voltage constant as shown in Fig.1.PI controller and discrete PWM generator controls the DVR. The PI controller generates the signal for the PWM generator that in turn injects the voltage into the line for mitigation [57].

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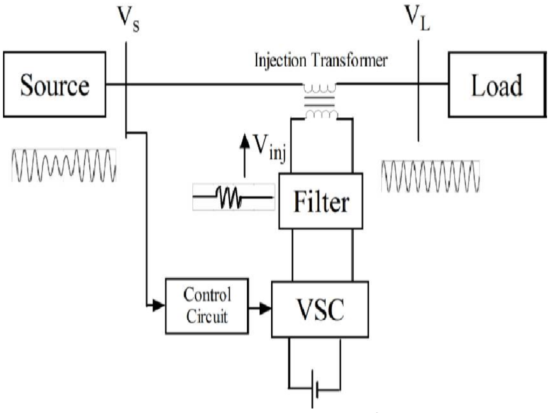

Fig.1 Control circuit of DVR

The hysteresis controller overcomes the disadvantages of PI controller [58] with the advantages like easy implementation, fast response, simple operation, etc. The two methods that generate the reference voltage in this paper are Fourier transform technique and Synchronous Reference Frame theory. These two methods detect the condition of voltage sag/swell and give the reference voltage. The difference between reference voltage and the injected voltage produces an error signal. The hysteresis controller receives the error signal as input for generating the gating pulse for IGBT used in voltage source converter.

B. HARMONIC MITIGATION TECHNIQUES

Harmonics is the major problem in the power system that causes many disturbances in the power system operation. There are various ways of mitigating the harmonics. One of the main methods is the use of filters: the active or passive filter. The paper [59] discusses the various types of passive filters such as Passive series filter, Passive shunt filter; Passive harmonic filters (single tuned and high pass filter). In [60], The Shunt Active Power Filter mitigates the harmonics and the hysteresis current controller produces the gating signals for the inverter. Adaptive hysteresis current controller and fixed band current controller are the two types of hysteresis current controller available. The fixed band hysteresis current controller offers good accuracy, good stability, fast response, and simple operation.

C. FLICKER MITIGATION TECHNIQUES

Flicker is the fluctuations in the voltage waveform that causes quite disturbances in the power system network. The dynamic Volt/VAR control is one of the flicker mitigation techniques that dispatches the reactive power based on voltage fluctuations within the flicker frequency band [61].In [62], a coordinated control of active and reactive power control mitigates the flicker contribution in the distributed wind generation. Active power control ensures the margin level of reactive power absorption for reducing the severity of flicker level.

V. CONCLUSION

Power quality is a major concern in today's power system network. This survey discussed the recent methodologies or techniques used to monitor the power quality events and parameters and controlling techniques for different power quality issues. According to the developed review, it can be concluded that the techniques commonly used for PQI estimation for are WT, ST, KF, filter bank and sometimes a combination of two of them, while the latter significantly improves the estimation results. Regarding event classification, the trend has been the use of algorithms based on AI and SVM. The major problems with these methodologies proposed are the increase on the required computational resources and the large amount of data that have to be continuously analyzed, which limits their online performance and implementation in technological platforms such as digital signal processors, field programmable gate arrays, microprocessors or microcontrollers.

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