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RESEARCH ARTICLE

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VOLTAGE CONTROL OF THREE-PHASE FOUR-LEG INVERTER FOR SOLAR PHOTOVOLTAIC APPLICATIONS

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ABSTRACT

Solar photovoltaics (PV) is one of the popular renewable energy sources in tropical countries like India which can help in supplementing the rising demand of electrical energy. DC input from solar PV strings needs to be converted into AC component both for ON and for OFF grid applications. Three-phase inverters are used for the above inversion when power levels are high. In OFF grid applications, task of maintaining stable terminal voltage across the loads lies with the inverter in the absence of utility grid. It also has to supply variety of balanced and unbalanced loads. In this paper, cascaded voltage control scheme, for a three-phase four-leg inverter, is designed.

Keywords: Cascaded voltage control, Four-leg inverter, PR controller, Solar inverter

I. Introduction

The constant growth of population and sharp rise in industrialization throughout the world is causing steep rise in energy demand, and the conventional energy sources cannot meet this in the long run due to their rapid depletion. Non-conventional sources are playing a key role in bridging this gap, and solar photovoltaic is one of the popular sources of energy because of its ease of harness and simplicity [1].

The energy obtained from alternative energy sources is transferred to the electricity grid via an inverter. High power applications use three-phase inverters and low-power single-phase inverters [1, 2]. Voltage inverters are often used in networked systems due to their simplicity and reliability. Three-phase voltage inverters can be implemented as three, four and four-wire systems [3-6]. The inverters connected to the network must have high energy quality, high efficiency and high reliability in renewable energy applications. Therefore, the topology and control techniques of the UPS in the systems connected to the network play an important role. Voltage inverters are connected to the network via filters. Inverters and grids can be used to select different filters. B. L, LC and LCL filters. The L filter allows the use of a simple strategy for controlling the current in the inverter.

The electrical energy produced by the solar PV modules is DC (through photovoltaic effect) and has to be converted into AC, a task achieved through inverters There are single-phase and three-phase inverters, and generally, the latter are used for higher-power applications.

The conventional three-phase inverters consist of three legs with two power electronic switches in each leg and can be used for ON grid applications or for balanced loads in OFF grid applications. But in case of unbalanced loads, there is no path for the neutral current flow. Addition of an extra leg and connection of its midpoint to the neutral point of the load can provide the path for neutral current flow [2, 3].

The schematic of three-phase four-leg inverter is given in Fig. 1. In the absence of utility grid, inverter has to maintain sinusoidal voltage at the load terminals, within the acceptable limits of THD for which an LC filter is added in each phase to filter out the high frequency switching harmonics.

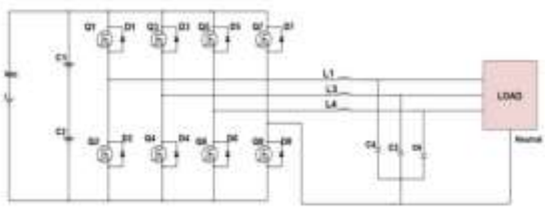

Fig. 1 Three-phase four-leg inverter

II. Related Work

In the available literature, voltage control of three-phase inverters is mainly performed in a-b-c or d-q-o coordinate systems [4]. In [5, 6] Vechiu and Zhang have utilized d-q-o rotating coordinate system, also called as synchronous reference frame control for achieving output voltage control. Independent per-phase control, also known as natural reference frame control, is introduced in [6, 7].

Zhang [6] have stated that incase of unbalance and nonlinearity in the system, the best strategy is to use the actual AC voltage and current for controller design. But the limitation of stationary reference frame comes from the fact that PI controller cannot remove the steady-state error since the steady-state variables in a-b-c coordinate are sinusoidal and the absence of the DC operating point makes it difficult for the controller to track the reference signal due to the time varying characteristics of the reference signal [6]. When it comes to d-q-o coordinate, the positive-sequence component shows constant DC values in channels d and q [5]. Hence, design of controllers in the d-q-o coordinate system is easier. But the drawback of d-q-o coordinate system is inability to perform in case of unbalanced and non-linear systems, where in the negative-sequence component travels in channels d and q at a frequency that is twice that of the fundamental.

Ramanarayanan [8] used proportional resonant (PR) controllers for a four-leg voltage source inverter.

Demirkutlu et al. [9] used control scheme called scalar resonant-filter-bank-based output-voltage control. PR controllers can be tuned to provide high gain at the required frequency and can help in reducing steady error at the grid frequency.

Dong et al. [10] uses grid voltage feed forward control for current regulation in three-phase four-leg inverters. Sinusoidal PWM is the simplest PWM switching scheme and is simple to execute both in analogue or digital circuits [11–13].

Hurde et al. [12] discussed that GDs are very suitable for a specific location and for specific applications because they require a short construction time and require little investment. It is defined on the basis of the size of the plant, which can vary from a few KW to MW (10-50 MW). GD options can be classified as renewable or non-renewable sources from fuel sources. This study deals with a newly-conceived voltage control method for three-phase four-leg voltage source inverters (VSIs) which are being required in autonomous power generating units devoted to supply both three-phase and single-phase electrical loads.

Traditionally voltage control has been achieved using single feedback of the terminal voltage. While it is simple in implementation, it suffers from drawbacks like huge inrush currents because of absence of control on device currents. In this paper, cascaded voltage control is developed for the three-phase four-leg inverter wherein there will be an outer voltage loop providing reference to the inner current loop. This is a very robust control scheme wherein we have a control over the current that can potentially avoid damage caused by large current transients in case of direct voltage control. PR controllers are used in both the loops to obtain reference tracking.

III. Mathematical Modeling of Three-Phase Four-Leg Inverter

Figure 2 shows the circuit diagram of the plant, where r_l is series resistance of the filter inductor, L is the filter inductance, C is the filter capacitance, $V_{inv}(t)$ is fundamental component of the inverter output voltage, $i_L(t)$ is inductor current, $V_c(t)$ is capacitor voltage, $i_c(t)$ is capacitor current, and $i_o(t)$ is load current.

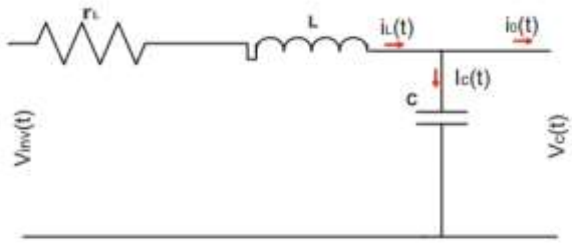

Fig. 2 Circuit Diagram of Plant

Plant transfer function can be derived from the following equations

$$V_{inv}(t) = r_l i_L(t) + L\frac{di_L(t)}{dt} + V_c(t) \qquad \text{(i)}$$

$$i_L(t) = i_c(t) + i_o(t) = C\frac{dV_c(t)}{dt} + i_o(t) \qquad \text{(ii)}$$

And applying Laplace transforms to the above Eqs. iii and iv.

$$\frac{V_{inv}(s) - V_c(s)}{r_l + sL} = I_L(s) \qquad \text{(iii)}$$

$$\frac{I_L(s) - I_o(s)}{Cs} = V_c(s) \qquad \text{(iv)}$$

Figure 3 shows the block diagram representation of the plant given by Eqs. iii and iv.

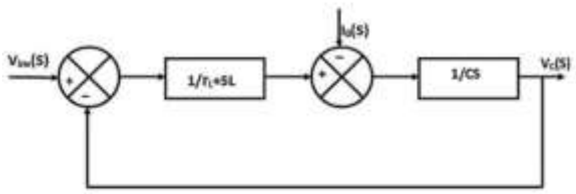

Fig. 3 Block diagram of Plant

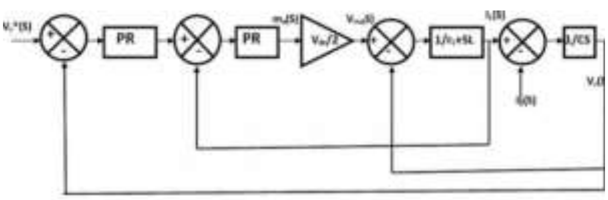

Fig. 4 Cascaded voltage control scheme of three-phase four-leg inverter

Figure 4 shows a cascaded voltage control scheme. Here, the actual capacitor voltage is taken as feedback from the plant and compared to reference voltage. The error is given to a controller whose output is the reference inductor current I. This is in turn compared to the feedback of actual inductor current $I_L(s)$ and the error is given to a controller, whose output is modulation index $m_a(s)$. This modulation index multiplied by half the DC input voltage $V_{dc}/2$ gives the fundamental of the inverter output voltage $V_{inv}(s)$. Here, the states are inductor current $I_L(s)$ and capacitor voltage $V_c(s)$. Inductor current $I_L(s)$ is also the control input for outer voltage loop, whereas the output current $I_o(s)$ is the disturbance input. Modulation index is the control input for inner current loop, and the capacitor voltage $V_c(s)$ is the disturbance input.

This control scheme is used in all the three phases of four-leg inverter, independently. Modulation index obtained from the output of the controller is compared to a common high frequency carrier signal (its frequency is same as the switching frequency) to generate PWM signals. Fourth leg of inverter is always given a constant modulation index of zero, to ensure its potential difference is zero with respect to the midpoint of the DC bus. In this way, we can ensure that the fundamental of inverter pole voltage is same as the fundamental of inverter phase voltage, since the loads are connected between the midpoints of first three legs and the fourth leg.

IV. Conclusion

A cascaded voltage control scheme has been developed for the voltage control of three-phase four-leg inverter. The main objective of the closed loop control has been fulfilled, and the total harmonic distortion will also be less. In this paper, a three-phase grid-connected inverter system is proposed. The objective is to generate a line current with low total harmonic distortion (THD) and to obtain the maximum efficiency of the inverter system. The inverter is controlled by pulse width modulation due to optimal circuit diagram.

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