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A Single-Phase Photovoltaic Boost-Buck inverter variable structure control for grid-connected systems

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Abstract— Module integrated converters (MICs) have been under rapid development for single-phase grid-tied photovoltaic applications. The capacitive energy storage implementation for the double-line-frequency power variation represents a differentiating factor among existing designs. This project introduces a new topology that places the energy storage block in a series-connected path with the line interface block. This design provides independent control over the capacitor voltage, soft-switching for all semiconductor devices, and the full four-quadrant operation with the grid. The proposed approach is analysed and experimentally demonstrated. Module integrated converters (MICs) have been under rapid development for single-phase grid-tied photovoltaic applications. This project introduces a new topology that used to perform in unity power factor operation.

Keywords— AC module, bidirectional power transfer, cyclo converter, dc-ac power converters, distributed power generation, double line-frequency ripple, grid-connected PV systems, high frequency ac-link, module integrated converter (MIC), multiport circuit, photovoltaic (PV) inverter, photovoltaic power systems, resonant power converters, single-phase energy storage, single-phase inverters, single-stage inverters, switching circuits, zero voltage switching.

1. INTRODUCTION

Grid tied inverters for photovoltaic systems represent a rapidly developing area. Module-integrated converters (MICs), sometimes known as micro inverters, are designed to interface a single, low-voltage (25–40 V, typically) panel to the AC grid. Such converters provide a number of benefits ease of installation, system redundancy, and increased energy capture in partially shaded conditions. MICs typically target single-phase electrical systems e.g.,at 240 V), and are typically restricted to the unity power factor operation . Therefore, the converter must deliver average power plus a time-varying power component at twice the line frequency, while drawing a constant power from the PV module. Figure illustrates the power transfer versus time for the grid and the PV module, with the shaded area between the curves indicating the temporal energy storage required for the inverter. To model this transfer of energy through the converter, a generalized three-port system can be used.

The constant power source of the PV and the sinusoidal power load of the grid can be written as
$P\mathrm{PV} = P\mathrm{avg}$
$P\mathrm{Line} = -P\mathrm{avg}(1 - \cos(2\omega l\ t))$

when no reactive power is transferred. The energy storage buffer must absorb and deliver the difference in power between these two ports, specifically
$P\mathrm{Buf} = -P\mathrm{avg}\cos(2\omega l\ t)$.

Inverters investigated in the past can be classified by the location and the operation of the energy storage buffer within the converter. Most single stage topologies, such as fly back and ac-link converters, place capacitance in parallel with the PV panel. This is an effective low-complexity implementation, but to avoid interfering with the maximum peak-power tracking (MPPT) efficiency, substantial energy storage is required to limit the voltage ripple across the panel. A second common method involves two complete cascaded conversion stages, providing energy storage at an intermediate dc bus. This arrangement can be implemented with less energy storage than the previous method, as a larger voltage fluctuation on the intermediate bus can be tolerated

2. PROPOSED PV ENERGY SYSTEM

The Proposed work describes the analysis, modelling and design of a power conditioning system for grid-connected photovoltaic (PV) systems. The proposed design on power stage consists of a transformer less Boost-Buck converter. The power conditioning system's control scheme includes a variable structure controller to assure output unity power factor. To maximize the steady-state input-output energy transfer ratio a linear controller is designed out of a large-signal sampled data model of the system. The achievement of the DC-AC conversion and the efficient PV's energy extraction are validated with simulation results.

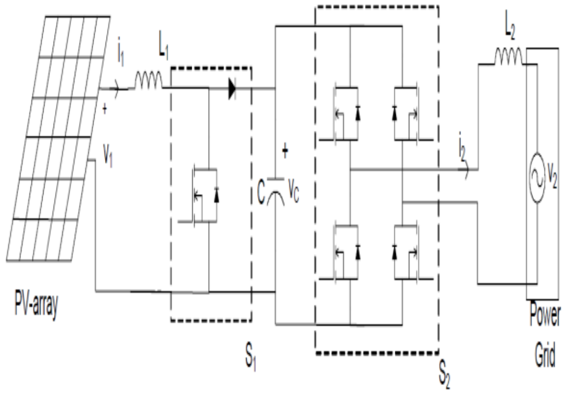

Fig 1. Proposd System Topology

3. OPERATION PRINCIPLE

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels.Solar cells are described as being photovoltaic irrespective of whether the source is sunlight or an artificial light. They are used as a photo detector (for example infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity. Solar PV is now, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity. More than 100 Countries use solar PV. Installations may be ground-mounted (and sometimes integrated with farming and grazing) or built into the roof or walls of a building (either building-integrated photovoltaic or simply rooftop).In 2013, the fast-growing capacity of worldwide installed solar PV increased by 38 percent to 139 gig watts (GW). This is sufficient to generate at least 160 terawatt hours (TWh) or about 0.85 percent of the electricity demand on the planet. China, followed by Japan and the United States, is now the fastest growing market, while Germany remains the world's largest producer, contributing almost 6 percent to its national electricity demands. The operation of a photovoltaic (PV) cell requires 3 basic attributes:

- The absorption of light, generating either electron-hole pairs or exactions.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.

In contrast, a solar thermal collector supplies heat by absorbing sunlight, for the purpose of either direct heating or indirect electrical power generation from heat. A "photo electrolytic cell" (photo electrochemical cell), on the other hand, refers either to a type of photovoltaic cell (like that developed by Edmond Becquerel and modern dye), or to a device that splits water directly into hydrogen and oxygen using only solar illumination.

FC Output voltage	Step down from 41 to 30V
AC Output voltage	100V RMS, Single phase, 50 Hz
Switching frequency	20 kHz
Output power	Step change from 40W to 500W

Table 1. Specifications of the PV System Based On the Boost-Inverter

Maximum power point tracking

Maximum power point tracking (MPPT) is a technique that grid connected inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic devices, typically solar panels,[1] though optical power transmission systems can benefit from similar technology.[2] Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions.[*citation needed*] MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

- Solar inverters convert the DC power to AC power and may incorporate MPPT: such inverters sample the output power (I-V curve) from the solar cell and apply the proper resistance (load) so as to obtain maximum power.
- MPP (Maximum power point) is the product of the MPP voltage (V mpp) and MPP current (I mpp): some solar panels have a higher maximum power than others.

I-V curve

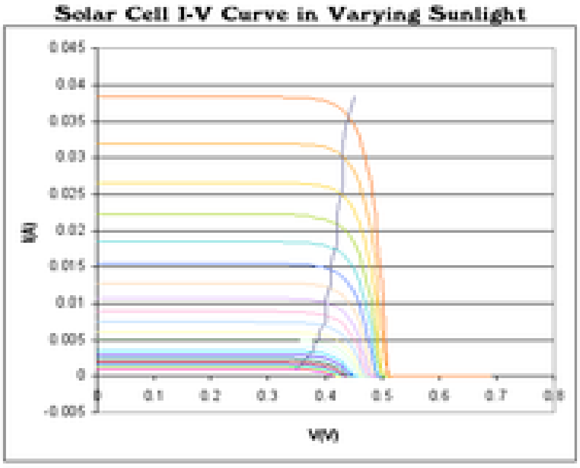

Fig 2 Solar Cell I-V Curve in Varying Sunlight

Solar cell I-V curves where a line intersects the knee of the curves where the maximum power transfer point is located. Photovoltaic cells have a complex relationship between their operating environment and the maximum power they can produce. The fill factor, abbreviated *FF*, is a parameter which characterizes the non-linear electrical behavior of the solar cell. Fill factor is defined as the ratio of the maximum power from the solar cell to the product of Open Circuit Voltage V_{oc} and Short-Circuit Current I_{sc}. In tabulated data it is often used to estimate the maximum power that a cell can provide with an optimal load under given conditions, $P=FF*V_{oc}*I_{sc}$. For most purposes, FF, V_{oc}, and I_{sc} are enough information to give a useful approximate model of the electrical behavior of a photovoltaic cell under typical conditions.For any given set of operational conditions, cells have a single operating point where the values of the current (*I*) andVoltage (*V*) of the cell result in a maximum power output. These values correspond to a particular load resistance, which is equal to *V* / I as specified by Ohm's Law. The power P is given by $P=V*I$. A photovoltaic cell, for the majority of its useful curve, acts as a constant current source. However, at a photovoltaic cell's MPP region, its curve has an approximately inverse exponential relationship between current and voltage. From basic circuit theory, the power delivered from or to a device is optimized where the derivative (graphically, the slope) dI/dV of the I-V curve is equal and opposite the I/V ratio (where $dP/dV=0$).[4] This is known as the maximum power point (MPP) and corresponds to the "knee" of the curve. A load with resistance $R=V/I$ equal to the reciprocal of this value draws the maximum power from the device. This is sometimes called the 'characteristic resistance' of the cell. This is a dynamic quantity which changes depending on the level of illumination, as well as other factors such as temperature and the age of the cell. If the resistance is lower or higher than this value, the power drawn will be less than the maximum available, and thus the cell will not be used as efficiently as it could be. Maximum power point trackers utilize different types of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell.

4. MODELING AND SIMULATION USING MATLAB

The modelling of the proposed system is done using MATLAB, and the simulation result is given for both boost mode and buck mode

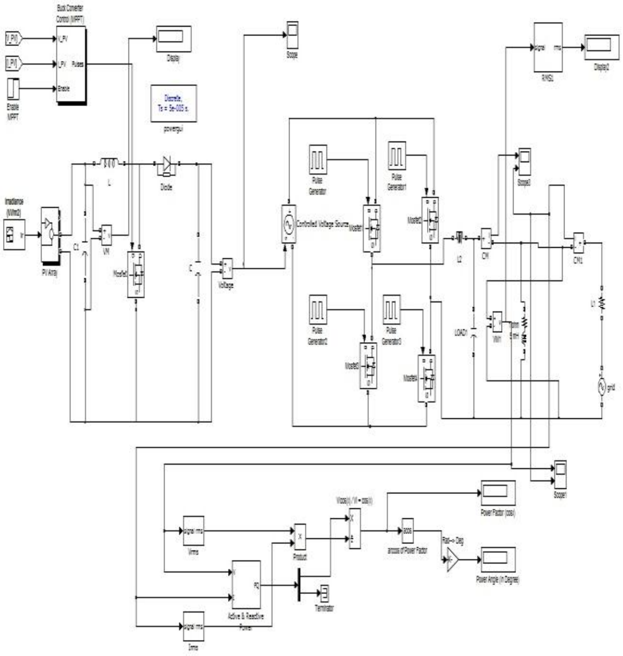

Fig. 2. Simulation Circuit of Proposed System

5. RESULT

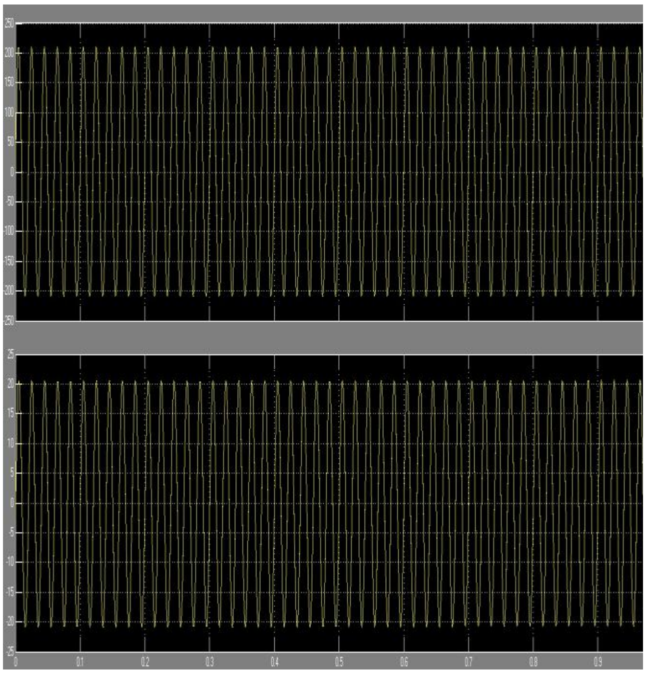

Fig 2. Output Voltage and Current Waveforms respectively.

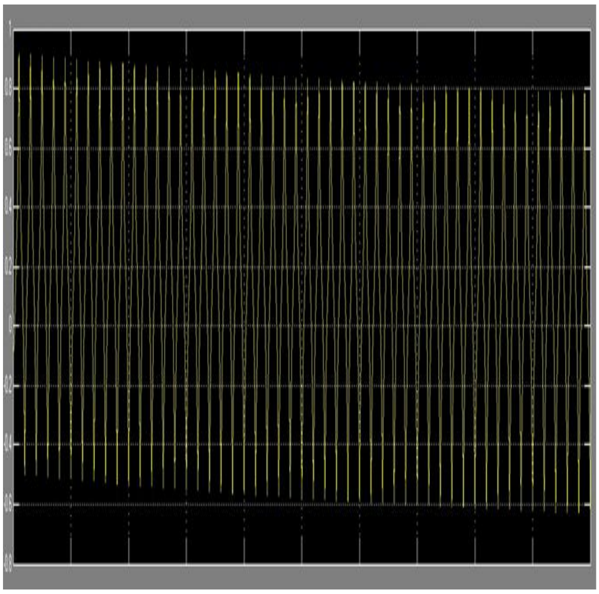

Fig 3.Powerfactor Waveform.

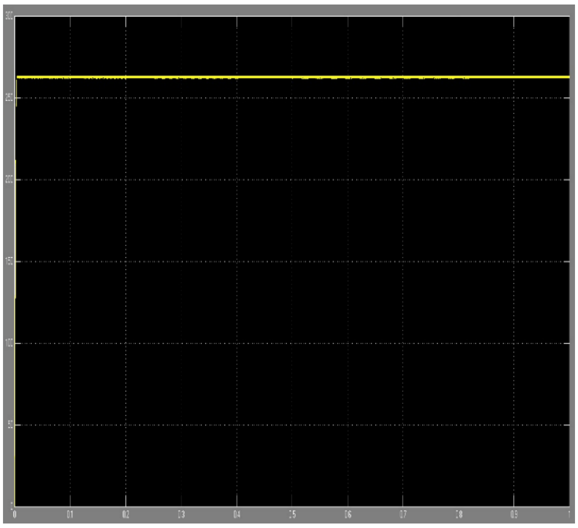

Fig 4. Boosted Voltage

6. CONCLUSION

The converter design and implementation presented in this paper has demonstrated a new topology with an energy-storage buffer in the series-connected path with the line interface. It has an increased complexity relative to traditional designs, but allows control over the energy storage voltage and ripple, permitting the use of electrolytic or film capacitors. It also maintains the capability of reactive power transfer and high efficiency, as demonstrated. The presented bench prototype provides verification of the functionality and performance of the design process. While not the primary focus, the standalone dc–ac test demonstrated 95.3% efficiency under representative operating conditions (100W, 32V input, 240V output), all inclusive. Further improvements on these successful results are expected with optimized magnetics and online tuning of control parameters.

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