LOVELY PROFESSIONAL UNIVERSITY

School of: EEE

DISSERTATION TOPIC APPROVAL PERFORMA

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SPECIALIZATION AREA: Power System (pick from list of provided specialization areas by DAA)

PROPOSED TOPICS

1. Power Quality Improvement by UPQC (Universal Power Quality Conditioner)
2. Deregulation of power factor
3. Power Line Communication Channel

Signature of Supervisor 18361

PAC Remarks:

Approved

APPROVAL OF PAC CHAIRPERSON: Signature: Date: 25/9/14

*Supervisor should finally encircle one topic out of three proposed topics and put up for approval before Project Approval Committee (PAC)

*Original copy of this format after PAC approval will be retained by the student and must be attached in the Project/Dissertation final report.

*One copy to be submitted to Supervisor.

18361

CERTIFICATE

I hereby certify that the Dissertation-II work entitled **"Power Quality Improvement in Electrical Network by Using Unified Power Quality Conditioner"** that is being presented by "Adarsh Kumar Pandey " in partial fulfillment of the requirements for the award of Master of Technology Degree in Electrical Engineering (Power Systems), is submitted in School of Electronics And Electrical Engineering (SEEE) Department of Lovely Professional University, Phagwara Punjab, is an authentic record of my own work carried out under supervision of Mr. Sanjeev Kumar Bhalla, Associate Professor (COD-PS)., SEEE. The content presented in this Dissertation-I work has not been submitted for the award of any other degree of this or any other university.

Mr. SANJEEV KUMAR BHALLA

ASSOCIATE PROFESSOR (COD- PS), SEEE

(LOVELY PROFESSIONAL UNIVERSITY)

Objective of the Thesis is satisfactory /unsatisfactory

Examiner I **Examiner II**

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First of all, I thank my parents and almighty GOD, Who gave me the opportunity and strength to carry out this work. I would like to thank Mr. Sanjeev Kumar Bhalla, Associate Professor (COD-PS) SEEE, for giving me opportunity to work with him and also for his trust, encouragement and unconditional support. Mr. Sanjeev Kumar Bhalla has been a mentor in true sense both academically and morally throughout this project work. I would also like to extend my gratitude to my friends who always encouraged and supported me in this thesis work. I would like to thank Lovely Professional University (Punjab) for giving me opportunity to use their resource and work in such a challenging environment. I am grateful to the individuals whom contributed their valuable time towards my Dissertation-I work. Last but not the least; I would like to thank all the staff members of School of Electronics and Electrical Engineering (SEEE) Department who have been very patient and co-operative with us.

Adarsh Kumar Pandey

Reg No: 11302852

DECLARATION

I, student of **Master of Technology Degree in Electrical Engineering (Power Systems)** Under School of Electronics and Electrical Engineering (SEEE) Department of Lovely Professional University, Punjab, hereby declare that all the information furnished in this Dissertation-I reports based on my own intensive research and is genuine. This Dissertation-I work does, to the best of my knowledge, contain part of my work which has been submitted for the award of my degree either of this university without proper citation.

Adarsh Kumar Pandey
Reg No: 11302852

List of Figures

Abbreviations

FACTS - Flexible AC Transmission System

PU - Per Unit

PQ - Power Quality

CPD - Custom Power Devices

UPS - Uninterruptible Power Supply

IEC - International Electrotechnical Commission

PCC - Point of Common Coupling

SLG - Single Line to Ground

UPQC - Unified Power Quality Conditioner

VSC - Voltage Source Converter

VSI - Voltage Source Inverter

SVC - Static VAR Compensator

DVR - Dynamic Voltage Restorer

SSSC - Static Synchronous Series Compensator

DSTATCOM - Distributed Static Synchronous Compensator

IGBT - Insulated Gate Bipolar Transistor

IGCT - Integrated Gate Commutated Thyristor

THD - Total Harmonic Distortion

PWM - Pulse Width Modulation

RMS - Root Mean Square

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CHAPTER 1

INTRODUCTION

1. **Introduction:** At present because of the growth of the nonlinear loads and power electronic (PE) equipments such as personal computers (PC), programmable logic controllers (PLC), variable motion drives (VMD), energy efficient lighting, into the power distribution networks (PDN) the power quality (PQ) has become the crucial concerned area. These types of loads are the prime source of PQ issues. These loads usually disturb the voltage waveform. To identify the PQ issues any one of the following signs can be used.

- Flicker
- Blackouts of frequency
- Frequency dropouts in electronic equipment
- Power line interference with communication
- Equipment and overhead elements
- Sudden voltage to ground

Any PE equipment has its own sensitivity with different type of PQ problems which depends on equipment's type and disturbance's type. The impact of PQ on PDN is because of use of PE equipments, depend on type of PE equipment used. The IEEE519-1992 standard has defined the nominal allowable values of harmonics in terms of total harmonic distortion (THD). Broad classification of PQ problems is shown below in Fig. 1

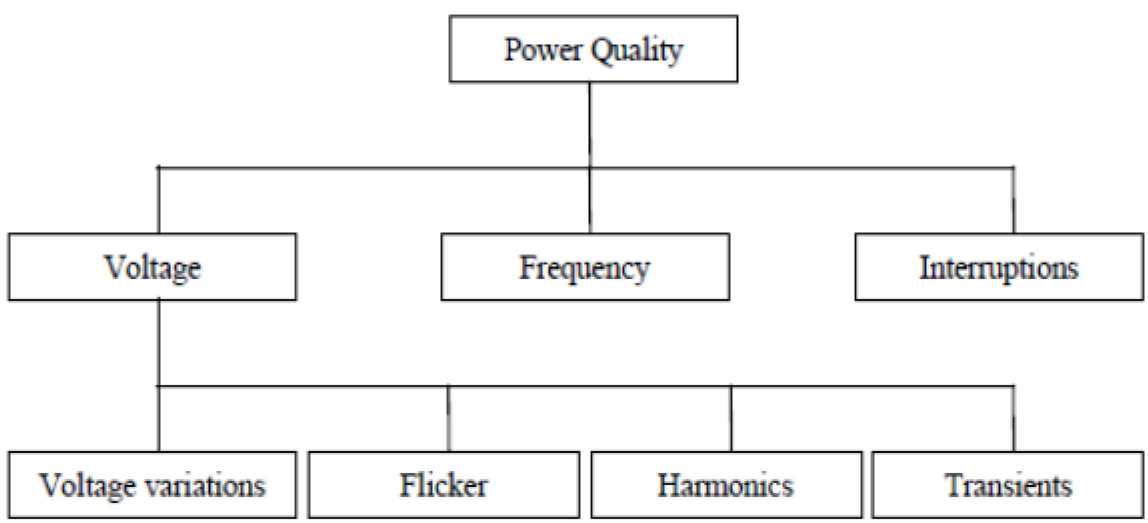

Fig. 1 Classification of PQ problems

1.2 Major Power Quality Problems

1.2.1 Short Duration Voltage Variation

This type of PQ problem occurs into the network depends on the present system conditions and fault location which may either temporary voltage sags (drops), voltage swells (rises), or a total loss of voltage/interruptions. These faults varies for a duration less than 1 min. reasons behind these type of variations are as follows

- Fault conditions
- Large load energization
- Intermittent loose connections on wiring

1.2.2 **Voltage sag:** voltage sag is defined as a nominal decrease in rms line voltage (V_{rms}). The magnitude of V_{rms} varies between 10 to 90 percent (%). Time duration for voltage sag is 0.5 cycle to 1 min. The major sources of voltage sags are PDN faults heavy load connection with the system and starting of large induction machines. A three phase voltage sag is shown in fig 1.1

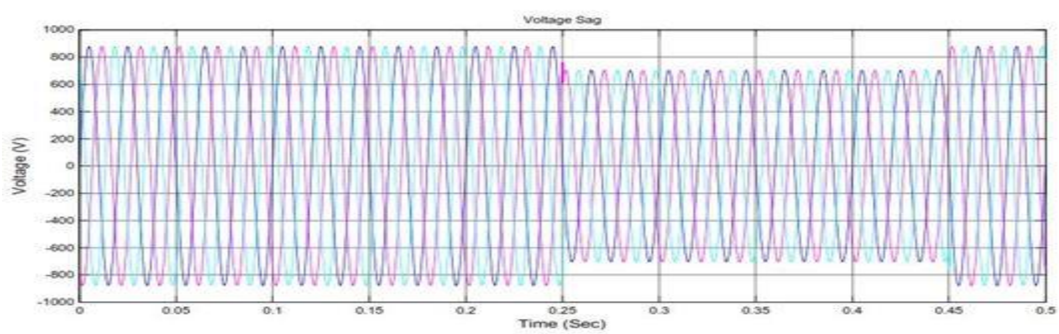

Fig. 1.1.1 Voltage Sag

1.2.3 **Voltage swell:** voltage swell is defined as a nominal increase in V_{rms}. The magnitude of V_{rms} varies between 1.1 to 1.8 %. Time duration for voltage swell is 0.5 cycle to 1 min. The major sources of voltage swell are energization of large capacitor banks (CB) and turning off large machines. A three phase voltage sag is shown in fig 1.2

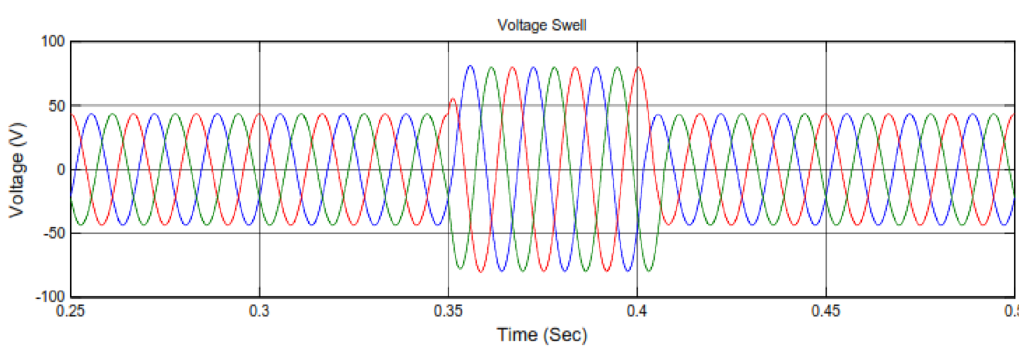

Fig. 1.1.2 Voltage Swell

1.2.4 **Interruptions:** An interruption can be defined as a decrease in the magnitude of V_{rms} or I_{rms} less than 0.1 per unit (pu) of the nominal, for time duration of less than 1 min. these may occur because of balanced or unbalanced faults, device failures and control errors. Fig. 1.1 Voltage Sag

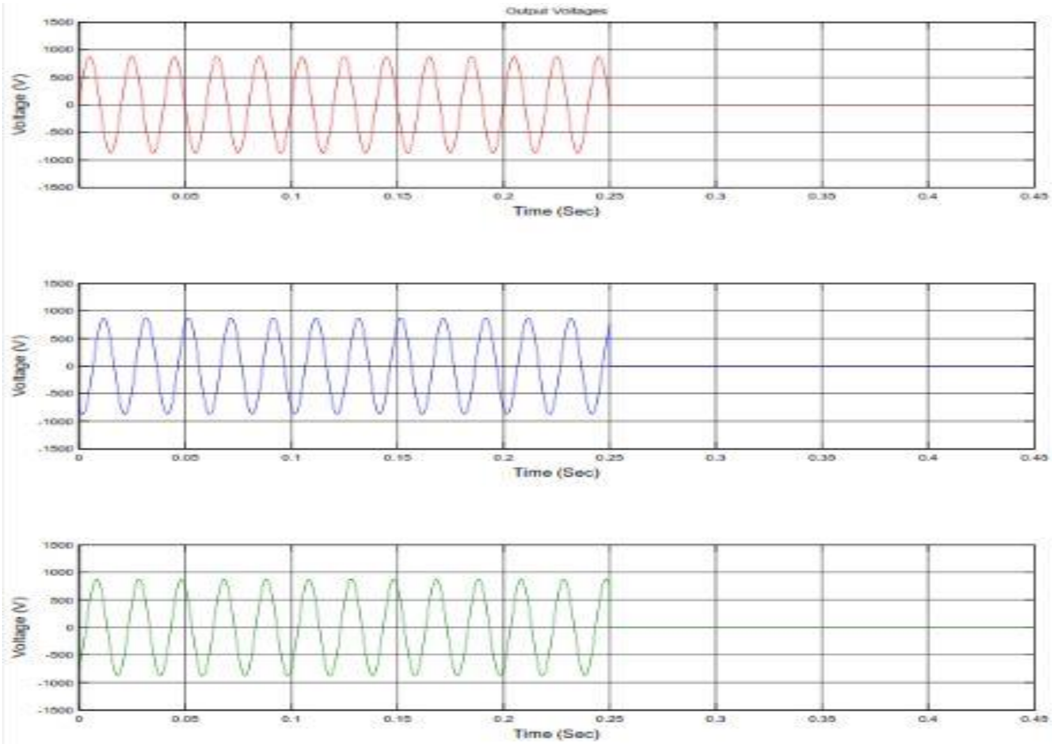

Fig. 1.1.3 Voltage Interruptions

1.2.3 Long Duration Voltage variation

These variations are classified as over voltages, under voltages or sustained interruptions.

(i) Over voltage: An increase in V_{rms} greater than 110 % at power frequency (PF) for time duration of more than 1 min is known as over voltage. Major source of over voltages are sudden loading and unloading or wrong tap setting of transformer (Tf).

(ii) Under voltage: A decrease in V_{rms} greater than 90 % at power frequency (PF) for a time duration of more than 1 min is known as over voltage. Major source of under voltages are turning on a load or turning off a CB and overloaded circuit.

(iii) Sustained Interruption: When the source voltage has become zero for certain time period in excess of 1 min this long duration variation is known as sustained interruption.

1.2.3.1 Transient: A transient is that part of the change in a variable that disappears during transition from one stable state operating condition to the other.

1.2.3.1(a) Impulsive transient: An impulsive transient has unidirectional (positive or negative) polarity and is characterized by the rise and decay times. An impulsive is the variation seen below in the figure as the wave shapes of voltage get disturbed from its normal position as seen in fig 1.1. Major source of this transient is lightning discharge or switching due to opening and closing of circuit breakers.

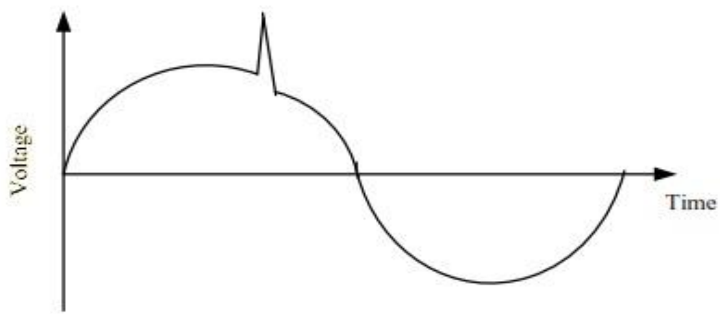

Fig. 1.1.4(a) Impulsive transient

1.2.3.1(b) Oscillatory transient: An oscillatory transient is a sudden non power frequency change that is bidirectional both positive and negative polarities. So oscillatory transient is the variation seen below in the figure as the wave shapes of voltage get disturbed from its normal position as fig 1.2. Major source of this transient is Ferroresonance and Transformer (Tf) energization.

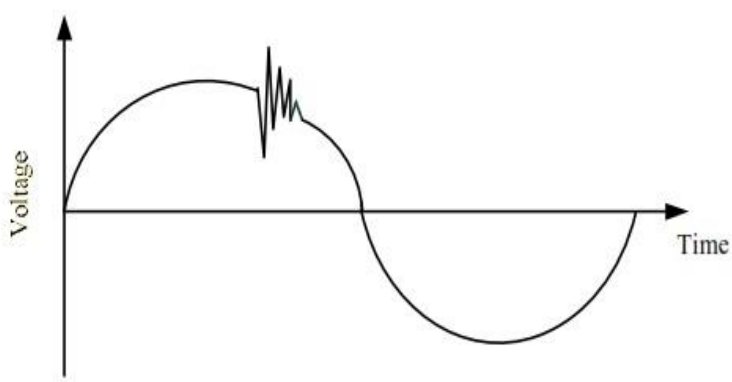

Fig. 1.1.4(b) Oscillatory transients

1.2.3.1(c) Voltage Fluctuations: Voltage fluctuations are regular variations of the voltage envelope or a series of unplanned deviations in the magnitude of V_{rms} which lies in the range of

90 % to 100 %. as seen in fig 1.3. Major source of Voltage fluctuations are arc furnaces and cycloconverters.

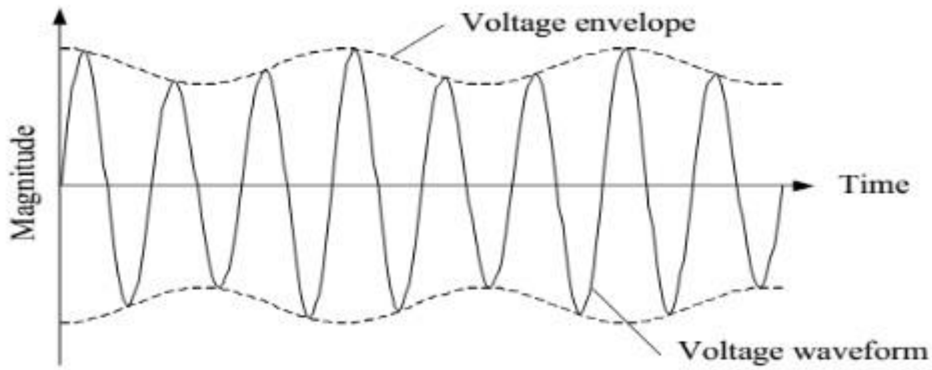

Fig. 2.2.1(c) Voltage Fluctuations or flicker

1.2.3.1(d) Voltage Unbalance: Voltage unbalance is defined as a variation in the magnitude of three phase (3P) voltages, relative to each other. Voltage unbalance can happen due to different loads on the phases, resulting in different voltage drops through the phase line impedances.

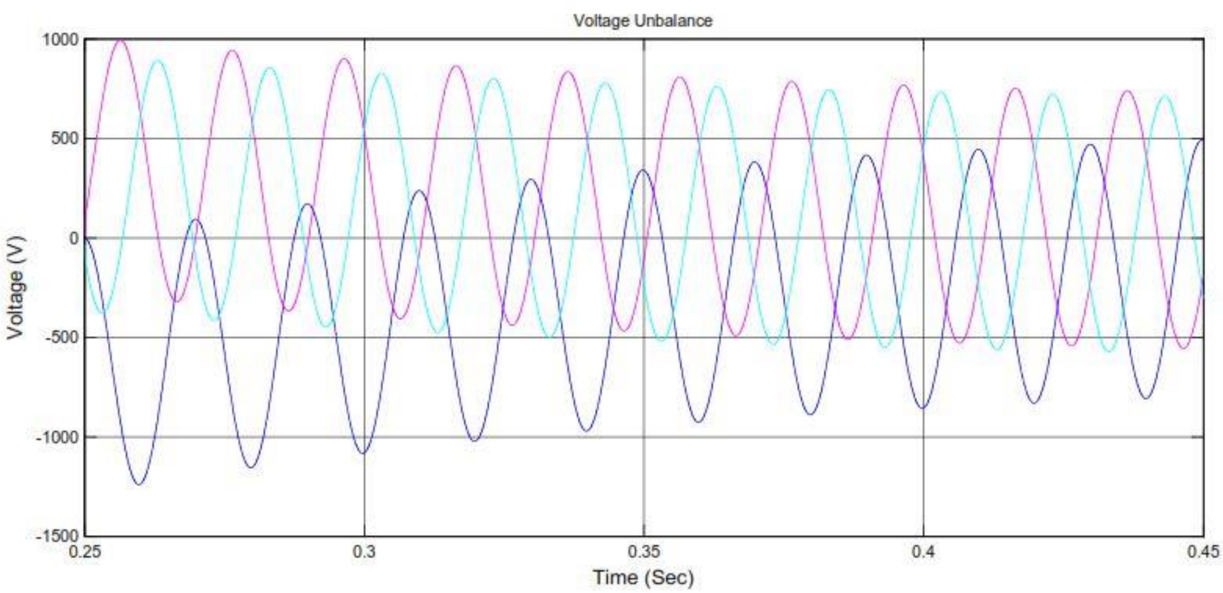

Fig. 2.2.1(d) Voltage Unbalance

1.2.4 Waveform Distortion: Waveform distortion is a steady state variation from actual power frequency sinusoidal wave mainly characterized by spectral content of the variation.

These are classified as

1.2.4 (a) DC offset: When a dc component of voltage or current is present in an ac power system is known as dc offset. Source of dc offset is geometric variation or asymmetry of electronic power converters.

1.2.4 (b) Harmonics: Harmonics are integral multiples of fundamental frequency at which the supply system has designed system to operate for either of sinusoidal voltages or currents. Normally fundamental frequency = 50 or 60 Hz. These are off two types even order harmonics and odd order harmonics. Ever order harmonics cancels each other because in ac waveforms they have half wave symmetry and only odd order harmonics are present in the voltage or current harmonics. Source of harmonics are Non linear loads, power electronic equipment etc

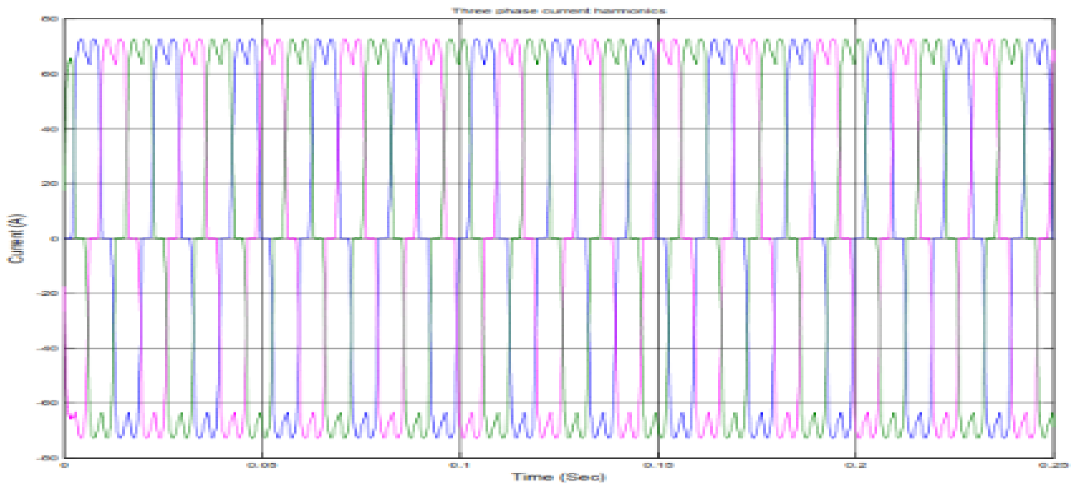

Fig. 2.2.2(b) Current Harmonics

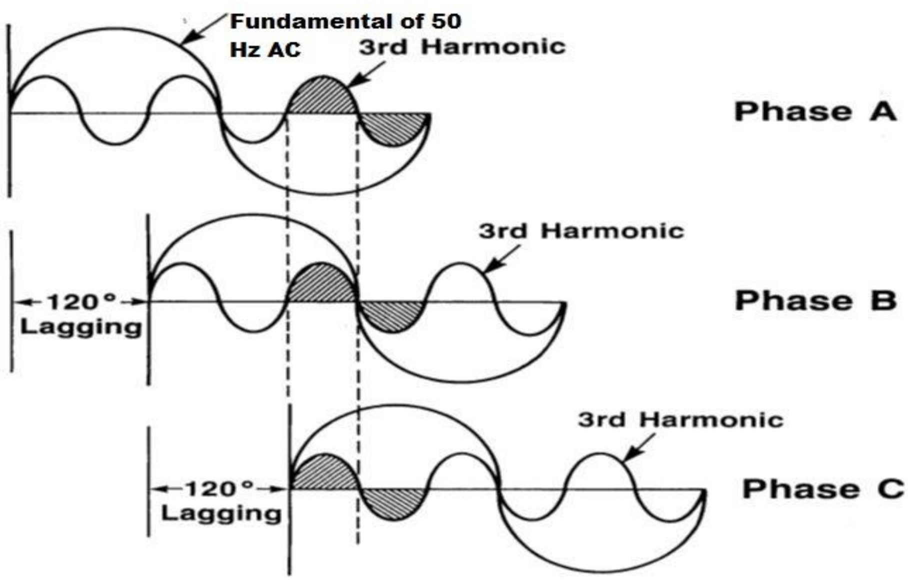

Fig. 2.2.2(c) Sinusoidal three phase harmonics

1.2.4 (c) Total Harmonic distortion (THD): THD is defined as the ratio of root mean square (RMS) of harmonic content to the RMS value of fundamental quantity. THD is expressed in terms of percent (%) of the fundamental. Total harmonic distortion is a measurement of the sum value of the waveform that is distorted.

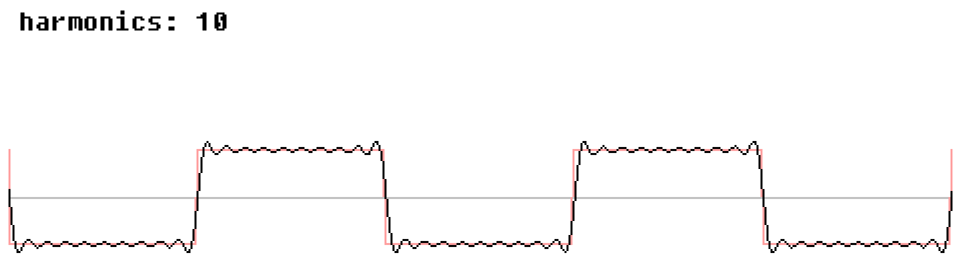

Fig. **2.2.2(d)** Total Harmonic distortion (THD)

To calculate the RMS values of voltages and currents are defined first then the voltage and current total harmonic distortion (THDs) are defined as follows

$$V_{rms} = \sum_{n=1}^{\infty} \left(\frac{V_n}{\sqrt{2}}\right)^2 \quad (1.1)$$

and

$$I_{rms} = \sum_{n=1}^{\infty} \left(\frac{I_n}{\sqrt{2}}\right)^2 \quad (1.2)$$

Here it has assumed that V_n and I_n are also in RMS values.

Now

To measure PQ most commonly used one is THD. THD_V is also known as voltage distortion factor (VDF), which is defined as folliws:

$$THD_V = \frac{\sqrt{\sum_2^{\infty} {V_n}^2}}{V_1} \quad (1.3)$$

or

$$THD_v = \sqrt{\left(\frac{V_{rms}}{V_1}\right)^2 - 1} \quad (1.4)$$

Where V_1 is the rated fundamental voltage in RMS and n is the harmonic order if n = 1 which is corresponds to the fundamental value.

Similarly THD_I is also known as current distortion factor (CDF), which is defined as follows:

$$THD_I = \frac{\sqrt{\sum_2^\infty {I_n}^2}}{I_1} \tag{1.5}$$

or

$$THD_I = \sqrt{\left(\frac{I_{rms}}{I_1}\right)^2 - 1} \tag{1.6}$$

Where I_1 is the rated fundamental current in RMS and n is the harmonic order if n = 1 which is corresponds to the fundamental value.

1.2.4 (e) Interharmonics: Interharmonics are not integral multiples of fundamental frequency at which the supply system has designed system to operate for either of sinusoidal voltages or currents. Normally fundamental frequency = 50 or 60 Hz. Source of Interharmonics are cycloconverters, static frequency converters, arcing devices etc.

1.2.4 (f) Notching: Notching is the periodic voltage disturbance occurred in the supply voltage due to use of power electronic devices when accumulation of current takes place from one phase to another. Fig 1.4 is showing notching.

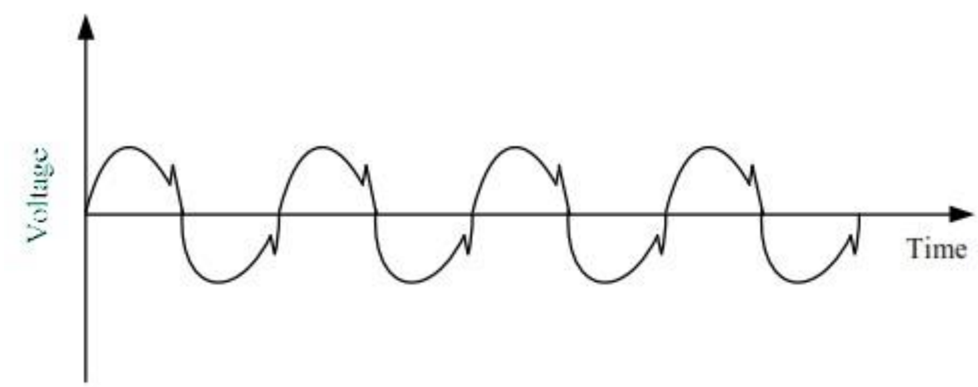

Fig 2.2.2(f) Notching

1.2.4 (g) Noise: Noise is the unwanted signal appeared in the broadband spectral content lower than 200 kHz superimposed with the utility system voltage or current in phase conductors, or signal lines.

2. **Solutions to PQ Problems:**

The PE based equipments have become crucial components in present PDN. In spite of the vast advantages offered by utilizing the power electronics based equipment for power processing, the operation of these devices gives rise to some serious drawbacks in terms of power quality. These devices generate harmonics polluting the power distribution system, and demand reactive power. In face new challenges imposed on PDN by PE based equipments we need to offer advanced technical solution to the PDN utilitty, in the late 1980s the theory of flexible AC transmission systems (FACTS) was presented. FACTS devices incorporate PE based controllers to boost the controllability as well as to raise the power transfer capability of transmission system.Methods to understand of PE based compensators are as follows: First method works on conventional devices such as TSC) and TSR and Second usages self-commutated switching converters. Both methods help to efficiently control the true power and VAR, however to compensate current and voltage harmonics only second one can be utilized. Moreover, these converters provide more compensation flexibility and a better response time. The SVC (static VAR compensator) is used to control AC voltage by generating or absorbing the reactive power by means of passive elements. A SVC consists of an antiparallel thyristors and passive elements such as a capacitor (TSC) or a reactor (TCR). The effective value of the capacitor or inductor reactance is changed continuously by controlling the firing angle of the thyristors. A major drawback in the use of SVC is that the reactive power handled by the SVC system is limited by the size of passive elements. One of the most versatile FACTS devices is the STATCOM. It consists of a VSC / VSI with pulse PWM and has a faster speed of response. In the transmission system, it can be used to improve the system stability and damping or to support the voltage profile. The same structure at the distribution level, known as D-STATCOM, can be used for reactive power support or for voltage regulation. The static series compensator (SSC) or dynamic voltage restorer (DVR) is a VSI joined in series with the supply side line and acts as a controlled voltage source to obtain the desired load voltage. When an external DC voltage source is utilized for VSI, the SSC/ DVR can be used to compensate harmonics in the voltage, to regulate load voltage, and to compensate voltage unbalance, sag and flicker. Another device, the active power filter (APF) is the most promising solution to mitigate some of the major power quality problems at the PDN level. They can be classified as parallel/shunt APFs, series APFs, hybrid APFs, and UPQC. Among these APFs, UPQC is the most versatile power quality enhancement devices which offer advantages of both the shunt and series APFs, simultaneously. The series APF is connected in series with the ac line and shunt APF is connected in shunt with the same ac line. These two are connected back to back with each other though a DC link. The series element of the UPQC inserts voltage so as to retain the voltage balanced at the load terminal of PDN and free from distortion. Additionally, shunt component maintains the DC link voltage within reference value. Simultaneously, the shunt element of the UPQC injects current in the ac system such that the currents entering the bus to which the UPQC is connected are balanced sinusoids.

CHAPTER 2

REVIEW OF LITERATURE

Today the presence of nonlinear loads in the power system is growing rapidly due to the deregulated power supply and has become the primary concern areas because nonlinear loads are the main source of harmonics and harmonics creates Power quality issues. Both electric power suppliers and customers are more concerned about power quality [1-3].

To improve the power quality many efforts are supported by researchers. The permissible harmonic component values are presented in IEEE standard in terms of total harmonic distortion (THD) [4].

N. G. Hingorani [5] proposed the theory of custom power.

Yash Pal *et al.* [6] presented the complete analysis of custom power devices (CPDs) primarily DVR, DSTATCOM, and UPQC and provided an extensive view on the status of these compensating devices in electric power distribution system to increase power quality.

T. Devaraju *et al.* [7] presented arrangements, working and important roles of CPDs mainly DSTATCOM, DVR and UPQC.

Bhim Singh *et al.* [8] presented the full analysis of true filters (AF) with their structures, control schemes, choice of components; other associated economic and technical considerations, and their choice for specific applications. They intended to provide an extensive view on the position of AF technology. This technology has been used for harmonic and retrue power compensation in different type ac power networks with nonlinear loads.

Hideaki Fujita *et al.* [9] presented UPQC as an arrangement of series true filters and parallel true filters. The presented UPQC has enhanced the utility's power quality on power distribution systems at the point of installation. Authors have discussed the control scheme of the UPQC with an emphasis on the flow of instant true power and retrue power inside the UPQC.

Gu Jianjun *et al.* [10] proposed UPQC incorporation of series true and parallel true power filters to compensate voltage difference, harmonics, retrue power(VAR) and negative sequence current. The compensation principle and control scheme for the proposed UPQC has discussed in detail.

Yunping Chen *et al.* [11] presented the theory and modeling of UPQC consists of thyristor controlled capacitor banks, series true power filters (APF) and parallel APF. The series true and parallel true filters developed to compensate negative sequence current and harmonics as the thyristor controlled capacitor banks is used to compensate the retrue power of power frequency.

Ahmed M. A. Haidar *et al.* [12] presented a broad study on the constraints that affecting the performance UPQC. Authors have concentrated primarily on PQ disturbance and the technique used to increase the PQ of delivered power such as UPQC.

V. Khadkikar *et al.* [13] discussed that UPQC can work in different true power mode. The UPQC has two portions series true APF portion which works in true power delivering type and absorption type through voltage sag and swell condition, respectively. The parallel APF portion of UPQC through these conditions helps series APF by sustaining dc link voltage at fixed level and also compensates the VAR required by the load as well as harmonics created by them.

V. Khadkikar *et al.* [14] presented mathematically UPQC stable state analysis based on true power and VAR flow through the parallel and series APF, where in series APF can absorb or deliver the true power whereas the VAR requirement is completely handle by parallel APF alone throughout all conditions.

M. Hosseini *et al.* [15] modeled UPQC in load flow calculations for stable state voltage compensation. Authors have derived and discussed UPQC model by analytical and mathematical approach in which phasor diagram technique is used. An accurate UPQC model is derived to use in load flow calculations and its maximum rating of retrue power injection is derived in large distribution systems.

B. Han *et al.* [16] proposed a novel configuration of a UPQC which is coupled to the distribution network without series injection transformers. Firstly the operation of the proposed system was analyzed then authors examined the UPQC capability of improving power quality at the connecting point on power distribution. UPQC increase well power quality at connecting point of the distribution network.

V. Khadkikar *et al.* [17] proposed the application of UPQC to handle power quality problems has become a matured subject. They have identified an incorporated method for source and load compensation by using UPQC. In this study performance of proposed UPQC has examined by connecting a usual industrial load with accurate constraints provided by a polluted distribution network. The proposed system performed well for voltage sag, voltage swell voltage harmonics and current harmonics.

Srinivas Bhaskar Karanki *et al.* [18] presented a custom power device (UPQC) which mitigates current and voltage related PQ issues in the power distribution network. Authors have proposed two novel Voltage Source Inverter (VSI) arrangements for UPQC. The proposed arrangements enable UPQC to have a decreased DC link voltage without conceding the compensation competency. The proposed arrangements also help to match the DC link voltage need of the parallel and series active filters present in the UPQC. In this paper the proposed UPQC arrangements are compared with the existing arrangements in the literature.

Kolhatkar and Das [19] discussed an optimized UPQC which aims at the incorporation of series active and parallel active power filters with minimum volt-ampere (VA) loading of UPQC. The series APF part is a dynamic voltage restorer (DVR) that controls the load side voltage with least VA loading of the whole UPQC by inserting the voltage at an ideal angle. An experimental prototype in the laboratory has been done to validated proposed scheme. The proposed system effectiveness is supported by the shown experimental results, reported along with analytical findings.

Khadkikar and Chandra [20] presented a new idea through a three phase UPQC to compensate the load VAR demand. Most of the UPQC based applications show the dependency on parallel inverter for load VAR compensation, whereas the series inverter is always looked as controlled voltage source to handle all voltage related problems. Authors have proposed a new working of UPQC in which both the parallel and series APFs supply the load VAR demand. The proposed UPQC not only helps to share the load VAR demand, but also helps to reduce the parallel APF rating, and hence, the total cost of UPQC. This results in enhanced operation of the current series inverter. The concept and complete mathematical analysis termed as "power angle control (PAC)" is presented. The proposed approach is also validated through experimental study.

Ghosh and Ledwich [21] discussed the arrangement and control of a UPQC which is used at the same time in voltage or current control approach in a power distribution network. In the voltage control approach, the UPQC can make the distribution bus voltage to be stable sinusoids. Simultaneously it can also execute load compensation resulting in the drawing of stable sinusoidal currents from the distribution network bus in the current control mode. Both these objectives are accomplished irrespective of harmonic distortions and unbalance in source voltages or load currents. They discussed a suitable UPQC structure which allows the tracking of voltage generated and reference current to meet the above defined objective. Authors have presented in detail about reference generation pattern beside the switching control pattern. To confirm the proposed arrangement and control a wide results of numerical computer simulation studies are presented

Khadkikar and Chandra [22] presented a new arrangement of UPQC for three phase four wire (3P4W) distribution network. They have analysed UPQC 3P4W arrangement from three phase three wire (3P3W) arrangement in which the neutral of series transformer is used in series portion of UPQC is measured as the fourth wire for 3P4W arrangement. A new control scheme to balance the imbalanced load currents is also presented in this paper. By using a four leg voltage source inverter (VSI) arrangement for parallel part of UPQC allows the neutral current to flow towards transformer neutral point. Thus under all working circumstances the series transformer neutral will be at virtual zero potential. The obtained MATLAB/Simulink results justify the effectiveness of proposed new arrangement.

M. Tarafdar Haque *et al*. [23] presented control strategy used in 3P3W utilities. The control scheme of parallel active filter (PAF) made on the arrangement of comprehensive p-q concept and instantaneous balanced components scheme whereas the control circuit of series active filter (SAF) is established on instantaneous balanced components scheme. The proposed control scheme has analytically analysed and explained with its operation. SAF operate to provide compensation for voltage imbalance and voltage harmonics whereas PAF operate to give compensation for VAR, imbalance currents and current harmonics

V. Khadkikar *et al.* [24] presented a control technique for UPQC combination of series APF and parallel APF, which based on unit vector template generation. They focused on the mitigation of voltage harmonics present in the utility voltage.

He Junping *et al.* [25] proposed a new single phase UPQC topology which is able to solve effectively power quality problems from the load side or from the power source side. Primarily they have discussed the new topological arrangement of single phase UPQC and its operational principle. After that they have explained the control methods mainly for the load side voltage compensation and grid harmonic current compensation.

M. Aredes *et al.* [26] introduced a numerical control scheme built on the instantaneous power theory (p-q theory) simplifications. In this control strategy the number of measurements was reduced thus allow computational efforts reduction. The proposed conditioner is capable of being connected in 3P3W systems and suitable to deal with instantaneous power factor regulation, harmonics and unbalances present at the load currents and the supply voltages as well.

Claudio A. Molina *et al.* [27] presented new configuration of UPQC with a Four Leg Full Bridge (FLFB) inverter used as a Parallel Active Filter the UPQC works in a 3P4W electrical network in order to provide compensation for nonlinear and unbalanced loads and for disturbances in the power supply voltage. Authors have used the 3D-Space Vector Modulation (3D-SVM) algorithm to create the essential zero, positive and negative sequence voltages required in FLFB inverter modulation For the creation of reference currents for the FLFB, authors have used the instantaneous power concept in the dqz reference frame is used and to adjust the stable state error of the regulated signals in the parallel and series compensator Proportional Integral (PI) controllers are used. So with the proposed UPQC topology and control scheme nonlinear and unbalanced load has been compensated and At the PCC unitary power factor, sinusoidal currents and neutral current mitigation can be attained as well as all of this with fixed rms voltage at the load side, independently of the PCC voltage disturbances.

K. Palanisamy *et al.* [28] proposed a novel control strategy for the case of 3P3W UPQC based on the concepts of instantaneous true power and VAR theory. The proposed control scheme is designed for harmonic detection, voltage sag and swell and VAR compensation.

Tan Zhili *et al.* [29] presented a direct control scheme based on p-q-r theory for UPQC used in the unbalance and nonlinear 3P4W system. Authors have proposed an algorithm to calculate the series compensation current and parallel compensation voltage in the proposed system. The harmonic current, VAR of load and neutral current are compensated.

Yash Pal A *et al.* [30] discussed UPQC is a incorporation of back to back connected parallel active power filter (APF) and series APF to a common DC link voltage. To improve PQ problems in a 3P4W distribution network, they have presented a comparative study of two arrangements beside the most used 4 leg voltage source inverter (VSI) built arrangement of 4 wire UPQC. The synchronous reference frame (SRF) theory is used as a control strategy of series and parallel APFs. Authors have examined performance of each topology of UPQC for different types of PQ problems like power factor correction, current harmonic mitigation, load balancing, voltage harmonic mitigation and source neutral current mitigation.

Sergio A. Oliveira da Silva *et al.* [31] presented compensation algorithm schemes used in power quality conditioners (PQC) applied to 3P4W networks, allowing harmonic current suppression and VAR compensation which results in a successful power factor improvement. Authors have presented and implemented the SRF based algorithms with the help of mathematical analyses for two PQC, such as the UPQC and the line interactive Uninterruptible Power Source (UPS) structure, that allow the selection of a appropriate compensation scheme resultant in either stable or unstable sinusoidal source currents under steady or unsteady load conditions, respectively. To simultaneously execute the compensation of the load current harmonics, utility voltage harmonics and the current and voltage unbalances they have implemented UPQC and the UPS system with 2, 4 leg PWM converters.

Tan Zhili *et al.* [32] introduced first the p-q-r instantaneous power then proposed an enhanced p-q-r theory and presented a composite control scheme of UPQC, which is the combination of the regular direct and indirect control scheme. The control formulas based on the p-q-r coordinate are deduced in detail. They have described the operating principle and analysis of the proposed control strategy after that introduced an algorithm of calculating the compensation current and the compensation voltage. The proposed control scheme is very effective to compensate harmonic current, VAR of loads as well as neutral current.

Xun Li *et al.* [33] introduced an organized control scheme based on ABC stationary frame for 3P4W UPQC to conquer the influences of non-ideal input voltage and non-ideal load. The series converter controlled as a current source in fundamental sine waveform and the parallel converter controlled as a voltage source in fundamental sine waveform. The proposed control scheme made the UPQC to carry out sinusoidal input current with unity power factor, sinusoidal and stable output voltage with rated value.

Tan Zhili *et al.* [34] proposed an ac equivalent PI controller in p-q-r axis to solve distort and unbalance in source voltage or load current. A new control scheme by using of it was presented and its principle of excluding stable state error to zero was analyzed. A principle analysis of the proposed control strategy is described specifically. For the meantime the control formulas on the enhanced p-q-r coordinate are realized in detail. The control schematic diagram based on these formulas is presented.

Yash Pal *et al.* [35] proposed various transformers supported 3P3W UPQCs topologies for the understanding of four wire (4W) distribution network along with PQ enhancement capabilities. In the proposed topologies of UPQCs, the neutral terminal of series APF (SER APF) injecting transformer by utility is taken as the 4^{th} wire to understand the 4W distribution network. And the performance of individually proposed topology of UPQC has also estimated for PQ enhancements such as current harmonics compensation, VAR compensation, load balancing and voltage harmonic compensation. Authors have proposed separately for the control of UPQC topology, a control scheme based on unit vector template generation (UVTG) is used. Likewise, in case of a transformer based 3P3W UPQC topology, no need of additional control for the compensation of neutral current; thus numbers of required current sensors are reduced.

Srinivas Bhaskar Karanki *et al.* [36] proposed a UPQC topology for applications through non-rigid source and complete design features of the series capacitor and VSI factors have been discussed. The proposed topology permits UPQC to have a compact dc-link voltage without conceding its compensation proficiency and similarly it helps to match the dc-link voltage necessity of the parallel and series APF of the UPQC. This topology used a capacitor in series with the combing inductor of the parallel APF and the network neutral is joined to the negative terminal of the dc link voltage to escape the condition of the 4^{th} leg in the VSI of the parallel APF. The usual switching frequency of the switches in the VSI too decreases, consequently the switching losses in the inverters decrease.

B.N.Singh *et al.* [37] employed a fuzzy logic algorithm to control a 3P UPQC. The UPQC works on APF that compensates the VAR, both voltage harmonics and current harmonics produced by nonlinear loads. UPQC is an incorporation of back to back connected parallel active power filter (APF) and series APF to a common DC link voltage with the nonlinear load. In the proposed structure the parallel inverter operates as a current source which compensates harmonics in current produced by nonlinear load and the series inverter operates as a voltage source which helps in compensating the harmonics in voltage produced by nonlinear load. A diode bridge rectifier serving R-L load is taken as nonlinear current load whereas a source of voltage harmonics is taken in parallel with the load. Authors have developed the UPQC appropriate mathematical model of the system to study the sable state and transient state performance. The ability of the UPQC is demonstrated towards filtering harmonics in voltage and current along with the VAR compensation of nonlinear load.

S.K. Jain *et al.* [38] presented the simulation and experimental study of a fuzzy controlled under steady state and transient conditions, 3P parallel APF to enhance PQ by compensating harmonics and VAR required by a nonlinear load. The fuzzy control is beneficial because it is based on a linguistic description and does not need a mathematical model of the system. The fuzzy control system is understood on an economical dedicated microcontroller made scheme. The compensation procedure is established on sensing line currents only, a method different from conventional approaches, which need harmonics or reactive VA condition of the load. The performance of the fuzzy logic controller (FLC) is compared with a conventional PI controller. The dynamic performance of the FLC is found to be superior to the conventional PI controller. To obtain the shifting signals, PWM shape generation is used which is established on carrierless hysteresis based current control.

G.K. Singh *et al.* [39] presented the extensive applications of power electronic based loads remain to increase worries over harmonic distortion. However, it is preferred to get purely sinusoidal current from the distribution network, but it is not possible because of presence of power electronic converters. The current harmonics created by these non-linear loads further impact in voltage distortion and leads to various PQ problems. Presented study uses FLC based robust APF to decrease the harmonics for large scale variations of load current in stochastic conditions. The proposed control system is not complex and capable of sustaining the compensated line currents stable, regardless of interruption in the load currents. The proposed approach is widely verified for extensive range of variable load current under stochastic conditions and results are found to be quite satisfactory to mitigate harmonics and VAR components from the utility load current. The presented results in this study clearly show the effectiveness of the proposed APF to fulfill the IEEE-519 standard recommendations on harmonic levels.

Suja and Raglend [40] discussed about Non-linear loads which are usually disturbed by PQ problems. Harmonic currents produce capacitor overloading, system resonance and decrease in efficiency. Voltage sags are regularly occurring PQ problems in electrical systems. The UPQC is a FACTS controllers utilised for mitigating the effect of voltage sags. For quadrature type of voltage injection the series compensator (SC) in the UPQC is used. So that at stable state the SC never consumes true power. The proposed technique presents a low power rating SC that injects the voltage which perfectly compensates the PQ problem of the system. The addition of FLC with the conventional UPQC decreases the voltage sag levels in the output voltage and also improves the power factor. The control circuit is designed using FLC and simulated using MA TLAB/SIMULINK.

Shankar and Kumar [41] presented the study about the rise of nonlinear loads and power electronic devices in the power system, it has given growth to two main restrictions harmonics generation and lagging current from the utility. In accumulation to these, the other PQ problems have performed in the system that decreases the overall efficiency of the system. In the proposed study, UPQC has been modeled for both true power and VAR compensation using fuzzy control

(FC) strategy. The performance of UPQC is analyzed with quick switching of loads along with occurrences of L-G fault. The control scheme has been formulated using FLC in UPQC.

CHAPTER 4

RESULTS AND DISCUSSIONS

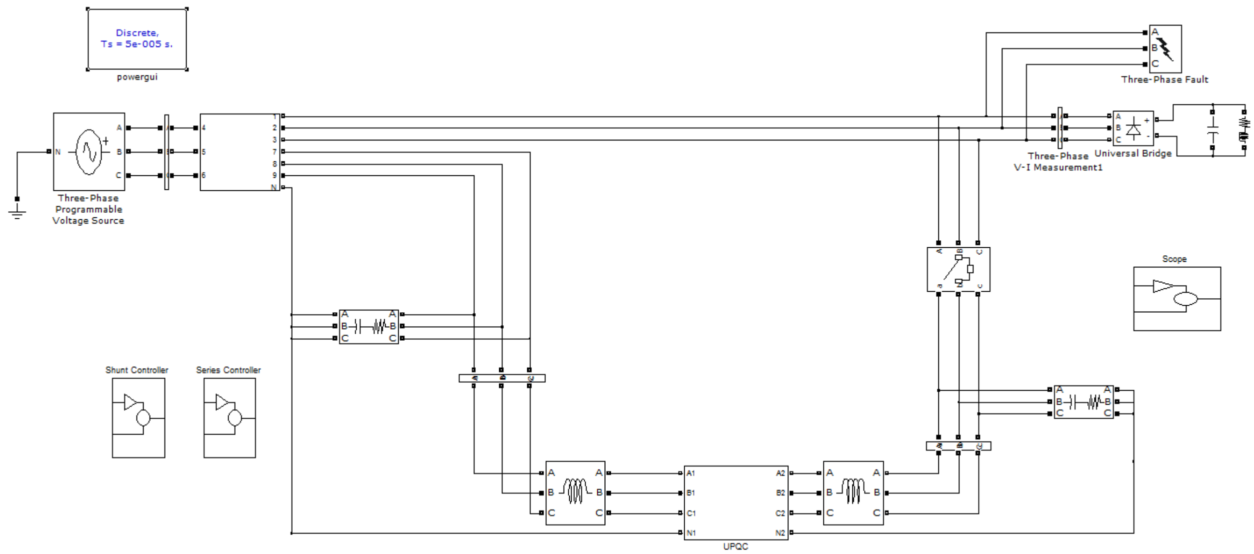

Fig. 4.1 MATLAB SIMULINK CIRCUIT DIAGRAM OF UPQC

In order to test the performance of the UPQC using the proposed FLC, it has been simulated for a 400 V, 50 Hz three-phase AC supply using MATLAB/Simulink. A three-phase diode rectifier feeding an RL load is considered as nonlinear load. The maximum load power demand is considered as 13 kW + j10 kVAR. The values of source resistance Rs = 0.1 Ω and source inductance Ls = 0.1 mH. DC link capacitor value is 2200 μF. To test the operation of UPQC under the voltage sag and swell conditions, 20% sag in line voltage has been created.

The UPQC has been simulated using the proposed FC. The source current waveform before and after connecting the UPQC is shown in Fig. 4.1 It may be noticed that the source current is distorted before connecting the UPQC and it becomes sinusoidal after connecting the UPQC at 0.1s.

The THD of the source current before connecting the UPQC is 22.97%. Harmonic spectrum of the source current after connecting the UPQC is shown in Fig. 7. The THD of the source current after connecting the UPQC is 0.13. The DC link capacitor voltage is held constant at its reference value by the FLC. To investigate the performance of the proposed UPQC using FLC, under voltage sag condition, 20% sag has been created in the all the phases of the supply voltage. The simulation results of these cases are shown in Fig. 4.2 to Fig. shows the supply voltage with 20% voltage sag in all the phases from 0.25s to 0.0.45s.

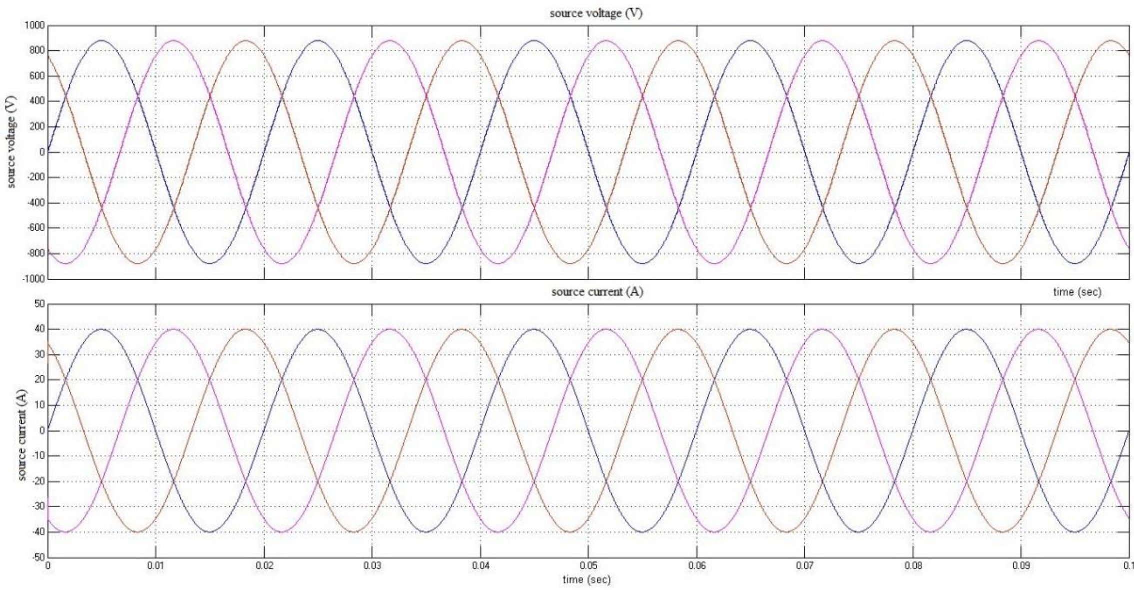

Fig. 4.2 Source voltage and current waveform

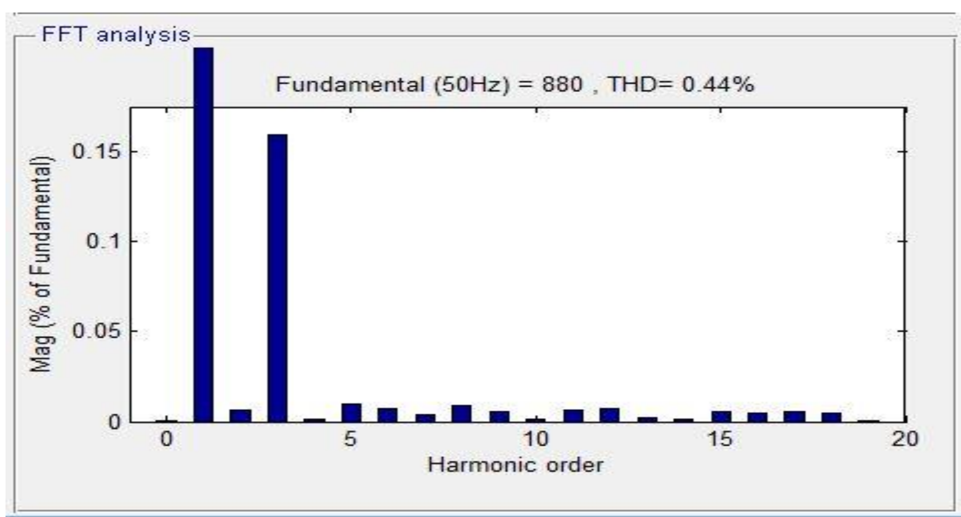

Fig. 4.3 THD of Source Voltage

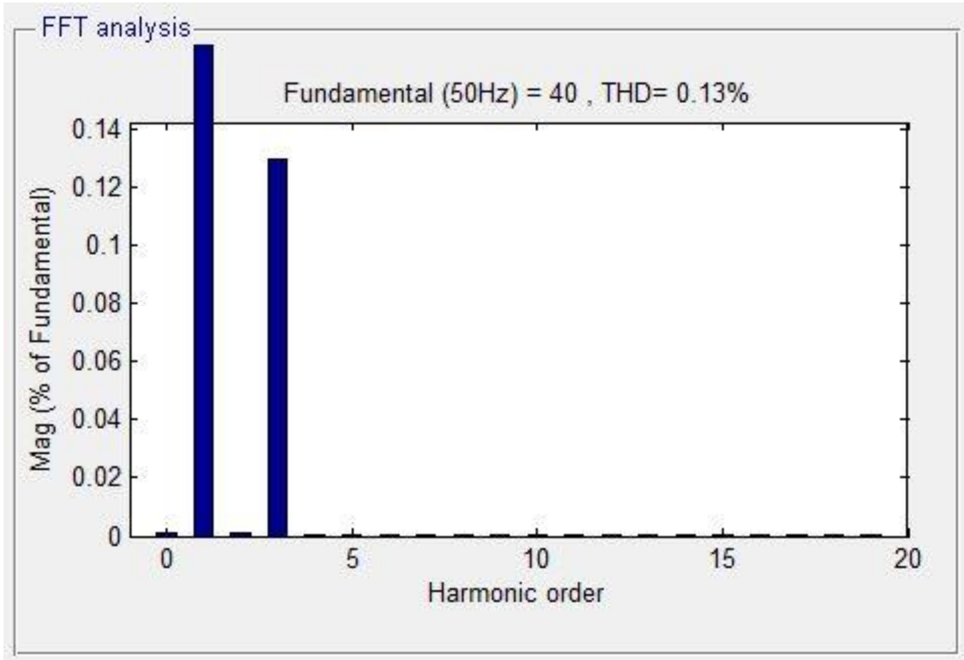

Fig. 4.4 THD of source current

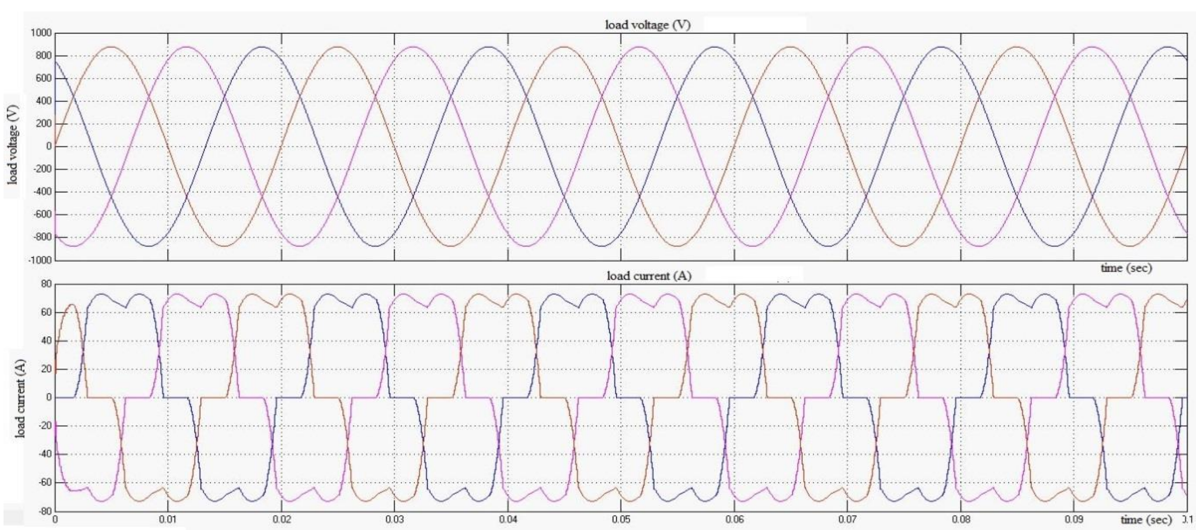

Fig. 4.5 Load voltage and current waveform

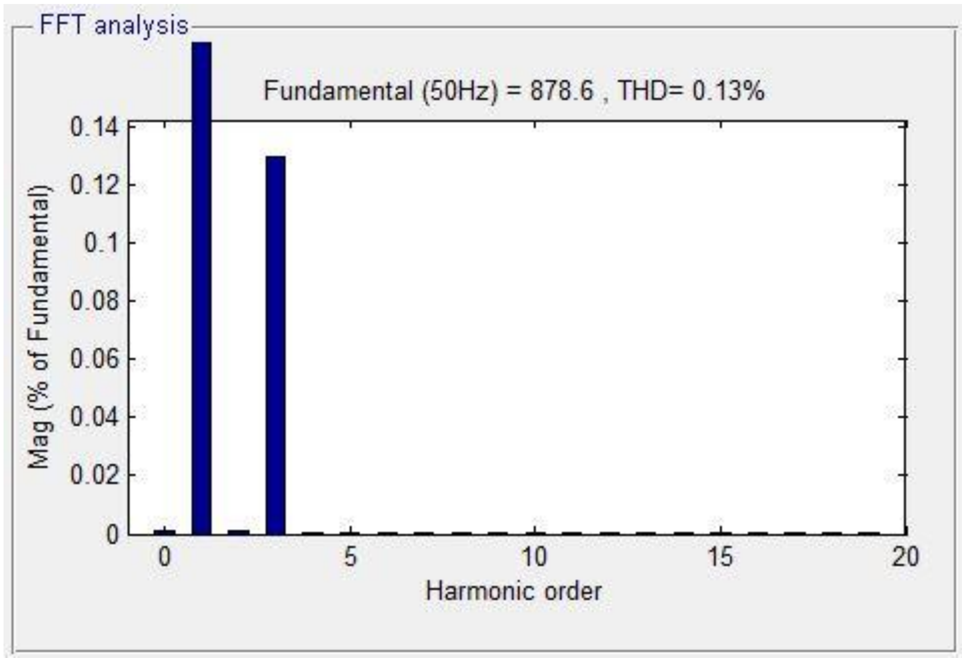

Fig. 4.6 THD load voltage

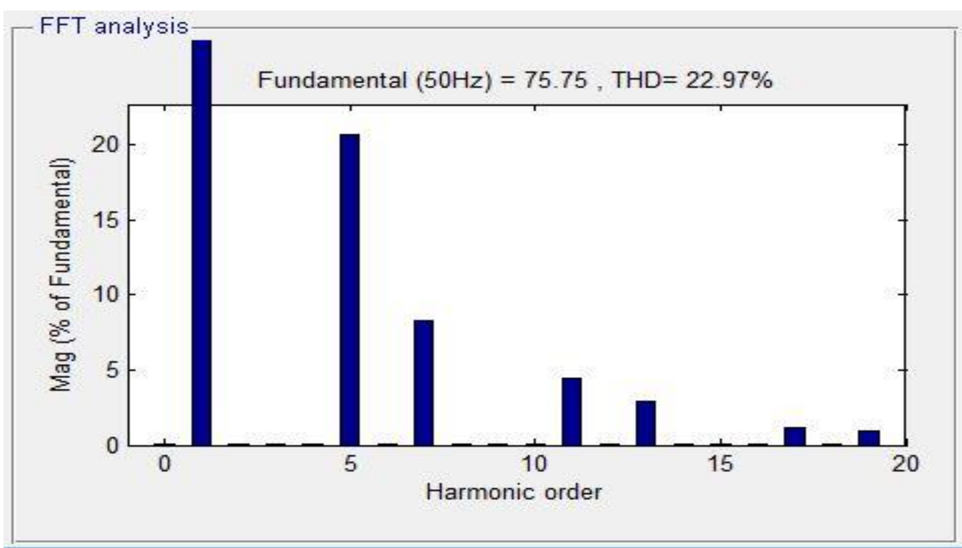

Fig. 4.7 THD of load current

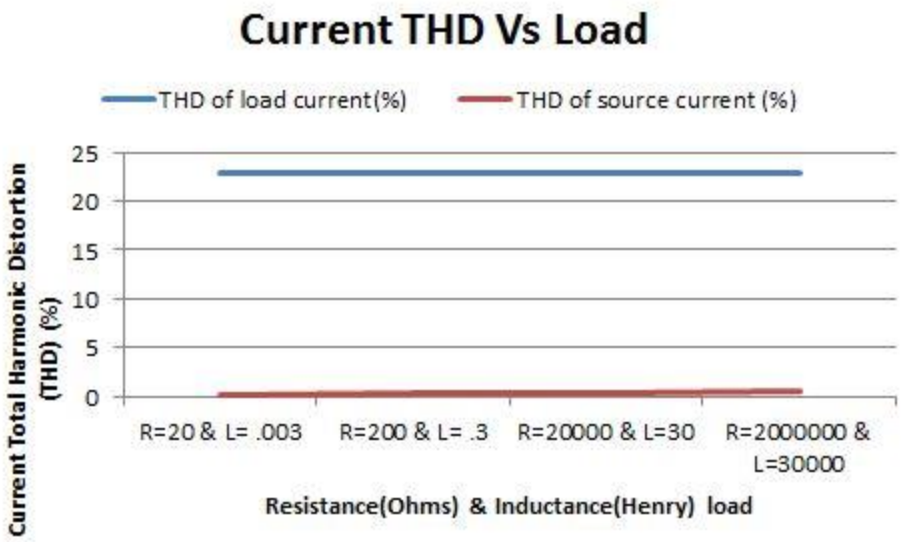

Fig 4.8 Current THD Vs Load

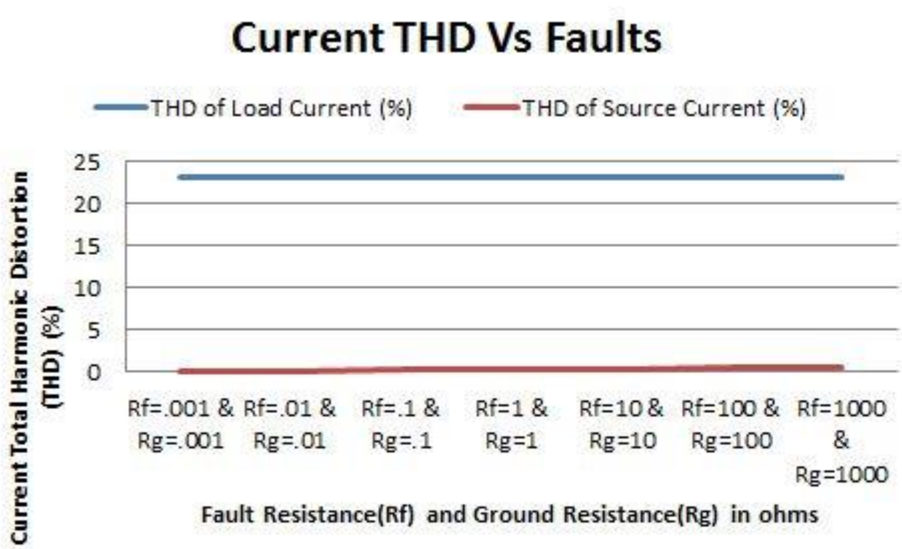

Fig 4.9 Current THD Vs faults

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

- UPQC using FC has been investigated for compensating reactive power and harmonics. It is clear from the simulation results that the UPQC using FC is simple, and is based on sensing the line currents only. The THD of the source current using the proposed FLC is well below 5%, the harmonic limit imposed by IEEE- 519 standard.
- The modern technology improves the power quality using different controllers with artificial intelligence technique. I have used one of them known as fuzzy logic controller (FLC) however one can do the same work with different artificial intelligence technique like ANN is one of the new controllers used at present.
- The UPQC model as developed can be modified to be more effective in eliminating power quality related problems in power system. The various paths in which the presented work can be extended are listed below:
- A laboratory prototype can be made for the developed model.
- The control strategy used here can be modified for three-phase four-wire system under unbalance load
- The model has been developed for right shunt UPQC configuration. The model can be modified for left shunt UPQC.
- Nowadays generation of electricity from renewable sources has improved very much. Utilizing wind energy and solar energy as a renewable source to generate electricity has developed rapidly. UPQC can be combined with one or several distribution generation (DG) system to provide good quality power to the consumers. Power generated by wind or solar energy can be fed to the DC link through converter to make the UPQC more effective during severe system conditions.

CHAPTER 6

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CHAPTER NO 3

PRESENT WORK

SCOPE OF THE STUDY

UPQC has the following areas under which we can do power quality improvement. These are as follows:

- Reactive Power Compensation
- Voltage Regulation
- Compensation for voltage sag and swell
- Unbalance compensation for current and voltage for 3-phase system
- Neutral current compensation for 3-phase 4-wire system

To perform this experiment I'm using MATLAB, Simulink software as a tool. In that proper UPQC is modelled and the above stated points are tried to implement.

OBJECTIVES OF THE STUDY

This dissertation-I proposes the model of unified power quality conditioner which is used for power quality improvement in electrical networks. The main objectives are as follows:

- Study of UPQC model
- Analysis of UPQC under balanced conditions.
- Analysis of UPQC under faulty condition
- Analysis of UPQC in the presence of nonlinear loads.

RESEARCH METHODOLOGY

- The electrical network connected with nonlinear loads is considered.
- The power quality of an electrical network is taken into account without using any custom power devices.
- To improve the power quality of the electrical network UPQC will be implemented.
- I am using MATLAB to simulate the proposal of integration of UPQC in electrical networks with nonlinear loads to enhance the power quality.
- After doing MATLAB simulation, I will conclude the results.

A detailed operating principle and the vast capabilities of UPQC are discussed as follows:

1. **UPQC : Unified power quality conditioner**

UPQC is a versatile power conditioner which can be utilized to compensate several voltage disturbance of the power source, to precise voltage fluctuation, and to inhibit load current harmonic from entering the power network. It is a CPD designed to mitigate the PQ issues that disturb the performance of sensitive and/or critical loads. UPQC has parallel/ shunt and series compensation capabilities for voltage and current harmonics, VAR, voltage disturbances (including sag, swell, flicker etc.), and power-flow control. Normally, a UPQC comprises two VSI/VSC with a common dc link designed in single phase, three phase three wire (3P3W), or three phase four wire (3P4W) configurations. One inverter is controlled as a variable voltage source in the series APF. The other inverter is controlled as a variable current source in the shunt APF. The series APF compensates for supply voltage disturbances like harmonics, imbalances, negative and zero sequence components, sag, swell, and flickers. The shunt APF converter compensates for load current distortions like harmonics, imbalances and VAR and to perform the voltage regulation dc link has used. [6, 22]. A fuzzy logic algorithm employed to control a 3P UPQC. The UPQC works on APF that compensates the VAR, both voltage harmonics and current harmonics produced by nonlinear loads. UPQC is an incorporation of back to back connected parallel active power filter (APF) and series APF to a common DC link voltage with the nonlinear load. In the proposed structure the parallel inverter operates as a current source which compensates harmonics in current produced by nonlinear load and the series inverter operates as a voltage source which helps in compensating the harmonics in voltage produced by nonlinear load. A diode bridge rectifier serving R-L load is taken as nonlinear current load whereas a source of voltage harmonics is taken in parallel with the load. Authors have developed the UPQC appropriate mathematical model of the system to study the sable state and transient state performance. The ability of the UPQC is demonstrated towards filtering harmonics in voltage and current along with the VAR compensation of nonlinear load. [37] A fuzzy controlled has analyzed under steady state and transient conditions, 3P parallel APF to enhance PQ by compensating harmonics and VAR required by a nonlinear load. The fuzzy control is beneficial because it is based on a linguistic description and does not need a mathematical model of the system. The fuzzy control system is understood on an economical dedicated microcontroller made scheme. The compensation procedure is established on sensing line currents only, a method different from conventional approaches, which need harmonics or reactive VA condition of the load. The performance of the fuzzy logic controller (FLC) is compared with a conventional PI controller. The dynamic performance of the FLC is found to be superior to the conventional PI controller. To obtain the shifting signals, PWM shape generation is used which is established on carrierless hysteresis based current control. [38] The UPQC is a FACTS controllers utilised for mitigating the effect of voltage sags. For quadrature type of voltage injection the series compensator (SC) in the UPQC is used. So that at stable state the SC never consumes true power. The proposed technique presents a low power rating SC that injects the voltage which perfectly compensates the PQ problem of the system. The addition of FLC with the conventional UPQC decreases the voltage sag levels in the output voltage and also improves the power factor. In the proposed study, UPQC has been modeled for both true power and VAR compensation using fuzzy control (FC) strategy. The performance of UPQC is analyzed with quick switching of loads along with occurrences of L-G fault. The control scheme has been formulated using FLC in UPQC. [41]

1.2 **Basic Configuration of UPQC** Fig. 4.1 shows system basic configuration of UPQC.

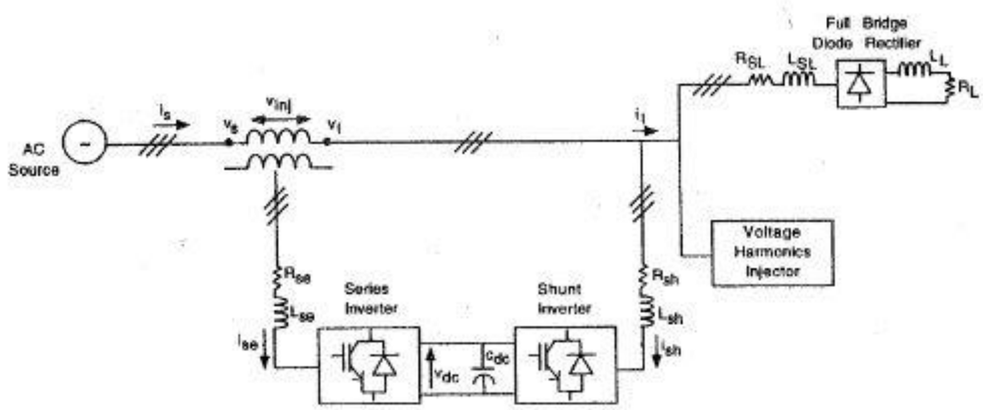

Fig. 4.1 Basic configuration of UPQC.

The key components of UPQC are as follows:

- **Series inverter:** It is a VSI/VSC connected in series with AC line through a series transformer and acts as a voltage source to mitigate voltage harmonics caused by non linear loads. It eliminates supply voltage flickers and imbalances from the load terminal voltage. Control of the series inverter output is performed by PWM.
- **Shunt inverter:** It is a VSI/VSC connected in parallel with same AC line by which current harmonics suppression, VAR compensation and PF enhancement is obtained. It also performs the regulation of DC link voltage.
- **DC link capacitor:** The two VSIs are connected back to back with each other through this capacitor. The voltage across this capacitor provides the self-supporting DC voltage for proper operation of both the inverters. With proper control, the DC link voltage acts as a source of active as well as reactive power and thus eliminates the need of external DC source like battery.
- **Low-pass filter** is used to attenuate high frequency components of the voltages at the output of the series converter that are generated by high-frequency switching of VSI.
- **High-pass filter** is installed at the output of shunt converter to absorb ripples produced due to current switching
- **Transformer:** The necessary voltage generated by the series inverter to maintain a pure sinusoidal load voltage and at the desired value is injected in to the line through these series transformers. A suitable turns ratio is often considered to reduce the current flowing through the series.

4.2 UPQC working principle and control scheme:

The perceived DC connection voltage (V_{dc}) is compared by a reference voltage (V_{dc}^*)the error signal acquired is treated in FLC. The output of the FLC I_{sb}^* is taken as the magnitude of 3P (three phase) reference currents. The 3P unit current vectors $U_{sa}, U_{sb} and\ U_{sc}$ are derived in phase with the 3P source voltages $V_{sa}, V_{sb} and\ V_{sc}$.The unit current vectors from the 3P of supply currents. Multiply of magnitude I_{sp}^* with $U_{sa}, U_{sb} and\ U_{sc}$ results in 3P reference supply currents $I_{sa}^*, I_{sb}^*\ and\ I_{sc}^*$ Subtraction of load currents $I_{sha}, I_{shb} and I_{shc}$from the reference currents, results in 3P reference currents $I_{sha}^*, I_{shb}^*\ and I_{shc}^*$ In case of shunt APF. The obtained reference currents are compared with the real shunt compensating currents $I_{sha}, I_{shb} and\ I_{shc}$ and the error signal is transformed into PWM gating signals, the shunt APF supplies harmonics currents and VAR demand of the load.

The amplitude of the source voltage is calculated from the 3P sensed values of voltages as

$$V_{sm} = \left[\frac{2}{3}(V_{sa}^2 + V_{sb}^2 + V_{sc}^2)\right]^{\frac{1}{2}} \qquad (1.7)$$

The 3P $U_{sa}, U_{sb} and\ U_{sc}$ are calculated as

$$U_{sa} = \frac{V_{sa}}{V_{sm}}, U_{sv} = \frac{V_{sb}}{V_{sm}}, U_{sc} = \frac{V_{sc}}{V_{sm}} \qquad (1.8)$$

Multiplication of 3P unit current vectors $U_{sa}, U_{sb} and\ U_{sc}$ with the amplitude of the source current I_{sp} consequences in 3P reference supply currents as

$$a = I_{sa}^*, b = I_{sb}^*\ and\ c = I_{sc}^* \qquad (1.9)$$

Where

$$a = I_{sp}.U_{sa},$$

$$b = I_{sp}.U_{sb} \qquad (2.0)$$

$$c = I_{sp}.U_{sc}$$

By subtracting 3P load currents are from 3P supply currents we can get reference currents as

$$I_{sha}^* = a_1, I_{shb}^* = b_1\ and\ I_{shc}^* = c_1 \qquad (2.1)$$

Where

$a_1 = I_{sa}^* - I_{la}$

$$b_2 = I_{sb}^* - I_{lb} \quad (2.2)$$

$c_1 = I_{sc}^* - I_{lc}$

Series APF working Principle and control:

In this 3P load voltages $V_{la}, V_{lb} and\, V_{lc}$ and are subtracted from 3P supply voltages $V_{sa}, V_{sb} and\, V_{sc}$ which gives 3P reference voltages $V_{la}^*, V_{lc}^* and\, V_{lb}^*$ that is inserted in series with the load. By taking a suitable transformation, the three reference currents $I_{sea}^*, I_{seb}^*\, and\, I_{sec}^*$ of the series APF are obtained from the 3P reference voltages $V_{la}^*, V_{lc}^* and V_{lb}^*$. The reference currents are fed to a current controller along with their sensed counterparts $I_{sea}, I_{seb} and\, I_{sec}$. Supply voltage and load voltage are sensed and there from the desired injected voltage is computed as

$$V_{inj} = V_s - V_l \quad (2.3)$$

The 3P reference values of inserted voltage are stated as

$$V_{1a}^* = \sqrt{2}\, V_{inj} Sin\, (\omega t + \delta_{inj}) \quad (2.4)$$

$$V_{1b}^* = \sqrt{2} V_{inj} Sin\, (\omega t + \frac{2\pi}{3} + \delta_{inj}) \quad (2.5)$$

$$V_{1b}^* = \sqrt{2} V_{inj} Sin\, (\omega t - \frac{2\pi}{3} + \delta_{inj}) \quad (2.6)$$

Where δ_{inj} is the phase with injected voltage.

The 3P reference currents of the series APF are computed as follows

$I_{sea} = \frac{V_{la}^*}{Z_{se}}$,

$I_{seb} = \frac{V_{lb}^*}{Z_{se}}$ and

$$I_{sec} = \frac{V_{lc}^*}{Z_{se}} \quad (2.7)$$

The impedance Z_{se} includes inserted transformer impedance. The currents $I^*_{sea}, I^*_{seb}\ and I^*_{sec}$ are the ideal currents to be maintained through the secondary winding of the transformer in order to inject voltages $V_{la}, V_{lb} and\ V_{lc}$ there by accomplishing the desired task of voltage sag compensation the currents $I^*_{sea}, I^*_{seb}\ and I^*_{sec}$ are compared with series compensating currents $I_{sha}, I_{shb}\ and\ I_{shc}$ in the PWM current controller for obtaining signals for the switches in inverter.

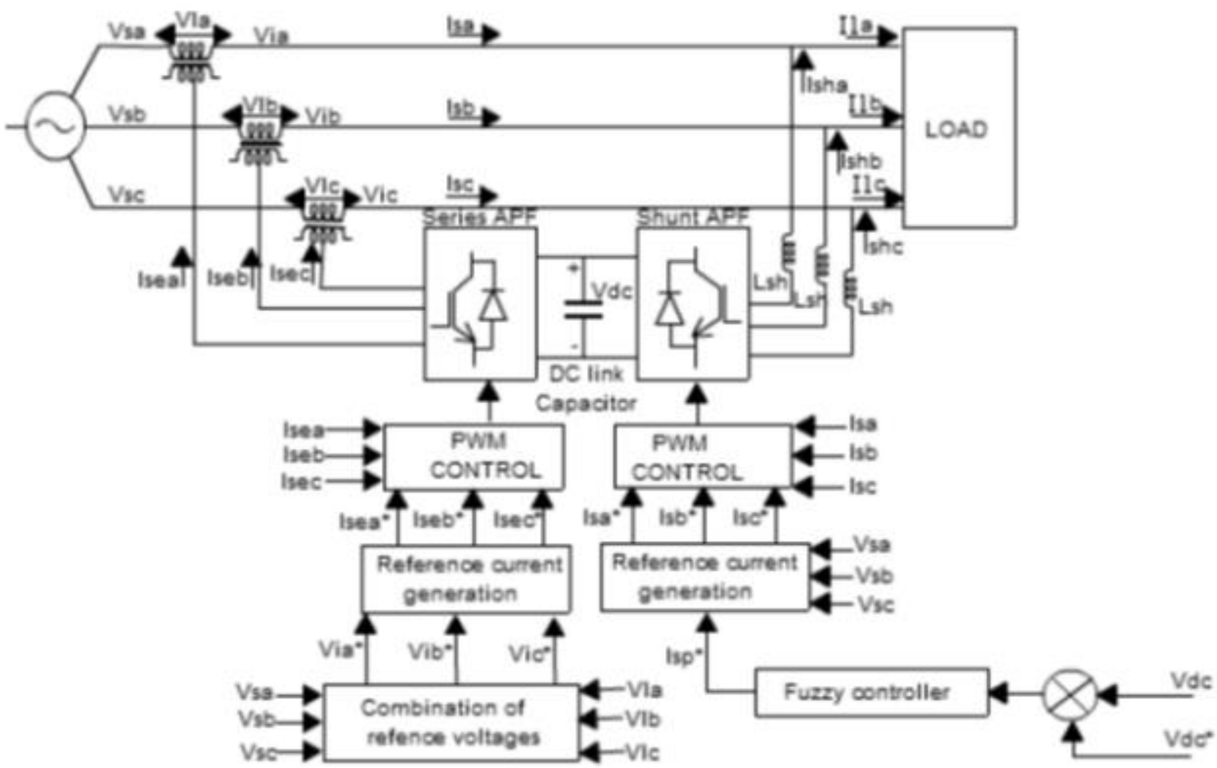

Fig. 4.2 Control structure 3P of UPQC.

Fuzzy Logic controller

Artificial intelligence (AI) is the ultimate tool to replace conventional controller. The first part of (AI) deals with fuzzy logic technique second deals with Artificial neural network technique (ANN) and last part deals with Neuro-fuzzy technique. I am using fuzzy logic controller (FLC) in place of conventional controller PI controller. FLC works on machine learning which is able to identify human action. Personal computers only predict yes (true) or no (false) values however humans can aim the at the degree of truthness or falseness. FLC models deduce the human actions so they called expert systems (ES). Process of changing process of a real scalar set of values into a fuzzy set of values is known as Fuzzification. To get different Fuzzification we need dissimilar types of fuzzifiers. FLC of expert system is a rule based system. Expert system has their database to store these rules. A scalar value input is given to the FLC which is fuzzified.

As FLC works on a set of linguistic rules which is taking control action. Expert system defined their rules accordingly. As the scalar value input is given to the FLC which is fuzzified into linguistic variables. FLC does not need a mathematical modeling. The ES/FLC has 3 sections fuzzification, interference engine and defuzzification. The ES is considered as seven fuzzy sets for each input and output, Triangular membership functions for easiness, Fuzzification using constant universe of discourse, Implication using Mamdani's "min" operator and Defuzzification using the "height'' scheme.

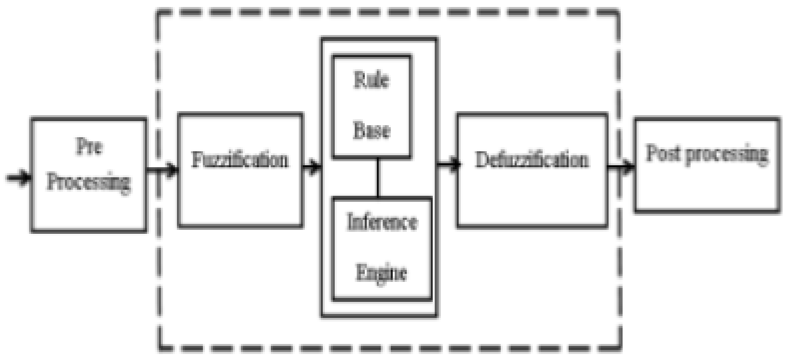

Fig. 4.3 Fuzzy Logic Controller

Fuzzification

Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The partition of fuzzy subsets and the shape of membership function adapt the shape up to appropriate system. The value of input error $\boldsymbol{E_{(k)}}$ and change in error $\boldsymbol{CE_{(k)}}$ are normalized by an input scaling factor shown in Fig. 4.3.

In this system the input scaling factor has been designed such that input values are between -1 and +1. The triangular shape of the membership function of this arrangement presumes that for any particular input there is only one dominant fuzzy subset. The input error $\boldsymbol{E_{(k)}}$ for the FLC is given as

$$E_{(k)} = \frac{P_{ph_{(k)}} - P_{Ph_{k-1}}}{V_{ph_k} - V_{ph_{(k-1)}}} \tag{2.8}$$

$$CE_{(k)} = \frac{P_{ph_{(k)}} - P_{Ph_{k-1}}}{V_{ph_k} - V_{ph_{(k-1)}}} \tag{2.9}$$

Table 1. Fuzzy Rules

Change in error	Error						
	NB	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

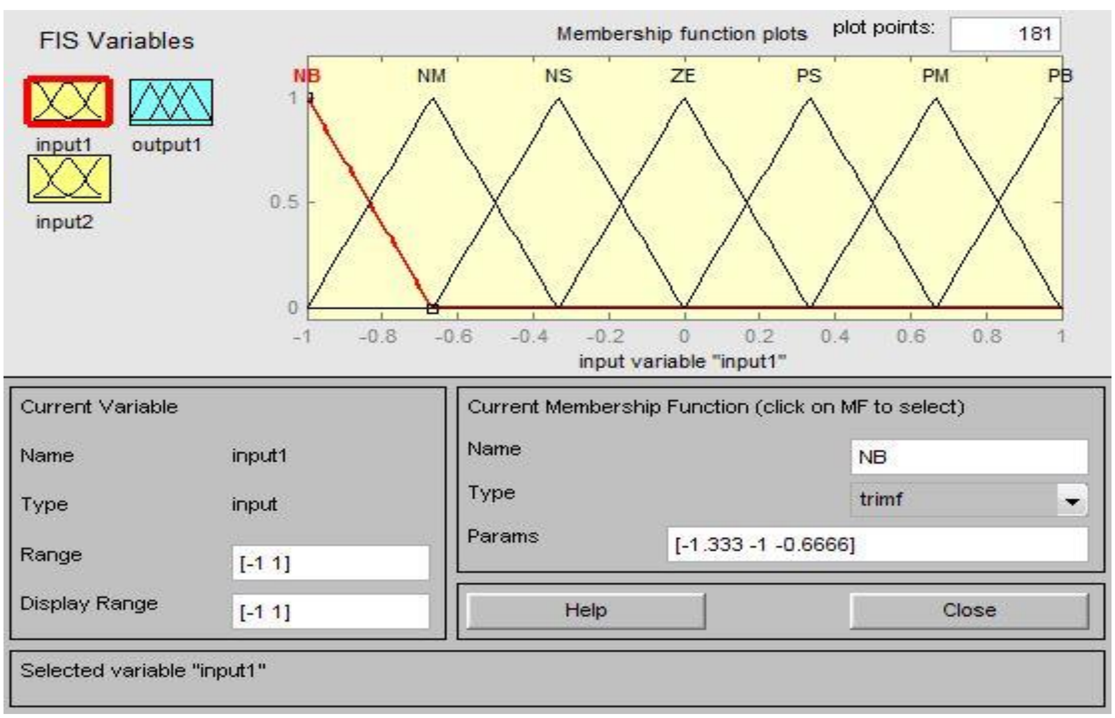

Fig. 4.4

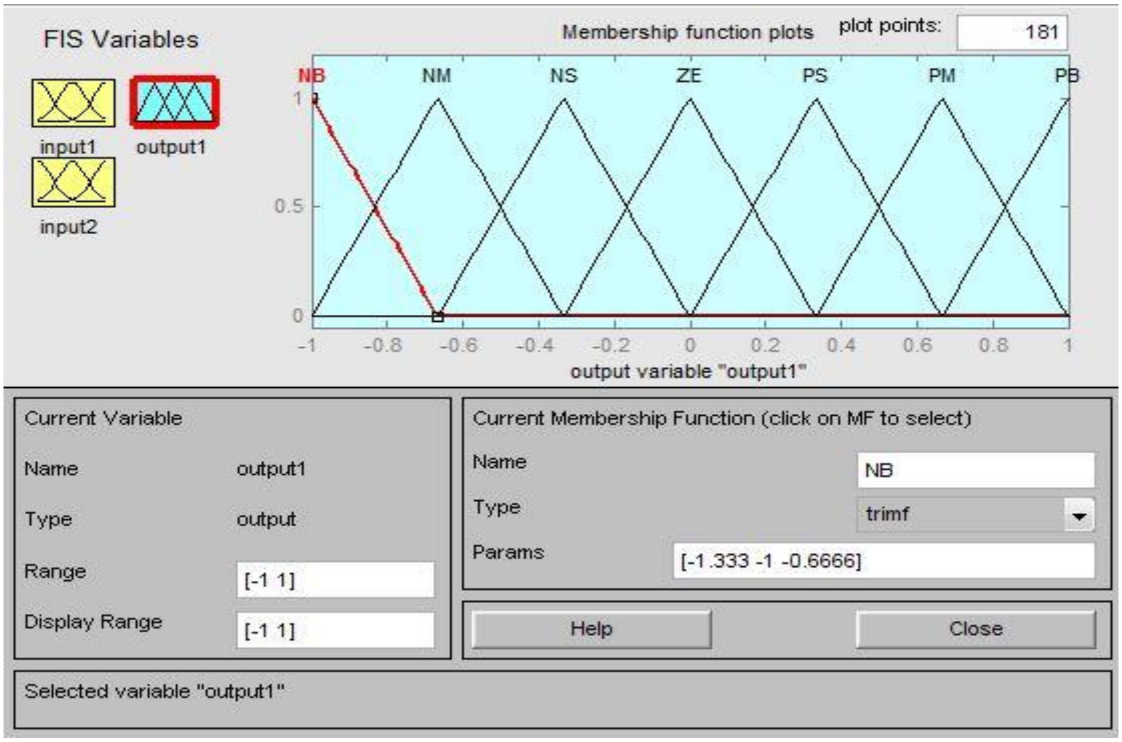
FIS Variables
Membership function plots
plot points:
181
input1
output1
input2
NB
NM
NS
ZE
PS
PM
PB
output variable "output1"
Current Variable
Name
output1
Type
output
Range
[-1 1]
Display Range
[-1 1]
Current Membership Function (click on MF to select)
Name
NB
Type
trimf
Params
[-1.333 -1 -0.6666]
Help
Close
Selected variable "output1"

Fig. 4.5

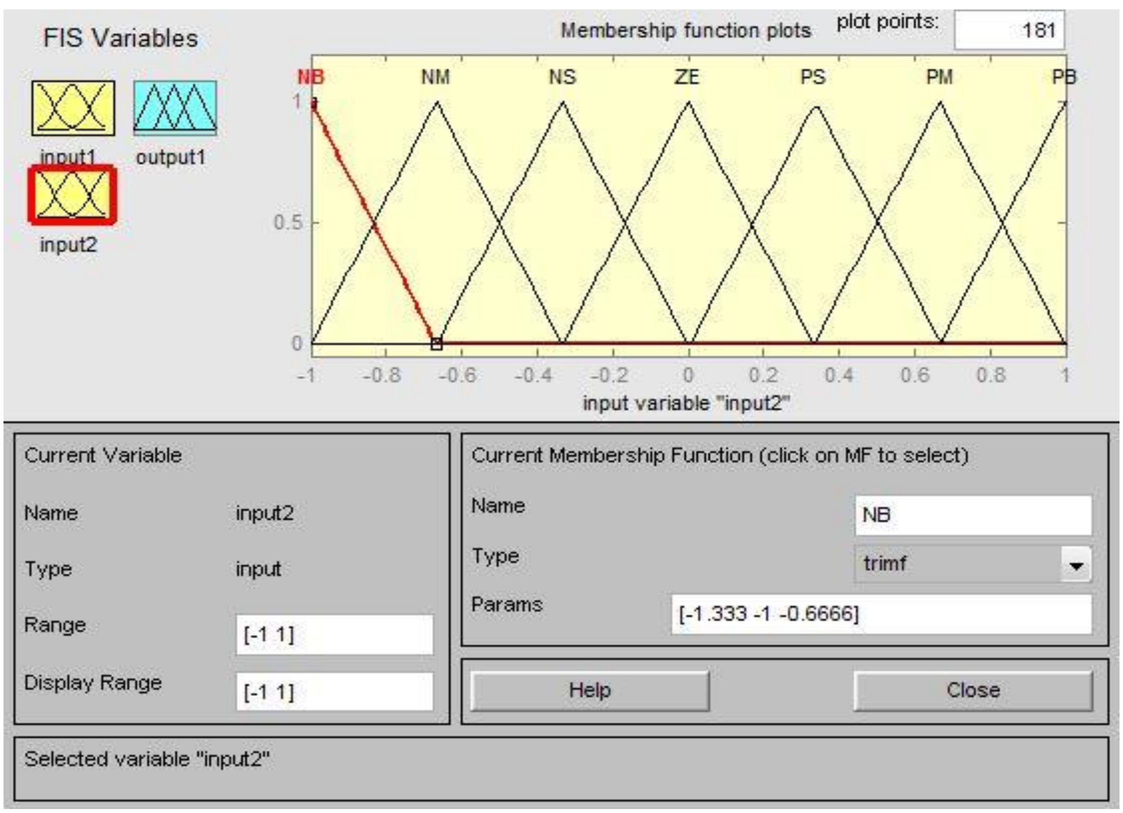
FIS Variables
Membership function plots
plot points:
181
input1
output1
input2
NB
NM
NS
ZE
PS
PM
PB
input variable "input2"
Current Variable
Name
input2
Type
input
Range
[-1 1]
Display Range
[-1 1]
Current Membership Function (click on MF to select)
Name
NB
Type
trimf
Params
[-1.333 -1 -0.6666]
Help
Close
Selected variable "input2"

Fig. 4.6

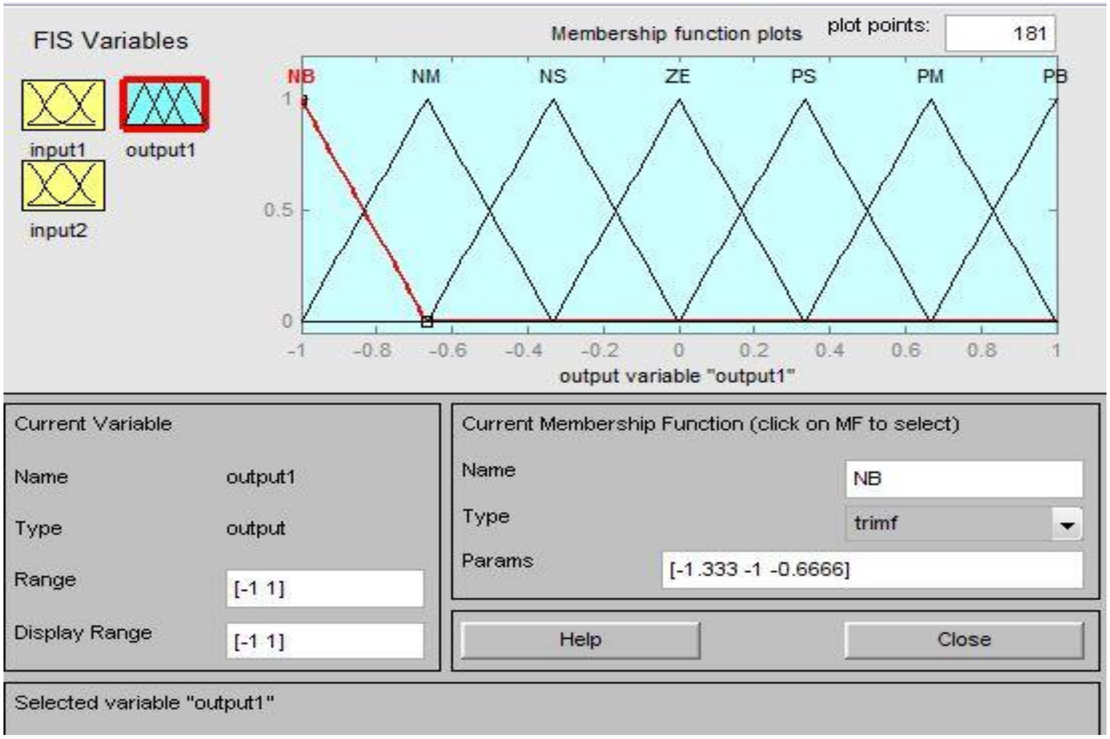

Fig. 4.7

Fig. (4.4)- (4.7) Membership functions

Interference Method

Several composition methods such as Max–Min and Max-Dot have been proposed in the literature. In this paper Min method is used. The output membership function of each rule is given by the minimum operator and maximum operator. Table 1 shows rule base of the FLC.

Defuzzification

As a plant usually requires a non-fuzzy value of control, a defuzzification stage is needed. To compute the output of the FLC, „height" method is used and the FLC output modifies the control output. Further, the output of FLC controls the switch in the inverter. In UPQC, the active power, reactive power, terminal voltage of the line and capacitor voltage are required to be maintained. In order to control these parameters, they are sensed and compared with the reference values. To achieve this, the membership functions of FC are: error, change in error and output as shown in Figs. (4.4) – Fig. (4.5) in the present work, for fuzzification, non-uniform fuzzifier has been used. If the exact values of error and change in error are small, they are divided conversely and if the values are large, they are divided coarsely. The set of FC rules are derived from (3.0).

$$u = -[\alpha E + (1 - \alpha) * C] \quad (3.0)$$

Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable. A large value of error E indicates that given system is not in the balanced state. If the system is unbalanced, the controller should enlarge its control variables to balance the system as early as possible. One the other hand, small value of the error E indicates that the system is near to balanced state. Overshoot plays an important role in the system stability. Less overshoot is required for system stability and in restraining oscillations. C in (12) plays an important role, while the role of E is diminished. The optimization is done by α. During the process, it is assumed that neither the UPQC absorbs active power nor it supplies active power during normal conditions. So the active power flowing through the UPQC is assumed to be constant. The set of FC rules is made using Fig. (4.4) - (4.7) is given in Table 1.