Improvement of Power Quality by UPQC Using Different Intelligent Controls: A Literature Review

Vinita Vasundhara, Rintu Khanna, Manoj Kumar

***Abstract*: This paper presents a comprehensive review on the unified power quality conditioner (UPQC) to improve electric power quality. This is intended to present a broad overview on the different possible intelligent controls used with UPQC. .**

***Index Terms*: Active power filters, ANN, Fuzzy logic controller, Power quality, Unified Power Quality Conditioner (UPQC).**

I. INTRODUCTION

The prime objective of power utility companies is to provide their consumers an uninterrupted sinusoidal voltage of constant amplitude [1]-[5]. In addition to this, adherence to different power quality standards laid down by different agencies has become a figure of merit for the power utilities [6]. Unfortunately, this is becoming increasingly difficult to do so, because the size and number of non-linear and poor power-factor loads such as adjustable speed drives, computer power supplies, furnaces, power converters and traction drives are finding its applications at domestic and industrial levels. These nonlinear loads draw non-linear current and degrade electric power quality. The quality degradation leads to low power-factor, low efficiency, overheating of transformers and so on [2]. 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 end becomes essential.

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.

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 [10]. Flexible AC Transmission Systems (FACTS) and Custom Power products like STATCOM (Static synchronous Compensator), DVR (Dynamic Voltage Restorer), and 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. This paper is intended to provide a comprehensive review on the topic of UPQC. Over 40 publications [7]-[47] are critically reviewed to get proper idea about different intelligent controller used with UPQC. Beside this, this paper also discusses the most significant concepts that are utilized to control the UPQC.

II. POWER QUALITY

Power Quality (PQ) related issues are of most concern nowadays. The widespread use of electronic equipment, such as information technology equipment, power electronics such as adjustable speed drives (ASD), programmable logic controllers (PLC), energy-efficient lighting, led to a complete change of electric loads nature. These loads are simultaneously the major causers and the major victims of power quality problems [8]. Due to their non-linearity, all these loads cause disturbances in the voltage waveform. Along with technology advance, the organization of the worldwide economy has evolved towards globalization and the profit margins of many activities tend to decrease [11]. The increased sensitivity of the vast majority of processes (industrial, services and even residential) to PQ problems turns the availability of electric power with quality a crucial factor for competitiveness in every activity sector. The most critical areas are the continuous process industry and the information technology services [15]. When a disturbance occurs, huge financial losses may happen, with the consequent loss of productivity and competitiveness. Although many efforts have been taken by utilities, some consumers require a level of PQ higher than the level provided by modern electric networks [12]. This implies that some measures must be taken in order to achieve higher levels of Power Quality.

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III. UNIFIED POWER QUALITY CONDITIONER

The Unified Power Quality Conditioner is a custom power device that is employed in the distribution system to mitigate the disturbances that affect the performance of sensitive and/or critical load [19]. It is a type of hybrid APF and is the only versatile device which can mitigate several power quality problems related with voltage and current simultaneously therefore is multi functioning devices that compensate various voltage disturbances of the power supply, to correct voltage fluctuations and to prevent harmonic load current from entering the power system.

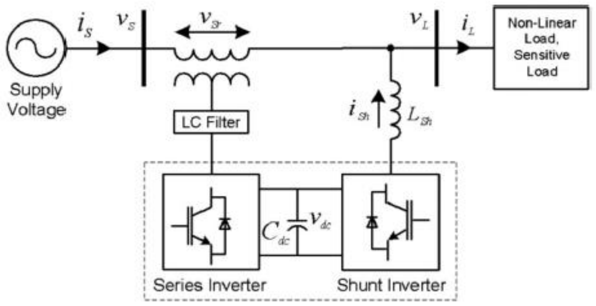

Fig. 1: UPQC general block diagram

The system configuration of a single-phase UPQC is shown in Fig. 1. Unified Power Quality Conditioner (UPQC) consists of two IGBT based Voltage source converters (VSC), one shunt and one series cascaded by a common DC bus. The shunt converter is connected in parallel to the load. It provides VAR support to the load and supply harmonic currents. Whenever the supply voltage undergoes sag then series converter injects suitable voltage with supply [2]. Thus UPQC improves the power quality by preventing load current harmonics and by correcting the input power factor. The main components of a UPQC are series and shunt power converters, DC capacitors, low-pass and high-pass passive filters, and series and shunt transformers

The main purpose of a UPQC is to compensate for supply voltage power quality issues, such as, sags, swells, unbalance, flicker, harmonics, and for load current power quality problems, such as, harmonics, unbalance, reactive current, and neutral current. The key components of this system are as follows.

1) Two inverters —one connected across the load which acts as a shunt APF and other connected in series with the line as that of series APF.
2) Shunt coupling inductor Lsh is used to interface the shunt inverter to the network. It also helps in smoothing the current wave shape. Sometimes an isolation transformer is utilized to electrically isolate the inverter from the network.
3) A common dc link that can be formed by using a capacitor or an inductor. In Fig. 1, the dc link is realized using a capacitor which interconnects the two inverters and also maintains a constant self-supporting dc bus voltage across it.
4) An LC filter that serves as a passive low-pass filter (LPF) and helps to eliminate high-frequency switching ripples on generated inverter output voltage.
5) Series injection transformer that is used to connect the series inverter in the network. A suitable turn ratio is often considered to reduce the voltage and current rating of series inverter.

In principle, UPQC is an integration of shunt and series APFs with a common self-supporting dc bus. The shunt inverter in UPQC is controlled in current control mode such that it delivers a current which is equal to the set value of the reference current as governed by the UPQC control algorithm [20]. Additionally, the shunt inverter plays an important role in achieving required performance from a UPQC system by maintaining the dc bus voltage at a set reference value. In order to cancel the harmonics generated by a nonlinear load, the shunt inverter should inject a current.

Similarly, the series inverter of UPQC is controlled in voltage control mode such that it generates a voltage and injects in series with line to achieve a sinusoidal, free from distortion and at the desired magnitude voltage at the load terminal.

In the case of a voltage sag condition, actual source voltage will represent the difference between the reference load voltage and reduced supply voltage, i.e., the injected voltage by the series inverter to maintain voltage at the load terminal at reference value. In all the reference papers on UPQC, the shunt inverter is operated as controlled current source and the series inverter as controlled voltage source except [112] in which the operation of series and shunt inverters is interchanged.

IV. OPERATION STRATEGY

Loads, such as, diode bridge rectifier or a thyristor bridge feeding a highly inductive load, presenting themselves as current source at point of common coupling (PCC), can be effectively compensated by connecting an APF in shunt with the load[4-6]. On the other hand, there are loads, such as Diode Bridge having a high dc link capacitive filter. These types of loads are gaining more and more importance mainly in forms of AC to DC power supplies and front end AC to DC converters for AC motor drives. For these types of loads APF has to be connected in series with the load [21].

The voltage injected in series with the load by series APF is made to follow a control law such that the sum of this injected voltage and the input voltage is sinusoidal. Thus, if utility voltages are non-sinusoidal or unbalanced, due to the presence of other clients on the same grid, proper selection of magnitude and phase for the injected voltages will make the voltages at load end to be balanced and sinusoidal. The shunt APF acts as a current source and inject a compensating harmonic current in order to have sinusoidal, in phase input current and the series APF acts as a voltage source and inject a compensating voltage in order to have sinusoidal load voltage. The developments in the digital electronics, communications and in process control system have increased the number of sensitive loads that require ideal sinusoidal supply voltage for their proper operation. In order to meet limits proposed by standards it is necessary to include some sort of compensation. In the last few years, solutions based on combination of series active and shunt active filter have appeared [8-9]. Its main purpose is to compensate for supply voltage and load current imperfections, such as sags, swells, interruptions, imbalance, flicker, voltage imbalance, harmonics, reactive currents, and current unbalance.

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V. REFERENCE GENERATION (PHASE LOCKED LOOP)

Reference currents and voltages are generated using Phase Locked Loop (PLL). The control strategy is based on the extraction of Unit Vector Templates from the distorted input supply. These templates will be then equivalent to pure sinusoidal signal with unity (p.u.) amplitude. The 3-ph distorted input source voltage at PCC contains fundamental component and distorted component. To get unit input voltage vectors Uabc, the input voltage is sensed and multiplied by gain equal to 1/Vm, where Vm is equal to peak amplitude of fundamental input voltage. These unit input voltage vectors are taken to phase locked loop (PLL). With proper phase delay, the unit vector templates are generated.

Ua = Sin (wt)
Ub = Sin (wt-120)
(1)
Uc= Sin (wt+120)

Multiplying the peak amplitude of fundamental input voltage with unit vector templates of equation (1) gives the reference load voltage signals,

V*abc = Vm. Uabc (2)

In order to have distortion less load voltage, the load voltage must be equal to these reference signals. The measured load voltages are compared with reference load voltage signals. The error generated is then taken to a hysteresis controller to generate the required gate signals for series APF. The unit vector template can be applied for shunt APF to compensate the harmonic current generated by non-linear load. The shunt APF is used to compensate for current harmonics as well as to maintain the dc link voltage at constant level. To achieve the above mentioned task the dc link voltage is sensed and compared with the reference dc link voltage. A PI controller then processes the error. The output signal from PI controller is multiplied with unit vector templates of equation (1) giving reference source current signals. The source current must be equal to this reference signal. In order to follow this reference current signal, the 3-ph source currents are sensed and compared with reference current signals. The error generated is then processed by a hysteresis current controller with suitable band, generating gating signals for shunt APF.

VI. FUZZY LOGIC CONTROLLER

The inherent characteristics of the changing loads, complexity and multi-variable conditions of the power system limits the conventional control methods giving satisfactory solutions. Artificial intelligence based gain scheduling is an alternative technique commonly used in designing controllers for non-linear systems. Fuzzy system transforms a human knowledge into mathematical formula [33-36]. Therefore, fuzzy set theory based approach has emerged as a complement tool to mathematical approaches for solving power system problems. Fuzzy set theory and fuzzy logic establish the rules of a nonlinear mapping. Fuzzy control is based on a logical system called fuzzy logic which is much closer in spirit to human thinking and natural language than classical logical systems. Nowadays fuzzy logic is used in almost all sectors of industry and science. One of them is using fuzzy logic controller with UPQC. The main goal of UPQC in interconnected power systems is to enhance the power quality of the system. The balance between production and consumption. Control algorithms based on fuzzy logic have been implemented in many processes [1, 15]. The application of such control techniques has been motivated by the following reasons[16]:

1) Improved robustness over the conventional linear control algorithms;
2) Simplified control design for difficult system models;
3) Simplified implementation

Low –frequency oscillations are a common problem in large power systems. A power system stabilizer (PSS) can provide an supplementary control signal to the excitation system and/or the speed governor system of the electric generating unit to damp these oscillations. Due to their flexibility, easy implementation, and low cost, PSSs have been extensively studied and successfully used in power systems for many years. Most PSSs in use in electric power systems employ the classical linear control theory approach based on a linear model of a fixed configuration of the power system. To improve the performance of UPQC, numerous techniques have been proposed for their design, such us using intelligent optimization methods (genetic algorithms, neural networks, fuzzy and many other nonlinear control techniques) [33]. It recent years, fuzzy logic control has emerged as a powerful tool and is starting to be used in various power system applications [1.11,15]. The application of fuzzy logic control techniques appears to be most suitable one whenever a well-defined control objective cannot specified, the system to be controlled is a complex one, or its exact mathematical model is not available. Recent research indicates that more emphasis has been placed on the combined usage of fuzzy systems and neural networks [1, 6, 15, 32, 33].The fuzzy logic controller designed can be of the form shown in Fig. 2[35]

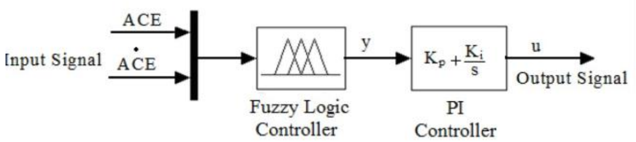

Fig. 2: Fuzzy Logic Controller

The fuzzy logic controller is comprised of four main components [1]: the fuzzification, the inference engine, the rule base, and the defuzzification, as shown in Fig. 3[35].

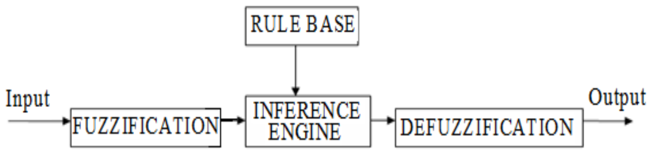

Fig. 3: Components of Fuzzy Controller

The fuzzifier transforms the numeric/crisp value into fuzzy sets; therefore this operation is called fuzzification. The main component of the fuzzy logic controller is the inference engine, which performs all logic manipulations in a fuzzy logic controller [38]. The rule base consists of membership functions and control rules. Lastly, the results of the inference process is an output represented by a fuzzy set, however, the output of the fuzzy logic controller should be a numeric/crisp value.

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Therefore, fuzzy set is transformed into a numeric value by using the defuzzifier. This operation is called defuzzification[39].

VII. ARTIFICIAL NEURAL NETWORK

The rapid detection of the disturbance signal with high accuracy, fast processing of the reference signal, and high dynamic response of the controller are the prime requirements for desired compensation in case of UPQC. The conventional controller fails to perform satisfactorily under parameter variations nonlinearity load disturbance, etc. A recent study shows that NN-based controllers provide fast dynamic response while maintaining stability of the converter system over wide operating range [43][45][46]. The ANN is made up of interconnecting artificial neurons. It is essentially a cluster of suitably interconnected nonlinear elements of very simple form that possess the ability to learn and adapt. It resembles the brain in two aspects: 1) the knowledge is acquired by the network through the learning process and 2) interneuron connection strengths are used to store the knowledge [50]-[51][52]. These networks are characterized by their topology, the way in which they communicate with their environment, the manner in which they are trained, and their ability to process information. ANN has gain a lot of interest over the last few years as a powerful technique to solve many real world problems. Compared to conventional programming, they own the capability of solving problems that do not have algorithmic solution and are therefore found suitable to tackle problems that people are good to solve such as pattern recognition. ANNs are being used to solve AI problems without necessarily creating a model of a real dynamic system. For improving the performance of a UPQC, a multilayer feed forward- type ANN-based controller is designed. This network is designed with three layers, the input layer with 2, the hidden layer with 21, and the output layer with 1 neuron, respectively [54].

VIII. CONCLUSION

The UPQC performance mainly depends upon how accurately and quickly reference signals are derived. By using conventional Akagi's principle reference signals was derived. The simulated result shows that it has considerable response time for yielding effective compensation in the network. This may not be desirable in modern power system control. Using conventional compensator data, a fuzzy logic controller (FLC) is tuned with large number of data points. Then conventional compensator was replaced with fuzzy logic controller and ANN. The simulation results have shown that the UPQC perform better with ANN and FLC proposed scheme eliminates both voltage as well as current harmonics effectively. The ANN controller also performs in a similarly with slightly better voltage compensation It is also observed that the response time for derivation of compensation signals reduces significantly with improved accuracy.

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