Multilevel Current-Source Inverter Grid-Connected Analytical Control Approach

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Abstract: *The DC/AC converters transform the DC into AC, usually called inverters, and are known as Voltage Source Inverters (VSIs) or Current Source Inverters (CSIs). The Multilevel Current-Source Inverters are a version of the CSI (MCSIs). A new predictive control strategy for an MCSI with multiple inputs and connected to the grid is proposed in this paper. In order to achieve an effective grid current, the control technique uses the advantages of Sliding Mode Control (SMC) for the balance of current in the input and Predictive Control (PC) as it distinguishes both functions. The calculations are based on the traditional Voltage Law of Kirchhoff (KVL) and knowledge of the system's mathematical model is not needed. Generally, massive input inductors (100-1000 mH) are used for conventional MCSIs. In this paper, a reduction in the size of the input inductors is achieved. To confirm the suggested power, simulation results are shown.*

Keywords: *multilevel inverter, grid-connected, predictive control, DC/AC converter, current-source.*

I. Introduction

The primary devices used in renewable energy management are the DC/DC and DC/AC converters. A new type of inverter has recently proposed, the Impedance Source Inverter, in addition to the Voltage-Source Inverters (VSIs) and the Current-Source (CSIs) (ZSIs). ZSIs are used to resolve some of the limitations present in conventional inverters, such as the susceptibility of EMI noise. On the other hand, with control strategies based on PWM, the ZSIs show a high Total Harmonic Distortion (THD).

Solar PV string voltages are usually weak, and conventional VSIs can only operate in buck mode, which requires a DC/DC converter to increase the DC voltage input. Nevertheless, the CSIs have built-in boost functionality and do not need an external voltage boosting component. Due to the existence of a DC connection inductor that results in low harmonic distortion and better load voltage regulations, this type of inverter has inherent short circuit protection. The general structure of a VSI for boost-stage RE applications is shown in Figure 1.

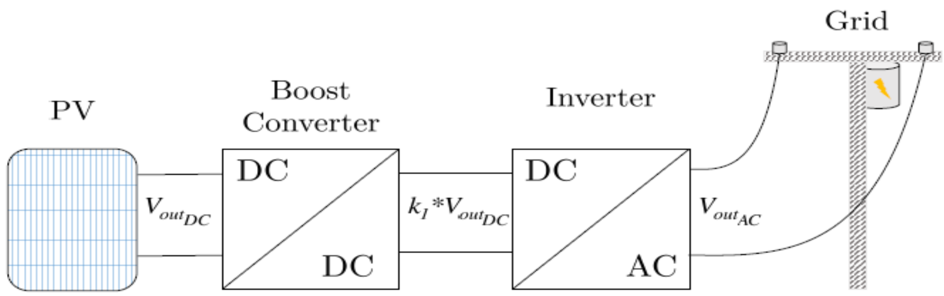

Figure 1. General block diagram of renewable system grid-connected.

A new control strategy for an MCSI topology of multiple grid-connected inputs is proposed in this paper. For the balance of current in the input and PC, the control technique utilizes the advantages of the SMC to obtain a good signal of grid current, as it distinguishes both functions. A variation of its original variant that does not involve knowledge of the system's mathematical model is the PC-based process. This value of the approach proposed can be particularly appealing, as it can be difficult to find the system model. Compared to the findings, the topology and the proposed strategy allow the reduction of the input inductors. The accumulated simulation results are analyzed.

II. Proposed Topology

In Figure 2, the suggested topology is shown. It consists of eight MOSFET-made unidirectional switches. The scheme has two sources of supply provided by the L_1 and L_2 inductors operating in continuous conduction mode (CCM). Since the control solution balances the current in both inputs, the CCM is assured. The suggested control chooses the input of greater energy, so the other raises it as one inductor injects current into the grid and reduces its energy. The peak amplitude of the reference grid current is, but at the other end, a function of the sum of the current of both inputs. The energy obtained from PV is simulated by each of the inputs. In parallel, this MCSI consists of two CSIs, obtaining a multilevel signal at the output. Five current levels and seven operating modes are proposed in the design. In the event that one of the sources does not have the requisite amount of energy, it can be supplied by the second source.

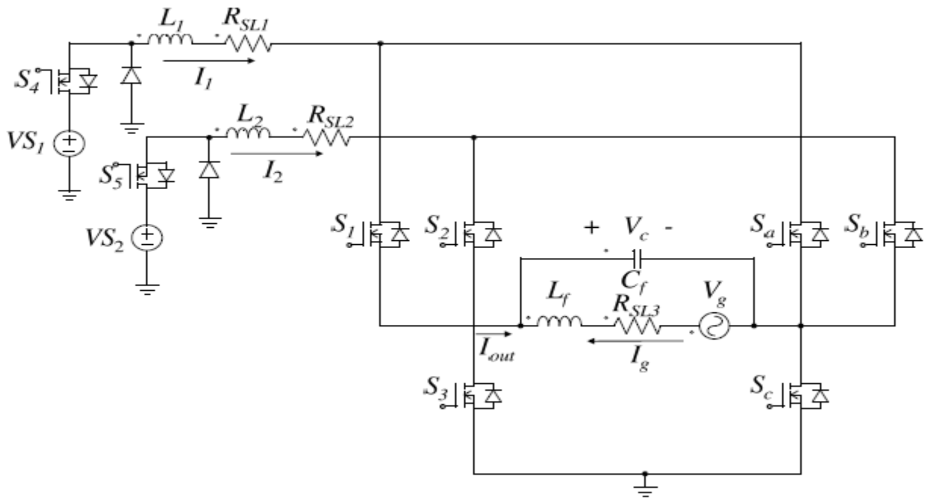

Figure 2. Multilevel Current–Source Inverter (MCSI) Proposed.

Where: VS_1 and VS_2 are the input voltage sources that simulate the sources of RE, L_1 and L_2 are the input inductors, R_{SL1} and R_{SL2} are the series resistors associated with the input inductors, I_1 and I_2 are the input currents to the inverter, I_g is the grid current, V_g is the grid voltage, L_f is the inductor of the filter, R_{SL3} is the series resistance associated to L_f, C_f is the capacitor of the filter and V_c defines the polarity of the capacitor C_f.

III. Comparative Performance Evaluation of the CSI Based PV System with the VSI Based PV System

In accordance with that of a VSI-based PV system, the purpose of this segment is to evaluate the performance of the CSI-based PV system. The results for the VSI-based PV system are produced by the presented system simulation.

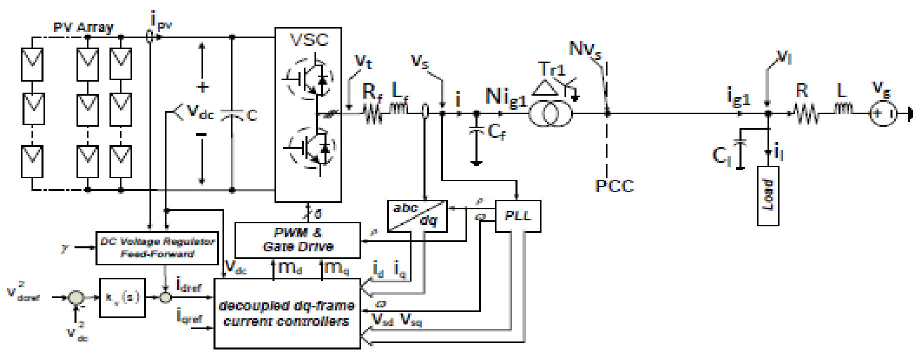

Figure 3. Single-line schematic diagram of a three-phase, single-stage, grid-connected PV system based on VSI

III-A *Case study 1: Change in Insolation Level*

In this case study, the behaviors of the VSI- and CSI-based PV systems in response to a change in insolation level are illustrated. Since VSI and CSI are dual topologies, the characteristic of voltage in CSI is analogous to that of current in VSI, and vice versa. Initially, the insolation level is set to 0.4 kW/m^2. At t = 1 s, the insolation level is step changed to 0.6 kW/m^2. With the change in insolation level, the CSI DC-side current reference changes from 0.7 kA to 1 kA by the maximum power point tracker.

III-B *Case study 2: Fault Conditions*

Fault on the grid-side of the inverter results in oscillations of current and voltage on the DC-side of the inverter. Oscillations in the DC-side current are not desirable as the inverter requires a smooth input DC-current. In case of VSI-based PV system, the controller regulates the DC-side voltage; therefore, there is no direct control on the DC-side current. On the contrary, in CSI-based PV system, the DC-side current is regulated and limited. As a result, the current on the AC-side of the inverter may not show a sharp rise under fault. This case study is designed to present a comparative analysis of behaviors during fault for CSI- and VSI-based PV systems. For this study, the insolation level is maintained at $1kW/m^2$. In real life, when the fault occurs on the grid-side, and the breaker B_r opens, the anti-islanding scheme must act to protect the inverter and personnel. Since the objective of this case study is to show the impact of a change in the AC-side voltage level on the performance of the PV system, the anti-islanding protection is disabled. Four fault types, i.e., Single Line-to-Ground (SLG), Double Line-to-Ground(DLG), Line-to-Line (LL), and Three-Phase-to-Ground (TPG) are studied.

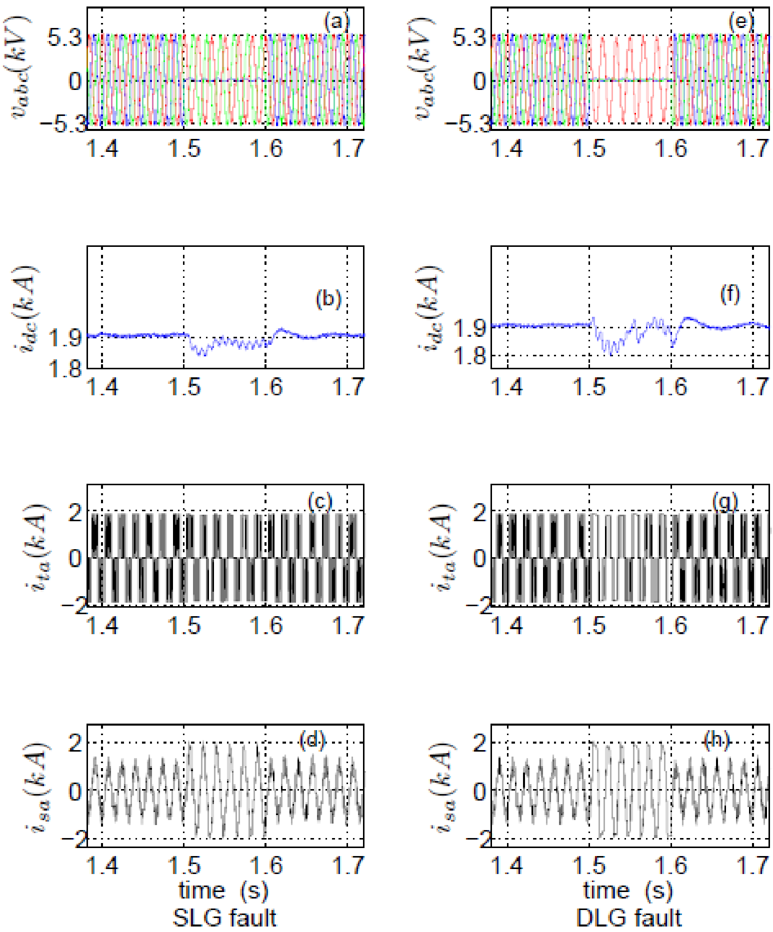

Figure 4. CSI based PV system performance during SLG and DLG faults (v_{abc}=three phase voltage on the secondary side of T_r; i_{dc}=DC side current of the CSI; i_{ta}=phase-a terminal current of CSI; i_{sa}=phase-a current injected to the grid).

IV. Controller for Multilevel Inverter Based on CSI

Figure 5 presents the closed loop control structure for multilevel CSI. Current reference corresponding to d-axis of current, i_{sd}, for the AC-side current controller is derived by summing the references produced by individual DC-side current controllers, as represented by equations (1) and (2). This summation results in reduction in number of controllers, sensors and capacitive filters. References for DC-side current controllers are derived from MPPTs corresponding to the unit.

$$i_{sdref} = \sum_{m=1}^{n} i_{sdrefm} \quad (1)$$

$$i_{sdrefm} = u_{in} + \left(\frac{P_{pvm}}{\frac{3}{2}v_{sd}}\right) \quad (2)$$

V. Sensitivity Analysis

A peer analysis is carried out on the linearized model represented in order to identify the possible interactions between the PV system and the distribution network, to identify the type of interaction and to assess the robustness of the PV system controllers against parameter variation.

The variance of eigen modes corresponding to the state variable i_{dc} is shown in Figure 5, with the insolation level varying from 0.1 to 1 kW/m^2, with allowed and disabled feed forward power. It can be observed from the plot that in the case where feed forward control is disabled, the own modes can have a positive real share of low levels of solar irradiation resulting in instability.

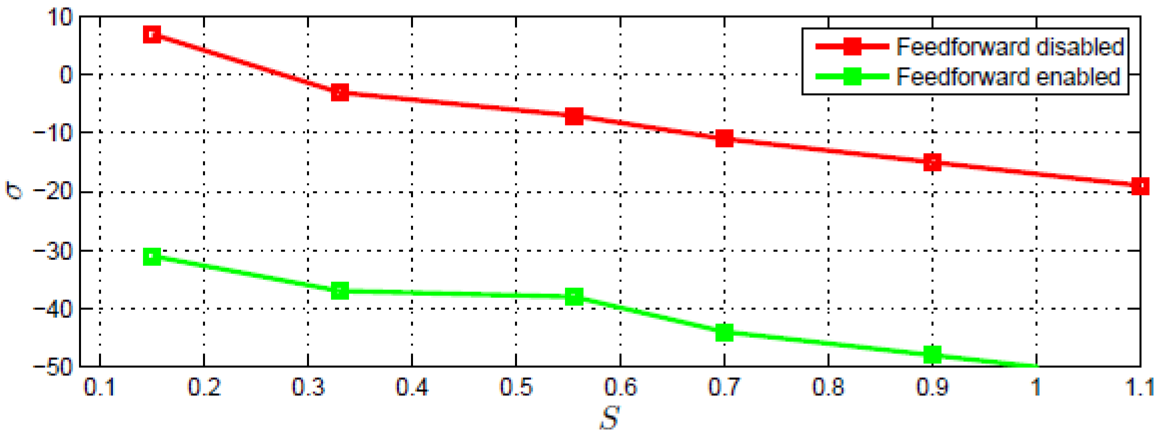

Figure 5. Pattern of variation of eigen modes corresponding to i_{dc} in the presence and absence of feed-forward compensation in the DC-link current controller.

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