A SIMPLE OPEN CIRCUIT DETECTION STRATEGY FOR A SINGLE PHASE 7 LEVEL GRID CONNECTED CASCADED H BRIDGE MULTI-LEVEL INVERTER FED FROM POWER OPTIMIZERS.

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ABSTRACT: In this paper, a single-phase grid-connected photovoltaic inverter supplied by series-connected power optimizers (POs); a straightforward and real-time open-circuit fault (OCF) detection technique is suggested. PO controllers periodically track differences in output voltage of power optimizers and calculate remaining mistakes in output voltage to implement the suggested technique. Then, on the PO side, the inverter's OCF identification rule is developed based on the voltage variation amount and the improved judgment criterion derived from residual voltage error and power. The proposed method for detecting open circuit fault (OCF) is low cost and real time, requiring no additional hardware and no communication between the inverter and power optimizers (PO).Generally speaking, in series-connected distributed DC power or energy storage systems, the technique offers a reliable and quick solution to detect OCFs. Experimental results verify its efficiency and reliability. The circuit simulation is carried out using MATLAB/SIMULINK. The experimental results are in good agreement with the simulation results and thus the model is validated.

Keywords - Open-circuit fault (OCF), Power optimizer (PO), Maximum power point tracking (MPPT) & Total harmonic distortion (THD).

I. INTRODUCTION

The grid-connected inverter plays a major role in the renewable energy system's robustness and reliability, such as photovoltaic (PV) [1] and wind turbine systems [2]. In some extreme situations, open-circuit faults **(OCFs)** in inverters can interrupt the PV system's normal operation [3]-[4]. The inverter OCFs includes auxiliary power failure, failure of the gate drive, failure of the power components, disorder of the controller, etc. All the faults, regardless of whether they are intermittent or permanent, may cause the inverter to stop an abnormal emergency. The detection of OCF in inverters has attracted significant attention. Large number of OCF detection methods has been proposed for inverters so far, which can be classified into two categories according to different detection variables: (1) Current-based detection method, (2) Voltage-based detection method.

In [5] and [6], by taking into consideration the amplitude and phase of the normalized average current vector, a current-based fault detection method is used to check the OCFs of inverters. This method requires additional current sensors and can only be used to detect three-phase inverters. In [7], depending on the wavelet analysis and neural networks, another current based method for detecting open-circuit faults in an inverter is developed. However, due to the complex detection algorithm, its probability is low.

In [8], the inverters fault condition is identified based on the radius of the Concordia current pattern. All current detection methods, however, are susceptible to load disturbance or noise and are easy to misreport when load changes suddenly. The voltage-based detection method is not easily affected by the load disturbance or noise compared to the current-based detection method. In [9], a method of fault diagnosis is suggested using the voltage error between estimated and measured value to identify the inverter faults.

In [10]-[12], the inverters output voltage variation features with open circuit fault (OCF) are thoroughly evaluated and the appropriate detection method is suggested.

II. PROPOSED TOPOLOGY

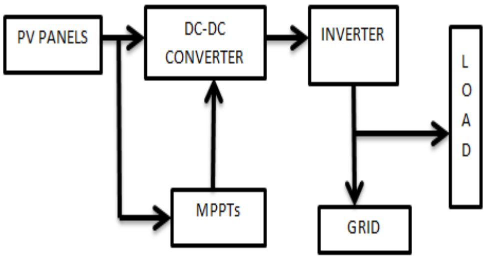

Figure 1: Block diagram representation of a 1 Φ, 7 level grid connected cascaded H-Bridge Multilevel Inverter.

The representation of a typical single-phase grid-connected PV system is shown in Fig.1. And that is based on a multi-level inverter powered by direct power optimizers. It primarily consists of PV modules, Power optimizers (PO) and an inverter. For maximum power point monitoring (MPPT) and energy conversion, each PO is a DC-DC converter. To feed the inverter, a number of Power optimizers are bound in sequence. Here boost converter is used to step-up a voltage to some higher level as of required by the load. The advantage of cascaded H-bridge multilevel inverter is that it provides a sinusoidal output.

BOOST CONVERTER

A boost converter (step-up converter) is a DC-to-DC power converter that increases voltage from input (supply) to output (load) while stepping down current. The boost converter operation is also referred to as a step-up converter. There is more than input voltage in this output voltage.

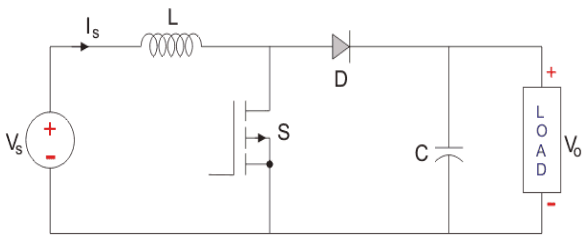

Figure 2: Equivalent Circuit of Boost Converter

Step 1: Switch turn-off Condition.

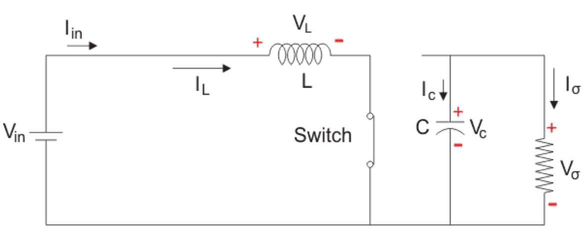

Fig 2 (a): Equivalent Circuit of Boost Converter when switch is closed

When switch is closed, diode will be reverse biased and hence the switch conducts. Applying Kirchhoff Voltage law to Fig 2 (a), we get,

$$v_L = V_s = L\frac{di_L}{dt} \quad \text{OR} \quad \frac{di_L}{dt} = \frac{V_s}{L} \text{ ………. } (1)$$

The difference in the inductor current is uniform then inductor current is given

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_s}{L} \text{ ………… } (2)$$

When switch is closed,

$$(\Delta i_L)\text{closed} = \frac{V_s DT}{L} \text{ ……….. } (3)$$

Step 2: Switch turn on condition.

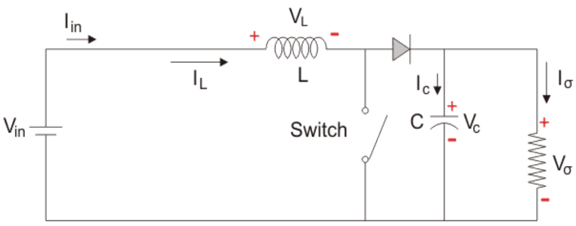

Fig 2 (b): Equivalent Circuit of Boost Converter when switch is open.

When switch is being opened diode will be forward biased, hence inductor current flows through diode. Applying Kirchhoff Voltage law for the loop in Fig 2 (b), hence we get

$$v_L = V_s - V_o = \frac{L di_L}{dt}$$

$$\frac{V_s - V_o}{L} = \frac{di_L}{dt} \text{ ……….. } (4)$$

The difference in the inductor current is uniform then inductor current is given by

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = \frac{V_s - V_o}{L}$$

$$(\Delta i_L)\text{ open} = \frac{(V_s - V_o)(1-D)T}{L} \text{ …………. } (5)$$

At steady state condition the sum of inductor current must be zero hence (Δi_L)closed+(Δi_L)open=0

$$\frac{V_s DT}{L} + \frac{(V_s - V_o)(1-D)T}{L} = 0$$

$$V_s(D + 1 - D) - V_o(1 - D) = 0$$

$$V_O = \frac{V_S}{1-D} \quad (6)$$

Output power is given by

$$P_o = \frac{V_o^2}{R} = V_o I_o$$

The input power is given by

$P_s = V_s I_s = V_s I_L$.

A. CASCADED H-BRIDGE MULTILEVEL INVERTER (CHBI).

The single phase full bridge inverters are linked successively in series to obtain H Bridge Inverter. The leg of phase has separate dc sources as depicted in Figure: 3(a). The output waveform is sinusoid and the harmonics are less even without the usage of filter. It showed a staircase waveform. The 3-level inverter is called as H Bridge Inverter with 120°phase shift. The drained voltage of the Inverter is $+Vdc, -Vdc$ and zero.

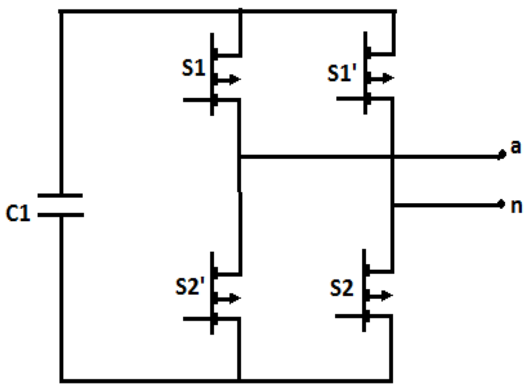

Figure (3): H-Bridge multilevel Inverter

The 7-level multi-level inverter needs a maximum of 12 IGBT switches and 3 sources of input voltage dc.

The cascaded multilevel H-bridge inverter is generally a multiple H-bridge inverter series connection. Each H-bridge inverter has the same configuration as a typical full-bridge single-phase inverter. The inverter's output is oscillating waveform staircase output, not as predictable a sinusoidal waveform. The waveform of the inverter output comprises of harmonics.

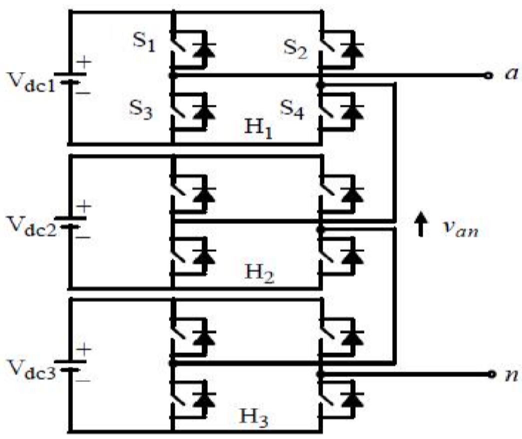

Figure 3 (a): Block diagram of 7-level CHBI

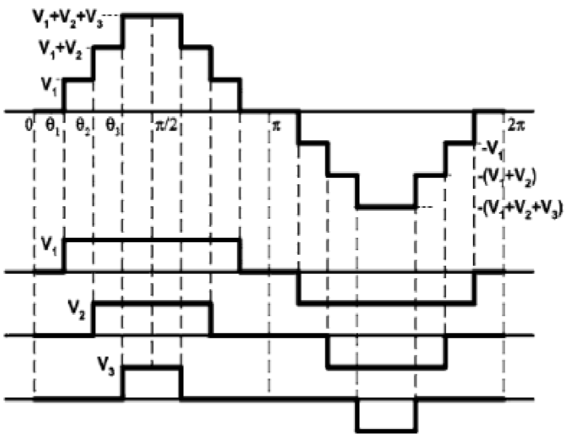

Figure 4: Output waveform of 7-level CHBI

III . PROPORTIONAL INTEGRAL CONTROLLER

A PID controller is a closed loop feedback system commonly used in industrial control systems and a range of other devices requiring steadily modulated control. And it estimates an error value as the difference between a desired set point (SP) and a measured process variable (PV) on an on-going basis and applies a correction based on proportional, integral, and derivative terms (referred to as P, I, and D), hence the name.

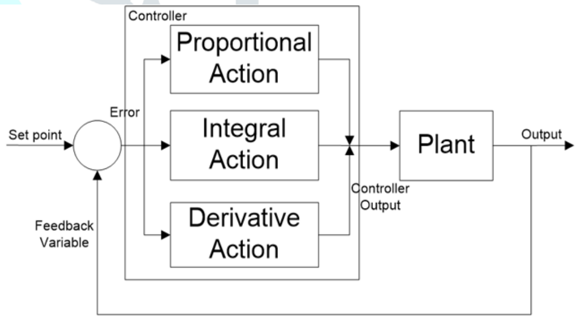

Figure 5: Representation of PID Controller

The Figure.5 illustrates the principles of how to generate and execute these conditions. It demonstrates a PID controller that continually calculates an error value e(t) as the distinction between a required set point SP= r(t) and a measured process variable PV= y(t) and a modification based on proportional, integral, and derivative terms is applied. By adjusting a control variable u (t), such as opening a control valve, the controller tries to limit the mistake over time to a real value determined by a measured sum of control terms.

TUNING OF PID CONTROLLER

Many regulations have evolved over the years to address the problem of how to tune a PID controller. The rules of Zeigler-Nichols (ZN) are likely the first, and certainly the most well-known.

TUNING OF PID CONTROLLER MANUALLY

The PID controller's manual tuning is done by adjusting the reset time to its peak value and the frequency to zero and increasing the gain to steady amplitude until the circuit oscillates. Then set the gain to half the value and adjust the reset time to review it for any offset in an appropriate moment. Finally, increase the rate until the overshoot has been minimized.

TUNING OF PID CONTROLLER GAIN

PID controller tuning can be complicated. The proportional technique is the most readily justifiable technique. Therefore, higher proportional profit or mistake increases the production of the proportional factor. If the proportional gain is set too high, a device constantly over-shoots the set point, leading in oscillation. While the proportional gain is set too low, the loop yield is negligible.

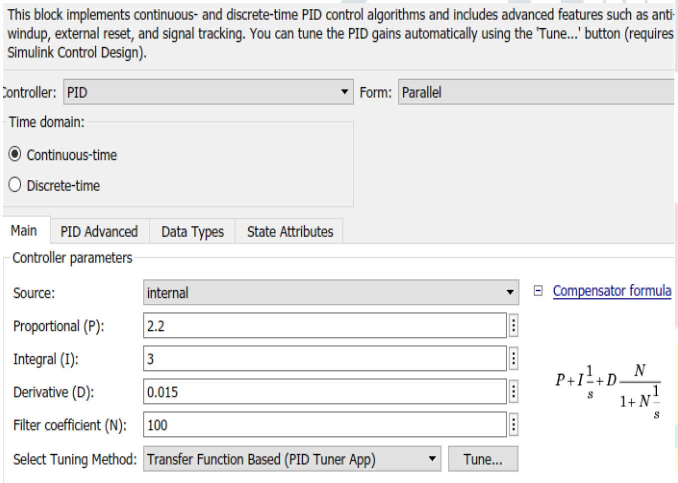

Figure 6: Parameters of PID controller.

IV. SIMULATION RESULTS

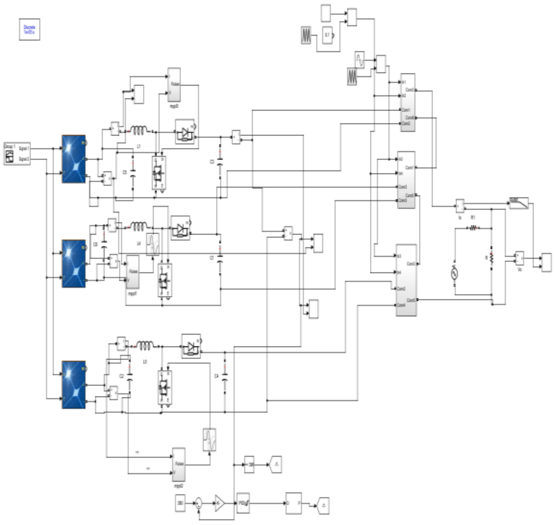

Figure7: Simulation of grid-connected multilevel inverter using MATLAB

The modified circuit of gird-connected multilevel inverter is shown in Figure.5.This model is simulated using MATLAB/Simulink and simulated model is shown above. The graphical extension of MATLAB is Simulink which is used for modelling and simulation of systems.

Description of Simulink Model

1. A PV Panel is given a supply voltage of 60V, which is boosted up to 120V with the help of boost converter. Here the function of boost converter is to step-up the voltage.
2. PID controllers are combined in such a way that it produces a control signal; it delivers the output at the desired levels.
3. By synthesizing the AC output terminal voltage from multiple voltage concentrations, it is possible to produce staircase waveforms that approach the sinusoidal waveform with small harmonic distortion, decreasing filter demands.
4. The Output is connected to a load or grid as seen above, which has low THD with removal of lower order harmonics.

The system consisting of boost converter and cascaded H-Bridge multilevel inverter was simulated. And the results of each stage are shown below:

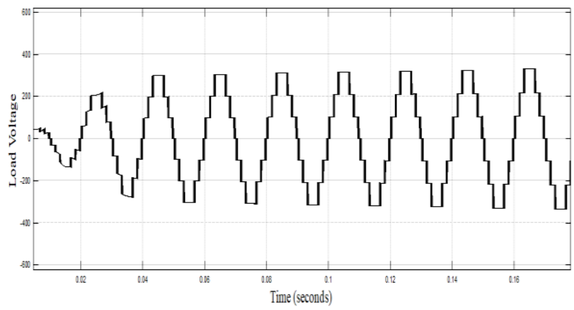

Figure 8: Load Voltage

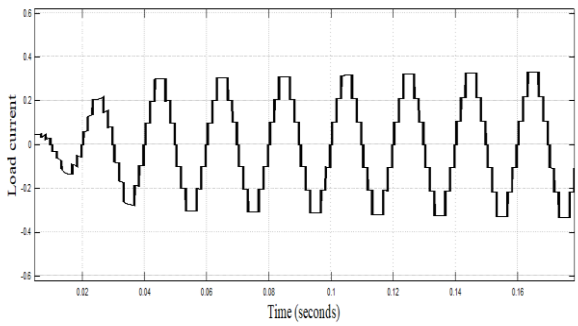

Figure 9: Load Current

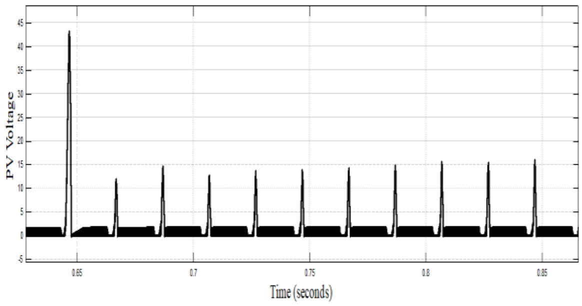

Figure 10: PV Voltage

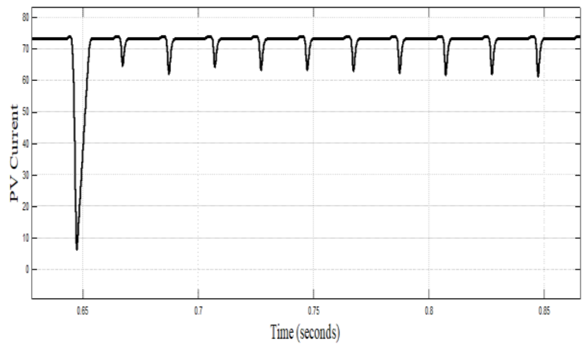

Figure 11: PV Current

THD performance

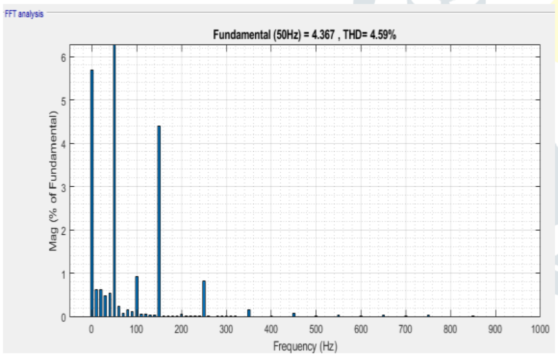

Figure 12: FFT Analysis of CHB INVERTER

Table1: PERFORMANCE OF BASE PVMLI AND MODIFIED PVMLI.

PARAMETERS	BASE PVMLI	MODIFIED PVMLI
THD%	48.35%	4.59%

This technique limits the lower order harmonics in the output voltage and there is substantial reduction in Total harmonic distortion (THD) from 48.35% to 4.59%, when compared with the existing grid-connected inverter.

Advantages

1. As the number of levels increases, the THD decreases.
2. Reliability of the system is high.

Disadvantages

1. To generate power, large numbers of solar cell modules are required.
2. Lower Efficiency.

V. CONCLUSION

This paper presents PV module and a boost converter configuration as well as inverters focusing on a cascaded H-Bridge multilevel inverter for 7 output level. In the grid-connected PV system, a reliable, fast, low cost and simple fault detection method is proposed for the inverter fed by series-connected POs. The proposed strategy not only works accurately, but also is immune to MPP variations. Moreover, this improved OCF detection method can be applied to DC micro-grid or other similar scenarios. In addition, a multicarrier PWM is used as a control method for these multilevel inverters. Results from this study show the suitable multilevel inverter for PV grid-connected application based on THD.

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