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A Comparative Investigation Multilevel Inverter For Three-Phase Stand-Alone Photovoltaic Application Using SPWM And SVM

S. Saravanan[1] and T.S. Sivakumaran[2]

[1]*Research Scholar, Department of Electrical and Electronics Engineering, Sathyabama University, Tamil Nadu, India.*

[2]*Professor & Dean, PG Studies, Arunai College of Engineering, Tiruvannamalai, Tamil Nadu, India.*

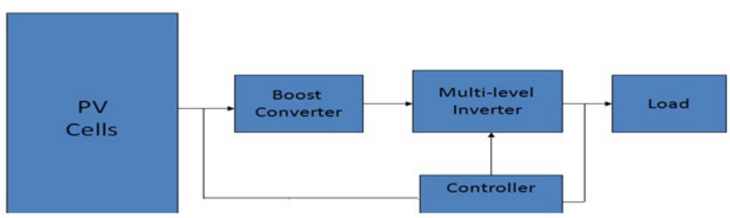
Abstract: *Solar energy is one of the favorable renewable energy resources, and the multilevel inverter has been proven to be one of the important enabling technologies in PV utilization. Multilevel voltage source inverters offer several advantages compared to their conventional counterparts. By synthesizing the ac output terminal voltage from several levels of voltages,staircase waveforms can be produced, which approach the sinusoidal waveform with low harmonic distortion; thus, reducing filter requirements. The need of several sources onthe dc side of the converter makes multilevel technology attractive for photovoltaic applications.Five level diode connected multilevel inverter is not only used to produce the staircase sinusoidal waveforms but also used to reduce the stress to the switching device. The control scheme is demonstrated using SVM and SPWM. In this study, a harmonic elimination technique is presented that allows one to control a multilevel inverter in such a way that it is an efficient low total harmonic distortion (THD) inverter that can be used to interface distributed dc energy sources with a main ac grid or as an interface to a motor drive powered by fuel cells, batteries, or ultra-capacitors. A prototype was built to verify the operation of the proposed topology, and it presented good performance in terms of efficiency and power quality.*

Key words: *DC-DC Converter, Incremental Conductance algorithm, Three phase VSI, Maximum Power Point Tracker, PV array*

I. INTRODUCTION

The continuous economic development of many countries and the environmental issues (gas emissions and the green house effect) observed in the last decades forced an intense research in renewable energy sources. Hydro, photovoltaic (PV) and wind energy conversion are the most explored technologies due to their considerable advantages [1]-[2], such as reliability, reasonable installation and energy production costs, low environmental impact, capability to support microgrid systems and to connect to the electric grid [3]. Among these energy sources the PV is pointed out as one of the most modular and environmentally friendly technologies. Therefore, PV systems have been frequently adopted

Block Diagram of Proposed System



worldwide, presenting a growth of 45% on the total PV power installed in 2009 [4] (the largest growth among the renewable energy sources). With the continuous improvement on the energy sector, an important situation should be brought out: approximately 1.4 billion people have no access to electricity worldwide [5], which a substantial fraction refers to communities distant from the electric grid. This feature makes the standalone system an interesting alternative for enabling electricity access for those people, and also for remote applications. This way, it is expected that the number of installed stand-alone systems should increase in the next years. Differently from the grid-connected systems, the stand-alone systems demand a back-up system (usually a battery bank and a charger/discharger converter) to supply the load during periods with low or no energy generated. It was demonstrated in [6] that the maintenance costs related to the batteries represent 46% of the overall PV system cost due to the batteries short lifetime. Thus, it is essential to optimize the back-up system lifetime.

II. PROPOSED STAND-ALONE PV SYSTEM

The proposed structure, depicted in Fig. 1(a), can be classified as a multi-string configuration, where the first stage is composed by "n" dc-dc converters connected to its correspondent PV string. Each dc-dc converter output is connected to a multilevel cell, performing the dc-ac stage. The back-up system is divided into "n" dc-dc battery converters (Decentralized Battery Converters – DBC) managing a small set of batteries, also connected at the output of the first stage. The arrangement composed by one PV string, one dc-dc converter, one battery converter and one multilevel cell will be considered a module of the system. The dc-dc converters of the first stage must track the maximum power point of the PV panels. In order to perform this task, step-up/step-down converters are usually chosen. However, in the proposed structure, the choice of the converter will depend on the voltage level of the dc bus, calculated by means of (1)

$$Vbus = \frac{v_m}{n_{sat}} \qquad (1)$$

where Vbus is the voltage level of the dc bus, Vm is the maximum voltage for implementing a desired sinusoidal output voltage and nstr is the number of strings/modules. The maximum voltage, Vm, is usually defined as 200 V (400 V) for synthesizing an output voltage of 110 Vrms (220 Vrms). Thus, if the input voltage of each module (PV string voltage) is higher than Vbus, a step-down converter should be employed. Otherwise, a step-up converter is the appropriated choice. In [9] it was developed a decentralized system for standalone applications, as seen in Fig. 1(b), with the first stage similar to the proposed structure. However, the second stage is composed by a series connection of all dc-dc converter outputs, implementing the dc bus, and an inverter that generates the output sinusoidal waveform. Furthermore, a single converter managing a single battery bank (Centralized Battery Converter – CBC), is connected at the output of the first stage. Although the DBC system increases the number of semiconductor devices, it is possible to perform a proper charge/discharge method on the batteries. Converters with battery system integrated on the dc-dc stage have been proposed in the literature [10]-[11] aiming to improve the efficiency of the overall system by eliminating the battery converter. However, this solution is only suitable for low power applications, since these integrated systems do not consider an appropriated charge/discharge method. Additional details about how the charge/discharge method affects the lifetime of the battery bank are presented section 2-B.

III. THE MULTILEVEL INVERTER

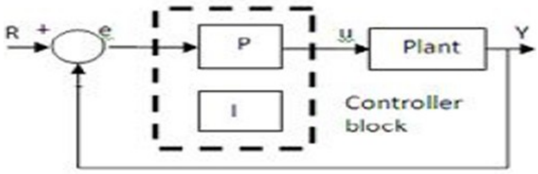
The chosen multilevel topology for the proposed system is composed by cascaded half-bridge cells, where each cell is connected in the output of the first stage of the module [2], [12]-[13], as shown in Fig. 2. The multilevel cells are responsible for producing a specified voltage level, and the series connection of them will generate the desired sinusoidal waveform. This topology presents modular characteristic, simple control and high efficiency due to the low frequency operation possibility. However, as can be seen in Fig. 2, only the multilevel cells cannot produce an ac voltage waveform. Thus, a full-bridge inverter is necessary at the output of the cascaded multilevel cells, which operates in the output frequency (50 or 60 Hz).

IV. PULSE WIDTH MODULATION TECHNIQUE

The most efficient method of controlling the output voltage is to incorporate PWM control within the inverters. In this method, a fixed DC input voltage is supplied to the inverter and a controlled AC output voltage is obtained by adjusting the on and–off periods of the inverter devices. Voltage-type PWM inverters have been applied widely to such fields as power supplies and motor drivers. This is because: (1) such inverters are well adapted to high-speed self-turn-off switching devices that, as solid-state power converters, are provided with recently developed advanced circuits (2) they are operated stably and can be controlled well. The commonly used PWM control techniques are: (a) Sinusoidal pulse width modulation (sin PWM) (b) Space vector PWM The performance of each of these control methods is usually judged based on the following parameters: a) Total harmonic distortion (THD) of the voltage and current at the output of the inverter, b) Switching losses within the inverter, c) Peak-to-peak ripple in the load current, d) Maximum inverter output voltage for a given DC rail voltage.From the above all mentioned PWM control methods, the Sinusoidal pulse width modulation is applied in the proposed inverter since it has various advantages over other techniques. Sinusoidal PWM inverters provide an easy way to control amplitude, frequency and harmonics contents of the output voltage.

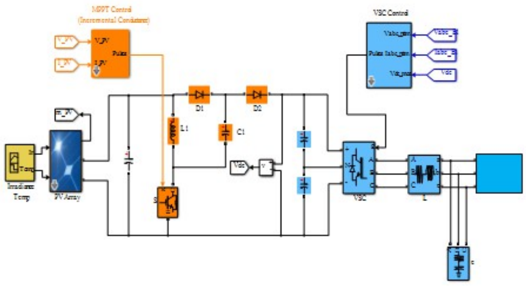
PI CONTROLLER In control theory, a controller is a device, possibly in the form of a chip, analogue electronics, or computer, which monitors and physically alters the operating conditions of a given dynamical system.In control engineering, a controlled system is primarily characterized by its dynamic behaviour which also determines the scope and quality required to solve a control task This is determined by measuring the controlled variable after a step change in the manipulated variable.

7340 ≗Δ + ≗ৱ ∫ Δ dt (3.1) where is the error or deviation of actual measured value (PV) from the setpoint (SP). Δ= ˛– ˛(3.2) The PI controller block is reduced to P and I blocks only as shown in figure 8 Figure 8 Proportional Integral (PI) Controller

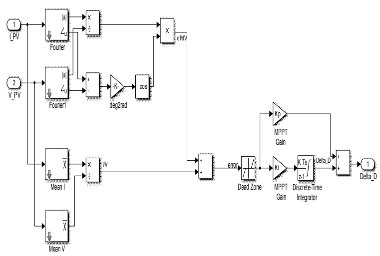


V. SIMULATION RESULTS

In order to validate the proposed topology, the PV system was simulated with three strings. Step-up dc-dc converters (boost) implement the first stage, tracking the maximum power point (MPP) of the panels. Connected at the output of the first stage, the multilevel inverter generates a seven-level waveform. In this stage, a phaseshift modulation was implemented, reducing the total harmonic distortion of the output signal. The simulation parameters are summarized



(a) Luo converter with PV array stand-alone system



(b) Simulink model arrangement Increment Conductance algorithm

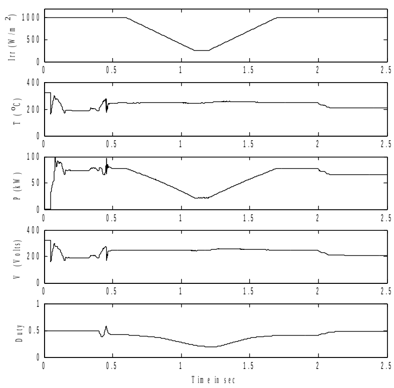


Fig. 6. Simulated overall response of Increment Conductance MPPT based PV system

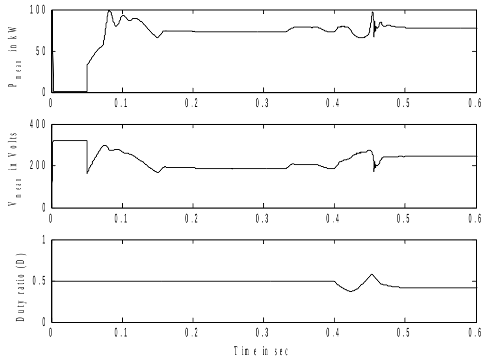


Fig. 7. Simulated response of proposed system at time t=0 sec to t=0.6 sec (Irr = 1000, T=25°C)

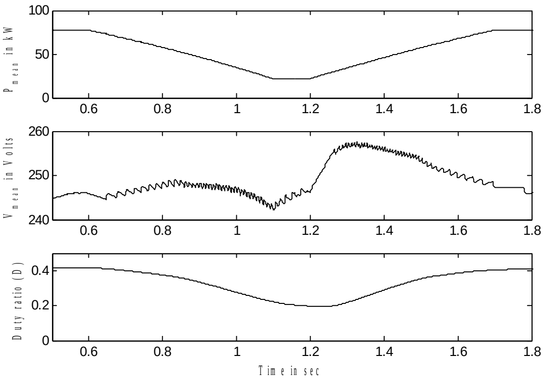


Fig. 8. Simulated response of proposed system at time t=0.6 sec to t=1.8 sec (Irr = 200, T=25°C)

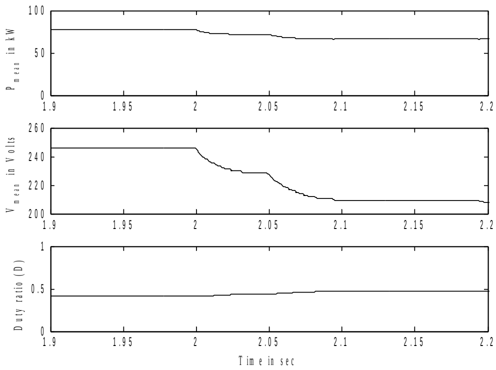


Fig. 9. Simulated response of proposed system at time t=0.6 sec to t=1.8 sec. (Irr = 1000,T=75°C)

Simulation is carried out over a time period of 2.5 Sec. Analysis has been carried out for both change in irradiance as well as temperature. At time t=0 to t=0.6 Sec input parameter for PV panel is Irr = 1000 W/m^2, T= 25°C; at t=0.6 to t=1.1, Irr = 200 W/m^2, T=25 °C; at t=1.2 to t=1.7 Irr = 1000 W/m^2, T=25°C and at t=2.1 Irr = 1000 W/m^2, T=75°C. Response of output power, voltage and duty ratio of the incremental conductance algorithm for proposed luo converter. Figs 6-9 show the simulated responses of the incremental conductance MPPT algorithm based stand-alone PV system. Fig.6 shows the overall performance of the proposed system. Fig.7 shows the response of power, voltage and duty ratio with 1000 W/m^2, 25°C. Fig.8 shows the response of power, voltage and duty ratio with 200 W/m^2, 25°C. Fig.9 shows the response of power, voltage and duty ratio at 1000 W/m^2, 75°C.

VI. CONCLUSION

This paper proposed a stand-alone PV system with a multilevel inverter in the dc-ac stage for medium power applications. The multilevel inverter presents attractive advantages when compared to conventional inverters, such as low harmonic distortion of the output waveform and employment of low voltage semiconductor devices. The structure is also composed by converters dedicated to small sets of batteries, called decentralized battery system. Moreover, several design possibilities can be achieved aiming the most efficient and low cost PV system project. It was also considered an appropriated charge/discharge method for the batteries aiming to minimize the maintenance costs of the batteries in stand-alone systems. By means of simulation results, the effectivity of the proposed structure, as well as its control system were verified.

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