Novel 1-ϕ Multilevel Current Source Inverter for Balanced / Unbalanced PV Sources

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Abstract: ***A new single phase multilevel current source inverter (MCSI) configuration which can generate symmetrical output current levels for both balanced and unbalanced PV sources is proposed in this paper. The proposed MCSI topology uses less number of power devices as compared to that of conventional MCSI. By using this proposed control strategy, good quality of current can be fed in to the utility when both types of PV sources operate at their respective maximum power point. Efficacy of the proposed MCSI topology is tested with two PV sources operating under partially shaded conditions i.e. the two sources are receiving different irradiation. The simulation results corresponding to the proposed configuration are presented for 500W system using MATLAB/Simulink.***

Keywords: Multilevel current source inverter, Grid, PV source, irradiation

1. Introduction

Renewable energy sources are gaining a lot of popularity on account of its various advantages such as pollution free, noise free, fuel free, sustainable source of energy. Among renewable energy sources PV sources are discussed in this paper.There are two types of PV sources based on its connection to grid; they are grid connected and standalone PV systems. Grid connected PV systems are considered in this paper. Basically grid connected PV sources are of two types, which are centralized and string connected configurations. These configurations consist of array of PV modules (parallel and series combination) to increase the outputpower level. Out of these two configurations, string type PV arrays have more advantages compared to that of centralized type PV arrays in case of grid connected systems. When these PV modules are connected in parallel in case of string type configuration, because of cloudy environmental (Partial shading/different irradiation) conditions mismatch of (Maximum power point) MPP will reduce their output power. This in turn reduces the system efficiency when these PV sources are connected in parallel or in series.

With the help of multilevel inverters, PV arrays can feed a good quality of power to the grid even at the time of partial shading conditions. Generally multilevel inverters (MU) are used for medium voltage andhigh powerapplications [1-3]. Due to presence of more number of levels/stepsin the output, MUs can produce ahigh good quality output power. Mus are classified in to two types. They are Current source fed MU (CSMU) and Voltage source fed MU (VSMU). VSMUs [3] are further classified into three types (Capacitor clamped,Diode clamped and Cascaded series MUs). In case of VSMU as the number of voltage levels increases number of input capacitors also increases. At different irradiation because of unequal charging and discharging of these input capacitors may introduce an offset in output voltage waveforms. To overcome this problem extra balancing circuits are needed which affect the efficiency of the system and increase the cost and complexity.

In case of CSMLIs [4-12]the number of current sharing inductors increases as the number of levels in the output increases. Inductors increase the losses in conducting devices, bulky and require more space. In recent trends super conducting magnetic materials (SCMM) are being used for designing an inductor, which reduces the losses in the conducting material below certain threshold temperature. The current sharing inductors not only introduce lossesbut also create the problem of balanced current sharing. The CSMLIs have several advantages Compared to that of VSMLIs, which are as follows:
(a) Shoot through fault.
(b) High reliability.
(c) Inherent over current protection.

Various CSMLI topologies are proposed [13]. These topologies contain more number of power switches to generate the multilevel in the output current waveform which increases losses in the system. This paper proposes a novel CSMU configuration, which uses less number of power switches compared to previous topologies. The proposed CSMU configuration has multiple inputs and can generate multi levels at the output. Different PV modules [14] can be assumed as multiple inputs for the proposed MU configuration. The main advantage of the proposed MU configuration is that can work with PV modules with different MPPTS and can still produce multi-levels without asymmetry in output current. This overcomes the mismatch problems arising out of partial shading conditions.

2. Proposed Multi Level Current Source Inverter

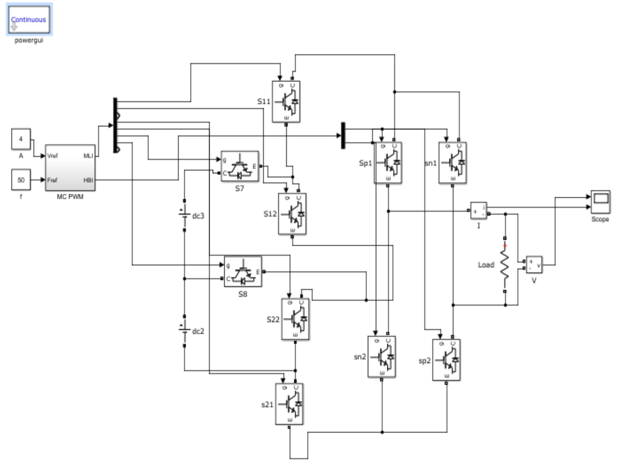

Figure 1: Simulink model

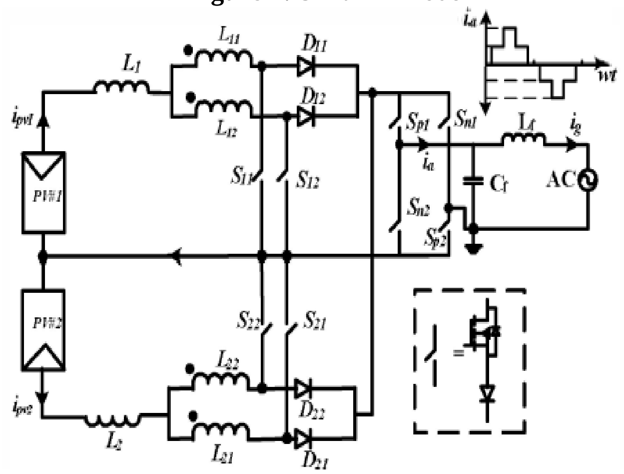

Figure 2: Proposed five level current source inverter

A. Operation principle

The circuit diagram of the proposed five level current source inverter (FLCSI) as shown in Fig. 2. It consists of two PV sources, parallel connection of high frequency operated five level current converters, low frequency five level dc-dc current converters, low frequency current unfolding circuit and CL filter. In this topology, power switches Sll, S12, S22 and S21 are operated at high frequency and SpJ, Spz, Snl and SnZare operated at low (grid) frequency. By using this configuration, five levels +ij, +i2,0,-i2,-ij can be generated in the current wave form as follows:

a) Level +ij or -ij: All high frequency switches are operated with sinusoidal pulse width modulation (SPWM) and the two low frequency switches are ON according to the polarity of grid voltage.

b) Level +i2 or -i2: one top and one bottom high frequency power switch is operated with SPWM and other two high frequency power switches are ON and two low frequency switches are in ON position according to the polarity of grid voltage.

c) Level 0: all high frequency power switches are in ON position. For each current level, there is a contribution of two PV sources. For (b), Lll and L12 (L22 and L21) are assumed to be equal in value. Thus current sharing is half of ipvl (ipv2). The proposed topology can be operated with balanced and unbalanced PV sources without affecting the quality of grid current by proposed control strategy and switching pattern of devices as shown in Table I.

Table-1: Switching states of proposed FLCSI

S_{11}	S_{12}	S_{21}	S_{22}	S_{p1}	S_{p2}	S_{n1}	S_{n2}	i_A
0	0	0	0	1	1	0	0	$+i_2$
0	1	1	0	1	1	0	0	$+i_1$
1	1	1	1	0	0	0	0	0
1	0	0	1	0	0	1	1	$-i_2$
0	0	0	0	0	0	1	1	$-i_1$

B. Modes of Operation

The operation of the proposed topology is divided into five modes in positive and negative half cycles of the grid voltage. These are explained next:

Mode-1 (+il level): Fig. 2(a) shows the equivalent circuit corresponding to this mode. During this mode, the FLCST is operated in positive half cycle of grid voltage to maintain the +illevel by turning ON the power switches (Spl and Sp2) and modulating the switches (SI]' S12, S22 and S21) at highfrequency according to sinusoidal grid current reference waveform. Tn this mode, the current magnitude is the summation of two PV module currents (ipvl and ipv2).

$$i.e \quad +i_1 = i_{pv1} + i_{pv2}\,; \tag{1}$$

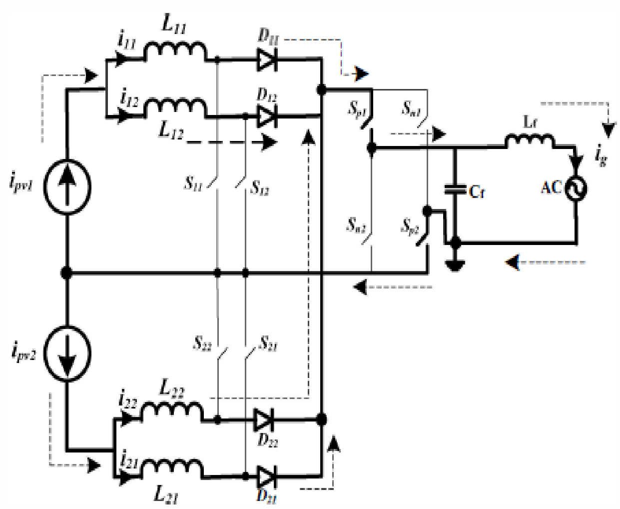

Fig. 2(a). Equivalent circuit in Mode-1

Mode-2 (+i2 level): Fig.2(b) shows the equivalent circuit in this mode-2. During this mode, the FLCST is operated in positive half cycle of grid voltage to maintain the +i2 level by turning ON the power switches (Spl and Sp2), turning OFF the power switches ((SI2, and S21) or (Sll, S22) and modulating the switches ((SII, S22) or (SI2, and S21» at high frequency according to sinusoidal grid current reference waveform. Tnthis mode, the current magnitude is given by the summation of half of two PV module currents (ipvl and ipv2).

$$+i_2 = \frac{i_{pv1}}{2} + \frac{i_{pv2}}{2} ; \qquad (2)$$

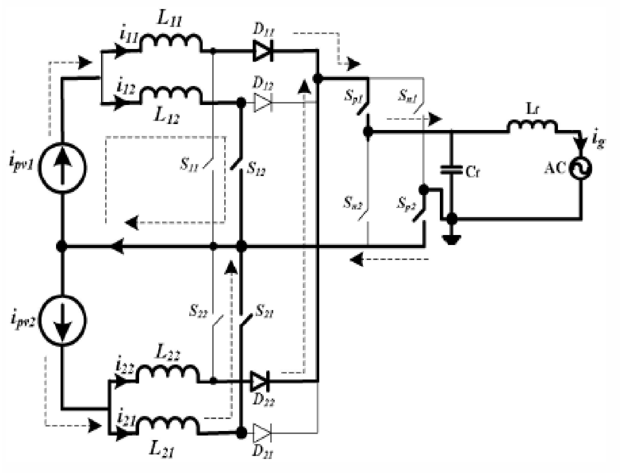

Fig. 2(b). Equivalent circuit in Mode-2

Mode-3 (0 level): Fig. 2(c) shows the equivalent circuit during this mode. During this mode, the power switches, Spl and Sp2 are turned OFF, while the remaining switches are in ON position.

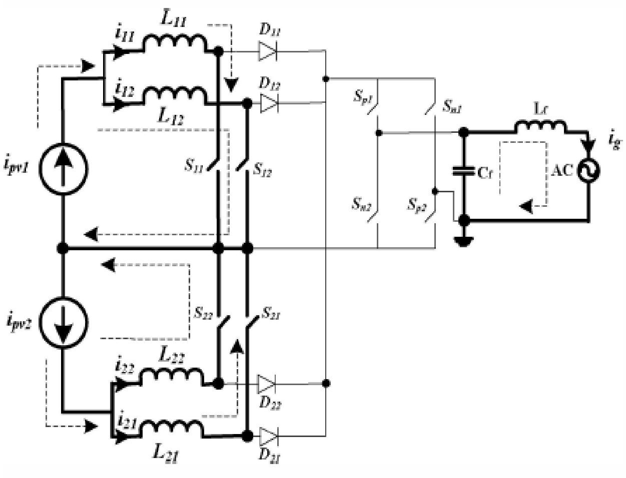

Fig. 2(c). Mode-3 (Zero state)

Mode-4 (-i2 level): Fig. 2(d) shows the equivalent circuit during this mode. During this mode, the FLCSI is operated in negative half cycle of grid voltage to maintain the -i2 level by turning ON the power switches (Snl and Sn2), turning OFF the power switches ((S12, S21) or (Sl1, S22) and modulating the switches ((Sl]' S22) or (S12, and S21)) in high frequency according to sinusoidal grid current reference waveform. In this mode, the current magnitude is the summation of half of two PV module currents (ipvJ and ipv2) as given below:

$$-i_2 = -\frac{i_{pv1}}{2} - \frac{i_{pv2}}{2} ; \qquad (3)$$

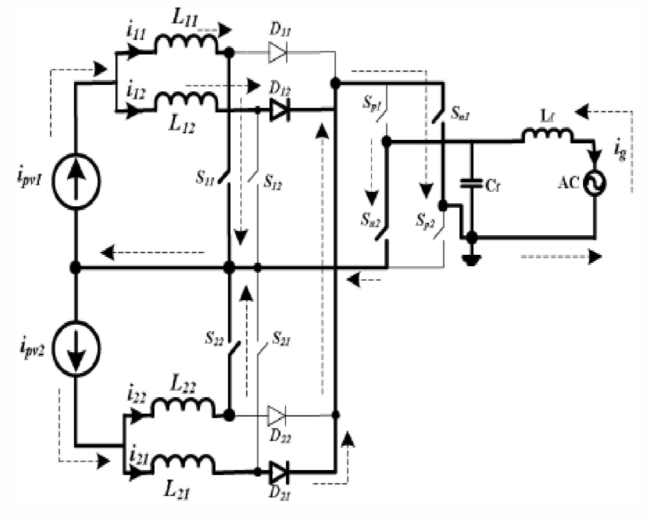

Fig. 2(d). Equivalent circuit in Mode-4

Mode-5 (-iJ level): Fig. 2(e) shows the equivalent circuitduring this mode. During this mode, the FLCSI is operated in negative half cycle of grid voltage to maintain the -iJlevel by turning ON the power switches (Snl and Sn2) and modulating the switches (Sl1, S12, S22 and S21) in high frequency according to sinusoidal grid current reference waveform. In this mode, the current magnitude is the summation of two PV module currents (ipvl and ipv2).

$$-i_1 = -i_{pv1} - i_{pv2} ; \qquad (4)$$

The complete synthesis of FLCSI output current for one grid frequency cycle is shown in Fig. 3.

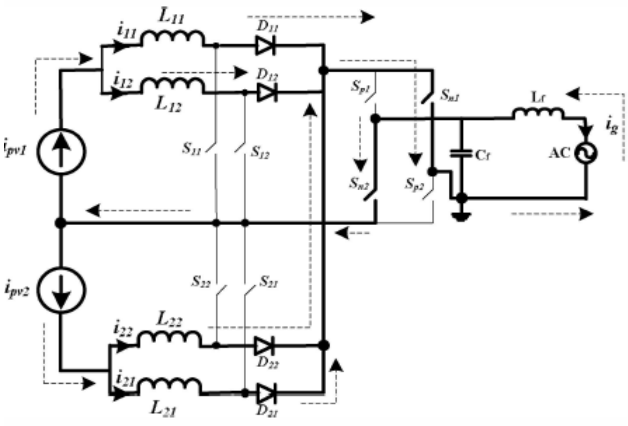

Fig. 2(e). Mode-5

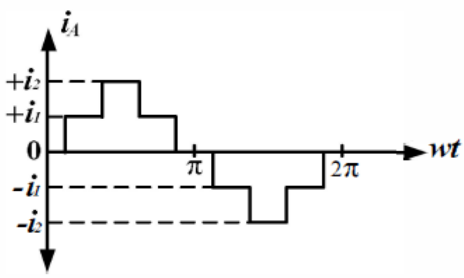

Fig. 3. Synthesis of FLCSI output current waveform.

C. Control strategy and switching pulse generation

Modulation strategy and control strategy of the proposed FLCSI is as shown in Figs. 4, 5.

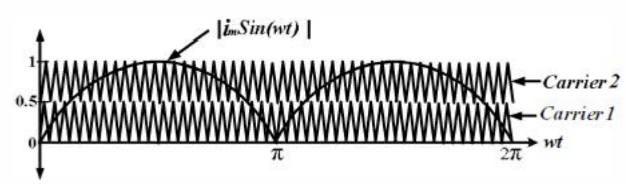

Figure 4: Modulation strategy used for the proposed FLCST

Available maximum power is fed into the grid from thetwo PV sources based on the impp1 and impp2 references, which are generated by the Incremental Conductance MPPT algorithm. Five level current output of FLCSI is generated by using the two carriers and Sinusoidal Pulse Width Modulation (SPWM) technique as per switching states shown in Table 1. This PWM technique compares the reference current wave form with two high frequency carrier waveforms. Reference current waveform is obtained by the multiplication of PLL output and addition of imp pI , impp2.

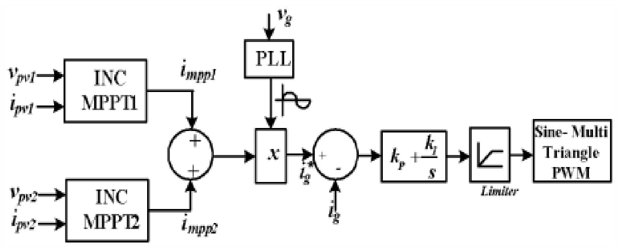

Fig. 5. Control strategy used in the proposed FLCSI.

3. Simulation Results

The proposed grid connected FLCSI is simulated in MATLAB for a 500W system. PV sources with MPP voltage and currents 50V, 5A are considered for simulation studies. Two cases (case 1 and 2) are consider to explain to the uniform and non-uniform irradiation conditions for the two PV sources.

Case-I: If both PV sources have uniform and same irradiation level then the MPP currents and voltages of both PV sources are identical. Then the currents shared by the various inductors Ll1, L12, L21, L22 are 2. 5A each. So that there is no asymmetry in the output current waveform. The inverter output current and grid current for this case are shown in Fig.6.

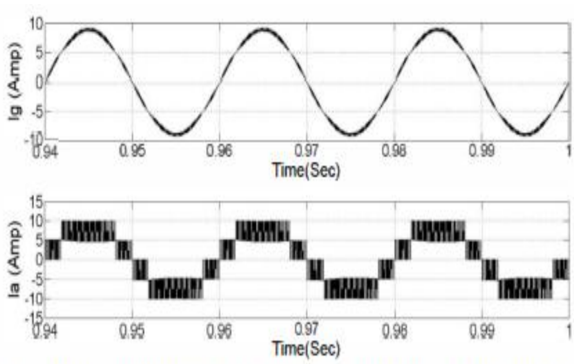

Fig. 6. Grid current and inverter output current with balanced PV sources.

Case 2: If one of the PV sources is not receiving uniformirradiation due to partial shading, then the MPP current of one PV source is 5A for the other PV source it may be say 3A. Because of this, currents shared by both inductors Ll1, L12 are 2. 5A each and inductors Ll1, L12are 1.5A each.

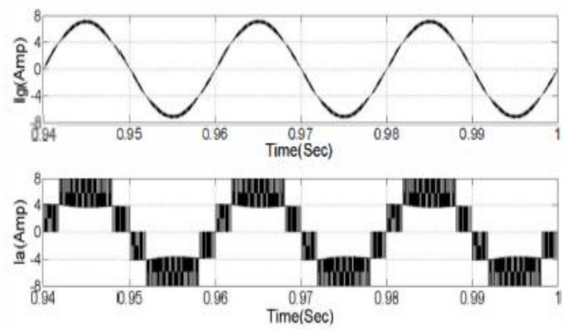

Fig. 7. Grid current and inverter output current with unbalanced PV sources.

In spite of using a combination of currents having differentlevels, a symmetrical output current waveform is obtained. So that there is no unbalance in the output current waveform. The inverter output current and the grid current for this case are shown in Fig. 7. Fig. 8 shows the hardware model of proposed method.

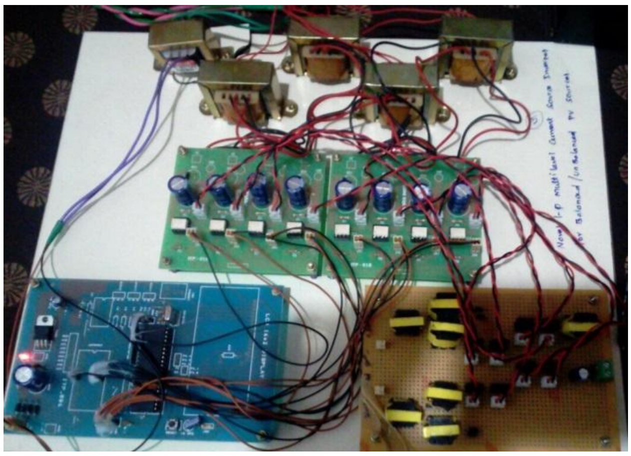

Figure 8: Hardware model of single phase multilevel current source inverter

4. Conclusions

The proposed FLCSI inverter is able to extract the maximum available power from both the PV sources. Even during the partial shading conditions FLCSI can extract and feed maximum available power in to the grid with both balanced and unbalanced PV sources with a current THD of 1.6%. Because of less number of power components present in the FLCSI system both size and cost is reduced.

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