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Reactive Power Management inSolar PV System using Matlab

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Abstract: Photovoltaic (PV) systems propose attractive alternative source of generation because these can be placed near to the load centers when compared with other renewable sourceof generation. It is therefore rooftop PV is the center of attractionfor majority PV systems. The rooftop PV system in general is grid connected and supports the off-grid load with battery backup. The designed system must ensure total evacuation ofgenerated power and with high efficiency of conversion, and utilizes the resource adequately to maximize the utilization of energy. This paper proposes single phase synchronous reference frame (SRF) theory based current controlled PWM controller forthe voltage source converter (VSC) to realize maximum generated power evacuation by maintaining the DC link voltage constant without battery support, low THD sinusoidal line synchronized current output, and limited reactive power compensation based on the unutilized capacity of the inverter. PVpower is being tracked always at MPP through incremental conductance (IC) method. MATLAB based simulation results shows the efficient working of rooftop PV with proposed control algorithms in grid connected mode with limited reactive power conditioning.
Keywords: MPPT, Synchronous reference frame (SRF), Incremental Conductance (IC), Photovoltaic (PV)

I. INTRODUCTION

World is moving towards the greener sources of energy to make the planet pollution free and environment friendly. The major utilization of these sources with grid integration is the challenging task. It is therefore Distribution Generation (DGs) particularly single-phase rooftop PV system are major research area for grid integration, since these sources have huge opportunity of generation near load terminal [1]. The rooftop application involving single phase DG's fed with PV source can be not only utilized for household use but the excess energy can be transferred to the grid through proper control scheme and adequate hardware.

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) is mainly used with three phase system in which sinusoidal varying quantities are being transferred to dc quantities that provides better and precise control than PQ based control evenunder distorted condition of mains [3]. But SRF based control scheme can be customized for single phase which can't be utilized to get the desired dc quantity to generate requiredreference command.

PV sources are interfaced with the grid through voltage source converters (VSC's). VSC's can be controlled either in PWM based voltage control method or hysteresis based current controlled method (HCC). HCC based controller gives fast response and better regulation but its major drawback lies with variable frequency. On the other hand, the PWM based control gives fixed switching frequency that could be utilized easily for proper design of LC or LCL filters [4].

With PV sources connected at the DC side of the inverter,it is utmost essential to fetch maximum power from the source to make the system efficient. Out of different algorithm to track maximum power point (MPP) such as perturb and observe (P&O), Incremental Conductance (IC) etc., IC based method provides fast dynamics and control over fast changing insolation condition [5] [6]. In this paper new control scheme based on SRF theory has been proposed for single phase rooftop PV grid connectedsystem. The VSC controller is designed in taking theadvantage of both current and voltage controller which is called current driven PWM based voltage controller. Through the VSC the maximum tracked power is pumped into the grid through proper control on DC link voltage. By maintaining theDC link voltage constant during operation, is ensured the total power being generated by PV transferred across the DC bus bythe inverter to the grid. Apart from active power transfer the system could be well utilized for providing limited reactive power compensation based on available capacity of the VSC. The detailed system configuration and various control schemesare briefly discussed and explained.

The rooftop PV system with proposed scheme is simulated under the MATLAB simulink environment for grid connectionto push real power into the grid along with limited power conditioning. The contents are dealt in the following sections: (II) System Configuration (III) PV array modeling and IC MPPT techniques, (IV) Control, (V) MATLAB Simulation, (VI) Performance evaluation.

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II. SYSTEM CONFIGURATION.

Fig.1 depicts the schematic diagram of single-phase grid connected PV system comprising PV panels, DC-DC converter, MPPT charge controller, tank capacitor, VSC and RL loads. IC based MPPT controller is used to extract the maximum available power from the PV panels. Control based on tank capacitor voltage is used to control the transfer of maximum power to the grid via VSC. The direct voltage controlled current driven VSC keeps the voltage across the tank capacitor constant by regulating the power evacuation through voltage control. Proper design of LCL filter at the output of VSC filters out harmonics at the PCC.

Template vectors. The output 'sin □□' of the PLL will be in phase with single phase voltage at PCC. For applying modified SRF theory to single phase system, phase voltage or current is assumed as alpha (α) component in α-β frame (stationary frame of reference), and β component is obtained by introducing phase delay of 90° to alpha components as shown in Fig. 3. Using modified SRF theory both DG and load currents are transformed into d-q components and passed through low pass filter (LPF) to obtain only DC components corresponding to fundamental frequency as shown in Fig. 3. For such synchronized modified SRF theory-based transformation □̄and □̄□ components correspond to real and reactive power components respectively. Assuming current reference as [8]

$$i_a = A\ sin(t \qquad (2)$$

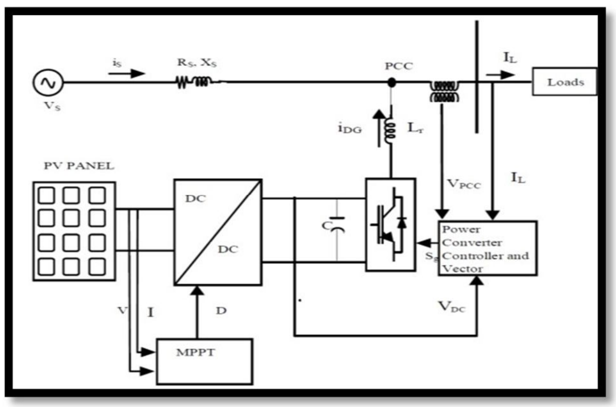

Fig. 1 Block Diagram for System Configuration of PVDGCC

III. MODELING OF PV ARRAYS

The basic equations that govern I-V characteristic of theideal photovoltaic cell are reported in literatures [7]. The typical equation governing the PV arrays is given by (1)

Table I

Parameters of the KYOCERA model KC200GT Solar arrayat nominal operating conditions

Ipmax	7.61A
Vpmax	26.3V
Pmax	200.13
Isc	8.21A
Voc	32.9V
Kv	-0.1230 V/K
KI	0.0032 A/k
Ns	54

$I = I$

$\underline{V + R_s I}$

$- I\ p\ [exp\ (\qquad) - 1] -$

$\frac{V + R_s I}{pv \qquad o}$

$V_t a$

R_p

Where, Vt= $\frac{NskT}{q}$, Ns-Number of cells connected in series;

Rp=Equivalent parallel Resistance; Rs= Equivalent contact series Resistance.

Commercially available KC200GT Kyocera make PV panels are considered here to design the array to deliver power of 800W by connecting 3 panels in a string and similar 2 strings in parallel in MATLAB Simulink. The parameters of the panel are shown in Table I. The proposed charge controlleroperates to extract the maximum power at one level of solar insolation by using Incremental Conductance based MPPT controller [7].

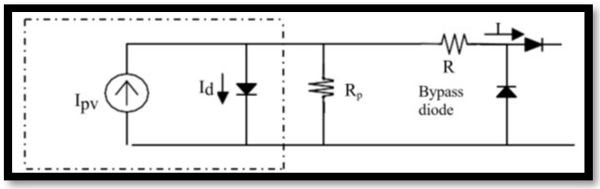

Fig. 2 PV Panel Model

IV. CONTROL THEORY

The proposed system the 3 phase SRF based theory ismodified for single phase system. The heart of the control scheme lays with correct estimation of phase voltage though phase locked loop (PLL), which is used for generation of unit

$-$ $\qquad$ $i_\beta = A\ sin\ (t - \frac{\pi}{2})$

The α-β component is then transformed to d-q using equations (4)

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

Id and Iq obtained through transformation are passed though LPF to obtain the at DC quantities which after proper control on this DC quantity, it's again converted back to α-β component using (5).

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

After transformation only α component is used for signal generation.

In the photovoltaic based grid connected system it is utmost important to extract MPP tracked power for economical operation and to avoid panels heating due to underutilization. To guarantee this, constant DC bus voltage is required to be maintained across DC link capacitor, and reference current is generated to obtain the command voltage reference for PWM control of the VSC as shown in Fig. 3. The control forces the output current of VSC to closely follow the reference current. The DG's main task is to send maximum power to the grid via VSC. In the event of varying insolationor during low insolation, the VSC capacity is not fully utilized for real power transfer. The unutilized capacity can be used for limited reactive power compensation. The depth of compensation is based on capacity remaining after deducting MPPT tracked.

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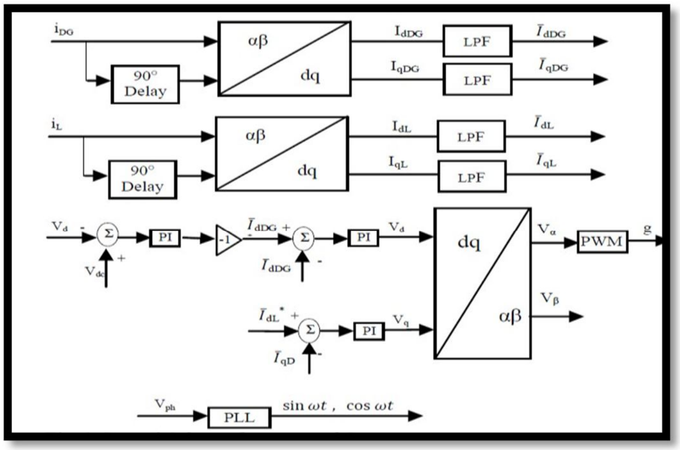

Fig. 3 Control Scheme for proposed System.

PV power from the total capacity of VSC. In view of this reactive power component in load is determined and multiplied with 'k' showing the selective or amount of power to be compensated as shown in Fig. 3. This reference reactive command is compared with DG '$\bar{I}_{0D}$ component and error are passed through PI controller to generate reference V^* component. This voltage reference d-q component is then reverse transformed to α-β using equations (8). Out of the two components in stationary frame of reference V^* component is used for PWM gating signal generation.

Table II Parameters for LCL Filter

L1	3 mH
L2	3 mH
Ls	0.3 mH
R1	0.02 Ω
R2	0.02 Ω
Rs	0.02 Ω
C	40° F
R	3 Ω

Table III. Parameters for Considered System

Vph	230 V
RL	5 Ω
LL	4 mH
DC link Voltage	400V
Supply Frequency	50 Hz
Max. PV power	8.5 kW

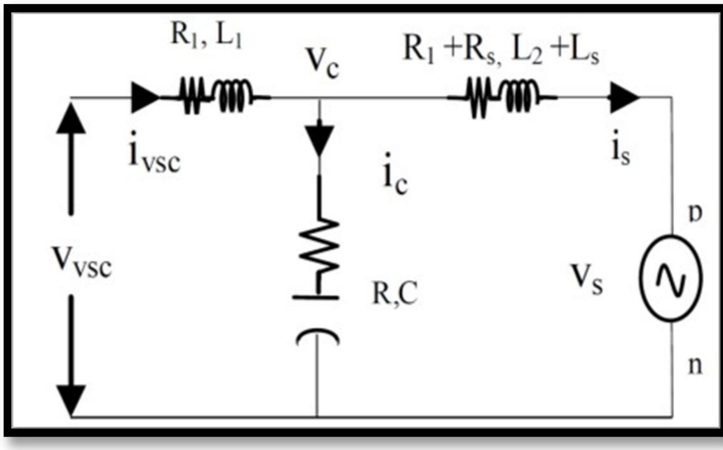

Fig. 4 LCL Model

A. LCL Filter Design

Fig. 4 shows the LCL filter which is placed at the VSC output terminal to get the filtered output. Proper design of filter is crucial from the stability point of view. Applying KCL to the LCL circuit following equations are synthesized:

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

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

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

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

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

Where N(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 as block diagram as shown in Fig. 5. For checking the stability ofthe filter design bode plot is drawn in the MATLAB for the parameters given in table II as shown in Fig. 6. From Fig. 6 it can be seen that the plot has overshoot near resonant frequencyother plot with low damping and other with proposed systemof LCL filter parameters show no overshoot and proper damping. The adequate passive damping provided avoids peakat resonant point and prevents loss of gain, by appropriately choosing the damping ratio. By keeping L1 and L2 same, reactive interaction of filter capacitance gets minimized with the line with minimized value of capacitance.

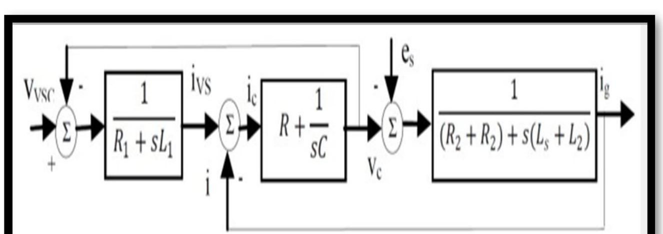

Fig. 5 Block diagram representation of LCL filter

V. SIMULATION RESULTS

The complete single-phase grid connected PV system is simulated under MATLAB Simulink with RL load (R= 4 Ω, L = 4 mH) as shown in Fig.7. PV panels are connected in series and parallel in such a way that array could deliver maximum power of 8.5 kW at 1000 W/ insolation level. IC based MPPT algorithm is verified by writing embedded MATLAB code. LCL filter is connected at the output of VSC as per parameters given in the table II. The simulated results are studied to compute the performance of single-phase gridconnected system under limited available capacity of VSC.The parameters of the considered system are shown in Table- III.

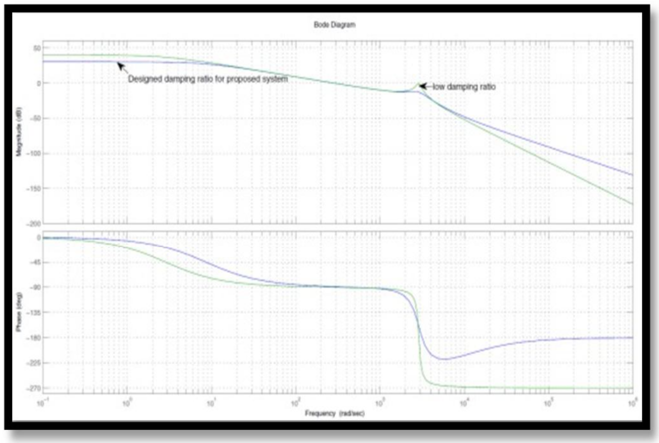

Fig. 6 Bode plot of the LCL filter

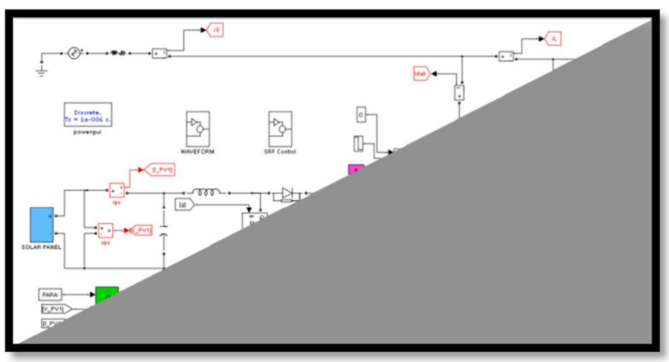

Fig. 7 Single phase roof top PV MATLAB model for grid connected system

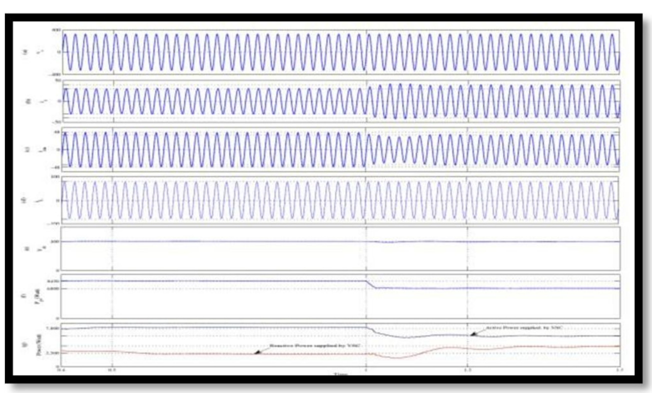

Fig. 8 Dynamic response of single-phase roof top PV systemfor voltage at PCC, source current from grid, VSC current, load current, DC link voltage, MPPT tracked power, Active and reactive power output of the VSC

VI. PERFORMANCE EVALUATION

Single phase grid connected photovoltaic based VSC with limited power conditioning is simulated under MATLAB Simulink environment. Fig. 8 (a)- (g) shows the waveform for PCC voltage, source current, VSC current, load current, DC link voltage, MPPT power, and VSC output active and reactive power respectively. To make the analysis clearer initial transient conditions is not shown and analysis is started when sustained steady state is reached, i.e. starting from t=0.4s onwards. With PCC point voltage maintained at 230 V total load demand which is 55.16 A is shared between two sources – the grid source and the PV source connected at PCC as 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, the MPPT extracted 8.5 kW power for transfer through VSC to maintain constant DC link voltage as shown in Fig. 8 (e). Till t=1s VSC and grid sources shared 21.6 A and 34.2 A respectively for total load demand as shown in Fig. 8 (b) - (c). During the same time VSC only supply a part of the total load reactive power demand (3.8 KVAr) which is 2.3 KVAr as shown in Fig. 8 (g). At t = 1s insolation level has changed to 800 W/m2 leading to decrease in PV power to 6.8 kW as shown in Fig. 8 (f).

This decrease in active power supply through VSC results into additional room created for more reactive power compensation. As per the rating of VSC, full reactive compensation is provided through VSC amounting to 3.8 KVAr as shown in Fig. 8 (g). In turn source current from grid and VSC current gets redistributed after t = 1s to 26.8 A and 29.4 A respectively as shown in Fig. 8 (b)-(c). With the full reactive power compensation after t = 1s source voltage and current comes in phase resulting into unity power factor operation.

VII. CONCLUSION

The simulated results clearly demonstrate the ability of the proposed control scheme to evacuate MPP tracked power from the PV array and provide limited reactive power compensation with grid connected mode. The MPPT used in the control tracks the power very fast even under step change of insolation, and the current controlled PWM controller injectadequate generated current for self-support of capacitor at DC bus and thereby providing storage less operation. Single phase SRF based estimation is employed which provides rugged control with cost effective solution. The proposed SRF based approach enable the control for providing limited compensation of reactive power depending on available unutilized capacity of VSC. The implemented scheme derives the advantage of simplicity and is capable of delivering under varying insolation conditions effectively. Such technique is envisaged to benefit the PV rooftop system and grid/microgrid by the limited compensation, thereby effectively utilizing the connected hardware.

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