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"Reactive Power Management in Distribution Feeder with Solar Pv System Using Matlab"

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ABSTRACT—
Photovoltaic(PV)systemsproposeattractivealternative source of generation because these can be placed neartotheloadcenterswhencomparedwithotherrenewablesourceof generation. It is therefore rooftop PV is the center of attractionfor majorityPV systems. The rooftop PV system in generalisgridconnectedandsupportstheoff-gridloadwithbatterybackup.Thedesignedsystemmustensuretotalevacuationofgeneratedpowerandwithhighefficiencyofconversion,andutilizestheresource adequatelytomaximizethe utilizationofenergy. This paper proposes single phase synchronous referenceframe (SRF) theory based current controlled PWM controller forthevoltagesourceconverter(VSC)torealizemaximumgenerated power evacuation by maintaining the DC link voltageconstantwithoutbatterysupport,lowTHDsinusoidallinesynchronizedcurrentoutput,andlimitedreactivepowercompensation based on the unutilized capacity of the inverter. PVpowerisbeingtrackedalwaysatMPPthroughincrementalconductance(IC)method.MATLABbasedsimulationresultsshows the efficient working of rooftop PV with proposed controlalgorithms in grid connected mode with limited reactive powerconditioning.

Keywords—
MPPT,Synchronousreferenceframe(SRF),IncrementalConductance(IC),Photovoltaic(PV)

I. INTRODUCTION

World is moving towards the greener sources of energy tomake the planet pollution free and environment friendly. Themajor utilization of these sources with grid integration is thechallenging task. It is therefore Distribution Generation (DGs)particularlysingle-phaserooftopPVsystemaremajorresearcharea for gridintegration, since these sources havehuge opportunity of generation near load terminal [1]. Therooftop application involving single phase DG's fed with PVsourcecanbenotonly utilizedforhousehold usebuttheexcess energy can be transferred to the grid through propercontrolscheme andadequatehardware.

Control scheme based on instantaneous PQ theory has beenpresented in some literatures for single phase system [2]. Othercontrol scheme such as synchronous reference frame (SRF) ismainlyusedwiththreephasesysteminwhichsinusoidalvarying quantities are being transferred to dc quantities thatprovides better and precise control than PQ based control evenunder distorted condition of mains [3]. But SRF based controlscheme can be customized for single phase which can't beutilizedtogetthedesireddcquantitytogeneraterequiredreferencecommand.

PV sources are interfaced with the grid through voltagesource converters (VSC's). VSC's can be controlled either inPWMbasedvoltagecontrolmethodorhysteresisbasedcurrent controlled method (HCC). HCC based controller givesfast response and better regulation but its major drawback lieswith variable frequency. On the other hand, the PWM basedcontrol gives fixed switching frequency that could be utilizedeasilyfor properdesignof LCorLCLfilters[4].

WithPVsourcesconnectedattheDCsideoftheinverter,it is utmost essential to fetch maximum power from the sourcetomakethesystemefficient.Outofdifferentalgorithm totrackmaximumpowerpoint(MPP)suchasperturbandobserve (P&O), Incremental Conductance (IC) etc., IC basedmethod provides fast dynamics and control over fast changinginsolation condition[5]

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[6].
In this paper new control scheme based on SRF theory hasbeenproposedforsinglephaserooftopPVgridconnectedsystem.TheVSCcontrollerisdesignedintakingtheadvantageofbothcurrentandvoltagecontrollerwhichiscalled current driven PWM based voltage controller. Throughthe VSC the maximum tracked power is pumped into the gridthrough proper control on DC link voltage. By maintaining theDC link voltage constant during operation, is ensured the totalpower being generated by PV transferred across the DC bus bythe inverter to the grid. Apart from active power transfer thesystem could be well utilized for providing limited reactivepower compensation based on available capacity of the VSC.The detailed system configuration and various control schemesarebrieflydiscussedandexplained.
The rooftop PV system with proposed scheme is simulatedunder the MATLAB simulink environment for grid connectiontopushreal power intothe gridalongwithlimited powerconditioning.Thecontentsaredealtinthefollowingsections:
(II)SystemConfiguration(III)PVarraymodelingandICMPPTtechniques,(IV)Control,(V)MATLABSimulation,
(VI)Performanceevaluation.

II. SYSTEM CONFIGURATION.

Fig.1 depicts the schematic diagram of transformation$\overline{I}_d$and$\overline{I}_q$componentscorrespondtoreal and

single-phase gridconnectedPVsystemcomprisingPVpanels,DC-DCconverter, MPPT charge controller, tank capacitor, VSC andRL loads. IC based MPPT controller is used to extract themaximumavailablepowerfromthePVpanels.Controlbased on tank capacitor voltage is used to control the transfer ofmaximumpowertothegridviaVSC.Thedirectvoltagecontrolledcurrent drivenVSC keeps the voltage across thetankcapacitor constant byregulatingthe powerevacuationthrough voltage control. Proper design of LCL filter at theoutputof VSCfiltersoutharmonicsat thePCC.

templatevectors.Theoutput‘sin ωt’ofthePLLwillbeinphase with single phase voltage at PCC. For applying modifiedSRF theory to single phase system, phase voltage or current isassumedasalpha(α)componentinα-βframe(stationaryframeofreference),andβcomponentisobtainedbyintroducing phase delay of 90° to alpha components as showninFig.3.UsingmodifiedSRFtheorybothDGand loadcurrentsaretransformedintod-qcomponentsandpassedthrough low pass filter (LPF) to obtain only DC componentscorresponding to fundamental frequency as shown in Fig. 3.ForsuchsynchronizedmodifiedSRFtheory-based

reactivepowercomponentsrespectively.Assuming currentreferenceas[8]

i_a=$Asin$(t (2)

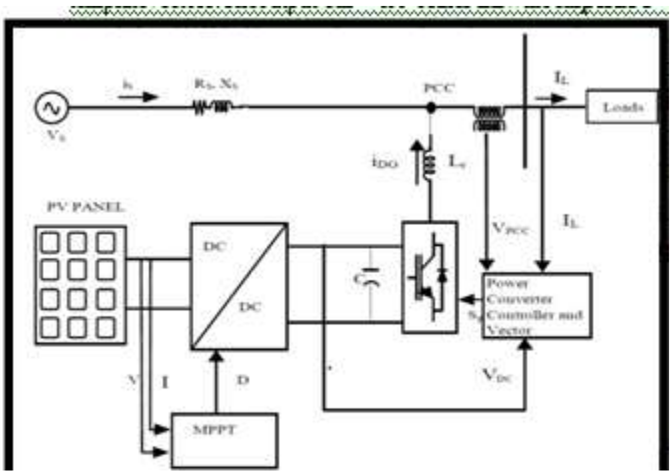

Fig.1BlockDiagramforSystemConfigurationof PVDGCC

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III. MODELING OF PVARRAYS

The basic equations that govern I-V characteristic of theideal photovoltaic cell are reported in literatures [7]. Thetypical equationgoverningthePVarrays isgivenby (1)

Table I
ParametersoftheSunpowermodelSPR-P3-415Solararrayatnominaloperatingconditions

$I=I$

Ipmax	9.22A
Vpmax	45 V
Pmax	415 W
Isc	9.90A
Voc	54.1V
Power Temp Coef.	-0.36% / ^{0}C
Voltage Temp Coef.	-0.29% / ^{0}C
Current Temp Coef.	0.05% / ^{0}C

V

$$I=I_{pv} \quad I_o \quad \frac{V+R_sI}{V_ta} \quad \frac{V+R_sI}{R_p}$$

$$i_\beta=Asin(t-\frac{\pi}{2}) \qquad (3)$$

Where, $V_t=\frac{N_skT}{q}$, Ns-Numberofcellsconnectedinseries; Rp=EquivalentparallelResistance;Rs=EquivalentcontactseriesResistance.

CommerciallyavailableSPR-P3-415SunpowermakePVpanels are considered here to design the array to deliver powerof 800W byconnecting apanels ina stringand similarstrings in parallel in MATLAB Simulink. The parameters ofthe panel are shown in Table I. The proposed charge controlleroperates to extract the maximum power at one level of solarinsolationbyusingIncrementalConductancebasedMPPTcontroller [7].

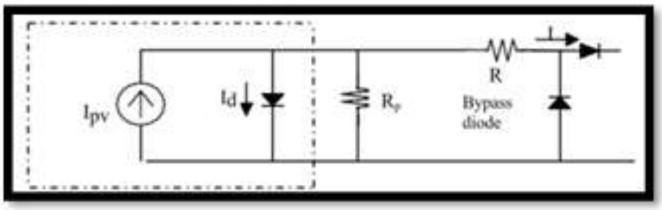

Fig. 2 PVPanel Model

IV. CONTROL THEORY

TheproposedsystemThe3phaseSRFbasedtheoryismodified for single phase system. The heart of the controlscheme lays with correct estimation of phase voltage thoughphaselocked loop(PLL),which isusedforgeneration ofunit

Theα-βcomponentisthentransformedtod-qusingequations(4)

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix}=[(\sin(t\&-\cos(t@\cos(t\&)(-sin)(t)] \qquad (4)$$

Idand Iqobtained through transformation are passed thoughLPF to obtain the at DC quantities which after proper controlonthisDCquantity,it'sagainconvertedbacktoα-βcomponentusing(5).

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix}=[(\sin(t\&(\cos)(t@\cos(t\&)(-sin)(t)] \quad (5)$$

After transformation only α component is used for signalgeneration. InthephotovoltaicbasedgridconnectedsystemitisutmostimportanttoextractMPPtrackedpowerforeconomicaloperationandtoavoidpanelsheatingduetounderutilization. To guarantee this, constant DC bus voltage isrequiredtobemaintainedacrossDClinkcapacitor,andreference current is generated to obtain the command voltagereferenceforPWMcontrolofthe VSCasshown in Fig. 3.The control forces the output current of VSC to closely follow thereference current. The DG's main task is to send maximumpowertothegridviaVSC.Intheeventofvaryinginsolationor during low insolation, the VSC capacity is not fully utilizedfor real power transfer. The unutilized capacity can be used forlimitedreactivepowercompensation.Thedepthofcompensation is based on capacity remaining after deductingMPPT tracked.

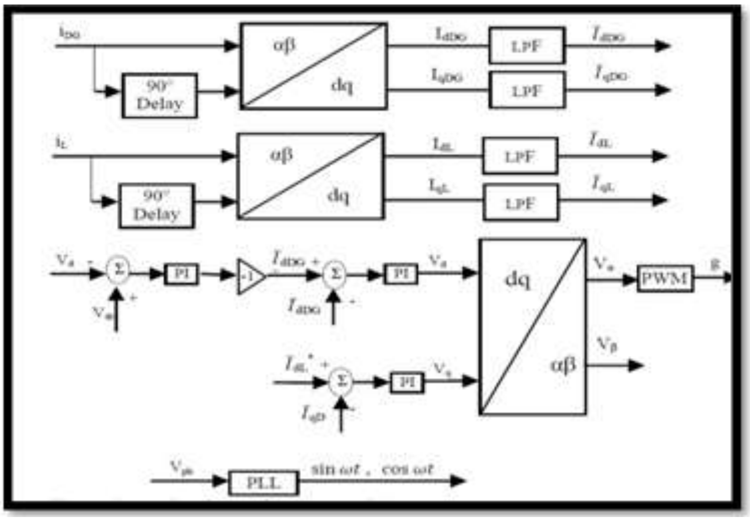

Fig. 3 ControlSchemeforproposed System.

PV power from the total capacity of VSC. In view of thisreactivepowercomponentinloadisdeterminedand multiplied with 'k' showing the selective or amount of powertobecompensatedasshownin Fig.3.Thisreferencereactive commandiscomparedwithDG'$\bar{I}_{DG}^{q}$componentanderrorare passedthroughPIcontrollertogeneratereferenceV^{*}_{α}component.Thisvoltagereferenced-qcomponentisthenreverse transformed to α-β using equations (8). Out of the twocomponentsinstationaryframeofreferenceV^{*}componentis

Table IIParametersforLCLFilter

L1	3 mH
L2	3 mH
Ls	0.3 mH
R1	0.02Ω
R2	0.02Ω
Rs	0.02Ω

C	40µF
R	3 Ω

TableIII
ParametersforConsideredSystem

Vph	230V,50Hz
RL	5 Ω
LL	4 mH
DClink Voltage	400V
SupplyFrequency	50 Hz
Max.PVpower	8.5 kW
VSC Switch frequency	2000 Hz

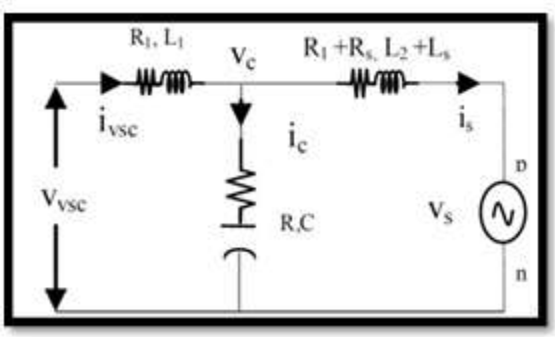

Fig.4 LCL Model

used forPWMgating signalgeneration.

LCLfilterdesign:
Fig. 4 shows the LCL filter which is placed at the VSC outputterminal to get the filtered output. Proper design of filter iscrucial from the stability point of view. Applying KCL to theLCLcircuitfollowingequationsaresynthesized:

$$i_{VSC}-i_C - i_S=0 \quad (6)$$

$$V_{VSC}-V_C=i_{VSC}(R_1+sL_1) \quad (7)$$

$$V_C-V_S=i_S[(R_1+R_s)+s(L_2+L_s)] \quad (8)$$

$$i_{VSC}=i_C(\frac{1}{sC}+R) \quad (9)$$

$$\frac{i_s}{v_{vse}}=\frac{N(s)}{D(s)} \quad (10)$$

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WhereN(s)=sRC+1

D(s)= [(L2+Ls) L1C]s3+[(L2+Ls) (R+R1) C+(R2+Rs)L1C+L1C]s2 +[(R2+Rs)(R1+Rc)C+R1C+L2+Ls)s+[(R2 +Rs)] (11)

Using above equations (6) - (10) circuit can be modeled asblock diagram as shown in Fig. 5. For checking the stability ofthe filter design bode plot is drawn in the MATLAB for theparameters given in table II as shown in Fig. 6. From Fig. 6 itcan be seen that the plot has overshoot near resonant frequencyotherplotwithlowdampingandotherwithproposedsystemofLCLfilterparametersshownoovershootandproperdamping. The adequate passive damping provided avoids peakatresonantpointandpreventslossof gain, by

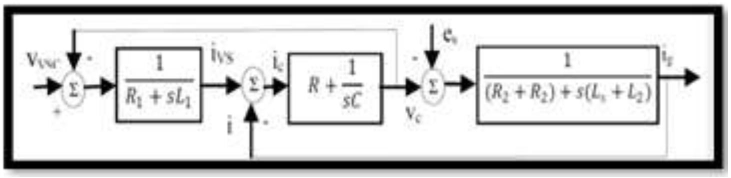

Fig.5BlockdiagramrepresentationofLCLfilter

appropriately choosing the damping ratio. By keeping L1and L2same, reactive interaction of filter capacitance getsminimizedwiththelinewithminimizedvalueofcapacitance.

V. SIMULATION RESULTS

Thecompletesingle-phasegridconnectedPVsystemis

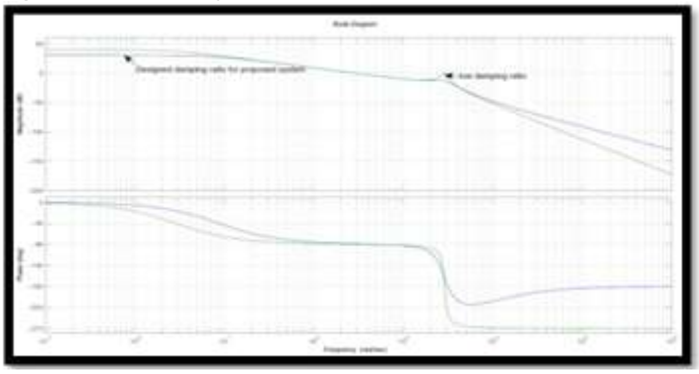

Fig. 6 BodeplotoftheLCLfilter

simulated under MATLAB Simulink with RL load (R= 4Ω, L = 4 mH) as shown in Fig.7. PV panels are connected inseriesandparallelinsuchawaythatarraycoulddeliver maximum power of 8.5 kW at 1000 W/insolation level.

ICbasedMPPTalgorithmisverifiedbywritingembeddedMATLAB code. LCL filter is connected at the output of VSCas per parameters given in the table II. The simulated resultsarestudied tocomputetheperformanceofsingle-phasegrid

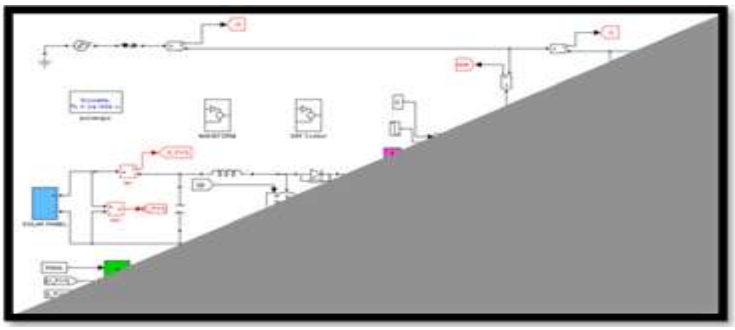

Fig.7 SinglephaserooftopPVMATLABmodelforgrid connectedsystem

connected system under limited available capacity of VSC.The parameters of the considered system are shown in Table-III.

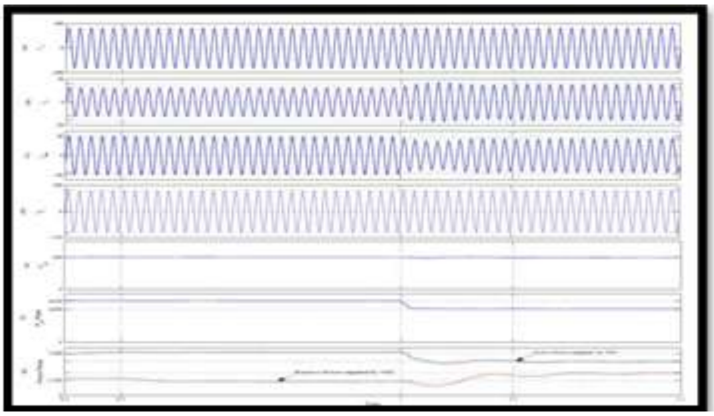

Fig. 8 Dynamic response of single-phase roof top PV systemfor voltage at PCC, source current from grid, VSC current,load current, DC link voltage, MPPT tracked power, Activeandreactive poweroutputoftheVSC

VI. PERFORMANCE EVALUATION

Single phase grid connected photovoltaic based VSC withlimitedpowerconditioningissimulatedunderMATLABSimulink environment. Fig. 8 (a)- (g) shows the waveform forPCC voltage, source current, VSC current, load current, DClinkvoltage,MPPTpower,andVSCoutputactiveandreactivepowerrespectively.Tomaketheanalysisclearerinitial transient conditions is not shown and analysis is startedwhensustainedsteadystateisreached,i.e.startingfromt =0.4s onwards. With PCC point voltage maintained at 230 Vtotal load demand which is 55.16 A is shared between twosources – the grid source and the PV source connected at PCCas shown in Fig. 8 (d). Assuming capacity of VSC 10.5 KVA,and available MPP power of 8.5 kW at 1000 W/m2 insolation,its capacity is shared between active and reactive power outputof VSC. Till t=1s when the insolation is at 1000 W/m2, theMPPT extracted 8.5 kW power for transfer through VSC tomaintain constant DC link voltage as shown in Fig. 8 (e). Tillt=1sVSCandgridsourcesshared21.6Aand34.2Arespectively for total load demand as shown in Fig. 8 (b) - (c).During the same time VSC only supply a part of the total loadreactive power demand (3.8 KVAr) which is 2.3 KVArasshown in Fig. 8 (g). At t = 1s insolation level has changed to800 W/m2 leading to decrease in PV power to 6.8 kW asshown inFig. 8(f).

This decrease in active power supply through VSC resultsintoadditionalroomcreatedformorereactivepowercompensation.AspertheratingofVSC,fullreactivecompensationisprovidedthroughVSCamountingto 3.8KVAr as shown in Fig. 8 (g). In turn source current from gridandVSCcurrentgetsredistributedaftert=1sto26.8 Aand 29.4 A respectively as shown in Fig. 8 (b)-(c). With the fullreactive power compensation after t = 1s source voltage andcurrentcomesinphaseresultingintounitypowerfactoroperation.

VII. CONCLUSION

The simulated results clearly demonstrate the ability ofthe proposed control scheme to evacuate MPP tracked powerfromthePVarrayandprovidelimitedreactivepowercompensation with grid connected mode. The MPPT used inthe control tracks the power very fast even under step changeof insolation, and the current controlled PWM controller injectadequate generated current for self-support of capacitor at DCbus and thereby providing storage less operation. Single phaseSRFbasedestimationisemployedwhichprovidesruggedcontrol with cost effective solution. The proposed SRF basedapproachenablethecontrolforprovidinglimited compensationofreactivepowerdependingonavailableunutilized capacity of VSC. The implemented scheme derivesthe advantage of simplicity and is capable of delivering undervaryinginsolationconditionseffectively.Suchte chnique isenvisaged to benefit the PV rooftop system and grid/microgridby the limited compensation, thereby effectively utilizing theconnectedhardware.

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