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UNIFIED POWER QUALITY CONDITIONER FOR POWER QUALITY IMPROVEMENT WITH ADVANCED CONTROL STRATEGY

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ABSTRACT

The unified power quality conditioner (UPQC) is being used as a universal active power conditioning device to mitigate both current and voltage harmonics at a distribution side of power system network. A Fuzzy logic controller (FLC) based unified power quality controller is proposed. The results obtained through the FLC are good in terms of dynamic response because of the fact that the FLC is based on linguistic variable set theory and does not require a mathematical model of the system. Moreover, the tedious method of tuning the PI controller is not required in case of FLC. Simulations done using MATLAB/Simulink to validate the theoretical findings.

Index Terms— fuzzy logic controller, harmonics, PI controller, reactive power, unified power quality controller.

I. INTRODUCTION

The power electronic devices due to their inherent non-linearity draw harmonic and reactive power from the supply. In three phase systems, they could also cause unbalance and draw excessive neutral currents. The injected harmonics, reactive power burden, unbalance, and excessive neutral currents cause low system efficiency and poor power factor Moreover, the harmonics generated by the nonlinear loads pollute the utility. The basic requirements for compensation process involve precise and continuous VAR control with fast dynamic response and on-line elimination of load harmonics. To satisfy these criterion, the traditional methods of VAR compensation using switched capacitor and thyristor controlled inductor [1-3] coupled with passive filters are increasingly replaced by active power filters (APFs) [4-8]. The APFs are of two types; the shunt APF and the series APF. The shunt APFs are used to compensate current related problems, such as reactive power compensation, current harmonic filtering, load unbalance compensation, etc. The series APFs are used to compensate voltage related problems, such as voltage harmonics, voltage sag, voltage swell, voltage flicker, etc. The unified power quality conditioner (UPQC) aims at integrating both shunt and series APFs through a common DC link capacitor. The UPQC is similar in construction to a unified power flow controller (UPFC) [9]. The UPFC is employed in power transmission system, whereas the UPQC is employed in a power distribution system. The primary objective of UPFC is to control the flow of power at, fundamental frequency. On the other hand the UPQC controls distortion due to harmonics and unbalance in
Voltage in addition to control of flow of power at the fundamental frequency. The schematic block diagram of UPQC is shown in Fig. 1.

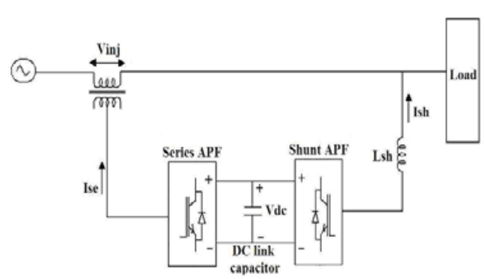


Fig.1. Schematic block diagram of UPQC.

It consists of twovoltage source inverters (VSIs) connected back-to-back, sharing a common DC link in between. One of the VSIs act as a shunt APF, whereas the other as a series APF. The performance of UPQC mainly depends upon how quickly and accurately compensation signals are derived. Control schemes of UPQC based on PI controller has been widely reported [10-13]. The PI control based techniques are simple and reasonably effective. However, the tuning of the PI controller is a tedious job. Further, the control of UPFCbased on the conventional PI control is prone to severe dynamic interaction between active andreactive power flows [10]. In this work, the conventional PI controller has been replaced by a fuzzy controller (FC). The FC has been used in APFs in place of conventional PI controller for improving the dynamic performance [14, 15]. The FC is basically nonlinear and adaptive in nature. The results obtained through FC are superior in the cases where the effects of parameter variation of controller are also taken into consideration. The FC is based on linguistic variable set theory and does not require a mathematical model. Generally, the input variables are error and rate of change of error. If the error is coarse, the FC provides coarse tuning to the output variable and if the error is fine, it provides fine tuning to the output variable. In the normal operation of UPQC, the control circuitry of shunt APF calculates the compensating current for the current harmonics and the reactive power compensation. In the conventional methods, the DC link capacitor voltage is sensed and is compared with a reference value. Theerror signal thus derived is processed in a controller. A suitable sinusoidal reference signal in-phase withthe supply voltage is multiplied with the output of the PI controller to generate the reference current.Hysteresis band is normally (most often but not always) is imposed on top and bottom of this referencecurrent. The width of the hysteresis band is so adjusted such that the supply current total harmonicdistortion (THD) remains within the international standards. The function of the series APF in UPQCis to compensate the voltage. The control circuitry of the series APF calculates the referencevoltage to be injected by the series APF by comparing the terminal voltage with a reference value ofvoltage.

II. CONTROL STRATEGY OF UPQC

Principle of Control of Shunt APF

The sensed DC link voltagev_{dc} is compared with a reference voltagev_{dc}*. The error signal obtained isprocessed in Fuzzy Logic Controller. The output of the Fuzzy ControllerI_{sp} is considered as the magnitudeof three-phase reference supply currents. The three-phase unit current vectors (u_{sa},u_{sb}, andu_{sc}) are derivedin phase with the three-phase supply voltages (v_{sa} ,v_{sb} and v_{sc}). The unit current vectors from the three phaseof supply currents. Multiplication of magnitudeI_{sp}* with (u_{sa},u_{sb}, and u_{sc}) results in three phasereference supply currents (i_{sa},i_{sb}andi_{sc}). Subtraction of load currents (i_{la}, i_{lb} andi_{lc}) from the referencecurrents, results in three-phase reference currents (i_{sha}*, i_{shb}*and i_{shc}*) for the shunt APF. These referencecurrents are compared with the actual shunt compensating currents (i_{sha}, $i_{shb}$and i_{shc}) and the error signal isconverted into PWM gating signals, the shunt APF supplies harmonics currents and reactive power demandof the load. The amplitude of the supply voltage is computed from the three-phase sensed values of voltages as

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

The three-phase unit current vectors are computed as

$$u_{sa} = \frac{v_{sa}}{v_{sm}},\ u_{sb} = \frac{v_{sb}}{v_{sm}} \text{ and } u_{sc} = \frac{v_{sc}}{v_{sm}}$$

Multiplication of three-phase unit current vectors (u_{sa},u_{sb}, and u_{sc}) with the amplitude of the supplycurrent (I_{sp}) results in three-phase reference supply currents as

$$i_{sa}^* = i_{sp}.u_{sa},\ i_{sb}^* = i_{sp}.u_{sb} \text{ and } i_{sc}^* = i_{sp}.u_{sc}$$

To obtain reference currents, three-phase load currents are subtracted from three-phase supply currents as

$$i_{sha}^* = i_{sa}^* - i_{la}, i_{shb}^* = i_{sb}^* - i_{lb} \text{ and } i_{shc}^* = i_{sc}^* - i_{lc}$$

Principle of Control of Series APF

In the series APF, the three load voltages (v_{la} ,v_{lb} and v_{lc}) are subtracted from three supply voltages (v_{sa} ,v_{sb} and v_{sc}) resulting into three-phase reference voltages (v_{la}*, v_{lb}*and v_{lc}*) to be injected 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 three-phase reference voltages (v_{ia}*, v_{ib}*and v_{ic}*). The reference currents (i_{sea}*, i_{seb}*and i_{sec}*) 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

$$v_{inj} = v_s - v_l$$

The three-phase reference values of injected voltage are expressed as

$v_{ia}^{*} = \sqrt{2}v_{inj}\sin(\omega t + \delta_{inj})$,

$v_{ib}^{*} = \sqrt{2}v_{inj}\sin\left(\omega t + \frac{2\pi}{3} + \delta_{inj}\right)$and

$$v_{ic}^{*} = \sqrt{2}v_{inj}\sin\left(\omega t - \frac{2\pi}{3} + \delta_{inj}\right)$$

Where $\delta_{inj}$is the phase of the injected voltage.
The three-phase reference currents of the series APF are computed as follows

$$i_{sea} = \frac{v_{ia}^{*}}{z_{se}},\ \ i_{seb} = \frac{v_{ib}^{*}}{z_{se}} \text{ and } i_{sec} = \frac{v_{ic}^{*}}{z_{se}}.$$

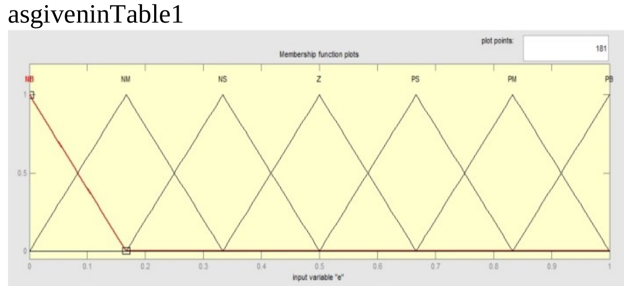
The impedance z_{se} includes the impedance of the transformer inserted. The currents (i_{sea}*, i_{seb}*and i_{sec}*) are the ideal currents to be maintained through the secondary winding of the transformer in order to inject voltages(v_{la},v_{lb} and v_{lc}) there by accomplishing the desired task 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.

III. FUZZY LOGIC CONTROLLER

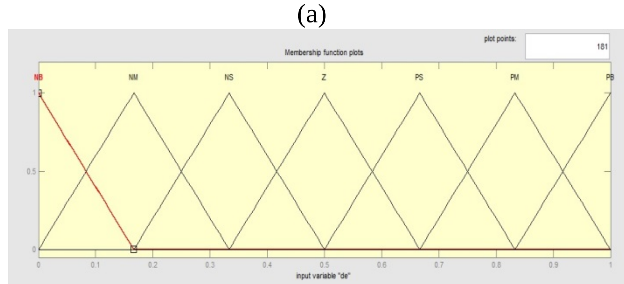
InFC,basiccontrolactionisdeterminedbyasetoflinguisticrules.Theserules aredeterminedby thesystem. Sincethenumericalvariablesareconvertedinto linguisticvariables,mathematicalmodellingofthesystemis notrequiredinFC. To convert the numerical variables into linguistic variables, the fuzzy levels chosenare:NB(negativesmall),NM(negativemedium),NS (negativesmall), ZE(zero), PS(positivesmall),PM(positivemedium)andPB(positivebig)[14]. TheFCischaracterized as:(i)sevenfuzzysets foreachinputandoutput,(ii) triangular membership functions for simplicity, (iii) fuzzificationusing continuous universe of discourse, (iv) implication using Mamdani's 'min' operator and(v) defuzzyfication using the 'height' method.InUPQC,theactivepower,reactivepower,terminal voltageoftheline andcapacitorvoltagearerequiredtobemaintained.Inorderto controlthese parameters,theyaresensedandcomparedwith thereferencevalues.Toachieve this,themembershipfunctionsof FCare:error,changeinerrorandoutputas shown in Figs. 3(a), (b) and (c). In thepresent work, for fuzzification, nonuniformfuzzifierhas beenused.Iftheexactvaluesoferrorandchangeinerroraresmall, theyaredividedconverselyandifthevalues are large, they are divided coarsely. The set of FC rules are derived frombelow equation.

$$u = -\lfloor \alpha E + (1-\alpha)C \rfloor$$

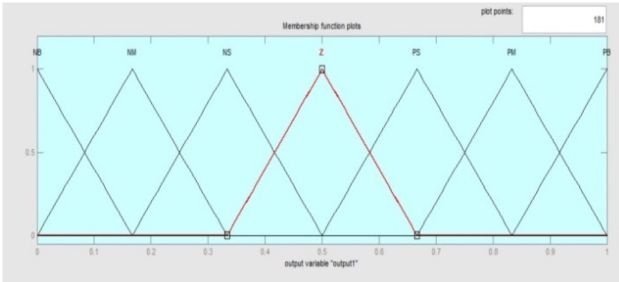
Whereαiscalled theself-adjustablefactorwhichcanregulatewholeregionof operation,E istheerrorofthesystem,C isthevaryingratioerrorand$u$ isthe controlvariable.Alargevalueoferror$E$indicatesthatgivensystem isnotinthe balanced state. If the systemis unbalanced, the controllershouldenlargeits controlvariablestobalancethesystem asearlyaspossible.Onetheotherhand, smallvalueoftheerror E indicatesthatthesystemisneartobalancedstate. Overshootplaysanimportantroleinthesystem stability.Lessovershootis requiredforsystemstabilityandinrestrainingoscillations.In suchconditions,C in (8) plays an importantrole, while the role of$E$is diminished. The optimization isdonebyα.Duringtheprocess,itisassumedthatneithertheUPQCabsorbs active power nor it supplies active power during normal conditions. So the active powerflowingthroughtheUPQCisassumedtobeconstant.Thecontrolsurface oftheproposedFCisshowninFig.4. Itindicatestwoinputs,oneoutputanda surfaceshowinginput-outputmapping.ThesetofFCrulesismadeusingFig.4 asgiveninTable1



(a)



(b)



(c)

Fig.3. Membership function of FC: (a) Error, (b)Change in error, (c) output

TABLE I
SET OF FC RULES

Error de/dt	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	Z
NM	NL	NM	NM	NM	NS	Z	PS
NS	NL	NM	NS	NS	Z	PS	PM
Z	NL	NM	NS	Z	PS	PM	PL
PS	NM	NS	Z	PS	PS	PM	PL
PM	NS	Z	PS	PM	PL	PL	PL
PL	Z	PS	PM	PL	PL	PL	PL

IV. SIMULATION RESULTS

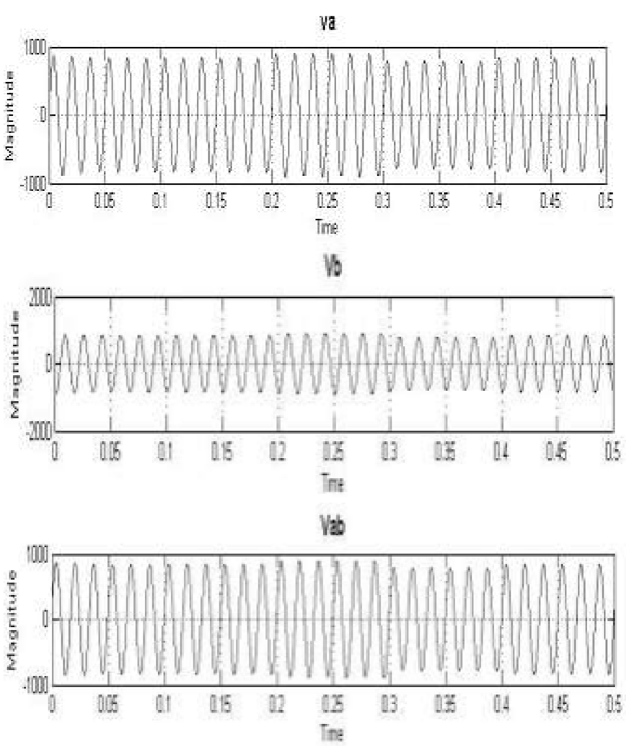


Fig.5Voltagewaveforms ofthesystemwithoutUPQC

To verify the operating performance of the proposed UPQC, a3-phase electrical system, a PLL extraction circuit with hysteresis is controlled UPQC is simulated using MATLAB software. The simulation results are shown in the Fig. Both the series and shunt APF's are put into the operation at different time instant. First series APF put into the operation at a simulation time of 0.1sec. At time 0.2 sec. shunt APF is put into the operation, such that both series and shunt APF's are operated as UPQC. It should be noted that, in spite of distorted voltage at PCC, the unit vector template is pure sinusoidal because of use of PLL. Before time'0.1 Sec.' when both APF's are not in operation the load voltage is equal to the distorted input voltage deliberately consisting of 5th and 7th order voltage harmonics. As soon as series APF is put into the operation at instant '0.1 sec.', immediately it starts compensating the load voltage by injecting sum of 5th and 7th harmonic voltage through series line transformer, such that the load voltage is perfectly sinusoidal, The voltage injected by the series APF which is nothing but the sum of 5th (20%) harmonic voltages in the supply.

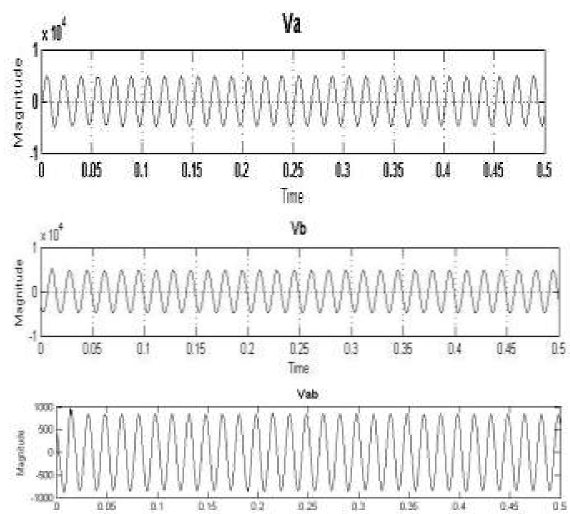


Fig.6Voltagewaveforms withFLC controlledUPQC

It may be noticed that the source current is distorted beforeconnecting the UPQC and it becomes sinusoidal after connecting the UPQC at 0.1s.Fig.7

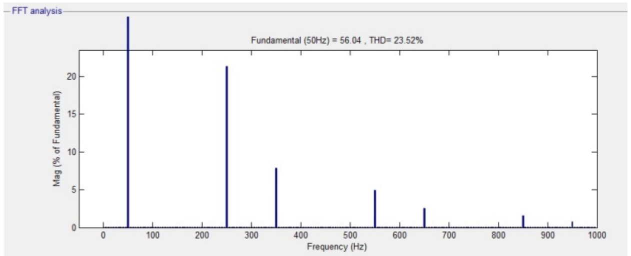


Fig. 7. Total Harmonic Distortion of system without FLC

The THD of the source current before connecting the UPQC is 24.54%. Harmonic spectrum of the sourcecurrent after connecting the UPQC is shown in Fig. 7. The THD of the source current after connecting theUPQC is 0.13. The DC link capacitor voltage is held constant at its reference value by the FLC. Toinvestigate the performance of the proposed UPQC using FLC, under voltage sag condition, 20% sag hasbeen created in the all the phases of the supply voltage. The simulation results of these cases are shown inFigs. 6 shows the supply voltage with 20% voltage sag in all the phases from 0.25s to0.45s.

V. CONCLUSION

UPQC using FC has been investigated for compensating reactive power and harmonics. It is clear from thesimulation results that the UPQC using FC is simple, and is based on sensing the line currents only. TheTHD of the source current using the proposed FLC is well below 5%, the harmonic limit imposed by IEEE-519 standard.

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