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Mitigation of Harmonics with Intelligent Controllers Based Multi Converter UPQC

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Abstract-*In this paper a Hybrid fuzzy logic controller based multiconverter unified power quality conditioner (MC-UPQC) to enhance the power quality issues mainly in harmonic reduction. This newly designed controller is connected to a source in order to compensate voltage and current in the two feeders. In the proposed configuration, all converters are connected back to back on the dc side and share a common dc-link capacitor. Therefore, power can be transferred from one feeder to adjacent feeders to compensate for sag/swell and interruption. The transient response of the hybrid fuzzy logic controller in dc-link voltage controller will be very fast. The compensation performance analysis of proposed MC-UPQC is compared with PI, Fuzzy and hybrid fuzzy logic controller is observed by using MATLAB/SIMULNK Software.*

Keywords: *MC-UPQC, VSC, Power quality, Hybrid Fuzzy Logic Controller.*

I. INTRODUCTION

UPQC is being used as a universal active power conditioning device to mitigate both current as well as voltage harmonics at a distributionend of power system network. The performance of UPQC mainly depends upon how quickly and accurately compensation signals are derived. Also, UPQC performances will depend on the design of power semiconductor devices, on the modulation technique used to control the switches, on the design of coupling elements, on the method used to determine active filters current and voltage references and on the dynamics and robustness of current and voltage control loops. A UPQC is a combination of shunt and series active power filter sharing a common dc link. Fig.1 shows simple structure of conventional UPQC [1]. It can compensate almost all power quality problems such as voltage harmonics, voltage unbalance, voltage flickers, voltage sags, voltage swells, current harmonics, current unbalance, reactive current, etc. More attention is being paid on mitigation of voltage sags andswells using UPQC recently. The aim is to maintain the load bus voltage sinusoidal and at desired constant level in all operating conditions.

The Multi-Converter UPQC (MC-UPQC) system has three Voltage Source Converter (VSC's) connectedto two feeder lines to compensate the voltage andcurrent imperfection in both feeders [2]. The control parts of the shunt and series Active Power Filters(APF) are proposed based on Synchronous ReferenceFrame (SRF) theory with Proportional Integral (PI)controller. SRF based control for a dynamic modelin three phase system under different load consideration is used to improve the Power Quality (PQ) by using multi converter with power conditioner [3]. The Interline Unified Power Quality Conditioner (IUPQC) consists of series VSC and shunt of VSC both joined together by a common dc bus. It can also be used to demonstrate how it is connected between two independent feeders in regulating the voltage across a sensitive load from the other feeder. The Generalized Unified Power Quality Conditioner (GUPQC) is a combination of one shunt and two series VSC to compensate current imperfections in one feeder and voltage imperfection inthe other two feeders [4]

A new scheme has been proposed in, which the required compensating current is determined by sensing load current which is further modified by sensing line currents only.The advantages or FLCs over conventional controllers are that they do not need an accurate mathematical model, they can work with imprecise inputs, can handle non-linearity, and they are more robust than conventional nonlinear controllers [5-7].

This paper presents a fuzzy logic control based unified power quality conditionerto mitigate all the power quality problems and comparesPI, fuzzy and hybrid fuzzy results. Unified power quality conditioner is thecombination of series and shunt active filter [8-10].Theperformance of UPQC mainly depends upon how quicklyand accurately compensation signals are derived. The PI control based techniques are simple indesign and reasonably. However, the tuning of the PIcontroller is a tedious job. Further, the control of UPQCbased on the conventional PI control is prone to severedynamic interaction between active and reactive power flows[11]. In this work, the conventional PI controller has beenreplaced by a fuzzy logic controller. The fuzzy logiccontroller has been used in APFs in place of conventional PIcontroller for improving the dynamic performance [12]. The FLC-based compensation scheme eliminates voltage andcurrent magnitude of harmonics with good dynamic response.TheFC is basically nonlinear and adaptive in nature. Again fuzzy controller is replaced with Hybrid fuzzy controller for getting better response in case of effectively reducing the harmonics in the entire system.

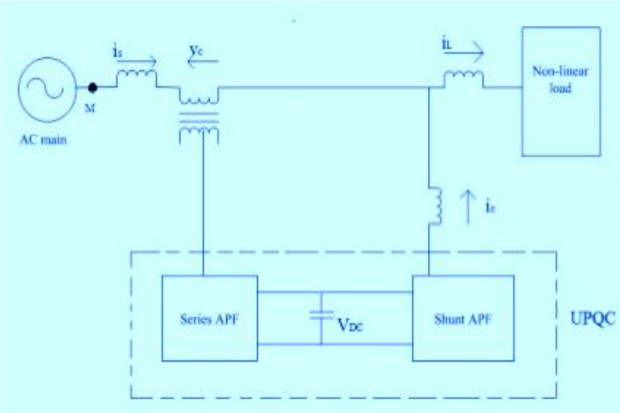


Fig.1. Simple UPQC System

II. PROPOSED MC-UPQC SYSTEM

A. Circuit Configuration

The single-line diagram of a distribution system with an MC-UPQC is shown in Fig.2.

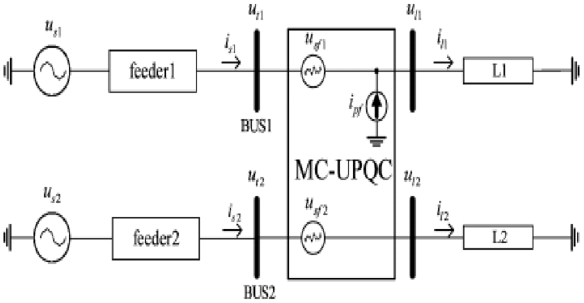


Fig.2. Single-line diagram of a distribution system with an MC-UPQC

As shown in this figure, two feeders connected to two different substations supply the loads L1 and L2. The MC-UPQCis connected to two buses BUS1 and BUS2 with voltages of u_{t1} and u_{t2}, respectively. The shunt part of the MC-UPQC is alsoconnected to load L1 with a current of i_{l1}. Supply voltages aredenoted by u_{s1}andu_{s2} while load voltages are $u_{l1}$and u_{l2}.Finally, feeder currents are denoted by is $i_{s1}$and i_{s2} load currents are $i_{l1}$and i_{l2}.

Bus voltages $u_{t1}$and $u_{t2}$are distorted and may be subjectedto sag/swell. The load L_1 is anonlinear/sensitive load whichneeds a pure sinusoidal voltage for proper operation while its current is non sinusoidal and contains harmonics. The load L_2 isa sensitive/critical load which needs a purely sinusoidal voltageand must be fully protected against distortion, sag/swell, and interruption. These types of loads primarily include production industries and critical service providers, such as medical centers,airports, or broadcasting centers where voltage interruption can result in severe economical losses or human damages.

B. MC–UPQC Structure

The internal structure of the MC–UPQC is shown in Fig.3.It consists of three VSCs (VSC1, VSC2, and VSC3) which areconnected back to back through a common dc-link capacitor. Inthe proposed configuration, VSC1 is connected in series withBUS1 and VSC2 is connected in parallel with load L1 at theend of Feeder1. VSC3 is connected in series with BUS2 at theFeeder2 end. Each of the three VSCs in Fig.3 is realized by a three-phaseconverter with a commutation reactor and high-pass output filteras shown in Fig.4. The commutation reactor (L*f*) and highpass output filter (R_f, C_f) are connected to prevent the flow ofswitching harmonics into the power supply.

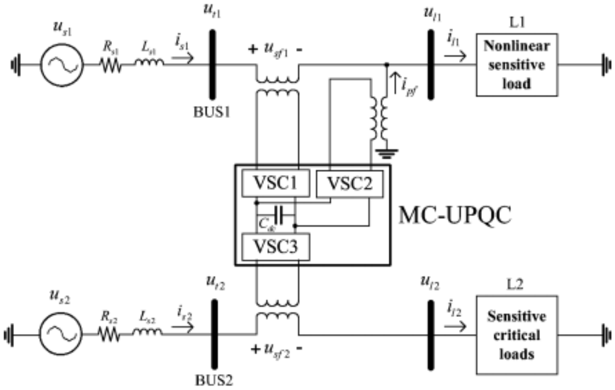


Fig.3. Typical MC-UPQC used in a distribution system.

As shown in Fig.3, all converters are supplied from acommon dc-link capacitor and connected to the distributionsystem through a transformer. Secondary (distribution) sidesof the series-connected transformers are directly connected inseries with BUS1 and BUS2, and the secondary (distribution)side of the shunt-connected transformer is connected in parallelwith load L1. The aims of the MC-UPQC shown in Fig.3 are:

1) to regulate the load voltage u_{l1}against sag/swell and disturbances in the system to protect then nonlinear/sensitive load L1;

2) to regulate the load voltage u_{l2} against sag/swell, interruption, and disturbances in the system to protect the sensitive/critical load L2;

3) to compensate for the reactive and harmonic componentsof nonlinear load current i_{l1}.

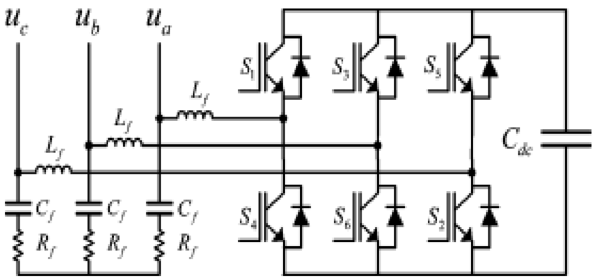


Fig.4. Schematic structure of a VSC.

In order to achieve these goals, series VSCs (i.e., VSC1 andVSC3) operate as voltage controllers while the shunt VSC (i.e.,VSC2) operates as a current controller.

C. Control Strategy

As shown in Fig.3, the MC-UPQC consists of two seriesVSCs and one shunt VSC which are controlled independently.The switching control strategy for series VSCs and the shuntVSC are selected to be sinusoidal pulsewidth-modulation(SPWM) voltage control and hysteresis current control, respectively. Details of the control algorithm, which are based on the d–q method [12], will be discussed later.

Shunt-VSC: Functions of the shunt-VSC are:

1) To compensate for the reactive component of load L1 current;
2) To compensate for the harmonic components of load L1current;
3) To regulate the voltage of the common dc-link capacitor.

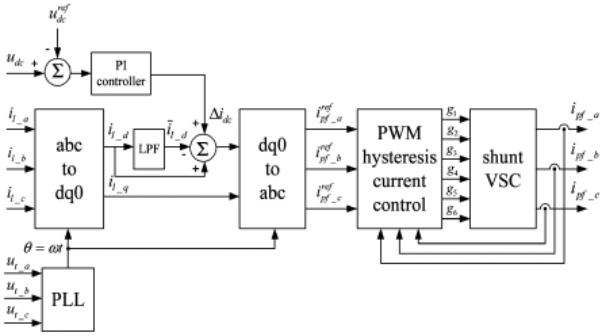


Fig.5. Control block diagram of the shunt VSC

Fig.5 shows the control block diagram for the shunt VSC.The measured load current (i_{l_abc}) is transformed into the synchronous dq0 reference frame by using

$$i_{l\_dq0} = T_{abc}^{dq0}\, i_{l\_abc} \tag{1}$$

where the transformation matrix is shown in (2),

$$T_{abc}^{dq0} = \frac{2}{3}\begin{bmatrix} \cos(\omega t) & \cos(\omega t - 120°) & \cos(\omega t + 120°) \\ -\sin(\omega t) & -\sin(\omega t - 120°) & -\sin(\omega t + 120°) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{2}$$

By this transform, the fundamental positive-sequence component, which is transformed into dc quantities in the d and q axes, can be easily extracted by low-pass filters (LPFs). Also, allharmonic components are transformed into ac quantities with afundamental frequency shift

$$i_{l\_d} = \bar{i}_{l\_d} + \tilde{i}_{l\_d} \tag{3}$$

$$i_{l\_q} = \bar{i}_{l\_q} + \tilde{i}_{l\_q} \tag{4}$$

Where i_{l_d} ,$i_{l_q}$are d-q components of load current,$\bar{i}_{l_d}$, $\bar{i}_{l\_q}$ are dc components, and$\tilde{i}_{l_d}$, $\tilde{i}_{l_q}$are the ac components of i_{l_d} and i_{l_q}.

If i_s the feeder current and $i_{pf}$is the shunt VSC current and knowing $i_s= i_l-i_{pf}$, then d–q components of the shuntVSC reference current are defined as follows:

$$i_{pf\_d}^{ref} = \tilde{i}_{l\_d} \tag{5}$$

$$i_{pf\_q}^{ref} = i_{l\_q} \tag{6}$$

Consequently, the d– q components of the feeder current are

$$i_{s\_d} = \bar{i}_{l\_d} \tag{7}$$

$$i_{s\_q} = 0. \tag{8}$$

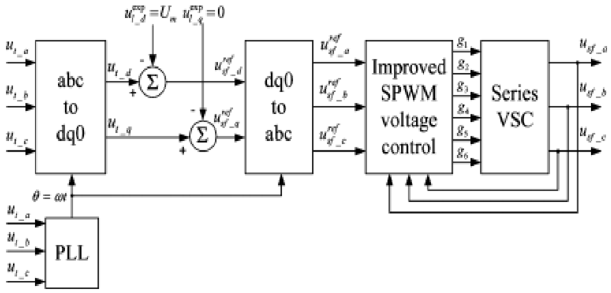


Fig.6. Control block diagram of the series VSC

This means that there are no harmonic and reactive components in the feeder current. Switching losses cause the dc-linkcapacitor voltage to decrease. Other disturbances, such as thesudden variation of load, can also affect the dc link. In orderto regulate the dc-link capacitor voltage, a proportional–integral (PI) controller is used as shown in Fig.5. The input of thePI controller is the error between the actual capacitor voltage (u_{dc}) and its reference value (u_{dc}^{ref}). The output of the PI controller (i.e.,Δi_{dc}) is added to the component of the shunt-VSCreference current to form a new reference current as follows:

$$\begin{cases} i_{pf\_d}^{ref} = \tilde{i}_{l\_d} + \Delta i_{dc} \\ i_{pf\_q}^{ref} = i_{l\_q} \end{cases} \tag{9}$$

As shown in Fig.5, the reference current in (9) is then transformed back into the abc reference frame. By using PWM hysteresis current control, the output-compensating currents in eachphase are obtained

$$i^{\mathrm{ref}}_{pf\_abc} = T^{abc}_{dq0} i^{\mathrm{ref}}_{pf\_dq0}; (T^{abc}_{dq0} = {T^{dq0}_{abc}}^{-1}) \tag{10}$$

Series-VSC: Functions of the series VSCs in each feeder are:

1) To mitigate voltage sag and swell;
2) To compensate for voltage distortions, such as harmonics;
3) To compensate for interruptions (in Feeder2 only).

The control block diagram of each series VSC is shown inFig.6. The bus voltage (u_{t_abc}) is detected and then transformedinto the synchronous dq0 reference frame using

$$u_{t\_dq0} = T^{dq0}_{abc} u_{t\_abc} = u_{t1p} + u_{t1n} + u_{t10} + u_{\mathrm{th}} \tag{11}$$

Where

$$\begin{cases} u_{t1p} = [u_{t1p\_d} \quad u_{t1p\_q} \quad 0]^T \\ u_{t1n} = [u_{t1n\_d} \quad u_{t1n\_q} \quad 0]^T \\ u_{t10} = [0 \quad 0 \quad u_{00}]^T \\ u_{\mathrm{th}} = [u_{th\_d} \quad u_{th\_q} \quad u_{th\_0}]^T \end{cases} \tag{12}$$

u_{t1p},$u_{t1n}$and u_{t10} are fundamental frequency positive-, negative-, and zero-sequence components, respectively, and u_{th} is the harmonic component of the bus voltage.

According to control objectives of the MC-UPQC, the loadvoltage should be kept sinusoidal with a constant amplitudeeven if the bus voltage is disturbed. Therefore, the expected loadvoltage in the synchronous reference frame ($u^{exp}_{i\_dq0}$) onlyhas one value

$$u^{\exp}_{l\_dq0} = T^{dq0}_{abc} u^{\exp}_{l\_abc} = \begin{bmatrix} U_m \\ 0 \\ 0 \end{bmatrix} \tag{13}$$

where the load voltage in the abc reference frame ($u^{exp}_{i\_dq0}$) is

$$u^{\exp}_{l\_abc} = \begin{bmatrix} U_m \cos(\omega t) \\ U_m \cos(\omega t - 120^\circ) \\ U_m \cos(\omega t + 120^\circ) \end{bmatrix} \tag{14}$$

The compensating reference voltage in the synchronousreference frame ($u^{ref}_{sf\_dq0}$) is defined as

$$u^{\mathrm{ref}}_{\mathrm{sf}\_dq0} = u_{t\_dq0} - u^{\exp}_{l\_dq0} \tag{15}$$

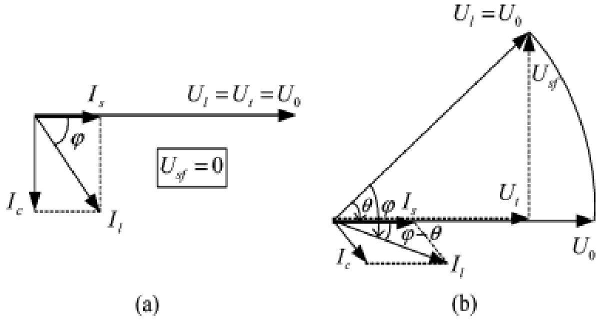
This means u_{t1p_d}in (12) should be maintained at Um whileall other unwanted components must be eliminated. The compensating reference voltage in (15) is then transformed back in to the abc reference frame. By using an improved SPWM voltagecontrol technique (sine PWM control with minor loop feedback)[8], the output compensation voltage of the series VSC can be obtained.

III. POWER-RATING ANALYSIS OF THE MC-UPQC

The power rating of the MC-UPQC is an important factor interms of cost. Before calculation of the power rating of eachVSC in the MC UPQC structure, two models of a UPQC areanalyzed and the best model which requires the minimum powerrating is considered. All voltage and current phases used in thissection are phase quantities at the fundamental frequency.

There are two models for a UPQC quadrature compensation (UPQC-Q) and inphase compensation (UPQC-P). In thequadrature compensation scheme, the injected voltage by the series-VSC maintains a quadrature advance relationship with thesupply current so that no real power is consumed by the seriesVSC at steady state. This is a significant advantage when UPQCmitigates sag conditions. The series VSC also shares the volt-ampere reactive (VAR) of the load along with the shunt-VSC,reducing the power rating of the shunt-VSC.

Fig.7 shows the phasor diagram of this scheme under a typical load power factor condition with and without voltage sag.When the bus voltage is at the desired value (U_l=U_t=U_0),the series-injected voltage (U_{sf}) is zero [Fig. 7 (a)]. The shuntVSC injects the reactive component of load current Ic, resulting in unity input-power factor. Furthermore, the shunt VSC compensates for not only the reactive component, but also the harmonic components of the load current. For sag compensation inthis model, the quadrature series voltage injection is needed asshown in Fig.7 (b). The shunt VSC injects Ic in such a way thatthe active power requirement of the load is only drawn from theutility which results in a unity input-power factor.



(a) (b)

Fig.7.Phasor diagram of quadrature compensation. (a) Without voltage sag.(b) With voltage sag.

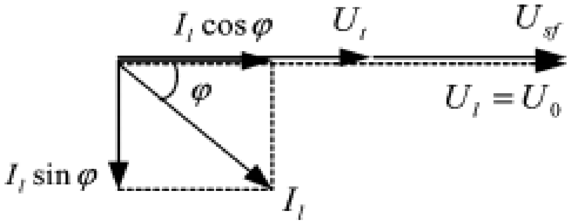


Fig.8. Phasor diagram of inphase compensation (supply voltage sag)

In an inphase compensation scheme, the injected voltage isinphase with the supply voltage when the supply is balanced. Byvirtue of inphase injection, series VSC will mitigate the voltagesag condition by minimum injected voltage. The phasor diagram of Fig.8 explains the operation of this scheme in case ofvoltage sag.

A comparison between in phase (UPQC-P) and quadrature (UPQC-Q) models is made for different sag conditions andload power factors in [13]. It is shown that the power ratingof the shunt-VSC in the UPQC-Q model is lower than that ofthe UPQC-P, and the power rating of the series-VSC in theUPQC-P model is lower than that of the UPQC-Q for a powerfactor of less than or equal to 0.9. Also, it is shown that the totalpower rating of UPQC-Q is lower than that of UPQC-P wherethe VAR demand of the load is high.

The power needed for interruptioncompensation in Feeder2 must be supplied through the shuntVSC in Feeder1 and the series VSC in Feeder2. This impliesthat power ratings of these VSCs are greater than that of the series one in Feeder1. If quadrature compensation in Feeder1 andinphase compensation in Feeder2 are selected, then the powerrating of the shunt VSC and the series VSC (in Feeder2) willbe reduced. This is an important criterion for practical applications.

Based on the aforementioned discussion, the power-ratingcalculation for the MC-UPQC is carried out on the basis ofthe linear load at the fundamental frequency. The parametersin Fig. 6 are corrected by adding suffix “1,” indicating Feeder1,and the parameters in Fig.7 are corrected by adding suffix “2,”indicating Feeder2. As shown in Figs.7 and 8, load voltages inboth feeders are kept constant at U0 regardless of bus voltagesvariation, and the load currents in both feeders are assumed tobe constant at their rated values (i.e., $I_{01}$and I_{02}, respectively)

$$U_{l1} = U_{l2} = U_0 \tag{16}$$

$$\begin{cases} I_{l1} = I_{01} \\ I_{l2} = I_{02} \end{cases} \tag{17}$$

The load power factors in Feeder1 and Feeder2 are assumedto be $\cos\varphi 1$ and $\cos\varphi 2$ and the per-unit sags, which must becompensated in Feeder1 and Feeder2, are supposed to be $x_1$and x_2, respectively.

If the MC-UPQC is lossless, the active power demand supplied by Feeder1 consists of two parts:

1) The active power demand of load in Feeder1;

2) The active power demand for sag and interruption compensation in Feeder2.

Thus, Feeder1 current (I_{s1}) can be found as

$$U_{t1}I_{s1} = U_{l1}I_{l1}\cos\varphi_1 + U_{sf2}I_{l2}\cos\varphi_2 \tag{18}$$

$$(1-x_1)U_0I_{s1} = U_0I_{01}\cos\varphi_1 + x_2U_0I_{02}\cos\varphi_2 \tag{19}$$

$$(1-x_1)I_{s1} = I_{01}\cos\varphi_1 + x_2I_{02}\cos\varphi_2 \tag{20}$$

$$I_{s1} = \frac{I_{01}\cos\varphi_1}{(1-x_1)} + \frac{x_2I_{02}\cos\varphi_2}{(1-x_1)} \tag{21}$$

From Fig.6, the voltage injected by the series VSC in Feeder1can be written as in (22) and, thus, the power rating of this converter (S_{svc1}) can be calculated as

$$U_{sf1} = U_{t1}\tan\theta = U_0(1-x_1)\tan\theta \tag{22}$$

$$\begin{aligned} S_{VSC1} &= 3U_{sf1}I_{s1} = 3U_0(1-x_1)\tan\theta \\ &\times \left(\frac{I_{01}\cos\varphi_1}{1-x_1} + \frac{x_2I_{02}\cos\varphi_2}{1-x_1}\right) \end{aligned} \tag{23}$$

The shunt VSC current is divided into two parts.

1) The first part (i.e., I_{c1}) compensates for the reactive component (and harmonic components) of Feeder1 current andcan be calculated from Fig.7 as

$$\begin{aligned} I_{c1} &= \sqrt{I_{l1}^2 + I_{s1}^2 - 2I_{l1}I_{s1}\cos(\varphi_1 - \theta)} \\ &= \sqrt{I_{01}^2 + I_{s1}^2 - 2I_{01}I_{s1}\cos(\varphi_1 - \theta)} \end{aligned} \tag{24}$$

Where $I_{s1}$is calculated in (21). This part of the shunt VSCcurrent only exchanges reactive power (Q) with the system.

2) The second part provides the real power (P), which isneeded for a sag or interruption compensation in Feeder2.Therefore, the power rating of the shunt VSC can becalculated as

$$\begin{aligned} S_{VSC2} &= 3U_{l1}I_{pf} = 3\sqrt{Q^2 + P^2} \\ &= 3\sqrt{(U_{l1}I_{c1})^2 + (U_{sf2}I_{l2}\cos\varphi_2)^2} \\ &= 3U_0\sqrt{I_{c1}^2 + (x_2I_{02}\cos\varphi_2)^2} \end{aligned} \tag{25}$$

Where I_{c1} is calculated in (24)

Finally, the power rating of the series-VSC in Feeder2 can becalculated by (26). For the worst-case scenario (i.e., interruptioncompensation), one must consider $x_2=1$. Therefore

$$S_{VSC3} = 3U_{sf2}I_{l2} = 3x_2U_0I_{02} \tag{26}$$

IV.INTELLIGENT CONTROLLERS

A. PI Controller

The proportional plus integral (PI) controller is widely used for industrial applications. The input to the PI controller is the speed error (E), while the output of the PI controller is used as the input of reference current block.

B. Fuzzy Logic Controller

Fuzzy logic control (FLC) is a rule based controller. It is a control algorithm based on alinguistic control strategy which tries to account the human’s knowledge about how to control a system withoutrequiring a mathematical model. The approach of the basic structure of the fuzzy logic controller system isillustrated in Fig.9.

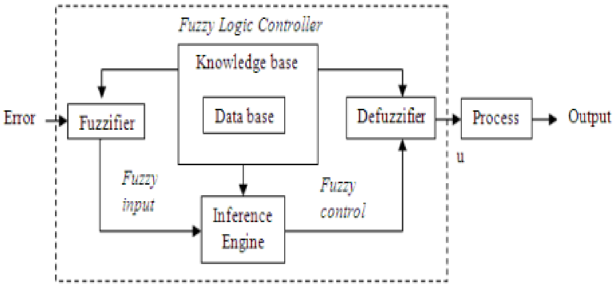


Fig.9 Basic structure of Fuzzy Logic controller

Fuzzy logic uses linguistic variables instead of numerical variables. The process of converting anumerical variable (real number or crisp variables) into a linguistic variable (fuzzy number) is called Fuzzification. Here the inputs for Fuzzy Logic controller are the speed error (E) and change in speed error (CE).Speed error is calculated with comparison between reference speed and the actual speed. The fuzzy logiccontroller is used to produce an adaptive control so that the motor speed can accurately track the referencespeed. The reverse of Fuzzification is called Defuzzification. The use of Fuzzy Logic Controller (FLC) producesrequired output in a linguistic variable (fuzzy number). According to real world requirements, thelinguisticvariables have to be transformed to crisp output.

The membership function is a graphical representation of the magnitude of participation of each input.There is different membership functions associated with each input and output response. Here the trapezoidalmembership functions are used for input and output variables. The number of membership functions determinesthe quality of control which can be achieved using fuzzy controller. As the number of membership functionincreases, the quality of control improves. As the number of linguistic variables increases, the computationaltime and required memory increases. Therefore, a compromise between the quality of control andcomputationaltime is needed to choose the number of linguistic variables. The most common shape of membership functionsis triangular, although trapezoidal and bell curves are also used, but the shape is generally less important thanthe number of curves and their placement.

The processing stage is based on a collection of logic rules in the form of IF-THEN statements, where the IF part is called the "antecedent" and the THEN part is called the "consequent". The knowledge basecomprises knowledge of the application domain and the attendant control goals. It consists of a data “base” anda linguistic (fuzzy) control rule base. The data base providesnecessary definitions, which are used to definelinguistic control rules and fuzzy data manipulation in an FLC. The rule base characterizes the control goals andcontrol policy of the domain experts by means of a set oflinguistic control rules. Decision making logic is the kernel of an FLC.

The most important things in fuzzy logic control system designs are the process design of membership functions for input, outputs and the process design of fuzzy if-then rule knowledge base. Fig.10 shows themembership function of speed error (E), change in speed error (CE)and figue.11 shows the membership function of output variable. In practice, one or two types of membership functions are Enough to solve most of the problems.

E\CE	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PS	PS	NS
NM	PB	PM	PM	PS	PS	Z	NS
NS	PM	PM	PS	Z	Z	NS	NS
Z	PM	PS	PS	Z	NS	NS	NM
PS	PS	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NS	NM	NM	NB
PB	Z	NS	NS	NM	NM	PB	NB

Table.1 Rule base of Fuzzy logic controller

The next step is todefine the control rules. There are no specific methods to design the fuzzy logic rules. However, the results from PI controller give an opportunity and guidance for rule justification. Therefore after thorough series of analysis,the total 49 rules have been justifiedas shown in Table 1.

The membership function is divided into seven sets: NB: Negative Big, NM: Negative Medium, NS:Negative Small, Z: Zero, PS: Positive Small, PM: Positive Medium, PB: Positive Big.

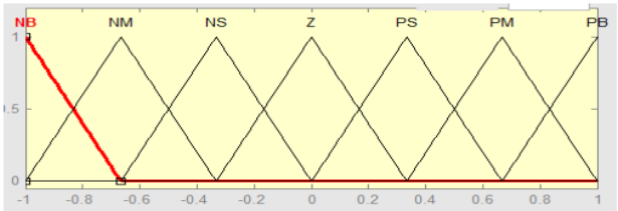


Fig.10. Membership function plots, error and change in error

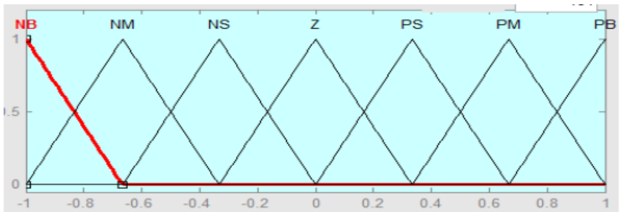


Fig.11. Membership function plots, output variable

C. Hybrid PI-Fuzzy Controller

The objective of the hybrid controller is to utilize the best attributes of the PI andfuzzy logic controllers to provide a controller which will produce better response than either the PI or the fuzzy controller. There are two major differences between the tracking ability of theconventional PI controller and the fuzzy logic controller. Both the PI and fuzzy controller produce reasonably good tracking for steady-state orslowly varying operating conditions. However, when there is a step change in any of the operating conditions,such as may occur in the set point or load, the PI controller tends to exhibit some overshoot or oscillations. Thefuzzy controller reduces both the overshoot and extent of oscillations under the same operating conditions.Although the fuzzy controller has a slower response by itself, it reduces both the overshoot and extent ofoscillations under the same operating conditions. The desire is that, by combining the two controllers, one canget the quick response of the PI controller while eliminating the overshoot possibly associated with it.

V.MATLAB/SIMULATION RESULTS

The model of the entire system has been developed using Sim Power System toolbox and Fuzzy Logic Toolbox in MATLAB.

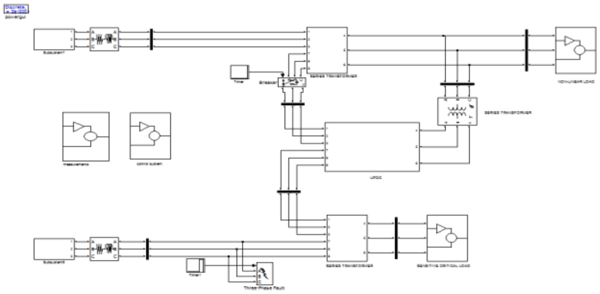


Fig.12.Matlab/Simulink model for typical MC-UPQC used in a distribution system.

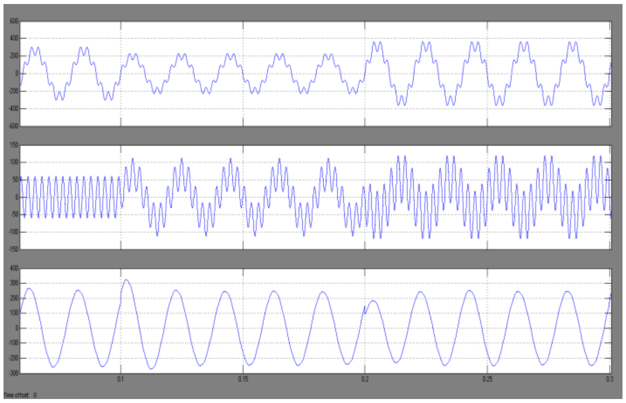


Fig.13. Simulation waveforms for BUS1 voltage, series compensating voltage, and load voltage in Feeder1.

The BUS1 voltage, the corresponding compensation voltage injected by VSC1, and finally load L1 voltage are shown in Fig.13. In all figures, only the phase waveform is shown for simplicity.

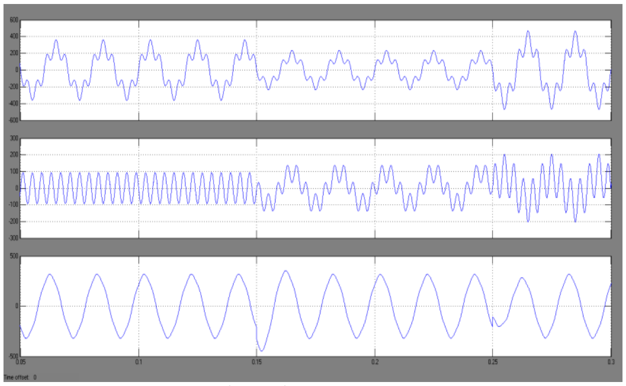


Fig.14. Simulation waveforms for BUS2 voltage, series compensating voltage, and load voltage inFeeder2.

Similarly, the BUS2 voltage, the corresponding compensation voltage injected by VSC3, and finally, the load L2 voltage are shown in Fig.14. As shown in these figures, distorted voltagesof BUS1 and BUS2 are satisfactorily compensated for across theloads L1 and L2 with very good dynamic response.

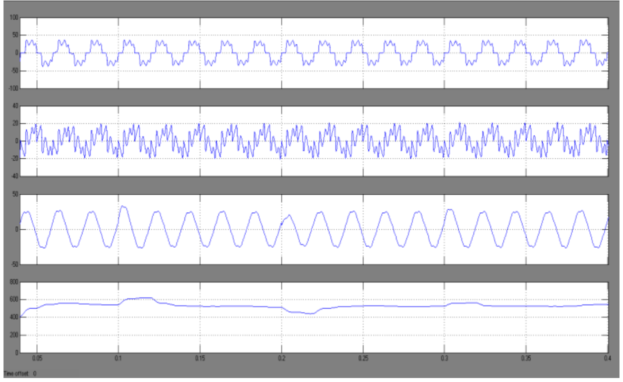


Fig.15. Simulation waveforms for Nonlinear load current, compensating current, Feeder1 current, andcapacitor voltage.

The nonlinear load current, its corresponding compensationcurrent injected by VSC2, compensated Feeder1 current, and,finally, the dc-link capacitor voltage are shown in Fig.15.

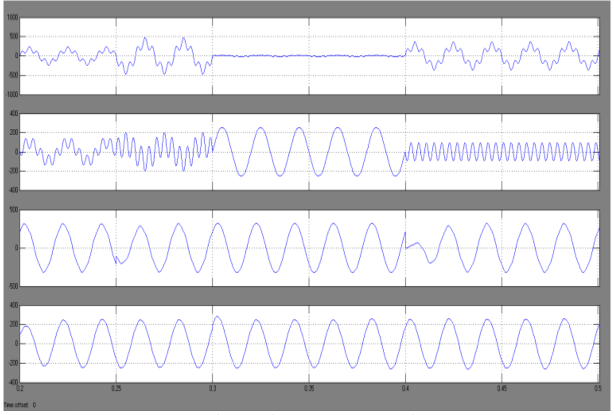


Fig.16. Simulation waveforms for an upstream fault on Feeder2: BUS2 voltage, compensating voltage, and loads L1 and L2 voltages.

Fig.16 shows the performance of the MC-UPQC under a fault conditionon Feeder2 is tested by applying a three-phase fault to ground on Feeder2.

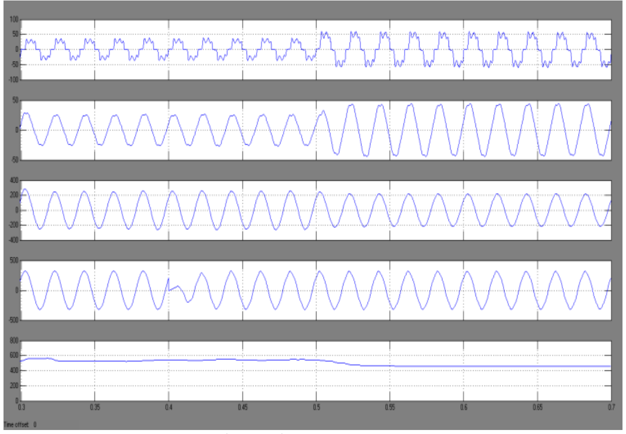


Fig.17. Simulation waveforms for load change: nonlinear load current, Feeder1current, load L1 voltage, load L2 voltage, and dc-link capacitor voltage.

Fig.17 shows that as loadL1 changes, the load voltages and remain undisturbed,the dc bus voltage is regulated, and the nonlinear load current iscompensated.

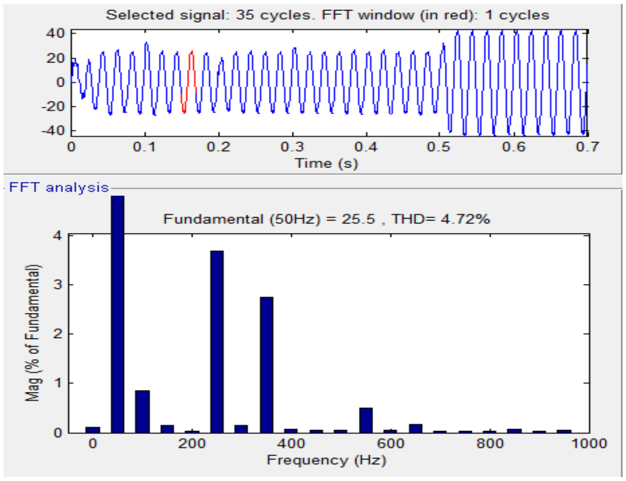


Fig.18. Simulation waveform for THD at PI Controller

Fig.18 shows THD attained to source current with PI controller is 4.72%.

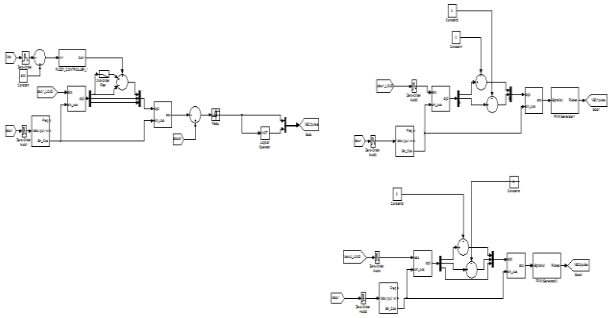


Fig.19. Matlab/Simulink model Control Circuit for MC-UPQC with Fuzzy Controller

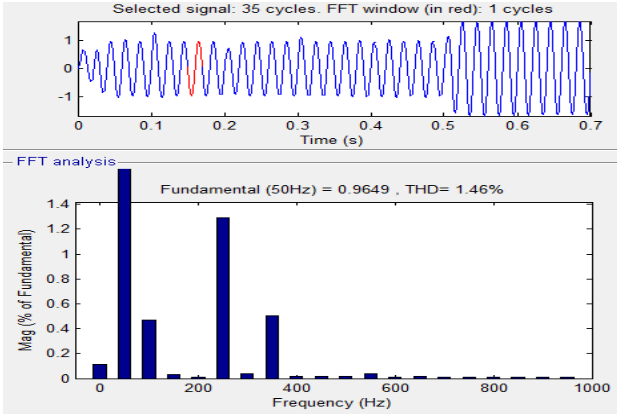


Fig.20. Simulation waveform for THD at Fuzzy Controller

Fig.20 shows THD attained to source current with Fuzzy controller is 1.46%. This is observed thatwhen compared with PI controller harmonic content is mitigated.

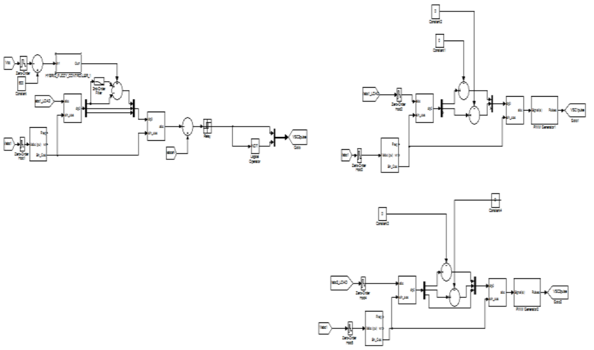


Fig.21. Matlab/Simulink model Control Circuit for MC-UPQC with Hybrid PI Fuzzy Controller

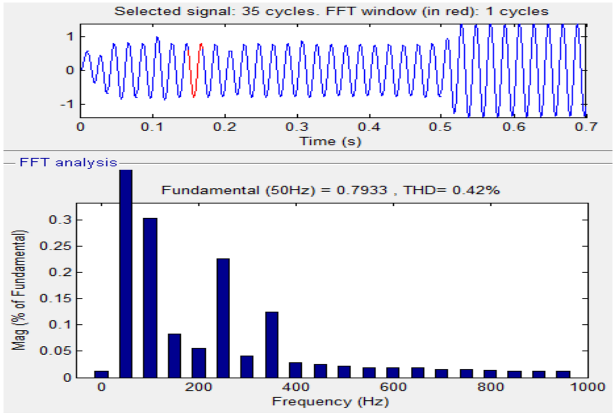


Fig.22. Simulation waveform for THD at Hybrid PI Fuzzy Controller

Fig.22 shows THD obtained at Hybrid Fuzzy Controller is 0.42% which observes that harmonics are greatly reduced when compared with conventional PI controller and Fuzzy logic controller.

VI. CONCLUSION

In this paper, a new configuration for simultaneous compensation of voltage and current in adjacent feeders has beenproposed. The new configuration is named multiconverterunified power-quality conditioner (MC-UPQC). Compared toa conventional UPQC, the proposed topology is capable offully protecting critical and sensitive loads against distortions,sags/swell, and interruption in two-feeder systems. With the help of proposed MC-UPQC system the voltage /current harmonics, reactive power compensationwas performed successfully. Additionally the voltage regulation was also done by protecting the loadsagainst any distortions, sag, swell, and interruptions. The simulation results shows that the Intelligent controllers PI, Fuzzy and Hybrid fuzzy controllers performed well and THD was reduced gradually up to 0.42% is attained.

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