Performance Analysis of Three-Phase Solar PVIntegrated UPQC Using Space VectorTechnique

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ABSTRACT

Due to the increase of load demand in future, the generation must also increase. The use of traditional resources such as coal, diesel fuels etc., causes global warming which is leading us to shift to renewable energy resources. Renewable energy resources may in include solar, wind, tidal as the source for production. These are used in small quantities as Distribution Generators(DG) at different locations in a bus system. As the generation of these sources is less when connected to grid, we call them as micro-grids. These micro grids generally use these DGs to distribute power to loads, and involve power electronic elements to control the generation. It induces energy into the system but also create a problem of harmonic distortions and voltage sags.

To eliminate these sags and harmonics in the micro grid system caused by the power electronic devices employed by the renewable sources, we induce a UPQC (Unified Power Quality Conditioner) system. The UPQC system eliminates the harmonics in the systems and restores the voltage of the micro-grid system. We introduce a new topology called instantaneous reactive power(IRP) theory in the UPQC control to operate in a more efficient way, by utilizing RES (Renewable Energy Sources) at the DC-link. The RES support the UPQC system by injecting the active powergenerated by the resources through DC-link.

In this project a UPQC is connected to a test system with harmonics and voltage variations creating sags and swells in source and load voltages. The UPQC is supported with kVAconnected at the DC link injecting active and reactive powers to the grid. Individual controllers aremodelled for shunt and series converters with feedback from the source and load voltages and currents. Both the converters work in synchronization to the source voltage withSRF controller using sinusoidal PWM technique. An MPPT is also used for magnitude generation of the reference current. For further improvement in the model the conventional sinusoidal PWM is replaced with space vector PWM reducing the harmonic content in the source voltages and currents. The design is modeled in MATLABSimulink environment with graphsgeneratedwithrespect to time.

I.INTRODUCTION

The concept of micro grid has offered consumers with increased reliability and reduction in total energy losses, and has become a promising alternative for traditional power distribution system. One area of study for the connection of a microgrid to the distribution grid is the impactof power quality (PQ) problems on the overall power system performance. These PQ problems include voltage and frequency deviations in the grid voltage and harmonics in the grid voltage and load currents. To overcome the aforementioned PQ problems, several pwer-conditioningequipments such as active filters, uninterruptible power supplies, dynamic voltage restorers andunified PQ conditioners are usually employed by consumers to protect their loads and systemsagainst PQ disturbances in the distribution network. However, these devices are usually installedat the consumer sides and the PQ problems that they are capable to handle are usually limited. This paper proposes a flexible ac distribution system device for the microgrid that is realizedusing a combination of series and shunt voltage source inverters (VSIs). The proposed device isinstalled at the point of common coupling (PCC) of the distribution grid that the microgrid andother electrical loads are connected to. The proposed source for the dc-link voltage of the flexible ac distribution system device consists of a photovoltaic (PV) array and a battery to store the excess energy generated by the PV array and to provide power during sunless hours. The devices equipped with the capability to improve the PQ and reliability of the microgrid. Furthermore, during islanded operation of the micro grid, the device can provide real and reactive power to themicrogrid. The proposed controller is based on a newly developed model predictive control(MPC) algorithm to track periodic reference signals for fast sampling linear time-invariant (LTI)systems that are subject to input constraints. This control methodology controls the input signals of the VSIs and decomposes the control problem into steady-state and transient subproblemswhichareoptimizedseparately. In this way, the computational times canbegreatlyreduced.

In what follows, this paper provides a comprehensive solution for the operation of theflexibleacdistributionsystemdeviceforamicrogridbasedonamulti-input–multi-output(MIMO)state-spacemodel.Thedevicewill accomplishthefollowingtasks simultaneously:

1) Compensatingforharmonics inthe gridvoltageandloadcurrents;
2) Realandreactive power controlforload sharingduringpeakperiodsand power factorcorrectionat thegrid side;
3) MaintainingPQdespiteslightvoltageandfrequencyvariationsinthegrid voltage and
4) Momentarily dispatchingrealandreactive powerto themicrogridwhenitbecomesislanded.

1.1SYSTEMDESCRIPTION

The configuration of the microgrid considered in this paper for implementation of theflexible ac distribution system device is shown in Fig. 1. The proposed microgrid consists ofthree radial feeders (1, 2 and 3) where feeders 1 and 3 are each connected to a distributedgeneration (DG) unit consisting of a microgenerator, a three-phase VSI, and a three-phase LCfilter. Feeder 2, however, is connected to an electrical load. The load types in the microgrid willbediscussedinSectionVI.Theflexibleacdistributionsystemdeviceisoperatedintwomodes:

1)PQcompensationand2)emergencyoperation.Duringgrid-connectedoperation,themicrogrid is connected to the distribution grid at the PCC. In this mode, the two DG units arecontrolled to provide local power and voltage support for loads 1–3 and hence reduce the burdenof generation and delivery of power directly from the utility grid. The flexible ac distributionsystem device functions to compensate for any harmonics in the currents drawn by the nonlinearloads in the microgrid so that the harmonics will not propagate to the rest of the electrical loadsthat are connected to the PCC. The device also functions to compensate for harmonics in the gridvoltage that are caused by other nonlinear loads that are connected at the PCC. The energizationof large loads and rapid changes in the load demand may also result in voltage and frequencyvariations in the grid voltage. Therefore, the device is also equipped with the capability to handlesuch voltage and frequency variations. When a fault occurs on the upstream network of the grid,the CBs operate to disconnect the microgrid from the grid. The DG units are now the sole powersources left to regulate the loads. In the case when the generation capacity of the microgenerators isunabletomeetthetotalloaddemand,theflexibleacdistributionsystemdevicetransitstooperate in the emergency mode and functions to momentarily provide for the shortage in real andreactive power. In Fig. 1, the detailed configuration of the three-phase flexible ac distributionsystemdeviceis shown.

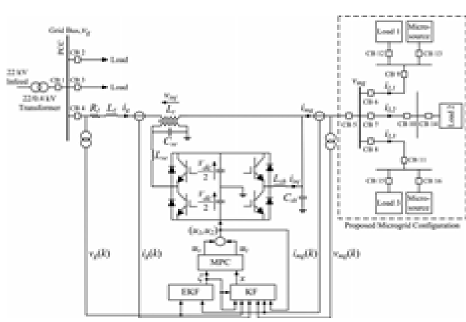

Fig-1:Thedetailedconfigurationofthethree-phaseflexibleacdistributionsystemdevice

The modem power distribution system is becoming highly vulnerable to the differentpower quality problems [1-2]. The extensive use of non-linear loads is further contributing toincreasedcurrentandvoltageharmonicsissues. Furthermore,thepenetrationlevelofsmall/large-scale renewable energy systems based on wind energy, solar energy, fel cell, etc.,installed at distribution as well as transmission levels is increasing significantly. Unified powerquality control was widely studied by many researchers as an eventual method to improve powerquality of electrical distribution system [1-3]. The function ofunified power quality conditioneris tocompensate supply voltage flicker/imbalance, reactive power, negative sequence current,andharmonics.

In other words, the UPQC has the capability of improving power quality at the point ofinstallation on power distribution systems or industrial power systems. Therefore, the UPQC isexpected to be one of the most powerful solutions to large capacity loads sensitive to supplyvoltage flicker/imbalance [2]. The UPQC consisting of the combination of a series active powerfilter (APF) and shunt APF can also compensate the voltage interruption if it has some energystorage or battery in the dc link [3]. The shunt APF is usually connected across the loads tocompensate for all current-related problems such as the reactive power compensation, powerfactorimprovement,currentharmonic,compensation,andloadunbalancecompensation(3,4)whereas the series APF is connected in a series with the line through series transformers. Itactsascontrolledvoltagesourceandcancompensateallvoltagerelatedproblems,suchasvoltageharmonics, voltagesag, voltage swell, flicker ,etc.

The proposed control technique has been evaluated and tested under non-ideal mainsvoltage and unbalanced load conditions using MATLAB/SIMULINK software. The proposedmethodisalsovalidatedthroughexperimentalstudy.ThefollowingdiagramsshowsthegeneralizedUPQCsystemTheUPQCconsistsoftwovoltagesourceinvertersConnectedbackto back with each of them sharing a common dc link. Fig-2 shows the control diagram of UPQCsystem. One inverter work as a variable voltage source is called series APF, and the other as avariable current source in called shunt APF. The main aim of the series APF isharmonicisolationbetweenloadandSupplythecapability ofvoltageflicker/imbalancecompensation as well as voltage regulation and harmonic compensation at the utility-consumerPCC. The shunt APF is used to absorb current harmonics, compensate for reactive power andnegative-sequencecurrent and regulatethe dc linkvoltagebetween bothAPFs.

II.SYSTEMCONFIGURATION

The GUPQC connected to a multi-bus/three-feeder distribution system which supply a nonlinearload (load1) by feeder1 and two sensitive critical loads (load2 and load3) by feeder2 and feeder3,is as shown in Fig.2. The shunt compensator, VSC1 which operates as a controlled currentsource is used to compensate feeder1 current harmonics, to provide the reactive power requiredby the load1 and to support the real power required by the two series compensators, VSC2 andVSC3.Thetwoseriescompensatorsareusedascontrolledvoltagesourcestoprotectthesensitiveloads (load2and load3)offeeder2 and feeder3 against voltageimperfections.

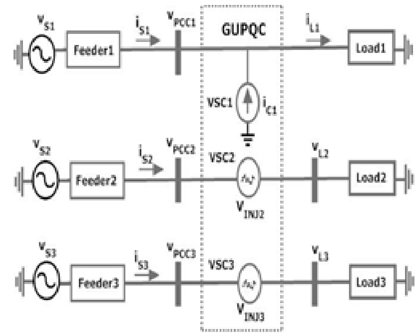

Fig-2:Multi bussystemwithUPQC

III.SYSTEMCONFIGURATIONANDDESIGNOFPV-UPQC

The structure of the PV-UPQC is shown in Fig The PV-UPQC is designed for a three-phasesystem. The PV- UPQC consists of shunt and series compensator connected with a common DC-bus.The shuntcompensatoris connectedatthe loadside. The solar PVarrayisdirectlyintegrated to the DC-link of UPQC through a reverse blocking diode. The series compensatoroperates in voltage control mode and compensates for the grid voltage sags/swells. The shuntandseriescompensatorsareintegratedtothegridthroughinterfacinginductors.Aseriesinjection transformer is used to inject voltage generated by theseries compensator into thegrid. Ripple filters are used to filter harmonics generated due to switching action of converters.Theload usedisanonlinearloadconsistingofabridgerectifier withavoltage-fedload.

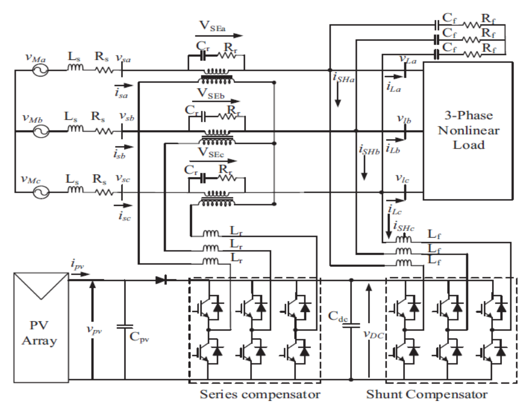

Fig-3:SystemConfigurationPV-UPQC

IV.DESIGN OF PV-UPQC

ThedesignprocedureforPV-UPQC beginswitchthepropersizingofPVarray, DC-linkcapacitor, DC-Link voltage leveletc. The shuntcompensatoris sized such thatit handles thepeak power output from PV array apart from compensating for the load current reactive powerand current harmonics. As the PV array is directly integrated to the DC-link of UPQC, the PVarray is sized such that the MPP voltage is same as desired DC- link voltage. The rating is suchthat, under nominal conditions, the PV array supplies the load active power and also feeds powerinto the grid. The detailed PV array specifications are given in Appendix A. The other designedcomponents are the interfacing inductors of series and shunt compensators and series injectiontransformerof theseriescompensator.

V.CONTROLOFPV-UPQC

The main subsystems of PV-UPQC are the shunt com- pensator and the series compensator. Theshuntcompensatorcompensatesfortheloadpowerquali typroblemssuchasloadcurrentharmonics and load reactive power. In case of PV- UPQC, the shunt compensator performs theadditional function of supplying power from the solar PV array. The shunt compensator extractspower from the PV-array by using a maximum power point tracking (MPPT) algorithm. Theseries compensator protects the load from the grid side power quality problems such as voltagesags/swellsby injecting appropriate voltageinphasewith thegrid voltage.

ControlofShuntCompensator

The shunt compensator extracts the maximum power from the solar PV-array by operating it atits maximum power point. The maximum power point tracking (MPPT) algorithm generatesthe reference voltage for the DC-link of PV-UPQC. Some of the commonly used MPPTalgorithmsarePer-turbandObserve(P&O)algorithm,incrementalconductanc ealgorithm(INC).Inthis work,(P&O)algorithmisusedforimplementingMPPT.The DC-linkvoltageismaintained at thegenerated referenceby usingaPI-controller.

To perform the load current compensation, the shunt compensator extracts the activefundamentalcomponent oftheload current.For thiswork,theshuntcompensatoriscontrolledbyextractin gfundamentalactivecomponentofloadcurrentusingSR Ftechnique. The control structure of shunt compensator is shown in Fig4. The load currents areconvertedtod-q-0do-mainusingthephaseandfrequencyinformationobtained fromPLL.The PLL input is the PCC voltage. The d-component of the load current (I_{Ld}) is filtered toextract DC component (I_{Ldf}) which represents the fundamental component in abc frame ofreference. To extract DC component without deteriorating the dynamic performance, amoving averagefilter(MAF)isusedto extracttheDCcomponent

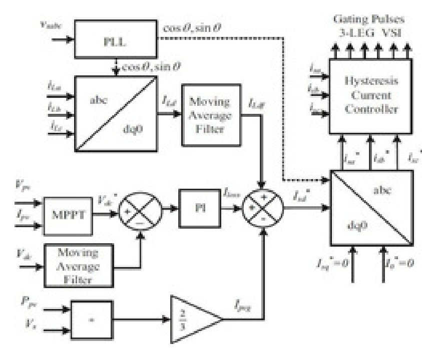

Fig-4:ControlStructureofShunt Compensator

ControlofSeriesCompensator

Thecontrolstrategyfortheseriescompensatorarepre-sag compensation in-phasecompensationandenergyoptimalcompensation.Ade taileddescriptionofvariouscompensation strategies used

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for control of series compensator is reported. In thiswork,the seriescompensator injectsvoltagein same phaseasthatofgrid voltage,whichresults in minimum injection voltage by the series compensator. The control structure of theseriescompensatorisshowninFig.Thefundamentalcom ponentofPCCvoltageisextracted using a PLL which is used for generating the reference axis in d- q-0 domain. Thereference load voltage is generated using the phase and frequency information of PCC voltageobtained using PLL. The PCC voltages and load voltages are converted into d-q-0 domain. Asthe reference load voltage is to be in phase with the PCC voltage, the peak load referencevoltage is the d-axis component value ofload reference voltage. The q-axis component is keptat zero. The difference between the load reference voltage and PCC voltage gives the reference voltage for theseries compensator. Thedifference between load voltage and PCCvoltage gives the actual series compensator voltages. The difference between reference andactual series compensator voltages is passed to PI controllers to generate appropriate referencesignals. These signals are converted to abc domain and passed through pulse width modulation(PWM)voltagecontrollertogenerate appropriate gatingsignalsfortheseriescompensator.

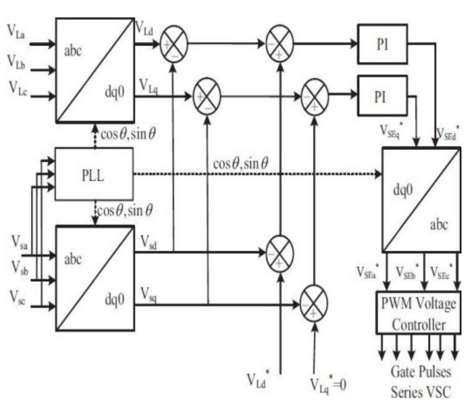

Fig-5: ControlStructureofSeriesCompensator

VI.CONVENTIONALSPACEVECTORPWMTEC HNIQUE

This method is easily implemented using the triangle comparison approach. It provides 15%higheracvoltageandlower voltageandcurrentTHDthan triangle comparisonPWM.Fig.6shows the conventional space vector diagram of two-level VSI with switching states in the sixsectors. A three- phase two level VSI has eight switching state, of them six states are activestates, produces a voltage vector of magnitude of either$+V_{dc}$or $\pm V_{dc}$and two zero states ornull states, produces a voltage vector of zero magnitude. The zero states are represented by 000and 111 switching states as shown in fig. 7. The active states divide the space vector planeintosixsectorsofequalmagnitudes.Switchingstatesi nallthesixsectorsareshowninTable

In SVPWM method, the reference voltage is provided by a rotating referencevector, which is sampled once in every subcycle, T_S. Fig. 7 shows the component of referencevoltagevectorofmagnitudeV_{ref}axisinsectorIan d T_1,$T_2$and$T_Z$arethedwelltimes for which active voltage vector 1, active voltage vector 2 and null vector are applied in asubcycleT_S.

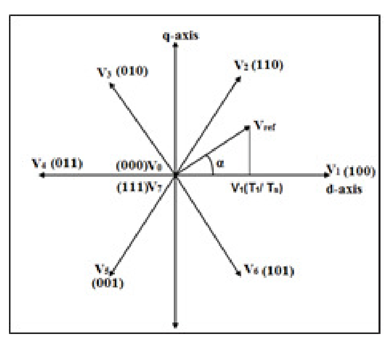

Fig-6:Conventional SVPWMdiagramoftwo-levelVSI

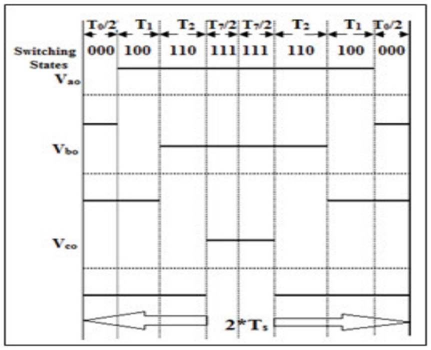

Fig-7:Pole voltagesanddifferenttimeintervals

VII.SIMULATIONRESULTSANDOUTPUTS

ThebelowisthemodelofproposedUPQCsystemwithPVAconnectedatDClinksupporting thegrid system.

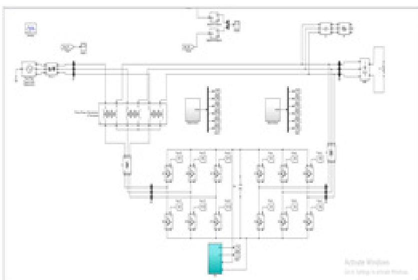

Fig-8:ProposedPVA-UPQCsystem

Inthe above modeling a UPQCconnectedtothegridsystemalongwithPVAattheDC link.A capacitoris connected attheDC linkin order toreduceripple inDC voltage.

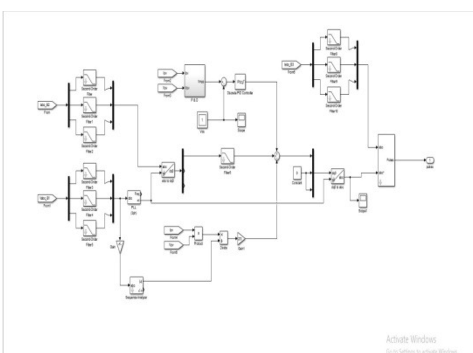

Fig-9:Shuntcontroller modeling

The above is the shunt controller modeling with MPPT technique which generates Vmpp(maximum voltage) connected to DC voltage regulator. The shunt controller operates with hysteresisiscurrentcontroller.

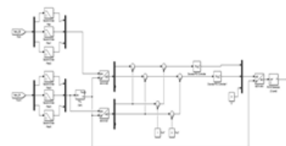

Fig-10: Seriescontrollermodeling

Theseriescontrollerisratherim plercontrolstructurewithsource andload voltagesfeedback.Thereference voltageforthesinPWMpulsegenerationi sgeneratedusingParkstransformation.

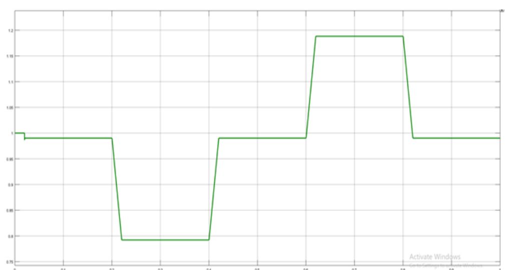

Fig-11:SourcevoltageandloadvoltagemagnitudewithoutPVA-UPQC(Voltagevstime)

Theabove arethegraphsof sourcevoltageandloadvoltagemagnitudesc ompared. Themagnitudesareoverlappedwith samevalues creatingsagsand swellsinboththevoltages.Thesimulation is run for 1sec, with sag introduced from 0.2-0.4sec and swell introduced from0.6-0.8sec.Thebelow graphisthe source currentswith noUPQCconnected tothegridsystem.Thesourcecurrent has very high harmoniccontent.

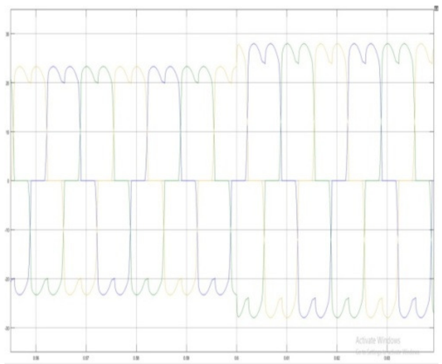

Fig-12:SourcecurrentswitchoutPVA-UPQC

The below are the graphs of source and load voltage magnitudes compared for sag and swell condition. The load voltage remains constant at 0.97pu where th Department e source voltage isvarying.

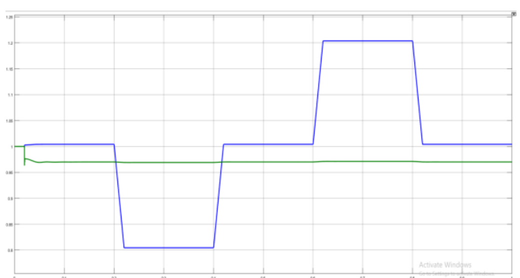

Fig-13:Sourcevoltage(blue)andloadvoltage(green)magnitudeswith PVA-UPQC

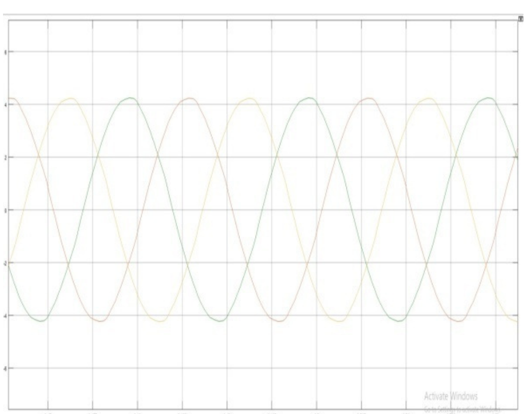

Fig-14:SourcecurrentswithPVA-UPQC

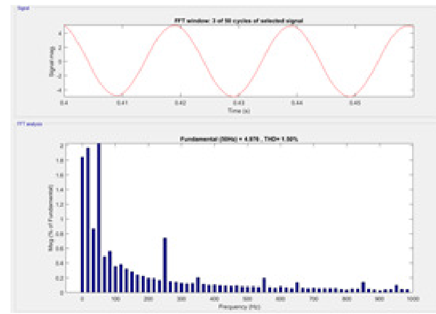

Fig-15:THDofsourcecurrent withPVA-UPQCcontrolled*byspacevectorPWMtechnique*

The test system is further updated with variable solar irradiation with 1000W/mt2 from 0-0.3sec,500W/mt2 from 0.3-0.6sec and 700W/mt2 from 0.6-1sec. Along with the variable solar irradiationand unbalanced load is connected between A and C phases which is disconnected from the grid at0.5sec.

COMPARISIONOFSYSTEMCONFIGURATION

S. No.	Configuration ofPV system	Power Quality Issue	THD (%)
1	Without UPQC	More fluctuations	27.14
2	With UPQC	Almost same as rated	1.73
3	With UPQC usingSV PWM		1.50

VIII.CONCLUSION

Finally with all the graphical representation and output analysis of the gridand micro system, implementation of UPQC FACTs device in a renewable grid system willimprove the quality of the system. The IRP method along with the space vector for the shunt andseries VSIs respectively improvise the THD of the grid current from 27% to a value of 1.76% andwith space vector the value is 1.5%. The voltages and the currents of the micro grid system areimprovisedwith injection ofactiveandreactivepowers fromtheUPQC system.

IX.FUTURESCOPE

The PV system source connected at the DC link can be replaced with wind farms or any otherrenewable sources like battery, fuel cell, super capacitor etc. Better adaptive controller can beintegrated into the shunt and series controllers for better results further improving the voltage andcurrent profiles. SV PWM is difficult to design ,high cost and limited to some kind of convertersonly so we can replace with simplified PWM technique that can suitable for any converter andresultsin reduction in THD.

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