A Review on Unified Power Quality Conditioner for 3P4W System

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Abstract – Power Quality is the hot issue in the power world. Due to continuous use of the non-linear loads the voltage and current waveform shows the distortions. This distorted waveform produces quality issues in the distribution system. Power quality (PQ) mainly deals with issues like maintain a fixed voltage at the point of common coupling (PCC) for various distributed voltage levels irrespectively of voltage fluctuation, blocking of voltage and current unbalance from various distribution levels. In this paper discuss the various type of harmonics generated due to presence of the non linear loads. Also discuss the literature behind the Unified Quality Conditioner (UPQC) for three phase four wire system (3P4W).

Key Words: Power Quality, PCC, PCC, UPQC, 3P4W, etc,…

1. INTRODUCTION

With the advent of power semiconductor switching devices, like thyristors, GTO's (Gate Turn off thyristors), IGBT's (Insulated Gate Bipolar Transistors) and many more devices, control of electric power has become a reality. Such power electronic controllers are widely used to feed electric power to electrical loads, such as adjustable speed drives (ASD's), furnaces, computer power supplies, HVDC systems etc. The power electronic devices due to their inherent non-linearity draw harmonic and reactive power from the supply. In three phase systems, they could also cause unbalance and draw excessive neutral currents. The injected harmonics, reactive power burden, unbalance, and excessive neutral currents cause low system efficiency and poor power factor. In addition to this, the power system is subjected to various transients like voltage sags, swells, flickers etc. These transients would affect the voltage at distribution levels. Excessive reactive power of loads would increase the generating capacity of generating stations and increase the transmission losses in lines. Hence supply of reactive power at the load ends becomes essential. Power Quality (PQ) has become an important issue since many loads at various distribution ends like adjustable speed drives, process industries, printers; domestic utilities, computers, microprocessor based equipments etc. have become intolerant to voltage fluctuations, harmonic content and interruptions. Power Quality (PQ) mainly deals with issues like maintaining a fixed voltage at the Point of Common Coupling (PCC) for various distribution voltage levels irrespective of voltage fluctuations, maintaining near unity power factor power drawn from the supply, blocking of voltage and current unbalance from passing upwards from various distribution levels, reduction of voltage and current harmonics in the system and suppression of excessive supply neutral current.

Conventionally, passive LC filters and fixed compensating devices with some degree of variation like thyristor switched capacitors, thyristor switched reactors were employed to improve the power factor of ac loads. Such devices have the demerits of fixed compensation, large size, ageing and resonance. Nowadays equipments using power semiconductor devices, generally known as active power filters (APF's), Active Power Line Conditioners (APLC's) etc. are used for the power quality issues due to their dynamic and adjustable solutions. Flexible AC Transmission Systems (FACTS) and Custom Power products like STATCOM (Static synchronous Compensator), DVR (Dynamic Voltage Restorer), etc. deal with the issues related to power quality using similar control strategies and concepts. Basically, they are different only in the location in a power system where they are deployed and the objectives for which they are deployed. Active Power Filters can be classified, based on converter type, topology and the number of phases. Converter types are Current Source Inverter (CSI) with inductive energy storage or Voltage Source Inverter (VSI) with capacitive energy storage. The topology can be shunt, series or combination of both. The third classification is based on the number of phases, such as single phase systems, three phase systems or three phase four wire systems.

The UPQC is now a day's more popular for reduction in voltage and current issue in power quality. In this paper discuss the literature regarding to the different approach utilize in reduction of harmonics in the UPQC

2. HARMONICS IN POWER SYSTEM

Many of researchers are work together for reducing the harmonics in the power grid. Due to growing use of non-linear loads and devices harmonics are generated. This harmonic produce distorted voltage in the supply system. So it reduces power quality. AhChoy Liew [1] analyzed excessive neutral currents in 3P4W fluorescent lighting due to harmonics. These effects cause the neutral current to exceed 75% to 157% of the phase currents. These high neutral currents are accounted by three main components, namely fundamental phase current unbalance, third-harmonic current caused by saturation of ballasts and more third-harmonic current caused by third harmonic voltage waveform distortion in the supply. Gruzs [2] proposed survey results across computer sites in U.S. which indicates a 22.6% of the sites showing neutral current exceeding the full-load phase currents due to the effect of non linear properties of the load. Such effects lead to the malfunction of other sensitive loads which are connected to the PCC. Po-Tai Cheng et al [3] proposed a method of new harmonics suppression scheme for the neutral current in 3P4W distribution system. In this method, a series active filter was connected in series with the neutral conductor which reduced the effect of harmonics on the neutral conductor without over loading the distribution transformer. Peng et al [4] published an article about the characteristics of the harmonics due to non-linear loads. The non-linear loads are characterized into two types of harmonic sources, namely current source non linear loads and voltage source non linear loads. These two types of harmonic sources are completely distinctive and exhibit dual properties and characteristics. Based on their properties and characteristics, the current-source nonlinear loads and voltage-source nonlinear loads have their own suitable filter configurations. The personal computers draw non-sinusoidal current with odd harmonics more significantly. Power quality of distribution networks is severely affected due to the flow of these generated harmonics during the operation of electronic loads. Ming -Yin Chan et al [5] conducted another case study in an office building with a large number of computers which are analyzed as a major source of harmonics. The study focused on the characteristics and effects of harmonic distortion of load current and voltages on distribution systems. It also suggested that proper planning and designing could minimize the harmonic-related problems in electrical systems. Venkatesh et al [6] suggested a method for optimal location of filters for harmonic analysis in the distribution system. The nonlinear loads used in domestic and small scale industrial distribution systems are also modeled and simulated. Jabbar Khan & Akmal [7] discussed the mathematical modeling of odd order harmonics in current like 3rd, 5th, 7th and 9th which influence the power quality.

3. BACKGROUND OF UPQC CONTROLLERS

In the three phase four wire system, many loads are connected in single phase and neutral. Due to this it produces system unbalance which leads to flow of current in the neutral conductor. The harmonics component of current will transfer along the fundamental current in the phase and neutral. The following survey discusses the elimination technique of the harmonics and compensation of neutral current in the power system with the help of UPQC. Hideaki & Akagi [8] presented a method with the integration of series active filter with double series diode rectifier. This method opened up a new harmonic current-free AC/DC power conversion system characterized by the integration of small rated series active filter with a large-rated double series diode rectifier. The DC terminals of the active filter are directly connected in parallel with those of the diode rectifier, thereby forming a common DC bus. The active filter enables the diode rectifier to draw threephase sinusoidal currents from the utility. In addition, it can provide the supplementary value-added function by regulating the common DC bus voltage to a limited extent of 5%. It slightly increases the rms voltage rating, while the peak voltage rating does not show any increase. Kim & Kim [9] performed a study on the control method of series active power filter for compensation of harmonics and reactive power. This method presents a control algorithm for a 3-phase 3-wire series active power filter. The control algorithm compensates the harmonics and reactive power which are generated by nonlinear loads, such as a diode or a thyristor rectifier. These control methods implements the generalized p-q theory. It is applied to both harmonic voltage source and harmonic current source. The advantage of this control method is the direct extraction of compensation voltage references. Po-Tai Cheng et al [10] proffered a design of a neutral harmonic mitigator for 3P4W distribution systems. The single-phase rectifier front-ends draw significant zero sequence triplen harmonics current from the line. These harmonic components accumulate in the neutral conductor due to their zero sequence nature and result in overloading of the conductor and the distribution transformer. In this method, an active filter inverter is placed in series connection with the neutral conductor to suppress the excessive current harmonics. They prevent the overloading problem of the neutral conductor and the distribution transformer. Han et al [11] introduced a series active filter for voltage drop compensation and voltage unbalance. It contributed to the study of a three phase series active power filter for compensate harmonic currents, voltage drop and unbalanced voltage in the power distribution system. The main circuit of the APF consists of voltage source inverter with a space vector modulation and high pass filter connected in parallel to the power system. APF is connected in series to the transmission line through a single phase transformer with turn ratio of 1:1.

Escobar et al [12] designed a controller to compensate voltage sags, unbalance and harmonic distortion using a series active filter. This method presented an adaptive controller for the series active filter to guarantee a sinusoidal balanced voltage on the load side despite of the presence of perturbations in the source voltage such as unbalance, harmonic distortion, sags and swells, as well as disturbances in the load current such as step changes, unbalance and distortion by higher order harmonics. To accomplish the objective, the series active filter is forced to inject the appropriate voltage to the line through a series connected transformer. Myoung Lee et al [13] employed a control of series active power filter that compensated for source voltage unbalance and current harmonics. In this method, a digital all pass filters and conventional space vector methods are used to generate the reference voltage and current compensation. Shafiee & Machmoum [14] advanced a simplified analogical control of a UPQC. This method deals with a UPQC consisting of a series and parallel active power filtering. An analogical method of perturbation detection for current and voltage parts is presented. To make them totally analogous, the regulators used for different parts of the system were also designed with analogue PID controllers. Carlos et al [15] explored the optimization of a series active filter under unbalanced condition acting in the neutral current. This method considered the limitations of the series active power filter operating in unbalanced 3P4W systems and recommended the insertion of series active impedance to neutral wire. The control of this active impedance uses a modified synchronous reference frame controller in order to mitigate the flow of zero sequence harmonic components. Inoue et al [16] postulated control methods and compensation characteristics of a series active filter for a neutral conductor. The distinct functions of the proposed active filter are the mitigation of the third harmonic voltage and the neutral current in a 3P4W distribution system in a building. The required power of the active filter is less than 10% of that of the harmonic-producing loads. A control method of the DC capacitor voltage on the active filter circuit was also described. Khadkikar & Chandra [17] discussed a method based on the p-q theory. This method presents a direct control strategy of UPQC used in the nonlinear and unbalance 3P4W system. An algorithm of calculating the series compensation current and shunt compensation voltage is introduced. An analysis of the proposed control strategy and its schematic diagram is described in particular. The results show that, the harmonic current, reactive power of load as well as neutral current are compensated well when unbalance and nonlinear occurs in load current and also power factor of the system maintains about unity.

Bingruo Xie et al [18] conducted a research on a new three phase series hybrid active power filter. This method is proposed to reduce inverter capacity and enhance system reliability in the distribution system. This method uses synchronous reference frame theory. It consists of a three phase series hybrid active power filter with a small self-inductance series transformer. Fatiha Mekri et al [19] pondered over the performance of UPQC for the improvement of power quality. This method presents a new control design of UPQC for current harmonics and voltage compensation in a power distribution system. The topology of the UPQC is based on a combination of two three-phase series and parallel active power filter. The determination of voltage references for series active power filter is based on a robust three phase digital PLL system using fuzzy regulator. The control strategies related to fuzzy hysteresis band voltage and current control methods, where the band is modulated with the system parameters to maintain the modulation frequency nearly constant. Bhim Singh & Venkateswaralu [20] presented a simplified control algorithm for a 3P4W UPQC to compensate load voltage distortions and unbalance, load current harmonics, neutral current, reactive power and the load unbalance as well as to maintain Zero Voltage Regulation (ZVR) at the point of common coupling. The UPQC is realized by the integration of series and shunt active filters sharing a common DC bus capacitor. The shunt AF is realized using a three-phase, four leg voltage source inverter and the series AF is realized using a three-phase, three leg VSI. The reference current and voltage are generated using Synchronous Reference Frame (SRF) controllers. A dynamic model of the UPQC is developed for different supply and loading conditions. Othmane et al [21] chose to use Adaptive Neuro-Fuzzy Inference System (ANFIS) and Fuzzy Inference System (FIS) methods to improve UPQC performance. This method introduces the preliminary results when compared to other methods. The theoretical foundations are laid down and the details of the adaptive fuzzy system are presented. The results of application of DC-bus voltage control are included during the compensation of several perturbations.

Teke et al [22] introduced a novel reference signal generation method for an UPQC which is adopted to compensate current and voltage quality problems on sensitive loads. The UPQC consists of a shunt and series converter having a common DC link. The shunt converter eliminates current harmonics originating from nonlinear load side and the series converter mitigates voltage sag/swell originating from the load and supply side. The controllers developed for shunt and series converters are based on an enhanced PLL and nonlinear adaptive techniques. Paduchuri et al [23] presented a design of a UPQC connected to 3P4W system. The neutral of series transformer is used as the fourth wire of the 3P4W system. The neutral current that may flow towards transformer neutral point is compensated by using a four leg voltage source inverter topology of shunt part. The series transformer neutral will be at virtual zero potential during all the operating conditions. Kalyanasundaram et al [24] implemented a new concept of UPQC for mitigating power quality problems in the distribution system. The new concept is also known as UPQC-S, in which the series inverter of UPQC is controlled to perform reactive power sharing. The reference voltage signal for controlling the series inverter is generated using the UPQC controller based on Power Angle Control (PAC) approach. The active power control approach is integrated with the theory of PAC approach to perform the two functions simultaneously.

Despandey et. al [25] proposed d-q-0 theory for referencing fundamental voltage in series active filter. The UPQC is realized by the integration of series and shunt active power filters (APF) sharing a common dc bus capacitor. The realization of shunt APF is carried out using a three-phase, four-leg Voltage Source Inverter (VSI), and the series APF is realized using a three phase, three-leg VSI. To extract the fundamental source voltages as reference signals for series APF, d-q-0 theory is used. For the control of shunt APF, Clark transformation concept is applied. The performance of the applied control algorithm is evaluated in terms of source neutral current mitigation, mitigation of voltage and current harmonics in a three-phase, four-wire distribution system for different combinations of linear and non-linear loads. The reference signals and sensed signals are used in a hysteresis controller to generate switching signals for shunt and series APFs.

4. PROBLEM FORMULATION

Power industry shapes and contributes to the welfare, progress, and technological advances of every nation and humanity. The growth of electric energy consumption in the world has been phenomenal. Electric energy sales have been grown well in the period between the turn of the century and the early 2020s. This growth rate was several hundred times as much as the growth rate in all other energy forms used during the same period. At the same time, it is very crucial to provide quality and reliable power supply to the consumers. But due to this development, maintaining the power quality within its standard becomes a very difficult task. With the development in the computer products, a lot of sensitive components are connected to the 3P4W systems which lead to the injection of harmonics in the distribution system. The harmonic current flowing through lines distorts the bus voltage and creates problem on sensitive loads operating on the same bus. So this harmful harmonics should be completely reduced or it can be limited within some safe guard limit to protect the loads connected in the line. The thesis deals with two important problems which occur due to harmonics.

The first problem relates to the effect of harmonics on the neutral conductor of 3P4W distribution system. Most of the loads connected to the distribution systems are connected between any one of the phase conductor and the neutral. It leads to an unbalance condition and the flow of current in the neutral conductor. The commercial buildings which have thousands of computers are connected in such a manner, which injects the harmonic components in the neutral conductor along with the fundamental due to unbalance loads. The survey shows that current in the neutral is more than 160% of the phase conductor due to harmonics. Its results in the following harmful effects on the neutral conductor:

- Wiring failure due to improper sizing of neutral conductor.
- Over heating of transformer due to harmonic currents and insulation damage and failure.
- Excessive neutral to ground voltage due to voltage drop caused by the neutral conductor results in malfunction of sensitive electronic components.
- Due to these harmonic currents, other loads connected to the PCC also get affected.
- De-rating of the distribution transformer which affects the three-phase sources and the phase conductors too.

The neutral current is predominant in the zero sequence components i.e. third order harmonics. This effect of harmonics on the neutral conductor should be eliminated in order to enhance the power quality in the distribution system.

The second problem is concerned with the influence of harmonics on the load current, load voltage and unbalance system. The non linear loads such as arc furnaces, power converters and diode rectifiers are commonly used in power systems. These switching devices have the properties of injecting harmonics which lead to the distortions in the load current and load voltage waveform. The following problems are identified in the 3P4W system due to non ideal relation between the voltage and current.

- Load current harmonics- impact of non linear loads causes this distortion which affects the phase conductor waveforms.
- Load voltage harmonics- due to load current distortion, the voltage across the load is affected and distorted. Consequently, other linear and sensitive load connected to PCC also gets distorted.
- Unbalance load currents- if the loads connected to distribution are not equal i.e. the loads connected to all the three phase are not same, and then the problem of unbalance on the load side occurs.

5. CONCLUSIONS

Literature review is the key feature to know the basic concept behind the research. Here in this paper discuss the all aspect of the power quality issues in the power grid. The basic research is concentrated on three phase four wire system because it connects many household appliances easily. These appliances fed the harmonics in the grid. To reduce the effect of harmonics UPQC play major role. So enhancing the performance of the UPQC is necessity for power quality issues. Lastly discuss the problem facing in the present scenario.

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