# Single Phase Dual- Mode Solar PV Inverter

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**Abstract**

In this project a single phase dual-mode inverter operating at 400V is designed. The input to the inverter is 400V, 1kW PV module. The specifications of the inverter are as follows: the inverter should operate at $230V_{rms}$ at 50Hz (as per South African standards) in a grid-tie and standalone modes.

## I. INTRODUCTION

PV renewable energy is prevent in countries such as United States because of its improvement in terms of power, reliability etc. According to literature, grid-tied and standalone PV systems exist. For the grid-tie mode power is injected to the electrical grid by controlling its current while the standalone mode powers the household appliances from PV system by controlling the output voltage.

A dual-mode inverter operates on both modes - grid-tie or standalone. When the electric grid/ grid-tied mode fails to deliver power, the PV system acts as a standalone voltage source inverter to power household appliances. The PV system is generally set by using three stages: PV module, inverter and grid filter with galvanic isolation. However, the filter stage introduces more power losses and since efficiency is one of the important issues in PV systems, transformer-less inverters have emerge to mitigate the losses.

An inverter is an electrical device that converts DC power to AC power. The generated AC power can be at desired voltage and frequency and can be reached using appropriate switching or control circuit such as, MOSFETs, IGBTs or PWM control. There are two types of types of inverters, the single phase and three phase inverter. Single phase uses only two conductors, live (L) and neutra l(N) and is used when low power is required. Three phase uses four conductors and used in industries because of its high efficiency in minimal losses. Generally most residential connections are single phase. Even if three phase connection is supplied, the inverter will only connect to one of those three phases, hence, single phase inveters are the common types.

To ensure proper switching for the inveter and appropriate switching between the two modes of operation, a controller is implemented. Thus controller design becomes an intergral part of the inverter design. Protection of the system is also important for safety measures where the inverter must be turned off if failure occurs. Hence, the goal of the project is to design and simulate a single phase dual-mode inverter and its controller.

## II. LITERATURE REVIEW

The crucial part of inverter design is the switching circuit because it ensures that proper/required output of the inverter is achieved. Inverters consist of switching devices which are typically MOSFETs, IGBTs, SCRs etc [1]. In most switching applications, e.g solar PV inverter and converter, motor driver systems, switch mode power supplies, etc. MOSFETs and IGBTs are predominant over other switching devices [2]. IGBTs are preferred for low frequencies, high voltage and more than $5kW$ output power appliances. They can handle more current than MOSFETs while MOSFETs are voltage-controlled power devices. The on-state resistance of a MOSFET is low which reduces the losses. The can operate at high frequencies, low voltages and suitable for faster switching with low voltage drop. MOSFETs are preffered for voltages around $500V$ [2]. The design of the inverter should therefore use MOSFETs for switching.

There are generally two topologies commonly used for inverter design which are Half-bridge and full H-bridge inverter. The most simple method is the half-bridge becauses it uses less semiconductors and easier to control the switching, however it needs higher blocking voltage power transistors which in turn increase the switching losses. Another disadvantage is that the semiconductors deal with $2V_dc$ meaning complex thermal cooling and the maximum AC output is half of the DC input [**?**]. The full H-bridge is better than Half-bridge because the AC ouptut amplitude is equal to the DC input, however due to more switching components the harmonic distortion increases. [3] shows that using multi-level switching can reduce distortion but this method requires more complex switching algorithms to be implemented. Hence the full H-bridge inverter topology is explored in this design.

Another crucial part of the inverter is the output waveform. Inverters can be classified as sine wave, modified sine wave and square wave inverter [4]. Most house appliances are designed to operate using pure sine wave and this design is expensive to implement compared to the other two [?]. Modified sine wave works for most equipments but has less power efficiency while square wave is the cheapest and runs simple things like tools with universal motors. The load of the system is resistive, hence the pure sine wave inveter is preffered. The goal is to obtain a stable output voltage with low total harmonic distortion (THD) and according to IEEE 519-1992 standard, the THD that is less than 5% is required. The distortion in the output can be reduced by selection a low pass filter. [5] implements a LC filter because of its good performance in noise damping. [6] using same inverter topology uses a LCL filter to reduce voltage harmonics and the design caters for both reactive and active current components to reduce the THD though it may be unstable due to resonance. Hence, a LCL filter is adopted for this design.

Sine pulse width modulation (SPWM) technique is preferred to obtain sinusoidal output voltage with reduced harmonics. The commonly used SPWM switching techniques for inverters are bipolar and unipolar switching. In bipolar switching, the diagonally opposite switches of the H-bridge inverter conduct simultaneously at the carrier frequency [7]. The H-bridge output voltage swings between positive DC input and negative DC input voltage level. In unipolar switching the two legs are controlled separately by comparing one carrier signal with control and its complementary signals. The bridge output voltage swings from positive DC input voltage level to 0 and negative DC input voltage level to zero [7]. Results from [8] shows that using a bipolar switching gives better results in a transformeless design because it reduces the current leakage better than unipolar. Thus the design adopts this type of switching. To model the output of the inverter a software simulation too LTSpice is used. There exists other simulation tools to model the inverter like Matlab [9] , multisim and pspice [10],[11]. LTSpice allows for easier simulating with different components unlike Matlab which has block diagrams where some of the components are treated as a black box.

Control of the output is another crucial part of the design in determining the system stability and performance dynamics. The inverter can be controlled using current source or voltage source. In grid-connected mode, current control is employed in inverters [12]. In island mode, there is no grid connection to regulate voltage and frequency profiles, and the inverter is required to determine the voltage and frequency of system, so the inverter generally adopts voltage-type control. Voltage control also known as droop contro, that uses voltage and current has been investigated. [13] added an extra phase loop to traditional droop control, which improved the systems dynamic response and maintained suitable damping performance. Xiaofei, et al. [14] proposed an improved design of the polynomial model mentioned in [13] and presented a state equation model of an inverter connected to the grid with droop control. These methods are suitable for simple single-phase inverters.

Other methods for controlling PWM exist such as self adaptive fuzzy controller[15] and MRAC [16]. The main disadvantage of this controllers is that they require micro-controllers and they are complex.

The goal is to design a dual -mode single phase inverter and controller for the switching of the modes, hence the rest of the paper is structured as follows. First an overview of the inverter design is presented which is followed by the design of the inverter. Section 5 shows the design of the controller circuit and protection of the system in section 6. Section 7 show the simulated results with their analysis, social impacts and critical discussion are presented in section 8 and 9 respectively. The last section concludes the paper design.

## III. SYSTEM OVERVIEW

The high level overview of the system is presented in Figure 1. The system is designed with the assumption that the MPPT circuit is functional and constantly supplies 400 V DC. A full H-bridge will be used for the design of the inverter. The H-bridge consist of four ideal switches which generate a sine wave output with the use of PWM. The two modes are encoparated by using two different controllers to drive the PWM circuit. The PWM alters based on the measurement of the inverter and grid voltage. For synchronisation, an ideal oscilator is provided as reference to the PWM circuit. The filtering stage ensures that a pure sine wave is generated. When the electric grid fails to deliver power, the grid monitoring circuit should open the connection between inverter and grid. When this occurs the inverter acts as a standalone voltage source inveter.

## IV. DESIGN OF INVERTER

The inverter design can be grouped as: H-bridge topology, low pass filter and measurement circuit.

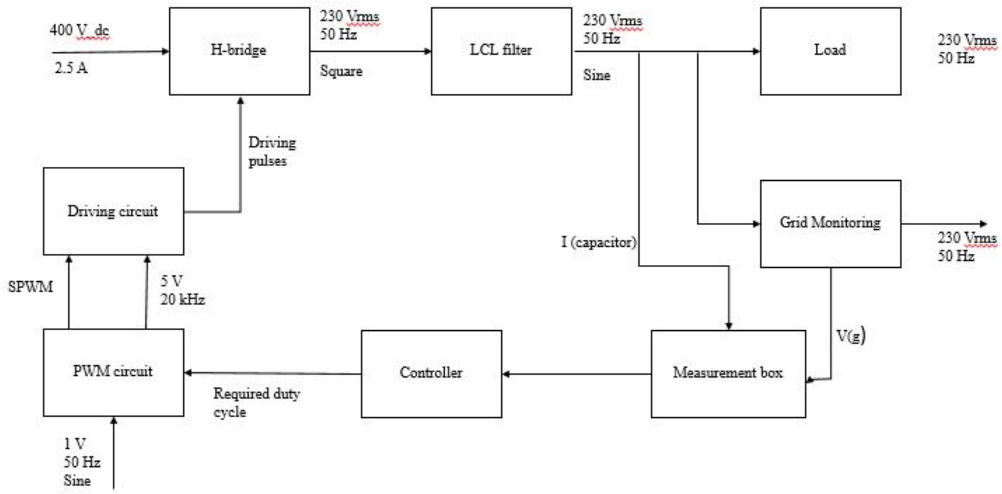


Fig. 1. General components of inverter

## *A. Inverter topology*

The inveter design consist of four N-channel MOSFETs switches configured as H-bridge and four protective anti-parallel diodes as shown by Figure 2. When switch M1 and M4 are closed (and M2 and M3 are open) a positive voltage will be applied across the load. When switch M2 and M3 are closed and the other two open, reverse voltage will flow and the diodes provide that conduction path. Switch M1 and M2 should never be open at the same time because this will cause a short circuit in the input known as shoot-through, and same applies to the remaining switches. The ac output will be of magnitude 230 $V_{rms}$ square wave at 50 Hz .

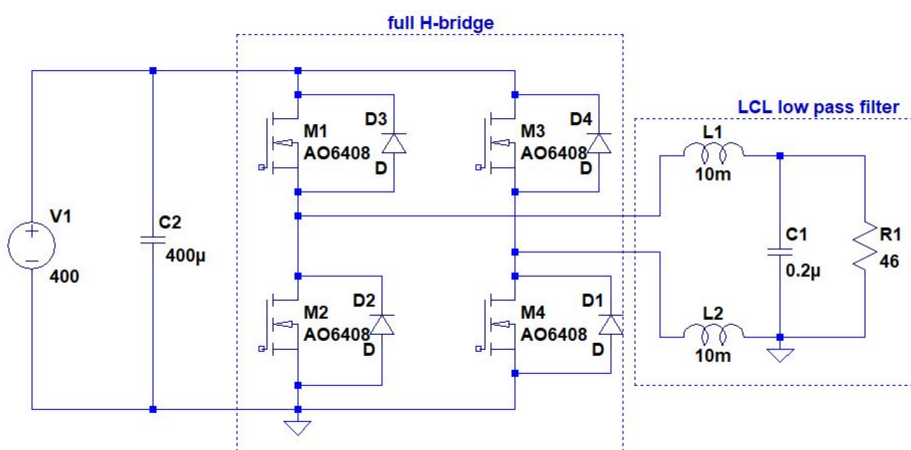


Fig. 2. Full H-bridge design and output filter

The input of the inverter is 400 V and depending on which switches are on, the output square wave is generated.The output has harmonics and it is a requirement for the inverter to have a pure sine wave as the load is resistive, hence a filter is needed to achieve the desired output.

## *B. Filter*

The system consist of a LCL filter that filters out the harmonics that are caused by the high switching frequency of the inverter bridge. This type of filter is more effective in reducing harmonics compared to other filters. The inverter design for grid-tie mode will satisfy the operation for standalone mode. The inverter side inductor is used to limit the maximum current ripple. The capacitance is chosen based on the reactive output power and the last inductor is chosen such that it reduces large volatge drop by limiting the current ripple to 20% of the rated current [6]. The purpose of the filter is to remove multiple harmonics generated by the system to obtain the fundamental harmonic which is a sine wave at 50 Hz required for powering the load.

### C. Measurement circuit

## V. CONTROLLER DESIGN

The controller design is split into two section, namely grid-tie control and standalone control.

### A. Grid-tie

### B. Standalone

## VI. SYSTEM PROTECTION

A very important consideration is the possibility of failures to the system. The components of the system can be exposed to high currents or over voltages that may result in deterioration or their breakdown. Hence, precautions are to be taken to ensure a safe operation of the inverter. Some of the most important risks will be analysed with proposed solutions for them.

### A. Overvoltage protection

On inverter, one of the common causes for overvoltage is the commutations of semiconductors. In real circuits, there are parasitic inductances due to conductors. When the semiconductors switch, current changes instantaneously and as a result there are overvoltages. One way to counteract this is by placing the components as close as possible []. The breakdown voltage varies for different MOSFETs and N-channel are chosen because they can handle higher voltages. In the case of gate-to-source voltage, its value should not exceed 20 V. in order to assure these values, a common solution it to use a zener diode between the gate and the source. Zener diodes are the best because unlike other diodes, when they are reversely polarized and the zener voltage is reached, they act as voltage regulators as they maintain this value. They do not allow MOSFETs to get into avalanche because of overvoltages.

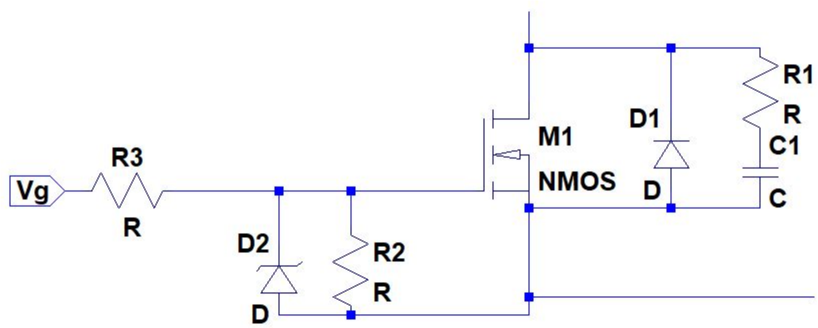


Fig. 3. Diagram of MOSFET protection for overcurrent

### B. Overcurrent protection

For a MOSFET, the continuous current can be up to 60 amperes but it must be noted that the current limits vary with the temperature of the junction. In the gate of the MOSFET there is a parasitic capacitance due to its internal structure. Therefore, switching of it can be modelled as the charge and discharge of this capacitance. It is thus admirable to minimise the switching time as the device deals with significant voltages and currents resulting in high losses. For this reason it is recommended to place a resistor between the driver and the gate to limit the current. The value of the gate resistor is determined by the maximum output voltage and current in the driver. The higher the value of the resistor, the longer the switching time, and therefore higher losses. In ideal switches, no current flows when they are open. Due to the small semiconductor low leakage current, the MOSFET gate capacitor can charge, turning it off and on or cause its destruction. To avoid this situation, a resistor between source and gate can be placed as shown in Figure 3. The value of the resistor should be high enough but below the limit determined by leakage current. Values are still to be calculated.

### C. Load overcurrent protection

At the time of designing it is important to define maximum values for the output. For safety reasons, the output current is not desired to be over 5A and the required resistance is therefore 46 ohm. For extra protection, a fuse can be placed in the output

## VII. SIMULATED RESULTS

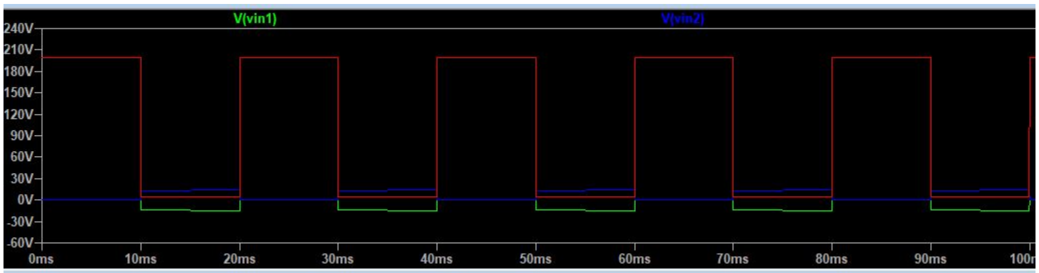


Fig. 4. The inverter with the pwm drive for the circuit

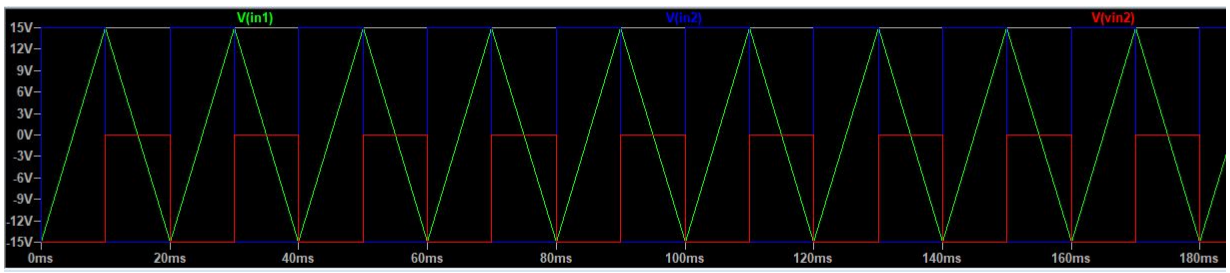


Fig. 5. The negative pwm side to drive the switches

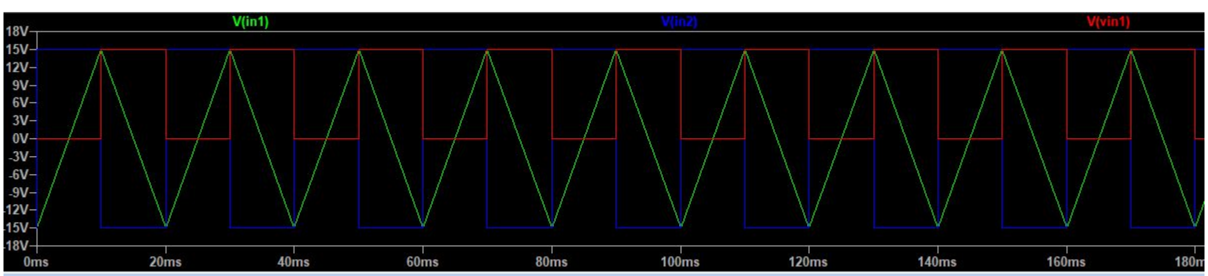


Fig. 6. The positive pwm side to drive the switches

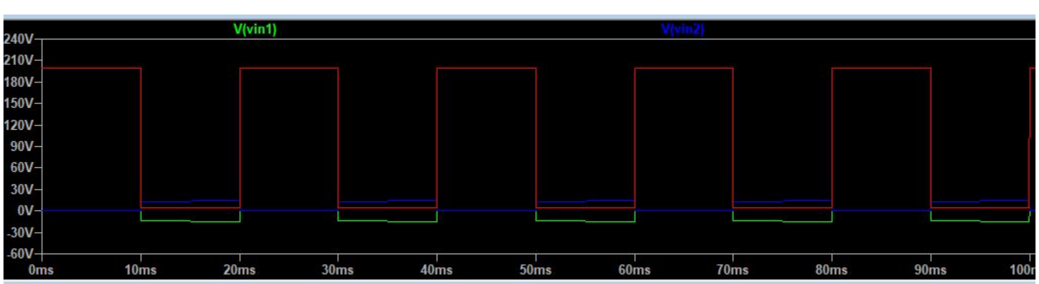


Fig. 7. The positive cycle of the inerter square output

# VIII. SOCIAL IMPACTS

# IX. CRITICAL ANALYSIS

# X. CONCLUSION

# XI. REFERENCES

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