SOLAR POWER CONVERSION USING 15-LEVEL CASCADED H-BRIDGE MULTI LEVEL INVERTER

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ABSTRACT: This project presents a single-phase 15-level (7 H-bridges) cascade multilevel DC-AC grid-tiedinverter. Each inverter bridge is connected to a 200 W solar panel. OPAL-RT lab was used as the hardware in the loop (HIL) real-time control systemplatform where a Maximum Power Point Tracking (MPPT) algorithm was implemented based on the inverter output power to assure optimal operation of the inverter when connectedto thepowergridas wellas a Phase LockedLoop (PLL) for phase and frequency match.

A novel SPWM scheme is proposed in this paper to be used with the solar panels that can account for voltage profile fluctuations among the panels during the day.Simulationandexperimentalresultsareshownfor voltage and current during synchronization mode and power transferringmodetovalidatethemethodologyforgrid connection of renewable resources.

KEYWORDS: Multilevel Converter, Cascaded H-Bridges, Solar Panel, Photovoltaic, MPPT, PWMetc.

INTRODUCTION

Becauseenergy resourcesand their utilizationwill be a prominentissueofthiscentury,theproblemsofnatural resource depletion, environmental impacts, and the rising demandfornewenergyresourceshavebeendiscussed ferventlyin recentyears.Several formsof renewablezero-pollution energy resources, including wind, solar, bio, geothermaland so forth, have gained more prominenceand are being researched by many scientists and engineers.

Solarcellinstallationsinvolvethe use of multiplesolar panelsor modules, which can be connectedin seriesor in parallelto providethe desiredvoltagelevel to the inverter. The cascaded H-bridge multilevel inverter topology requires a separateDCsourceforeachH-bridgesothathighpower and/or high voltage that can result from the combination of the multiple modules in a multilevel inverter would favor this topology.

To maximize the energy harvested from each string, a maximum power point tracking (MPPT) strategy is needed.Thetaskoffindingtheoptimumoperationpoint mightincreasethe complexityandcomponentcountas the number of isolated DC sources increase. The approach chosen to deal with the number of input sources was to monitor AC output power parameters instead of DC input measurements.

Traditional multilevel inverters include cascaded H-bridge inverter, diode clampedinverter,and flying capacitors inverter. This paper focuses on the single-phase 15-level (7 H- Bridge) cascade multilevel inverter.

MULTILEVELINVERTERANDPVINTERFACE

An overview of the system is shown in Figure 1. The core component of this inverter design is the four-switch combination shown in Figure 1. By connecting the DC source to the AC output by different combinations of the four switches, Q11, Q12, Q13, and Q14, three different voltage output levels can be generated for each DC source, +Vdc, 0, and -Vdc. A cascadeinverterwith N inputsourceswill provide (2N+1) levels to synthesize the AC output waveform. The DC source in the inverter comes from the PV arrays, and the switching signals come from the multicarrier sinusoidal pulse width modulation (SPWM) controller.

The 15-level inverter connects Seven H-bridges in series and is controlled by seven sets of different SPWM signals to generate a near sinusoidal waveform.The connection to the grid is done through a variable transformer to as sure that at anytime the number of H- Bridges used can be controlled, the grid voltage generated by the inverteris met and to givemore flexibility to the experiment since irradiance levels might not be enough. For that reason, an additional fixed 10m H inductance was added as the connection inductance for power transferring mode.

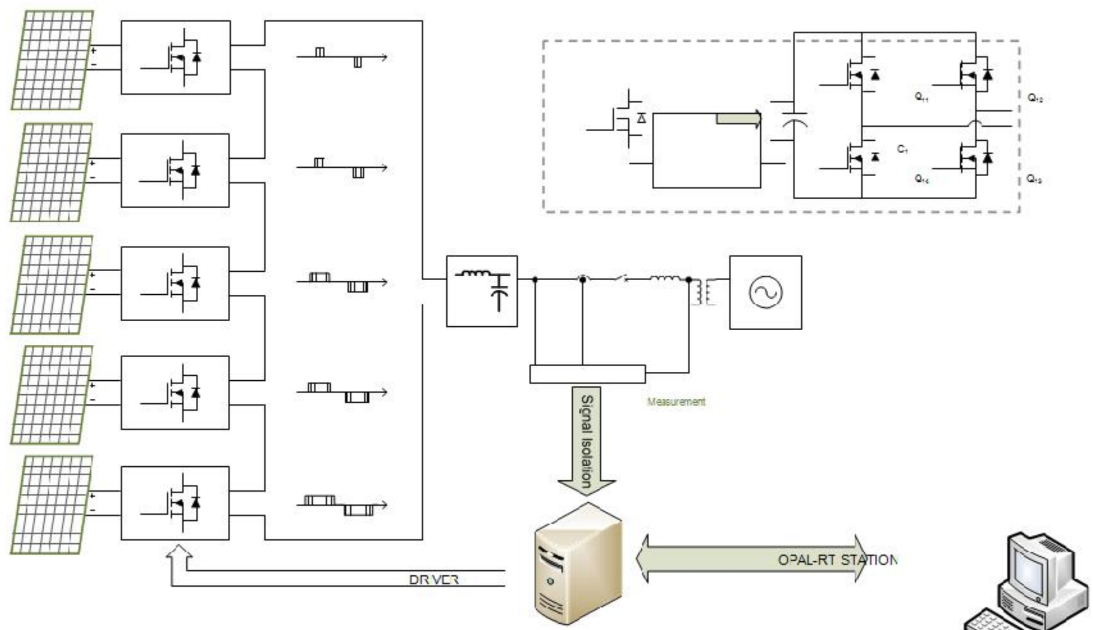
The individual solar panel output power is proportional to solar irradiance variations that occur during the day. The MPPT algorithm will work sensing the output powers on feedback from the individual panels is provided to reduce the number of sensors.

As can be seen in Figure-1, the lower panels, interms of control signals, will deliver more energy than the upper panels. In order to avoid uneven power to be drawn from the panels by the inverter, a different inverter control approach for the SPWMs chemeis proposed here to be used with the solarpanels that can account for the voltage profile variation of the panels that occurs during the day. The MPPT and grid synchronization algorithm are fed by output and voltage current signals to generate the gate driver signals as shownin Figure-2.

In Figure-3 are shown the inverter and its cycle-by-cycle SPWM control methodology. The irradiance profile over a day changes a few orders of magnitude than a 60Hz system i.e. means that a control change action over the modulation index can be taken over a few cycles of the 60Hz controlsystem. It is desired to get the same amount of power from each string, which cannot be achieved using a conventional SPWM approach. For example, the lower panels in Figure-1 would send more power than the upper panels as they are switching for a longer time. The sinusoidal nature of the current comes as another fact or that makes the power drawn from different panels uneven.

The multi level cascade to pology doesnot require any of the H-bridg estobe switched in a determined sequence, as would be the case for a diode clamped multilevel (DCM) converter. This gives freedom to switch the H-bridges in the circuit in any order, which can be used as strategy to equalize the power transferred from individual panels.The control strategy implemented shifts the carrier signal over Ncycles in the case of a (2N+1) level inverter to make it possible to draw the same amount of power from each string.

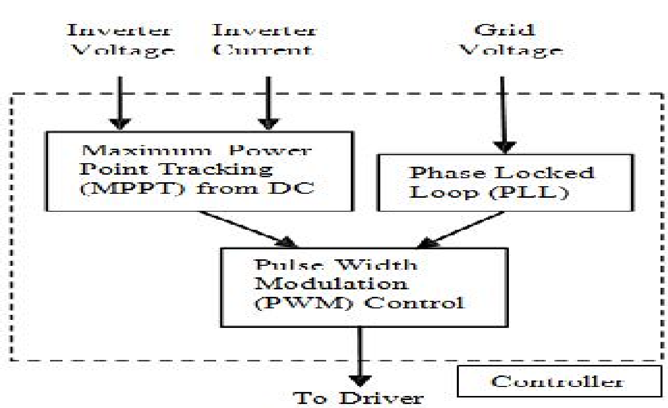
Figure-1: Multilevel Inverter System Overview



Sources: Authors Compilation

Shifting the carrier down for each cycle is the same as physically changing the position of the H-bridges shown in Figure-3(a) for an 15-level inverter. In that figure, five cycles of the fundamental frequency areneeded to haveeachpanelswitchpositionwiththeotherfour.The energystoredinthecapacitorwillcometohelpinthis processinacycle-by-cyclebasistoavoidaconsiderable voltage drop due to its considerable large capacitance (1000 uF).

Figure-2: Control Block Diagram



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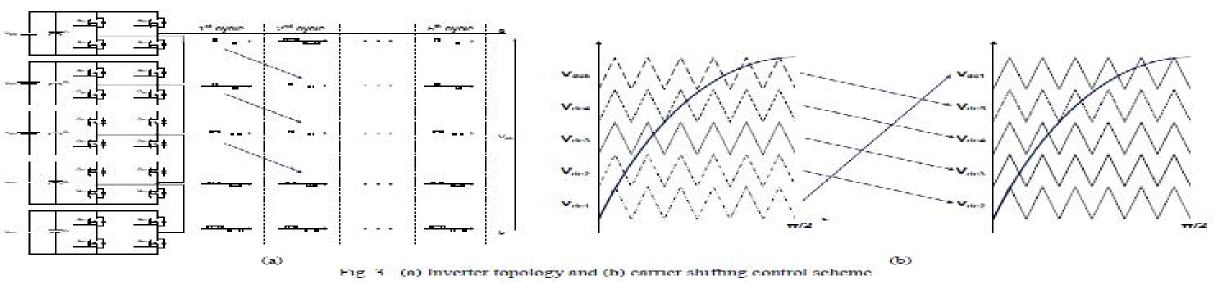
SYNCHRONIZATION AND TRACKING CONTROL SYSTEM

Synchronization between inverter and grid means that both will have the same phase angle, frequency and amplitude. This can be done noise proof with respect to the grid by sensing the grid voltage in a Phase Locked Loop (PLL). Typical PLL algorithms include inverse Park-based PLL, Hilbert transformer – based PLL, and transport delay-based PLL. The one to be included in this design is the transport delay-based PLL.

PLL algorithm notice that the delayed angle can be directly controlledat the computer station during the experimentto provide the signal in quadraturewith the grid, which is the input to the Park transform block.

PLL output is the actual angle position of grid voltage. This signal is used to generate the sine wave that is used as the reference signal to control system, which will generate the SPWM signals to drive the switches. The time required for synchronization will be dependen to nthe PI block parameters. PLL synchronization simulation. In that figure, the PLL starts its synchronization at 0.03 second, and it is in synchronization after about 0.13 second. Since the angle is now known, it is possible to control the phase difference between inverter and grid by controlling δ. This allows the power flow to be controlled according to (1).

Figure-3:(A)InverterTopology, and(B)CarrierShiftingControlScheme



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$$P = \frac{V_{inv} \cdot V_{grid}}{X_L} \sin \delta \qquad (1)$$

Where V_{inv} is the inverter voltage, V_{grid} is the grid voltage, X_L is the connection impedance, and δ is the angle between grid and inverter.

Instead of sensing the individual panel voltages, the maximum power point tracking (MPPT) algorithm determines the optimal point of operation of the panel by calculating the output power and phase angle variation [18]. It monitors output voltage and current parameters by making small changes on the phase angle and looking at the power variation, as In a hill climbing optimization method to track the maximum power point.

EXPERIMENTAL DEMONSTRATION

Each one of five H-bridges has its own 200WPV panel connected as an independent source.The panels' specification can be seen in Table-1. The control signals to the bridges are sent by the OPAL-RT workstation where software and I/O boards are installed.The system acquires grid voltage and inverter output current and voltage to the control block (OPAL-RTwork station) to generate the driver signals to the inverter.

Table-1: Solar Panel Specifications

Sanyo HIP-200DA3	
Rated Power	200 W
Maximum power voltage	56.2 V
Maximum power current	3.56 A
Open circuit voltage	68.8 V
Module efficiency	16.5 %

Sources: Authors Compilation

The RT-Lab control platform, which connects the software (PWM, PLL, MPPT) with the hardware (solar panel, grid, 11- level cascaded H-bridge inverter), to create a real time platform, is the main tool to perform the experiments. Due to hardware limitation, the maximum achievable frequency for the SPWM signals is 2 kHz, which requires bulk filtering components as shown in Table 3.2. A 2 kHz discrete-time RTLab drives the inverter with five solar panels as DC inputs and provides a waveform to interface with the 60 Hz AC grid.

Figure-4: (A) Transport Delay-Based PLL Algorithm, and (B) Voltage Synchronization Using PLL

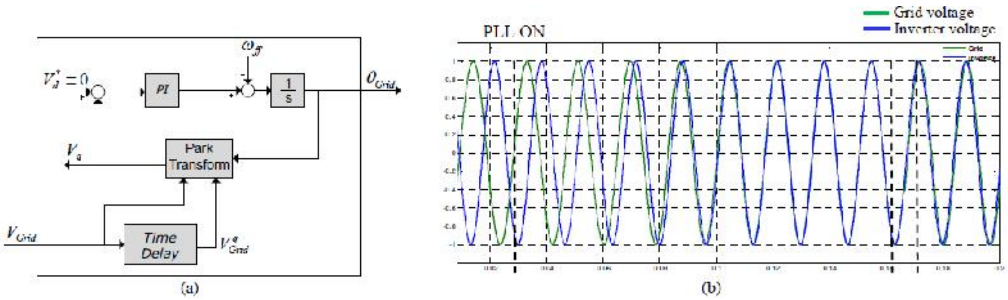

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Table-2: Passive Components Specification

Filter Inductance	1 mH
Filter Capacitance	92 uF
Connection inductance	10 mH

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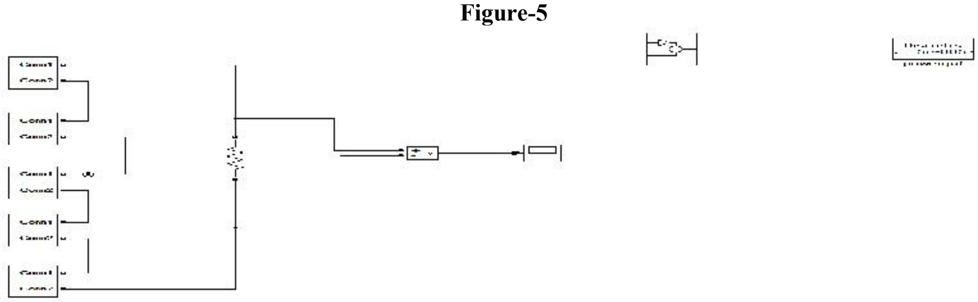
Matlab Modeling and Results

Figure-5



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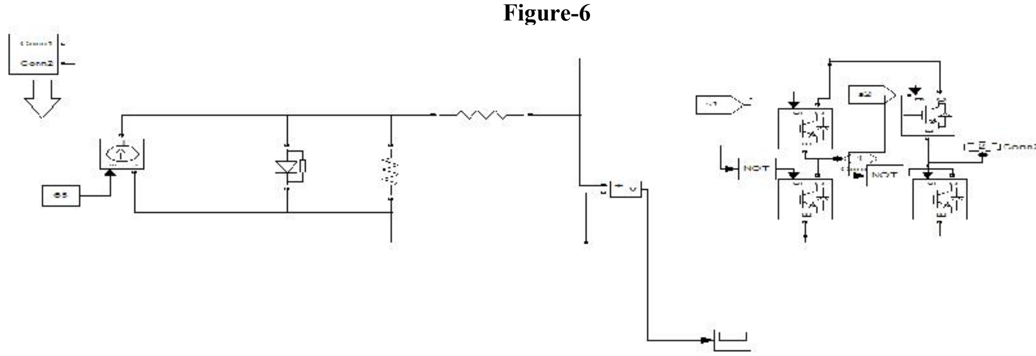
The above circuit represents the solar power conversion using 15 level-cascaded H-Bridge multi level inverter.

Figure-6



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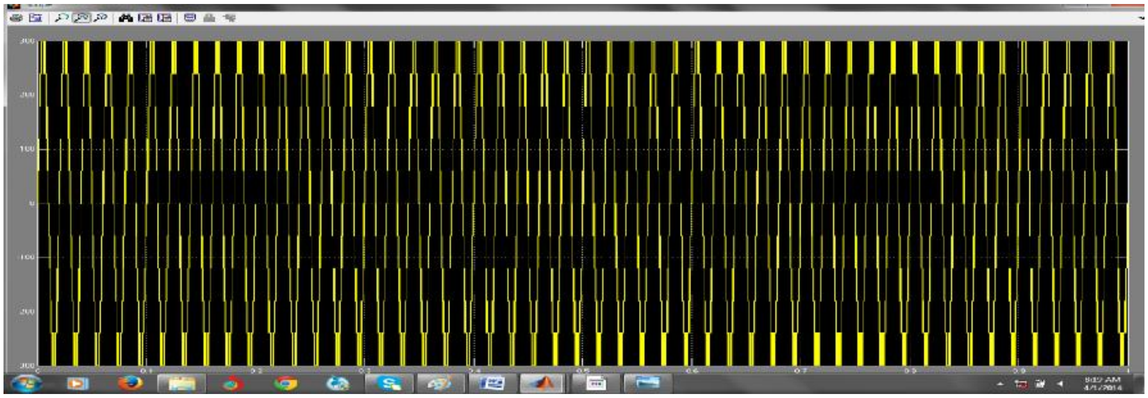
The above circuit represents internal circuit of subsystem1.

Figure-7



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The above figure represents the output waveform of the solar power conversion using 15 level cascaded H-Bridge multilevel inverter.

CONCLUSION

This project presented an fifteen-level cascade H-bridge inverter, which uses PLL and MPPT with separate solar panels as DC sources to interact with the power grid. A SPWM approach was presented to deal with the uneven power transferring characteristics of the conventional SPWM modulation technique. This technique proved to be successful due to the irradiance profile and the use of capacitors to smooth the voltage fluctuation. The system was driven at 2 kHz because of speed constrains of the control platform, which required bulk filter components. Grid connection results were shown using the proposed MPPT algorithm. Future work includes the use of a DSP platform to increase switching frequency and reduce filterrequirements. The entire PV system structure and its interaction with the grid through PLL and MPPT algorithms were shown by the simulation and experimental results.

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