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Power Quality Improving In Distribution Lines by Using Fuzzy Controlling Method

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ABSTRACT:

This paper presents the design of a three phase DSTATCOM (Distribution Static Compensator) and its control algorithm based on fuzzy controlling approach for power quality improvement under linear/ nonlinear loads in a distribution system. In this approach, an extraction of fundamental active and reactive power components of load currents is based on correlation and fuzzy functions in time domain. For estimation of fundamental active and reactive power components of load currents, a numerical integration is applied in correlation and fuzzy function. The DSTATCOM is modeled under linear and nonlinear loads and its performance is simulated in the MATLAB environment using SIMULINK and Sim Power System (SPS) toolboxes. The performance of DSTATCOM is found satisfactory under time varying and unbalanced loads.

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.

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.

II. POWER QUALITY IN POWER DISTRIBUTION SYSTEMS

Most of the more important international standards define power quality as the physical characteristics of the electrical supply provided under normal operating conditions that do not disturb the customer's processes. Therefore, a power quality problem exists if any voltage, current or frequency deviation results in a failure or in a bad operation of customer's equipment. However, it is important to notice that the quality of power supply implies basically voltage quality and supply reliability. Voltage quality problems relate to any failure of equipment due to deviations of the line voltage from its nominal characteristics, and the supply reliability is characterized by its adequacy (ability to supply the load), security (ability to withstand sudden disturbances such as system faults) and availability (focusing especially on long interruptions). Power quality problems are common in most of commercial, industrial and utility networks. Natural phenomena, such as lightning are the most frequent cause of power quality problems. Switching phenomena resulting in oscillatory transients in the electrical supply, for example when capacitors are switched may contribute substantially to power quality disturbances. Also, the connection of high power non-linear loads contributes to the generation of current and voltage harmonic components. Between the different voltage disturbances that can be produced. The most significant and critical power quality problems are voltage sags due to the high economical losses that can be generated. Short-term voltage drops (sags) can trip electrical drives or more sensitive equipment, leading to costly interruptions of production. For all these reasons, from the consumer point of view, power quality issues will become an increasingly important factor to consider in order satisfying good productivity. On other hand, for the electrical supply industry, the quality of power delivered will be one of the major factors for ensuring

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customer loyalty in this very competitive and deregulated market. To address the needs of energy consumers are trying to improve productivity through the reduction of power quality related process stoppages and energy suppliers are trying to maximize operating profits while keeping customers satisfied with supply quality, innovative technology provides the key to cost-effective power quality enhancements solutions.

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.

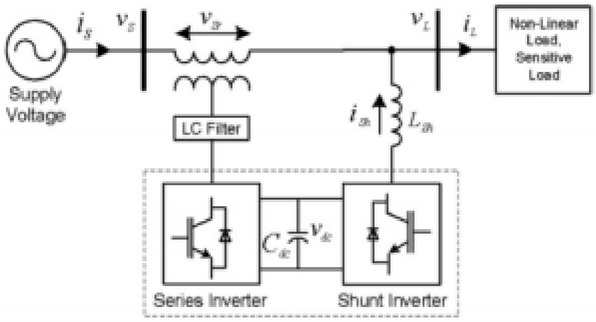

Fig. 1: UPQC general block diagram

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

- 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.
- 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.
- 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.
- 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.
- 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

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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.FUZZY LOGIC CONTROLLER

Fuzzy logic control is deduced from fuzzy set theory in 1965, where transition is between membership and non membership function. Therefore, limitation or boundaries of fuzzy sets can be undefined and ambiguous. FLC's are an excellent choice when precise mathematical formula calculations are impossible. Fig 6 shows block diagram of the fuzzy logic control scheme. In order to implement the control algorithm of a shunt active power filter in a closed loop, the dc capacitor voltage VDC is sensed and then compared with the desired reference value VDC,ref . The error signal e (n) =VDC, ref −VDC is passed through Butterworth design Based LPF with a cut off frequency of 50 Hz, that pass only the fundamental component. The error signal e(n) and integration of error signal is termed as c e(n) are used as Inputs for fuzzy processing. The output of the fuzzy logic controller limits the magnitude of peak reference current Imax. This current takes care of the active power demand of the non-linear load and losses in the distribution system. The switching signals for the PWM inverter are generated by comparing the actual source currents (isa, isb, isc) with the reference current (isa*,isb*,isc *) using the HCC method.

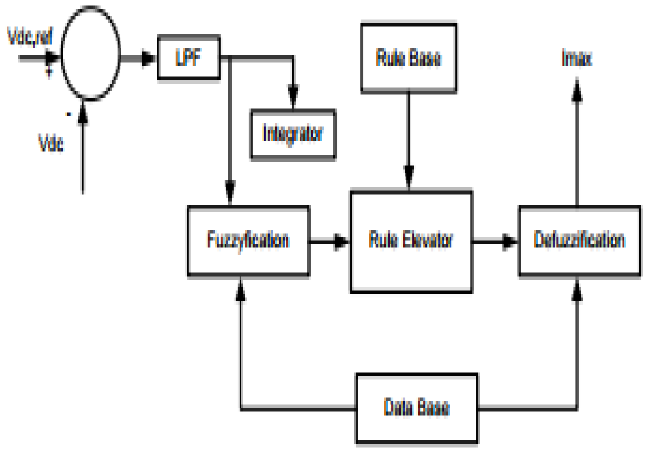

Fig. 6 Fuzzy logic controller

Fuzzification

Fuzzy logic uses linguistic variables instead of numerical variables. In a control system, error between reference signal and output signal can be assigned as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive small (PS), Positive Medium (PM), Positive Big (PB). The triangular membership function is used for fuzzification. The process of fuzzification convert numerical variable (real number) to a linguistic variable (fuzzy number).

Rule Elevator

Conventional controllers like PI and PID have control gains which are numerical values. Fuzzy logic controller uses linguistic variables instead of the numerical values. The basic fuzzy logic controller operation uses the following fuzzy set rules to control the system

Defuzzification

The rules of fuzzy logic controller generate required output in a linguistic variable (Fuzzy Number), according to real world requirements; linguistic variables have to be transformed to crisp output (Real number). This selection of strategy is a compromise between accuracy and computational intensity.

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Database

The Database stores the definition of the triangular membership function required by fuzzifier and defuzzifier.

Rule Base

The Rule base stores the linguistic control rules required by rule evaluator (decision making logic). The rules used in this proposed controller are shown in table II.

The output of the fuzzy controller is estimating the magnitude of peak reference current Imax. This current Imax comprises active power demand of the non-linear load and losses in the distribution system. The peak reference current is multiplied with PLL output for determining the desired reference current.

V. 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].

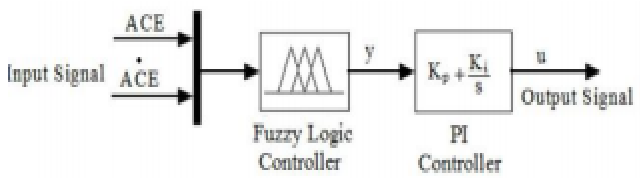

Fig. 2: Fuzzy Logic Controller

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].

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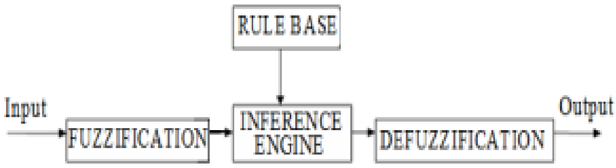

Fig. 3: Components of Fuzzy Controller

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

VI. 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].

VII. 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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