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## Active Strategy in Load Flow Control of 3-PH Solar PV Inverter using Modified IC Method

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**ABSTRACT**: This paper proposes an analytical expression for the calculation of active and reactive power references of a grid-tied inverter, which limits the peak current of the inverter during voltage sags. The key novelty is that the active/reactive power references are analytically calculated based on the dc-link voltage and grid codes, while they do not depend on the implemented current reference calculation algorithm and, as a general formulation, can be implemented in combination with various current reference calculation algorithms. Furthermore, based on the inverter nominal current and the injected reactive power to the grid during voltage sags, an analytical algorithm is introduced for the calculation of the active power reference, which can be extracted from PV strings.

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.

KEYWORDS: VSC, Reactive Compensation, Power Quality,

## I. INTRODUCTION

High penetration of distributed generation (DG) units in the power system has resulted in new electricity regulation requirements, particularly during grid voltage sags. Initially, low-voltage ridethrough (LVRT) capability was introduced by power system operators in order to withstand voltage sags and maintain the connection to the grid and avoid loss of power generation [1, 2]. Later, reactive power injection was added in grid codes with the intention of supporting the grid voltage and reducing the possibility of voltage collapse during network faults. Furthermore, negative-sequence current injection appears to be a new important requirement of next generation of grid codes for enhancing the DG capabilities in supporting unbalanced voltage sags [3]. Among various DG units, grid-connected photovoltaic power plants (GCPVPPs) have recently achieved a drastic increase in the installed capacity due to the decreased module prices and favorable incentive policies [4]. As a result, LVRT became a necessary requirement for mediumand large-scale GCPVPPs. Several studies have been performed on LVRT capability of singleand two-stage GCPVPPs considering the injection of balanced active/reactive currents to the grid during voltage sags [5–7]. Unbalanced voltage sags are more common in power systems, causing several adverse effects including overloading of distribution transformers, higher losses and lower stability of the power system. The negative-sequence component of the voltage results in double fundamental frequency oscillation of the injected active or reactive power to the grid. On the other hand, injection of balanced reactive currents during unbalanced grid voltage sags, may result in overvoltage of nonfaulty phases [8–10]. Therefore, the design of the controller of the grid-connected inverter becomes more challenging during unbalanced grid voltage sags. Various flexible active power injection algorithms have been implemented in [11, 12] with the ability to minimize oscillations of either active or reactive power during unbalanced voltage sags. However, injection of reactive power during voltage sags can be more beneficial in voltage enhancement of point of common coupling (PCC) [8]. A number of studies have been carried out on flexible active/reactive power injection to the grid during unbalanced voltage sags with various control aims such as oscillating power control [10, 13], grid voltage support [8], maximizing inverter power capability [14] and in-phase current compensation.

## II. MULTI-STRING PV POWER PLANT CONFIGURATION

The multi-string two-stage GCPVPP structure, depicted in Fig. 1, is among state-of-the-art configurations for medium- and large-scale GCPVPPs, because of its several advantages [22–24]:

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• The extraction of maximum power from all of the PV strings during partial shading and mismatch between PV panels.

• Ability to extract power from PV strings during sunrise/sunset or cloudy sky with low irradiation. • Higher modularity compared to the single-stage power conversion with a central inverter.

• Elimination of low frequency bulky transformer when isolated dc-dc converters with high frequency transformer are used.

• Simpler structure and control algorithms compared to the single-stage power conversion structure with microinverters. It consists of multiple PV strings, dc-dc converters and a central grid-connected inverter. In this study, a dcdc boost converter is used in each PV string and a 3L-NPC inverter is utilized for the connection of the GCPVPP to the grid. The Y $\Delta$  transformer steps up the output voltage of the inverter to the grid voltage. It also provides electrical isolation between the grid and GCPVPP, which eliminates possible earth leakage currents in the grid and ensures standard safety requirements. The LCL filter, connected between the inverter and grid, aids in improving the total harmonic distortion performance in order to comply with grid codes and standards.



Temperature

Fig. 1. Schematic diagram of 5 kW grid connected solar PV system.

### **III. PROBLEM FORMULATION**

To control the solar PV penetration level a modified incremental conductance (IC) method is introduced in this paper. 5 kW solar PV inverter is considered for active and reactive power control. The schematic diagram of the system used in this study is shown in Fig. 1.Two separate controllers for the grid-connected 3L-NPC inverter and the dc-dc converters are required to operate the GCPVPP system. These controllers along with the proposed algorithms for calculation of the active/reactive power references and current references are presented in detail in the following subsections. Each of these controllers require separate control strategies, which are specific for a GCPVPP operation mode. Therefore, a fast and precise voltage disturbance detection algorithm is required to determine the operating mode of the GCPVPP. The voltage sag detection algorithm, used in this work, is presented in the following subsection.

## IV. THREE PHASE GRID TIE INVERTER MODELING

The modeling 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.

A. Modeling 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 Cin are calculated considering 1% current ripple and 10 % voltage ripple respectively. DC link capacitor of boost converter Cdclink is calculated considering 1% voltage ripple [8]. The boost converter parameters are listed in Table I..



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# TABLE I BOOST CONVERTER PARAMETERS Boost Converter Parameters Values Cin, Input capacitor 125 μF L\* Inductor 30 mH

L*, Inductor	30 mH
Cdclink, DC link capacitor	1000 µF
MOSFET switch's switching frequency	20 kHz
Vin, Input voltage to boost converter at STC	600 V
V <sub>dclink</sub> , DC link/Output voltage from boost converter	1200 V

However, a low-power transformer is bulky with load acoustic noise and may not be very efficient. In Fig. 1(b), a high-frequency transformer is introduced to obtain voltage amplifications. Since, high switching frequency is essential to achieve the compact inverter size, the switching loss of the semiconductor devices and the transformer loss are the dominated limitations for efficiency improvement [8]. Figure. 1(c) shows the z-source inverter as another solution which has the capability of boosting and inverting the dc voltage in a single stage with few solid-state switches. However, this topology has relatively high input current ripples, resulting high stresses on the dc-link inductors and capacitors [9]. A singlestage topology based on the current source inverter (CSI) is depicted in Fig 1(d). The CSI can be a viable alternative for other topologies so that circuitry complexity and the overall system losses may be reduced, as discussed in [9], [11]. Also, the CSI has been well documented for high-power drive and rectifier applications, but it is rarely considered in low power ranges (up to 500W) especially in PV MIC industry [12]-[14]. This paper scrutinizes the application of the single-stage CSI topology for the three-phase grid-connected PV MIC system. The proposed structure is implemented in hardware and experimentally tested with 300-W laboratory prototype. While designing a circuit, an effort to minimize the number of switches conducting at any given instant is pursued based on a modified space vector pulse width modulation (SVPWM) method, where possible to reduce the overall system losses and increase the efficiency of the system. A real-time control method with fast transient response and good stability based on the d-q axis principle is also proposed to independently control the active and reactive powers in order to meet power system needs.

C. Modeling of PWM Inverter Previously modeled boost converter feeds power to three phase PWM inverter. Data sheet of KACO TL 5.0 (5 kW Central Inverter) is referred while modeling PWM inverter. dq-axis based synchronous reference frame control is utilized for inverter control [10] 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 orianting the grid voltage vector along d axis. Phase Lock Loop (PLL) is utilized to calculate the grid voltage angle  $\theta$  and frequency



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Fig. 3. Synchronous reference frame control of three phase inverter

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.



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The current control loop transfer function (9) 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 consdering pole zero cancellation method [10]. Voltage control loop transfer function is given in (10). For voltage controller modeling, the characteristic equation of second order closed loop system is considered and PI controller parameters for this loop is evaluated using [11]. All parameters and their values are given in Table II

## TABLE II INVERTER PARAMETERS

Parameters	Values
3 Phase grid voltage and frequency	415 Vma, 50 Hz
DC link voltage	1200 V <sub>dc</sub>
C <sub>dclink<sub>2</sub></sub> DC link capacitor	1000 µF
L, Filter inductor	10.96 mH
R, AC side resistor	1.7225 Ω
mi, Modulation index	0.85
Current controller parameters	K <sub>p</sub> = 5.48, K <sub>i</sub> = 861.25
Voltage controller parameters	K <sub>p</sub> = 0.1568, K <sub>i</sub> = 11.109
Switching frequency	10 kHz

## **D. 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  $\Delta V$  from solar array.  $\Delta V$  is positve in left hand side of PV curve and negative in right hand side of PV curve shown in Fig. 5. This  $\Delta V$  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  $\Delta V'$  will be generated and it will reduce the MPP voltage to off-MPP voltage and operatingpoint will shift to OP 2. From this new operating point OP 2, off-MPPT mode voltage and active power will be calculated.

Simulation Design & Results.



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## **Proposed System Design**

Fig.4.2(b)Irradiation at different voltage and power conditions



Fig.4.2 (c) Active power w.r.to Temparature



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Fig 4.2(d) Active and Reactive power control

## **V. CONCLUSION**

For large solar PV plant, regulation in penetration level is becoming challenging due to insufficient use of storage devices. Moreover due to high penetration level of solar PV, the grid voltage and power fluctuation degrade the 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 modified and 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-MPPT depending on the preset 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. cases as ancillary service provided by solar inverter.

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