SINGLE PHASE GRID CONNECTED PV SYSTEM USING ZETA CONVERTER

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Abstract
Solar photovoltaic systems provide an attractive alternative source of power generation. As it can be placed near to the load centers when compared with other renewable source of generation. The rooftop PV system in general is grid connected and supports the off grid load with battery backup. A maximum power point is tracked using Zeta Converter with variation in the irradiations all throughout the year .This paper proposes single phase synchronous reference frame (SRF) theory based current controlled PWM controller for the 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. Zeta converter (Buck-boost) acts as a better alternative to MPPT has been proposed. MATLAB based simulation results shows the efficient working of rooftop PV with proposed control methodologies in grid connected mode with limited reactive power conditioning.

Index Terms: PV Array Mathematical model, Zeta Converter, VSC controller, SRF, MATLAB-Simulink

I. INTRODUCTION

ELECTRIC utilities and end users of electric power are becoming increasingly concerned about meeting the growing energy demand. Seventy five percent of total global energy demand is supplied by the burning of fossil fuels. But increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it necessary to look towards renewable sources as a future energy solution. Since the past decade, there has been an enormous interest in many countries on renewable energy for power generation. The market liberalization and government's incentives have further accelerated the renewable energy sector growth. Renewable energy source (RES) integrated at distribution level is termed as distributed generation (DG). The utility is concerned due to the high penetration level of intermittent RES in distribution systems as it may pose a threat to network in terms of stability, voltage regulation and power-quality (PQ) issues. It is therefore Distribution Generation (DGs) particularly single phase Solar PV systems which are major research area for grid integration, since these sources have huge opportunity of generation near load terminal [1]. The 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 been presented in some literatures for single phase system [2]. Other control 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 even under 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 required reference 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]. MPPT face problems in maintaining the voltage profile constant when there is change in irradiance. Zeta converter based system has proved more reliable and efficient than the MPPT based one. Zeta converter is also called as Buck-boost converter. A voltage follower approach is used for the control of Zeta DC-DC converter operating grid connected system. The DC link voltage is controlled by DC link capacitor. Vdc (sensed DC link voltage) is compared with Vdc* (reference voltage) to generate an error signal which is the difference of Vdc* and Vdc. The error signal is given to a PI (Proportional Integral) controller to give a controlled output. Finally, the controlled output is compared with the high frequency saw tooth signal to generate PWM (Pulse Width Modulation) pulse for the MOSFET of the Zeta converter [7].

In this paper new control scheme based on SRF theory has been proposed for single phase rooftop PV grid connected system. The VSC controller is designed in taking the advantage 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 the DC link voltage constant during operation, is ensured the total power being generated by PV transferred across the DC bus by the 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.

II. SYSTEM CONFIGURATION

Figure 1 depicts the schematic diagram of single phase grid connected PV system comprising PV panels, Zeta converter, tank capacitor, VSC and RL loads. 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. The conventional 3 phase SRF theory is modified to suit the single phase system. The modified SRF theory is applied to decompose the load current to generate the reference reactive power current command. Reference for the real current component is obtained by applying PI controller on the error between measured voltage and the reference voltage.

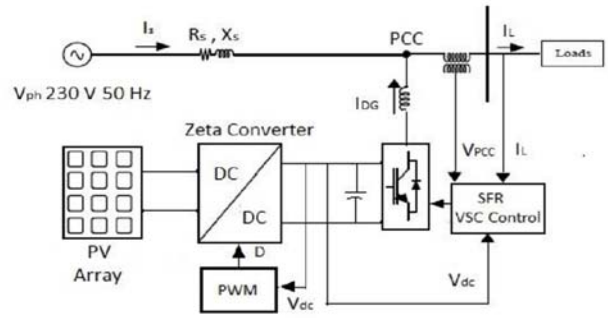

Fig. 1.Block diagram for system configuration of Single phase grid connected PV DG

A. PV Array

PV arrays are built up with combined series/parallel combinations of PV solar cells, which are usually represented by a simplified equivalent circuit model such as the one given in Fig. 1 and/or by an equation as in (1)

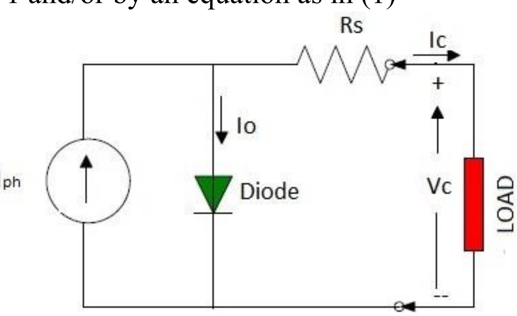

Fig. 2: Simplified-equivalent circuit of photovoltaic cell

The PV cell output voltage is a function of the photocurrent that mainly determined by load current depending on the solar irradiation level during the operation.

$$V_c = \frac{A*k*T_c}{e} \ln\left(\frac{I_{ph}+I_0-I_c}{I_0}\right) - R_s I_c \quad\text{……… (1)}$$

Where the symbols are defined as follows: e: electron charge (1.602 × 10-19 C) k: Boltzmann constant (1.38 × 10-23 J/°K).

Ic: cell output current, A.

Iph: photocurrent, function of irradiation level and junction temperature (5 A).

I0: reverse saturation current of diode (0.0002 A).

Rs: series resistance of cell (0.001 Ω).

Tc: reference cell operating temperature (20 °C).

Vc: cell output voltage, V

The solar cell operating temperature varies as a function of solar irradiation level and ambient temperature. The variable ambient temperature Ta affects the cell output voltage and cell photocurrent. These effects are represented in the model by the temperature coefficients C_{TV} and C_{TI} for cell output voltage and cell photocurrent, respectively, as:

$$C_{TV} = 1 + (T_a - T_x) \ldots\ldots\ldots\ldots (2)$$

$$C_{TI} = 1 + \frac{\gamma_T}{S_c}(T_x - T_a) \ldots\ldots\ldots\ldots (3)$$

Where, $\beta_T = 0.004$ and $\gamma_T = 0.06$ for the cell used and T_a=20°C is the ambient temperature during the cell testing. This is used to obtain the modified model of the cell for another ambient temperature T_x. Even if the ambient temperature does not change significantly during the daytime, the solar irradiation level changes depending on the amount of sunlight and clouds. A change in solar irradiation level causes a change in the cell photocurrent and operating temperature, which in turn affects the cell output voltage. If the solar irradiation level increases from S_{x1} to S_{x2}, the cell operating temperature and the photocurrent will also increase from T_{x1} to T_{x2} and from I_{phl} to I_{ph2}, respectively. Thus the change in the operating temperature and in the photocurrent due to variation in the solar irradiation level can be expressed via two constants, C_{SV} and C_{SI}, which are the correction factors for changes in cell output voltage V_C and photocurrent I_{ph}, espectively:

$$C_{SV} = 1 + \beta(S_x - S_C) \ldots\ldots\ldots\ldots (4)$$

$$C_{SI} = 1 + \frac{1}{S_C}(S_x - S_C) \ldots\ldots\ldots\ldots\ldots (5)$$

Where S_C is the benchmark reference solar irradiation level during the cell testing to obtain the modified cell model. Sx is the new level of the solar irradiation. The temperature change, ΔT_C, occurs due to the change in the solar irradiation level and is obtained using

$$\Delta T_C = \alpha_S(S_x - S_C) \ldots\ldots\ldots\ldots\ldots (6)$$

The constant α_S represents the slope of the change in the cell operating temperature due to a change in the solar irradiation level [1] and is equal to 0.2 for the solar cells used.

Using correction factors C_{TV}, C_{TI}, C_{SV} and C_{SI}, the new values of the cell output voltage V_{CX} and photocurrent I_{phx} are obtained for the new temperature Tx and solar irradiation Sx as follows:

$$V_{CX} = C_{TV}C_{SV}V_C \ldots\ldots\ldots\ldots (7)$$

$$Vphx = CTICSIIph \ldots\ldots\ldots\ldots (8)$$

V_C and I_{ph} are the benchmark reference cell output voltage and reference cell photocurrent, respectively.

B. Zeta Converter

The duty ratio D for the Zeta converter (buck-boost) is given as [7],

$$D = \frac{Vdc}{(Vin + Vdc)} \ldots\ldots\ldots\ldots (9)$$

Where V_{dc} represents the DC link voltage of Zeta converter. If the permitted ripple of current in input inductor Li and output inductor Lo is given as ΔiLi and ΔiLo respectively, then the inductor value Li and Lo are given as,

$$Li = \frac{D*Vin}{\{fs*(\Delta iLi)\}} \ldots\ldots\ldots\ldots (10)$$

$$Lo = \frac{(1-D)*Vdc}{\{fs*(\Delta iLo)\}} \ldots\ldots\ldots\ldots (11)$$

Where fs is the switching frequency. For the critical conduction mode,

$$\Delta iLo = 2 * Idc$$

$$Lo(crictical) = \frac{(1-D)*Vdc}{\{fs*(2*Idc)\}} \ldots\ldots\ldots\ldots (12)$$

The value of intermediate capacitor CI is given as,

$$C_i = \frac{D*Idc}{\{fs*(\Delta VC1)\}} \ldots\ldots\ldots\ldots\ldots (13)$$

Where ΔVC1 is the permitted ripple in C1. The value of DC link capacitor Cd is given as,

$$C_d = \frac{Idc}{(2*\omega*\Delta Vdc)} \ldots\ldots\ldots\ldots\ldots (14)$$

When Zeta converter is used by replacing the MPPT DC-DC Boost converter the results shows that Zeta converter is more reliable and efficient for the grid connected DG. The ripple in input inductor (ΔiLi) current is considered to be 10% and ripple in DC link voltage (ΔVdc) as 4%.

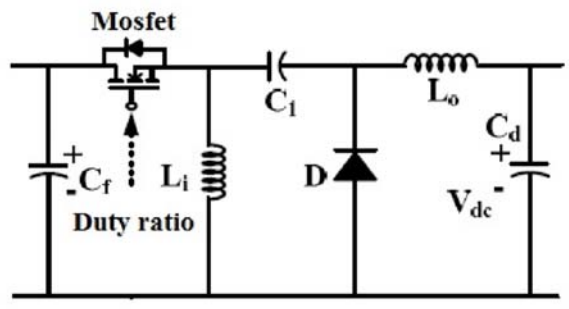

Fig.3 Zeta Converter

C. VSC Controller

The proposed system the 3 phase SRF based theory is modified 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 template vectors. The output 'sin(ωt) ' 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 I_d and I_q components corresponds to real and reactive power components respectively. Assuming current reference as

$$i_\alpha = A \sin(t)$$

$$i_\beta = A(t - \pi/2) \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

The α-β component is then transformed to d-q using equations (16)

$$\begin{bmatrix} id \\ iq \end{bmatrix} = \begin{bmatrix} \sin t & -\cos t \\ \cos t & \sin t \end{bmatrix} \ldots\ldots\ldots\ldots\ldots (16)$$

Id and Iq obtained through transformation is 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 (17)

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \begin{bmatrix} \sin t & \cos t \\ \cos t & -\sin t \end{bmatrix} \ldots\ldots\ldots\ldots (17)$$

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. 4.

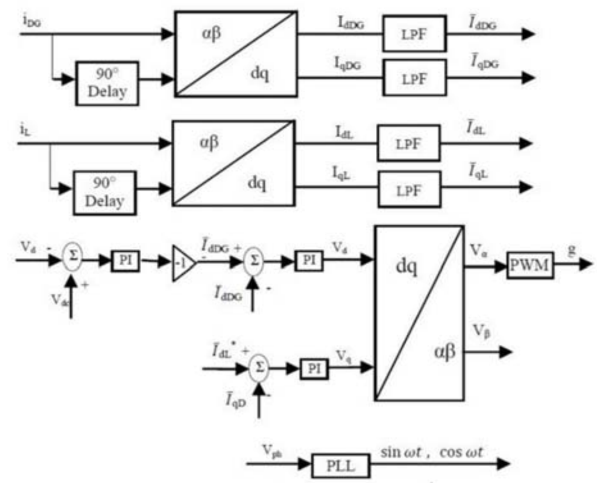

Fig. 4 VSC Control Scheme

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 insolation or 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 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. 4. This reference reactive command is compared with DG ' IqDG' component and error is passed through PI controller to generate reference V_{q*} component. This voltage reference d-q component is then reverse transformed to α-β using equations (17). Out of the two components in stationary frame of reference v_α* component is used for PWM gating signal generation.

D. LCL Filters

Using above circuit can be modeled as block diagram as shown in Fig. 5. Parameters for the given system is shown in table II and table I shows proposed LCL filter parameters for the given system.

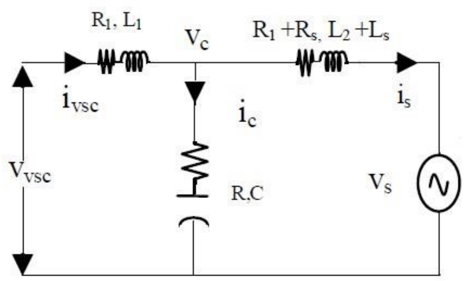

Fig. 5 LCL Filter circuit model

Table No. 1 LCL Filter Parameters

Parameters	Rating
L1	3 mH
L2	3 mH
Ls	0.3 mH
R1	0.02 Ω
R2	0.02 Ω
Rs	0.02 Ω
R	3 Ω
C	40 µF

Table No. 2 Grid Connected Parameters

Parameters	Rating
V_{ph}	230 V
Supply Frequency	50 Hz
R_L	4 Ω
L_L	4 mH
DC Link Voltage	400 V
Maximum PV Power	8.5 kW
VSC Switching Frequency	2000 Hz
Zeta Converter Switching Frequency	45000 Hz

Table No. 3 Zeta Converter Parameters

Parameters	Rating
Vo (operating voltage input)	50-200 V
Vdc Output	400 V
Switching Frequency	45000 Hz
Li	2.463 mH
Lo	60 µH
C_1	330 nF
C_d	2500

III. MATLAB-BASED SIMULATION AND RESULTS

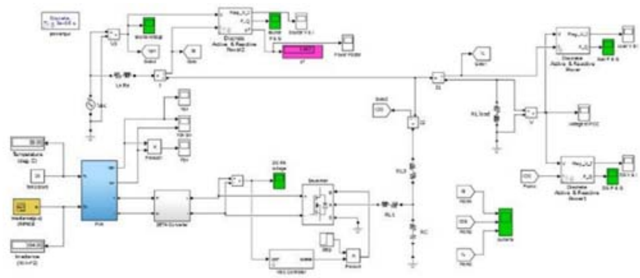

Fig.6: Matlab Model of Grid connected DG with Zeta converter

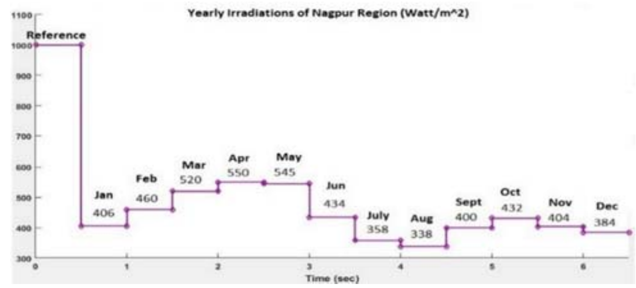

Fig.7 Yearly irradiation data of Nagpur Region Input to PVA

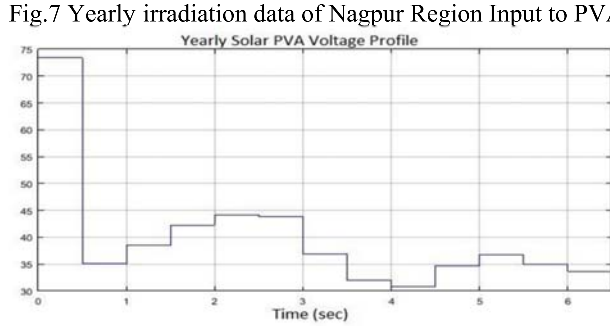

Fig.15: PVA Voltage Profile at different Irradiance (DG with Zeta Converter Controller)

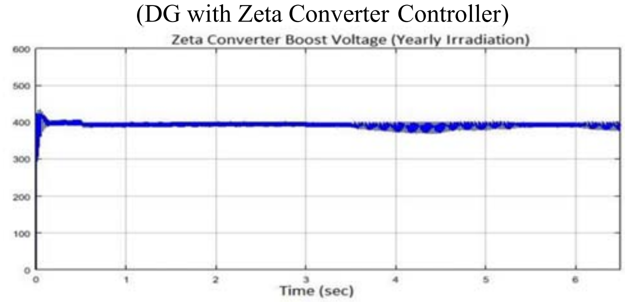

Fig.17: Vdc Boost Voltage profile at different irradiance
(DG with Zeta Converter Controller)

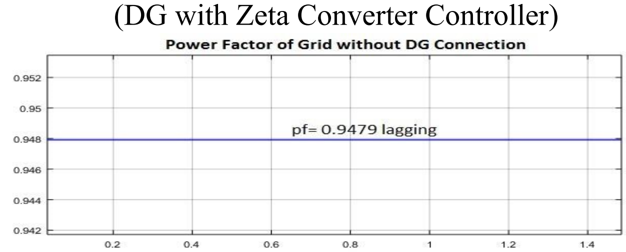

Fig.18: Power Factor without DG

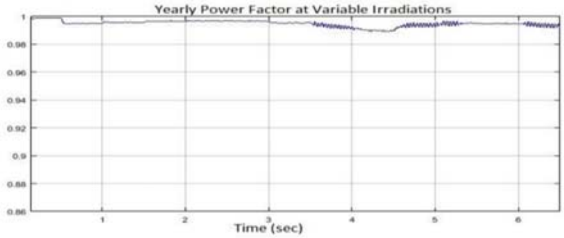

Fig.19: Power Factor at different irradiance (DG with Zeta Converter Controller

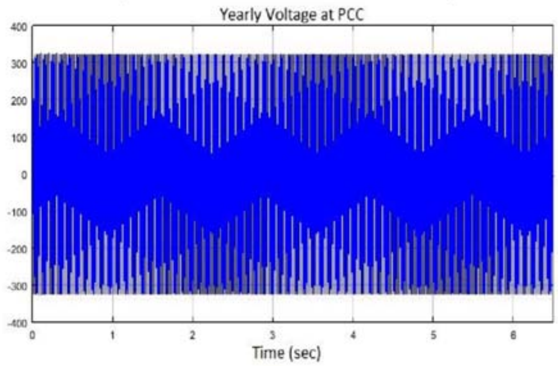

Fig.20 Voltage at PCC at different irradiance (DG with Zeta Converter Controller)

IV. RESULTS AND DISCUSSION

The proposed new control on PV solar system will help accomplishing the following objectives:

- Increasing the utility of the Rooftop Solar PV system
- Power Factor improvement through reactive power compensation
- Incentives from the Utility for maintaining power factor near to unity

MPPT fails to provide required results when there are changes in irradiations. Zeta Converter provides a better alternative to MPPT controller when the irradiations are varied throughout the year.

From the experimental results PCC voltage is pure sinusoidal of 230 Volts, having frequency 50 Hz same as grid voltage and frequency.

V. CONCLUSIONS

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 current controlled PWM controller inject adequate generated current for self-support of capacitor at DC bus and thereby providing storage less operation. Single phase SRF (Synchronous Reference Frame) 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.

Comparative study and comparison between to MPPT with DC-DC boost converter and Zeta Converter for single phase grid connected PV system has been carried out. Power Factor is maintained near to unity even though there are changes in irradiations and also the limited reactive power compensation is provided by DG with Zeta converter.

VI. REFERENCES

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