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Grid Connected Inverter with Unity Power Factor for Renewerable Energy (PV) Applications

Amakye Dickson[1] N Mensah Sitti[2] Daniel Owusu Donkor[3] Nina Pearl Doe[4] Ernest A. Amakye[5]

[1]ME Scholar, Power Electronics and Drives Anna University CEG

[2,4]Dept. of CSE, Anna University, Chennai, India

[3]Dept. of CSE, Anna University, Chennai, India

[5]Newmont Golden Ridge Limited (Akyem Project) C825/26 Lagos Ave. East Legon, Accra Ghana.

***Abstract*— Low power factor presents a heavier generation and transmission burden on the power grid and also deposits a larger carbon footprint. Because of this, most tariffs have provisions allowing the utility to charge a penalty for low power factor. But it is possible to address this problem. The current source of grid connected inverter is implemented by controlled the voltage in phase with current in order to the power flows from variable dc source to power line all time. The system characteristic of the voltage and current of grid-connected inverter as before and after synchronization to power utility are investigated by using MATLAB/SIMULINK simulation and hardware experiment. The experiment results are given, which the inverter output voltage and current are sinusoidal at 50 Hz. of frequency, the both waveform are low harmonic distortion and the current is enforced in phase with the voltage both before and after synchronization all time.**

***Index Terms*— Grid Connected; Inverter; Power Factor; Solar (photovoltaic) Energy**

I INTRODUCTION

Reduction in of carbon dioxide emissions for the prevention of global warming is a big challenge for the entire world. Hence, Global energy crisis encouraged for research and development in new clean energy sources to outwit harmful effects from existing conventional sources. As a result more renewable energy sources are introduced in system like wind, geothermal and solar etc. Solar energy is often called as non- emission based source. Now a day's renewable energy contribution for world is approximately 30% as compared with other non renewable sources. At this condition the renewable sources are secondary sources till now, but it will becomes primary at the end of 2035 [1.]

In tropical countries like India, as well as other places where solar energy is available in abundance, photovoltaic (PV) has emerged as a major candidate for meeting the energy demand. It offers an option for clean (pollution free) energy source, with almost no running and maintenance cost. However, the cost factor remains a major impediment. While the cost of the PV itself contributes to about 57% of the total cost of the system, the cost of battery and inverter (with maximum power point tracking (MPPT) control) amounts to 30% and 7% respectively [2]. Due to increased attention and research efforts in the PV technology, it is expected that the cost of PV will decrease to 1 U.S.$ per watt by the year 2020 [3]. However, to decrease the total cost of a PV system, it is necessary to decrease the cost of other components (inverter components, storage devices etc). Residential energy conservation is also an important issue. Because power conservation will reduce cost, methods to reduce wasteful energy consumption without the consciousness of the consumer are required. Home Energy Management System (HEMS) is mentioned as a solution that can be used to reduce energy consumption and achieve energy conservation [3, 4]. Currently, PV systems are widely used in houses, and a stand-alone mode must be done manually, though it is possible to supply power to only emergency outlets. Also, the transition to grid-connected mode from the stand-alone mode must be switched manually. Solar energy sources are suffering from high capital cost and less efficiency as compared to wind. Now day's solar cells are manufactured with mono and polycrystalline basis. Generally monocrystalline solar cells are having high efficiency (16-20%). PV system gaining more popularity due to following reasons,

- Improved technology for manufacturing of solar cell in terms of material, non- reflective coating glass etc.

- Monocrystalline cells are higher efficient and acquires less space for installation as compared to polycrystalline. Thus installation cost and floor area is reduced and requires less maintenance and reduced number of labors.
- Encouragement from government by giving 40% capital financial support on renewable systems. Although it's true that benefits gained from solar systems, it yields certain drawback factors which is also taken into account like:
- Higher Capital cost, Installation cost, and lifecycle of Inverter and energy storage system.
- Irregular solar radiations, Environmental and seasonal weather conditions.
- Partial shading effects, Mismatching PV array behavior.
- Grid islanding and fault conditions etc.

Inverters are also classified on the basis of single and multi-stage type. In single or mono stage inverter PV arrays are connected in series and parallel in order to maximize output voltage and current. Later these PV arrays fed to AC- DC converter and connected to grid. Multi-stage inverters consists group of PV modules which is individually connected to converter. Advantage of this system is that if any one PV module or array gets out of service or faces partial shading, system will continues producing power with reduced capacity. Efficiency of multi-stage inverter is also high as compared to single stage.

II THEORY

A PV CONVERSION

PV cells are semiconductor devices with electrical characteristics similar to that of a diode. However, a PV cell is a source of electricity and operates as a current source when light energy, such as sunlight, makes contact with it. The most common technologies today are the monocrystalline and multi-crystalline silicon modules. A PV cell can be modeled as shown in Figure 1. Rp and Rs are parasitic resistances that, in an ideal world, would be infinite and zero, respectively.

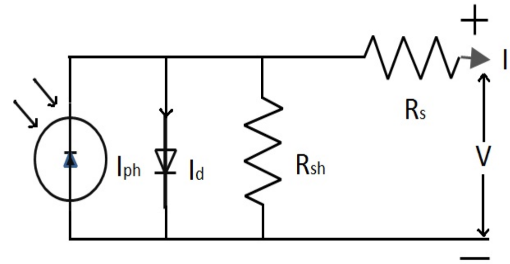


Fig. 1 equivalent circuit of PV

The electrical equivalent of PV cell is shown in figure 1. The generated current can be found from this equation:

I=Iph-Id-(V-IRs)/Rsh [1]

and,

Iph= Iscr +K[T-Ti]×G/1000 [2]

Id= Io [exp(q(V+ IRs) /α KT) -1]- V+IRs / Rsh [3]

Where,

Iscr = short circuit current of PV cell,
K= Boltzmann's constant (1.381×10-23 J/K)
T= Reference temperature ok
Ti= actual temperature ok
G= Solar Irradiance in w/m2
q =electron charge (1.602×10-19C)
Io= saturation current
A= diode ideality constant.

Short circuit current is a function of solar irradiance, temperature is of voltage. From equation 2 its found that temperature goes on increasing, PV voltage gets reduced. Due to this it exerts non-linear characteristics. Hence need of implementation of maximum power point tracking is required. Rs contact resistance which is negligible. The maximum peak power is shown in fig.2.

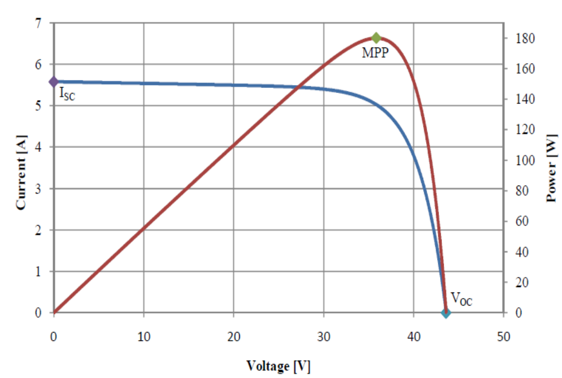


Fig.2 I-V and PV characteristics of PV cell

A real solar cell can be characterized by the following fundamental parameters, which are also sketched in Fig. 2.

• Short circuit current: Ish = Iph. It is the greatest value of the current generated by a cell. It is produce by the short circuit conditions: V = 0.

• Open circuit voltage correspond to the voltage drop across the diode (p-n junction), when it is transverse by the photocurrent Iph (namely IL = Iph), namely when the generated currents is I = 0.

B. GRID CONNECTED INVERTER

The grid-connected inverter is important to couple between the PV generator and utility system. It acts as bridge to transfer the power that produces from PV cells to utility. However, the inverters must produce good-quality sine-wave output, must follow the frequency and voltage of the grid. The inverter must observe the phase of the grid, and inverter output must be controlled both voltage and frequency variation. There are two broad categories of inverter control techniques, namely voltage and current control. Each type of control has a specific use. Voltage control is not employed for a grid connected inverter since the voltage on the output is generally dictated by the grid/utility power source. Instead current control is used to export a predetermined amount of current. With the effective value of the grid voltage being approximately constant this corresponds to a predetermined level of power transferred to the grid. Maximum Power Point Tracking (MPPT) can be utilised with current controlled photovoltaic connected inverters by monitoring both the photovoltaic voltage and current, and maximising the power by varying the amount of exported power. The source is not necessarily characterized by the energy source that it is an inverter topology characteristic. It is practicable to substitute from one source type to another source type by addition of inductor. In voltage source inverter, the dc side is made for dc source of the inverter. The voltage-source inverters have a capacitor in parallel with the dc input whereas the current source inverters have an inductor in series with the dc input. The simplify converter topology of grid-connected are shown in figure 3&4. The grid-connected converter can operate in two functions; inverter and rectifier, depending on current controlling.

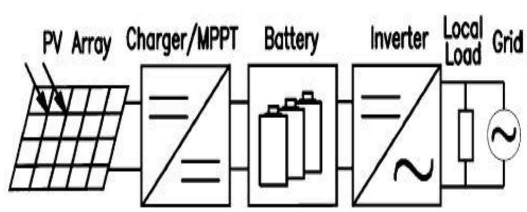
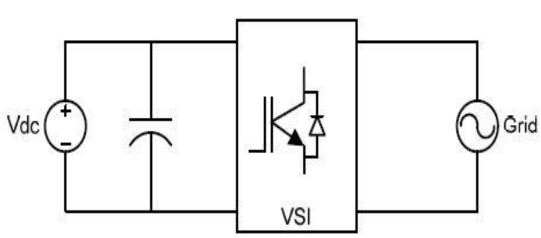
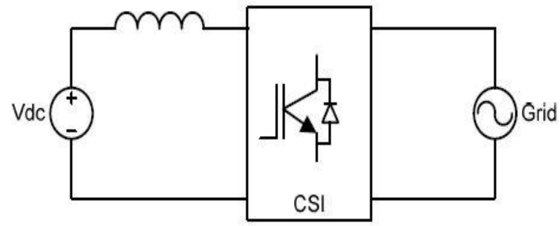


Fig.3 PV connected system



(a)



(b)

Fig.4 Simplify converter topology of grid-connected (a) VSI topology (b) CSI topology

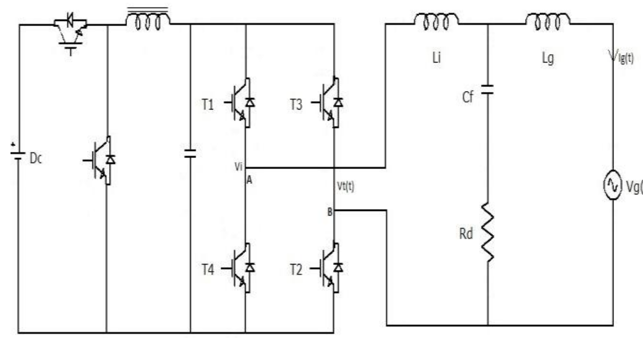


Fig5: Power stage circuit configuration single phase PV full-bridge inverter.

The purpose of the full-bridge single-phase inverter is to provide a voltage across the inductor to generate a current as defined by the equation below:

$$i_L(t)=\frac{1}{L}\int V_L\,dt + c \quad [4]$$

where V_L is the voltage across the inductor and C is a constant of integration.
For low voltage application CSI voltage is not suitable hence additional buck converter is used. For minimizing CSI switching losses, new reverse blocking IGBT techniques are employed. [6], this reduces the power loss and increases efficiency of system.
HF link inverter is used between DC-DC converters. The inverter is used to converts the direct input voltage into an HF square wave, which, in turn, is rectified and filtered using LPF low pass output is a high-level direct voltage that is converted into a low frequency wave. In an alternative version, the HF bridge inverter produces an HF PWM wave, thus reducing the transformer losses [5, 6].

III COMPUTER SIMULATION AND RESULTS

The simulation is implemented using MATLAB/SIMULINK that is shown the simplified diagram for simulation is shown in figure 6. and the simulation results expresses in figures below. The following equations are used for defining different values in the simulation;

$$V_g=A_g\sin(2\pi f_g t) \quad [5]$$

$$V_R=A_R\sin(2\pi f_R t+\phi) \quad [6]$$

The DC-DC converter converts non-constant voltage from renewable resources into a constant 24V DC voltage and supplies it to the inverter. The inverter converts this DC voltage to AC and feed to the grid at unit power factor. Before synchronization, the results show the output voltage and current of inverter are sinusoidal at frequency 50 Hz. including the voltage in phase with the current as depicted in fig. 7. The inverter voltage nearly equals the magnitude and frequency with utility voltage. Also phase of grid voltage and utility are the same. After synchronization, the voltage and current waveform remain sinusoidal and unity power factor.

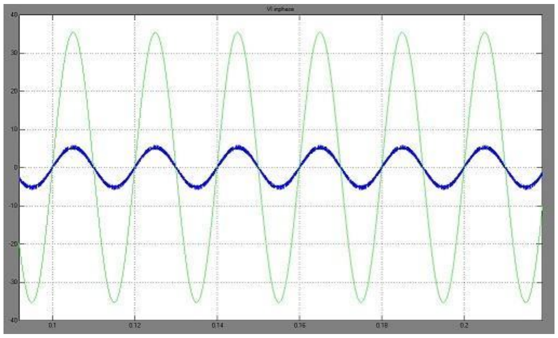


Fig 7 MATLAB/IMULINK simulation result

PV conditions are divided into two stages namely low insolation and high insolation. For the low insolation condition, the power from the PV is only transferred to the load due to produced low energy. Fig.8 shows that the mains supply current waveform is nearly sinusoidal and in-phase with respect to the grid voltage. As a consequence, power factor is nearly unity. For the high insolation condition, the power from the PV is transferred to the load and the grid due to produced excess energy. Fig.9 shows that the mains supply current waveform is nearly sinusoidal and out of phase with respect to the grid voltage. This shows that the power generated from the PV is transferred to the grid and the nonlinear load. According to the obtained results, it shows that the proposed system is able not only to transfer energy produced from the PV but also to filter the power harmonics out from the grid.

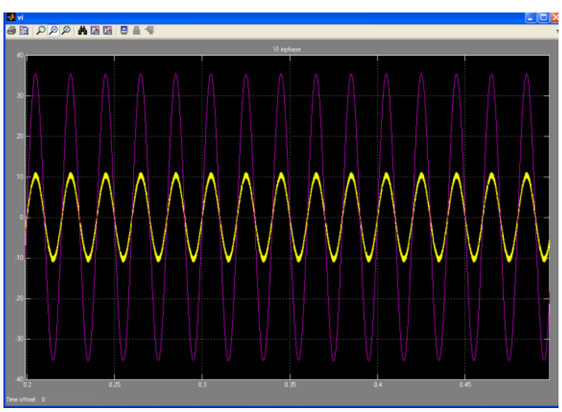


Fig.8. Supply voltage and current in phase

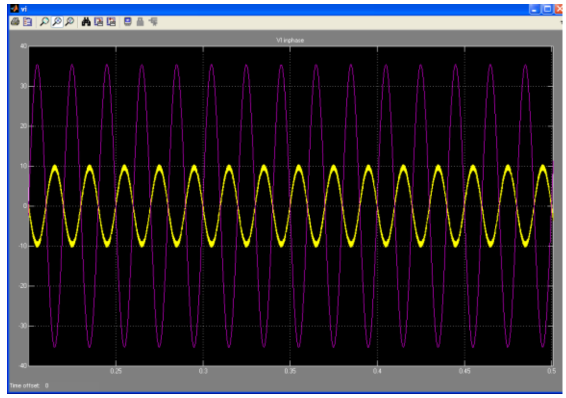


Fig.9. Supply voltage and current out of phase

PARAMETERS	VALUES
Frequency of the grid voltage f_g	50Hz
Nominal DC link Voltage V_{dc}^n	400V
Rated grid voltage V_g^{rated}	250(RMS)
Switching frequecy f_{sw}	10-45KHZ
Rated grid current I_g^{rated}	10A
Percentage DC-link voltage ripple (peak to nominal)	10%
Phase diference between the grid and reference current, ϕ	0^0
Bridge side inductor L_i	300uH
Filter capacitor C_f	30uF
Filter damping resistor Rd	1.5Ω
Amplitude of the grid voltage Ag	339.4V

Table- 1: parameters used

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IV HARDWARE DESCRIPTION

The hardware experiment interface configuration of grid connected experiment shows in figure 5. DC-Dc convreter is fed from a fluctuating Dc source to be converted to fixed Dc value of 24V. this falls to be the input for the inverter. The full H-bridge inverter consits of four IRF540 (N-channel, enhancement) MOSFET switches rated for 60 to 100V and 27A, with fast switching time (22 nSecond rise times and 25 nSecond fall times). This switch also has ultra low resistance (90 mΩ), resulting in less power dissipation and higher efficiency.

The IFR540 MOFET switches were driven using four fully isolated IR2110 drivers to ensure that no voltages or currents damage the control hardware. The IR2110 is a high voltage half- bridge gate driver designed to drive both the high side and the low side N-Channel MOSFETs in a synchronous buck or half bridge configuration. The rising edge of each output can be independently delayed with a programme. The PWM gate pulses to drive the MOSFET are generated using Arduino ATmega 328 microprocesor which turns at a clock peed of 16MHz. The Op-Amps and transistors convert the two PWM signals coming from the microcontroller into four signals going to the MOSFET drivers. Optocouplers 6N25 are used to electrically isolate the electronic low voltage circuits from the power electronic section that includes the MOSFETs and drivers that are higher voltage.the inverter is connected to an inductor and capacitor. The cut off frequency of the LC filter is:

$$F_c = \frac{1}{2\pi\sqrt{LC}} \qquad [7]$$

For L=37mH and C=2.6μF, Fc=513Hz

The output impedance (Z) of the filter is given by

$$Z = \frac{1}{2\pi\sqrt{f c C}} \qquad [8]$$

With the same values for L and C, Z= 4.26Ω

Again damping resistors are connected in parallel with the capacitor to match the input impedance of the grid in order to improve the output waveform and maximize the power transfer to the grid.

The inverter tracks the phase and frequency of the grid waveform, and generates output signals to drive the low and high-side switches of the H-bridge. A sketch of the hardware interface architecture is presented in fig. 10

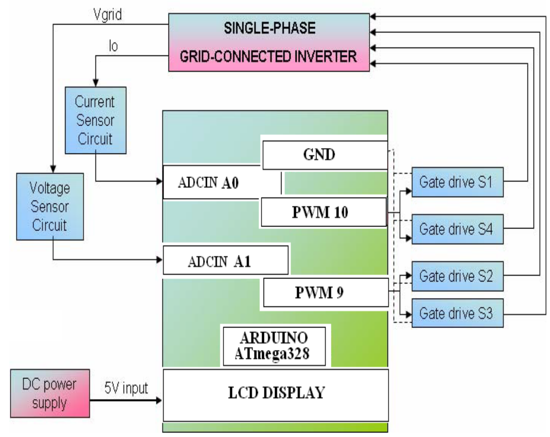

Fig-10: Hard ware interface Architecture

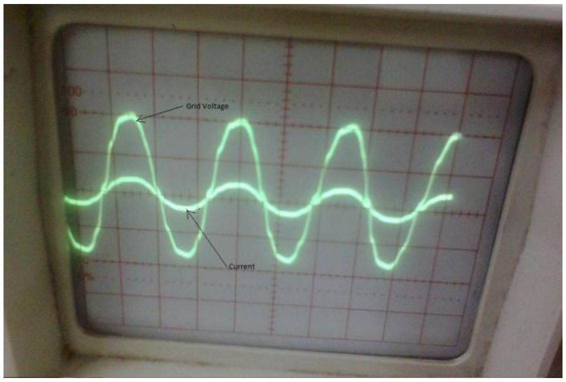

Fig.11 Inverter voltage and grid voltage before and after synchronized to grid

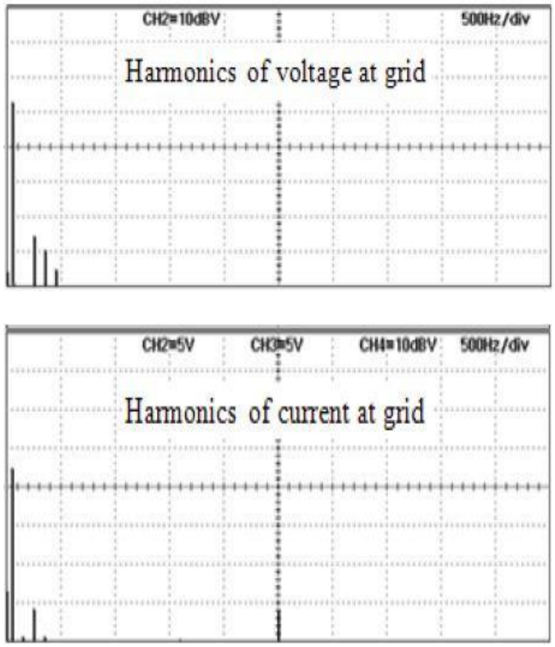

Fig.12 Harmonics of voltage and current wave form of output grid-connected inverter after synchronize to grid

The experiments investigate the system characteristic of the voltage and current of grid-connected inverter as before and after synchronization to grid conditions by using simulation and hardware experiment. The experiment results in figure 11 show that the comparison the inverter voltage and grid voltage before and after synchronize to grid. When the grid connection is achieved, the inverter voltage is enforced to follow the grid voltage. The waveform of voltage and current are purely sine wave resulting to the harmonic of them are minimal when compare with before synchronize. The harmonic histogram results of voltage and current after synchronize are shown in figure 12.

V. CONCLUSIONS

Thus this paper investigates the modeling and simulation to obtain the characteristic of the voltage and current of grid-connected inverter as before and after synchronization to grid utility by using simulation and hardware experiment.. The power is only transferred from the PV to the nonlinear load for a low value of the insolation. For a high value of the insolation, the power is transferred from the PV to both the nonlinear load and the grid. The obtained power factor is nearly unity. The experiment results before synchronization demonstrate the output voltage and current of inverter are sinusoidal at frequency 50 Hz. and in phase. The amplitude and frequency of inverter voltage equals to utility voltage and phase of grid voltage and utility are the same. After synchronization, the voltage and current waveform remain sinusoidal and unity power factor. This system can use for stand-alone and for grid connected for others renewable power application.

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