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Controlling of Active and Reactive Power in Three Phase Solar Inverter by Modified IC Method

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ABSTRACT: With the increment of solar photovoltaic installation in power grid, solar power penetration level, over loading of grid and power fluctuation are becoming prominent issues. To address the problems, active and reactive power fed to the grid from solar inverter are needed to be controlled. Regulation of active power from solar inverter is performed by modifying maximum power point tracking algorithm of photovoltaic generation and run in off maximum power mode. To operate the solar plant in off maximum power mode, fractional voltage based modified incremental conductance method is introduced in this paper. The solar photovoltaic inverter over which this active power control is operated, is modeled in MATLAB/Simulink and this model is tested for real irradiance and temperature conditions. Reactive power control is also performed in standard test condition. Simulation results illustrate the desired limited active power injection into the grid. power can be controlled by the grid in using capacitor banks and synchronous condensers and static var compensators in the grid.

I. INTRODUCTION

This high level of solar PV installed in power grid rises the issue related to penetration level if sufficient amount of storage is not integrated to the system. To control this penetration level of solar PV, maximum power point tracking (MPPT) algorithm is needed to be modified. In case of solar PV integrated with two stage two level inverters, the off MPPT mode causes fluctuation in DC link voltage. Here new kind of MPPT control based on modified incremental conductance (IC) method for fractional voltage change is introduced. This fractional voltage based incremental conduction (FV-IC) is used to run solar PV in off MPPT voltage to extract desired power. To control the solar PV penetration level a modified incremental conductance (IC) method is introduced, and 5 kW solar PV inverter is considered for active and reactive power control. To control the active and reactive power output of athree-phase solar PV inverter using modified IC method, we first need to understand the basics of power control in a solar inverter. A solar inverter is a device that converts DC power generated by solar panels into AC power that can be used by household appliances or fed into the grid. The amount of power output by this fractional voltage based incremental conduction (FV-IC) is used to run solar PV in off MPPT voltage to extract desired power. To control the solar PV penetration level a modified incremental conductance (IC) method is introduced, and 5 kW solar PV inverter is considered for active and reactive power control. To control the active and reactive power output of a three-phase solar PV inverter using modified IC method, we first need to understand the basics of power control in a solar inverter. A solar inverter is a device that converts DC power generated by solar panels into AC power that can be used by household appliances or fed into the grid. The amount of power output by the inverter can be controlled by adjusting the DC voltage input from the solar panels. The active power output of the inverter is controlled by adjusting the DC voltage input to the inverter. This can be done by using maximum power point tracking (MPPT) algorithms that adjust the DC voltage input to the inverter to ensure that the maximum power is extracted from the solar panels. The reactive power output of the inverter can be controlled by adjusting the phase angle between he voltage and current of the inverter output. This is done by adjusting the firing angle of the inverter's power electronic switches. The modified IC method is a control technique that uses an integrated circuit (IC) to generate a pulse-width modulation (PWM) signal to control the firing angle. The IC generates a PWM signal that controls the average voltage output of the inverter, which in turn controls the active power output. To control the reactive power output using the modified IC method, the IC generates a second PWM signal that controls the phase angle between the voltage and current of the inverter output. This is achieved by adjusting the delay between the two PWM signals. The modified IC method is a simple and cost-effective control technique that can be used to control the active and reactive power output of a three-phase solar PV inverter. It is widely used in commercial solar inverters and can be easily implemented using off-the-shelf ICs and components.

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Aim of the Project:
To control the active and reactive power in the grid and the fluctuations in the active and reactive power which may leads to the fluctuations in the grid. It may cause degradation of the power supply. It leads to change in power supply. It may lead to power factor at lagging cases.

Problem Formulation:
The 5 kW solar PV system is simulated using irradiance and module temperature data of sunny and cloudy day collected from SCADA system of a 100 kW rooftop mounted solar PV plant situated at. On these input data of sunny and cloudy days the input active power control of solar PV system is performed. The modified IC method is utilized to control the solar PV output voltage or DC-DC converter input voltage, thus modified IC method controls input and output power of solar inverter as well. The off-MPPT mode results are compared with MPPT mode case for same input conditions. To control the reactive power, the reactive power references are generated from active power and varying the power factor in between 1 to 0.7 leading and lagging cases under standard test condition (STC).

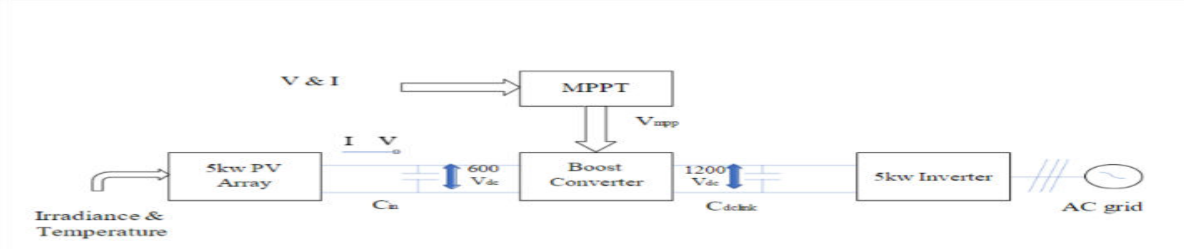

Fig 1: Schematic diagram of 5kw grid connected PV system

Modeling of Solar Photovoltaic Array:

In this paper, 5 kW PV array has been modeled in MATLAB/Simulink using ploy crystalline solar PV panel (ELDORA 250) data. The modeling equations of solar PV module is depicted in representing IV characteristics of solar PV module. The equivalent solar PV module is shown in Fig. 1.

$$I = I_{ph} - I_d - I_p \quad (1)$$

$$I = I_{ph} - I_0\left[exp\left(\frac{q(V+IR_s)}{N_{cell}nkT}\right) - 1\right] - \frac{V+IR_s}{R_p} \quad (2)$$

$$I_{ph} = \left(\frac{G}{G_{ref}}\right)\left[I_{sc} + \alpha_T(T - T_{ref})\right] \quad (3)$$

$$I_0 = I_{0,ref}\left(\frac{T^3}{T^3{}_{ref}}\right) exp\left[\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\frac{qE_g}{nk}\right] \quad (4)$$

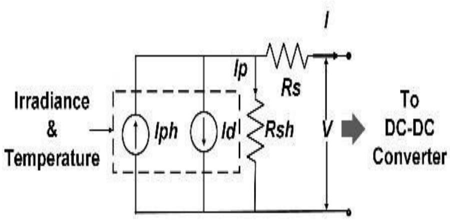

Fig:2 Equivalent circuit of solar cell

From the above Fig. 2, I and V are output current and voltage of single module respectively. Iph is photocurrent and Id is body diode current and Ip is parallel branch current of the module. T (K) and G (kW/m2) are module temperature and solar irradiance respectively. Trev (k) and Grew (kW/m2) are module reference temperature and irradiance, are taken as per STC. k and q are Boltzmann constant and electronic charge respectively. αT, n, and I0, ref, are temperature coefficient of photocurrent, body diode idealistic factor and body diode reference current respectively and they are considered as 3.49 mA/K, 1.1~1.2 and 1.585 × 10-8 A respectively. cell is number of cells connected in series in a module and it is taken as 60. Rs and Rp equivalent series and shunt resistors are taken as 1.79 mΩ and 187.8 Ω with respect to slope of I-V curve of a single solar PV module respectively. Short circuit current and open circuit voltage of solar module are taken as 8.75 A and 37.25 V respectively from the data sheet of ELDORA 250. The solar module equation (2) has been appropriately modified to represent solar array.

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$$I_A = N_p I_{ph} - N_p I_0 \left[exp\left(\frac{q\left(V_A + I_A \frac{N_s}{N_p} R_s\right)}{N_s N_{cell} nkT} \right) - 1 \right] - \frac{V_A + I_A \frac{N_s}{N_p} R_s}{\frac{N_s}{N_p} R_p} \quad (5)$$

THREE PHASE GRID TIE INVERTER MODELING

The modelling of 5 kW gird tie central inverter is performed considering two stage two level PWM inverter and boost converter is taken as intermediate DC-DC converter

Modelling of Boost Converter

A boost converter is used as DC-DC converter inside the three phase inverter. Boost converter's inductor L* and input capacitor C_{in} are calculated considering 1% current ripple and 10 % voltage ripple respectively. DC link capacitor of boost converter C_{dclink} is calculated considering 1% voltage ripple.

k Factor Control of Boost Converter

The open loop voltage control transfer function from small signal modeling of boost converter, transfer function between input voltage *Vin* and duty ratio *d* are $G_{Vind}(s)$ is calculated as shown in (6)

$G_{Vind}(s)$ is calculated as shown in (6).

$$G_{Vind}(s) = \frac{-213148222.2}{s^2 + 15.277 \times s + 222222.22} \quad (6)$$

Voltage of input capacitor and current of inductor of boost converter are considered as states of the system to formulate $G_{Vind}(s)$. This boost converter voltage control transfer function is compensated using PI lead-lead compensator $G_c(s)$ by k 3 factor.

Modelling of PWM Inverter

Previously modelled boost converter feeds power to three phase PWM inverter. Data sheet of KACO TL 5.0 (5 kW Central Inverter) is referred while modelling PWM inverter. dq-axis based synchronous reference frame control is utilized for inverter control shown in Fig. 3. This synchronous reference frame based control provides simple and independent control of active and reactive power of inverter. Three phase grid voltages and currents are converted into synchronously rotating dq frame so that control variables become DC quantities. The grid voltage magnitude is found out by orienting the grid voltage vector along d axis. Phase Lock Loop (PLL) is utilized to calculate the grid voltage.

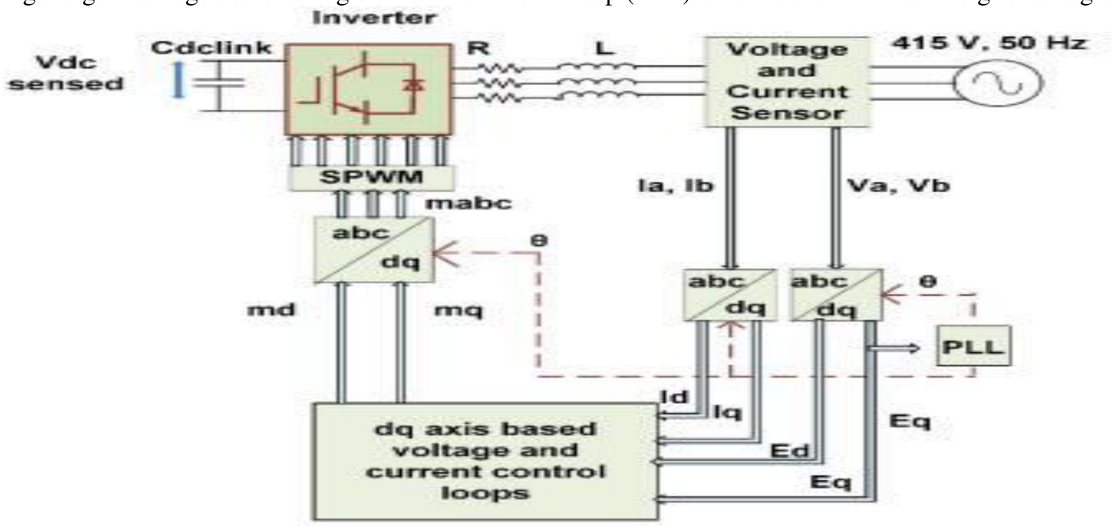

Fig:3 Synchronous reference frame control

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Two levels of PWM inverter comprise of six IGBT switches. Switching pulses for IGBT switches are generated from completely decoupled but cascaded voltage and current control loops. The cascaded voltage and current control loops are integrated with dq-axis based control and are shown in Fig. 4.

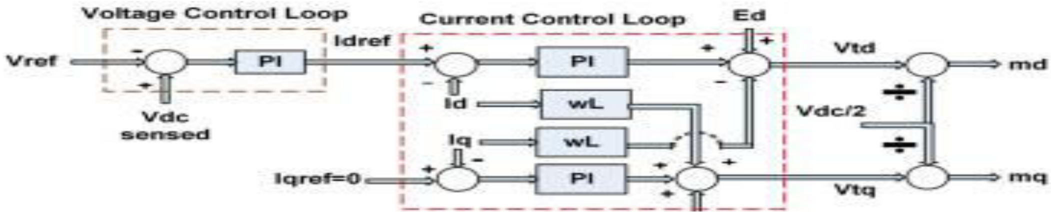


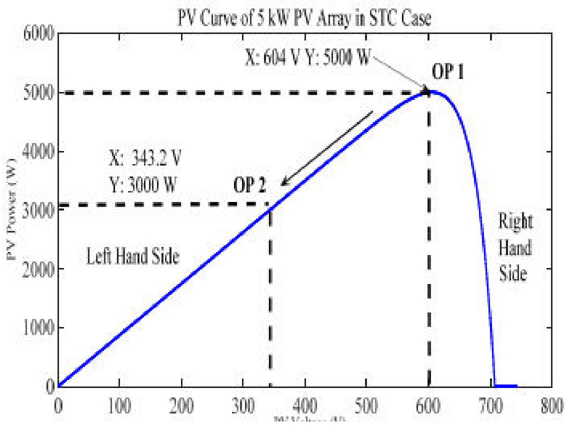
Fig :3 cascaded and voltage and current loops

The current control loop transfer function is formulated considering L filter. The AC side resistor and filter inductor values are evaluated by taking 10% and 5% of base impedance. PI controller is utilized for inner current loop and the PI controller parameters are calculated considering pole zero cancellation method [10]. Voltage control loop transfer function is given in (10). For voltage controller modelling, the characteristic equation of second order closed loop system is considered and PI controller parameters for this loop is evaluated using. All parameters and their values are given in Table II.

Parameters	values
3 phase grid voltage	415 V_{rms}
Dc link voltage	1200 vdc
L filter	1000µf
R,Ac side resistor	10.96 mH
Current controller	Kp=6 ki=863
Voltage control	Kp=0.1568 ki=11.09
Switching frequency	10khz

Modified IC Method of Active Power Control

The 5 kW solar system with single string configuration is integrated with single MPPT logic. IC method is used to track the maximum power point voltage. As per the proposed method, IC will generate change of voltage ΔV from solar array. ΔV is positive in left hand side of PV curve and negative in right hand side of PV curve shown in Fig. 5. This ΔV is changed until conductance equation (11) become zero and thus maximum power and maximum power point (MPP) voltage are found. For MPPT mode the operating point is OP 1 in Fig. 5. In case of off-MPPT mode, if PV power increases from the reference power (off-MPPT mode power reference), a fractional voltage change ΔV' will be generated and it will reduce the MPP voltage to off-MPP voltage and operating point will shift to OP 2. From this new operating point OP 2, off-MPPT mode voltage and active power will be calculated.



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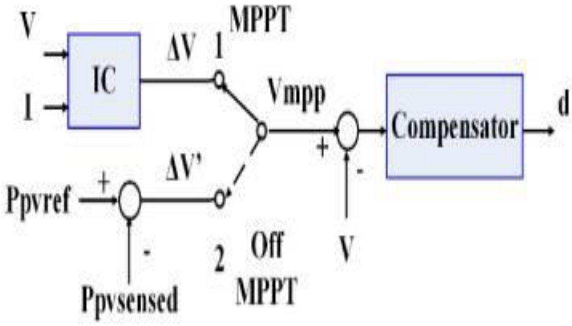


The modification in IC method for off-MPPT mode of operation and modified duty ratio generation are shown in Fig. 6. In MPPT and off-MPPT operation, the voltage error generates duty ratio d in the boost converter using compensator.

Reactive Power Control:

The reactive power is controlled from active AC power sent to the grid by solar inverter at STC and changing power factor from 1 to 0.7 for unity, leading and lagging cases. The reactive power reference will change the q-axis current in dq axis current control loop inside the inverter. By this, solar inverter is operated in upf., leading and lagging pf. modes.

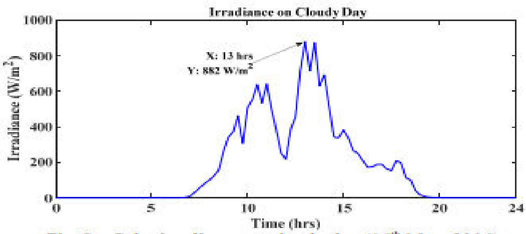
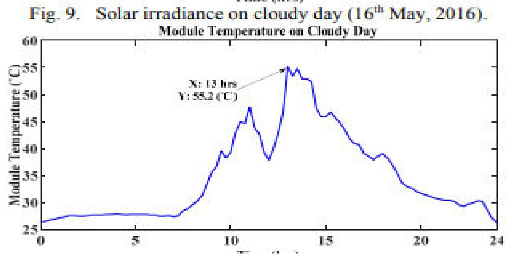


Fig. 9. Solar irradiance on cloudy day (16th May, 2016).



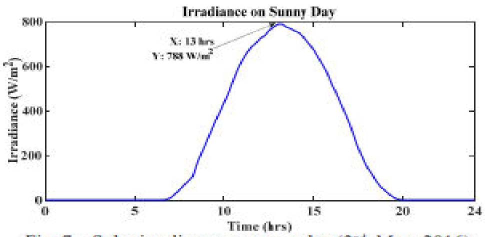
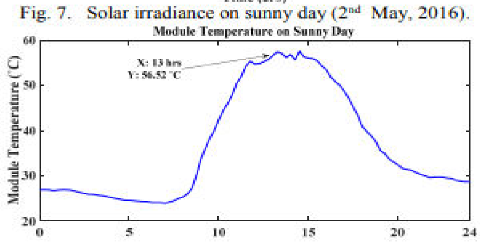


Fig. 7. Solar irradiance on sunny day (2nd May, 2016).



In case of cloudy day (16th March, 2023) due to cloud shading, the random rise and fall of solar irradiance and module temperature are seen from Fig. 9-10. Due to the intermittent solar irradiance and module temperature change on the solar array, the solar power output reduces drastically. Active power control of the solar inverter system on sunny day is performed on the solar irradiance and module temperature data shown in Fig. 7-8. To control active power in case of sunny day, the the solar power references are set as 3 kW and 2 kW in FV-IC. Depending on the power references (3 kW and 2 kW) provided to MPPT, the sunny day's actual solar PV power reduces from its original peak due to off MPPT voltage. This off MPPT mode voltage is tracked by compensator of boost converter.

II. SIMULATION RESULTS

From the above fig the three-phase supply is grid after the control of the active and reactive power control normalized waveforms of the instantaneous voltages in a three-phase system in one cycle with time increasing to the right. The phase order is 1-2-3. This cycle repeats with the frequency of the power system. Ideally, each phase's voltage, current, and power is offset from the others' by 120°.

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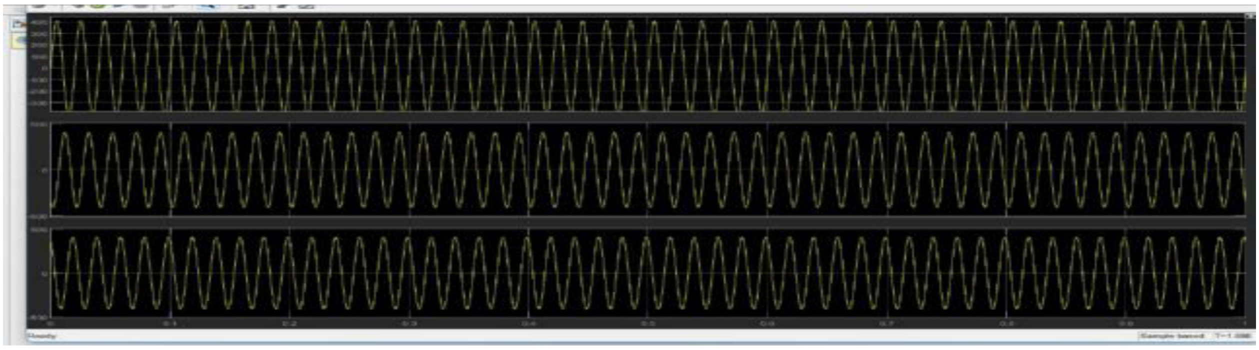

Fig: three phase output supply (R, Y, B) of the grid

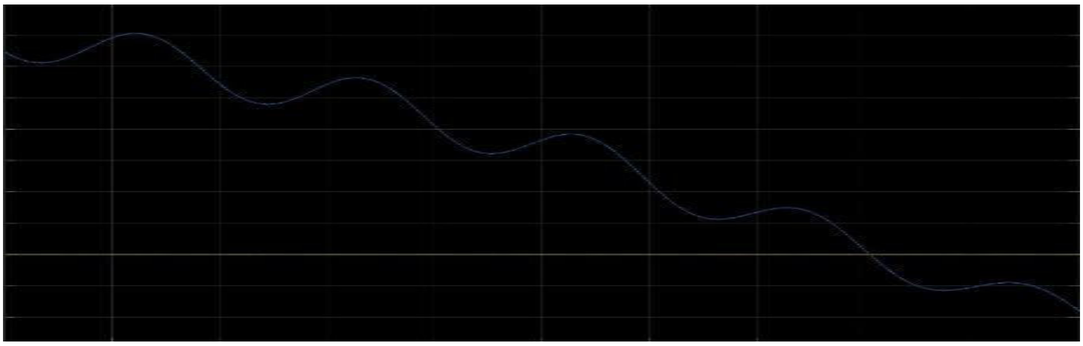

Fig:15 active and reactive power with respect to temperature

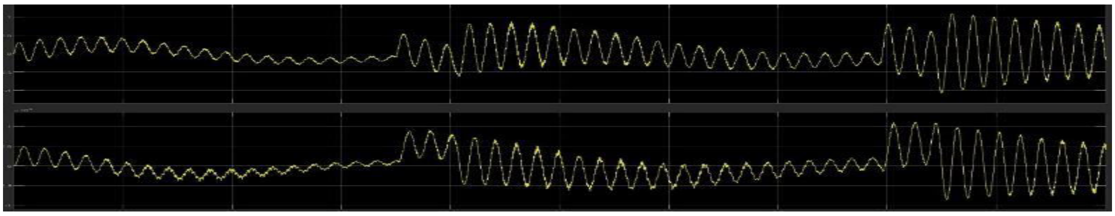

Fig:16 Active and reactive power factor by modified IC method

From this simulation we observed that the active and reactive power can be control by modified IC method. The fluctuations in the grid mainly caused due to harmonics. These harmonics are controlled by the RC and rl and rlc filters. These filters input was given to the solar inverter. The solar inverter feds the AC power as output to the grid. Active power and reactive power can be controlled by using the capacitor banks and synchronous condenser and static var compensators. Modified incremental conductance method is a combination of incremental conductance method and frictional voltage compensators. Modified incremental conductance method is a combination of incremental conductance method and frictional voltage method.

III. CONCLUSION

For large solar PV plant, regulation in penetration level is becoming challenging due to insufficient use ofstorage devices. Moreover, due to high penetration level of solar PV, the grid voltage and power fluctuation degrade t he grid stability. To address the concerning issue the active power injected from solar inverter should be regulated. To control active power from solar inverter, MPPT logic is modifiedand solar PV is operated in reduced voltage and power mode. For this a fraction voltage based IC method is proposed in this paper. Regulating MPPT of solar PV by FV-IC the solar power generated from inverter is controlled in any type of ambient situation. For sunny and cloudy day, the solar PV operated in both MPPT and off-

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MPPT depending on the pre- set active power reference and limited active power is sent to the grid. Additional to the active power control, reactive power control is simulated on unity, legging and leading pf.

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