Design and Simulation of PV Power Generation with Analysis of Grid Interconnection

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Abstract **- Compared to the traditional energy resources, photovoltaic (PV) system that uses the solar energy to produce electricity considered as one of renewable energies has a great potential and developing increasingly fast compared to its counterparts of renewable energies. The system needs no battery so therefore the system price is very cheap.**

A grid-connected photovoltaic power system with high voltage gain is proposed, and the steady-state model analysis and the control strategy of the system are presented in this paper. For a typical PV array, the output voltage is relatively low, and a high voltage gain is obligatory to realize the grid-connected function. The proposed PV system employs a ZVT-interleaved boost converter with winding-coupled inductors and active-clamp circuits as the first power-processing stage, which can boost a low voltage of the PV array up to a high dc-bus voltage. Accordingly, an accurate steady-state model is obtained and verified by the simulation and experimental results, and a full-bridge inverter with bidirectional power flow is used as the second power-processing stage, which can stabilize the dc-bus voltage and shape the output current. Two compensation units are added to perform in the system control loops to achieve the low total harmonic distortion and fast dynamic response of the output current. Furthermore, a simple maximum-power-point-tracking method based on power balance is applied in the PV system to reduce the system complexity and cost with a high performance.

The disadvantage is that PV generation depended on weather conditions. An LC filter also is necessary to filter the output current and voltage from the harmonics and protect the grid from their destructive effect. This paper presents detailed modeling of the grid-connected photovoltaic generation system in Simulink / MATLAB softwares 2012.

Keywords: *Grid Connected PV Systems, ZVT-interleaved boost converter, PV array, Maximum-Power-Point-Tracking.*

I. INTRODUCTION

Today photovoltaic (PV) power systems are becoming more and more popular, with the increase of energy demand and the concern of environmental pollution around the world. Grid-connected photovoltaic power systems are power systems energized by photovoltaic panels which are connected to the utility grid. In the grid-connected PV system, power electronic inverters are needed to realize the power conversion, grid interconnection, and control optimization.

First, the dc-bus voltage of the inverter should be stabilized to a specific value because the output voltage of the PV modules varies with temperature, irradiance, and the effect of maximum power-point tracking (MPPT). Second, the energy should be fed from the PV modules into the utility grid by inverting the dc current into a sinusoidal waveform synchronized with utility grid. The inverter-based PV system, the conversion power quality including the low THD, high power factor, and fast dynamic response, largely depends on the control strategy adopted by the grid-connected inverters.

The most important design constraint of the PV DG system is to obtain a high voltage gain. The grid connected PV system includes two power processing stages: a high step-up ZVT-interleaved boost converter for boosting a low voltage of PV array up to the high dc-bus voltage, which is not less than grid voltage level; and a full-bridge inverter for inverting the dc current into a sinusoidal waveform synchronized with the utility grid. For a typical PV module, the open-circuit voltage is about 21V and the dc–dc converter is responsible for the maximum power point (MPPT) voltage is about 16 V. The grid-connected PV power system can offer a high voltage gain and guarantee the used PV array voltage is less than 50 V, and the utility grid voltage is 220 or 110 Vac.

Therefore, the high voltage amplification is obligatory to realize the grid-connected function and achieve the low total harmonic distortion (THD). The required quantity of PV modules in series is greatly reduced.

II. GENERAL OVERVIEW OF PV TECHNOLOGY

Photovoltaic offer consumers the ability to generate electricity in a clean, quiet and reliable way. Photovoltaic systems are comprised of photovoltaic cells, devices that convert that convert light energy directly into electricity. Because the source of light is usually the sun, they are often called solar cells. The word photovoltaic comes from "photo" meaning light and "voltaic" which refers to producing electricity therefore, the photovoltaic process is producing electricity directly from sunlight photovoltaic are often referred to as PV.

A) PV Energy Advantages:

1. It is plentiful and sustainable. The sun provides 6000 times more than the energy consumed by humans.
2. It is clean and safe. PV will not cause environmental problems such as greenhouse effect, acid rain, deforestation and noise. Its use is pollution free; manufacturers of PV materials are committed to minimize pollution during production.
3. It is more reliable. PV power generation has no moving parts and the maintenance costs are very low. When used as a distributed generation source, it can improve grid reliability and reduce the need for transmission lines.
4. PV devices have a very long life, up to 3 times longer than other renewable technologies.

B) Types of Photovoltaic System:

PV technology was first applied in space, by providing electricity to satellite today. PV systems can be used to power to just about anything on Earth. On the basis working operation PV systems operate in four basic forms.

i) Grid Connected PV Systems:

These systems are connected to a broader electricity network. The PV system is connected to the utility grid using a high quality inverter, which converts DC power from the solar array into ac power that conforms to the grid's electrical requirements. During the day the solar electricity generated by the system is either used immediately or sold off to electricity supply companies. In the evening when the system is unable to supply immediate power, electricity can be bought back from the network.

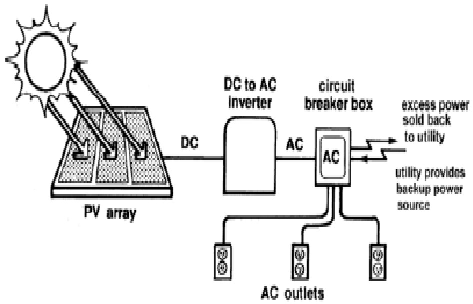

Fig.1. Grid Connected PV systems.

ii) Standalone Systems:

PV systems not connected to the electric utility grid are known as off grid PV Systems and also called 'stand-alone systems' direct systems use the PV power immediately as it is produced, while battery storage systems can store energy to be used at a later time , either at night or during cloudy weather. these are used in isolation of electricity grids, and may be used to power radio repeater stations, telephone booths and street lighting PV systems also provide invaluable and affordable electricity in developing countries like India, where conventional electricity grid are unreliable or non-existent.

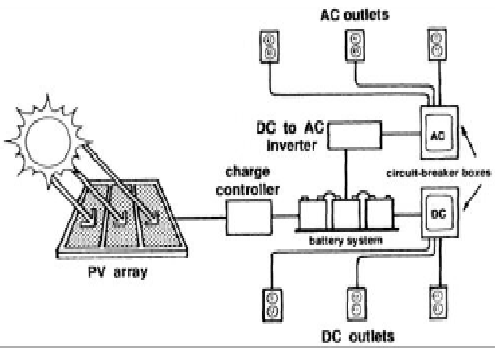

Fig. 2. Off Grid PV System.

C) *Preference of Grid Connected PV System:*

Because as day by day the demand of electricity is increased and that much demand cannot be meeting up by the conventional power plants. And also these plants create pollution. So if we go for the renewable energy it will be better but throughout the year the generation of all renewable energy power plants. Grid tied PV system is more reliable than other PV system. Nonuse of battery reduces its capital cost so we go for the grid connected topology .if generated solar energy is integrated to the conventional grid. It can supply the demand from morning to afternoon (total 6 hours mainly in sunny days) that is the particular time range when the SPV system can fed to grid .as no battery Backup is there, that means the utility will continue to the rest of the time period grid-connected systems have demonstrated an advantage in natural.

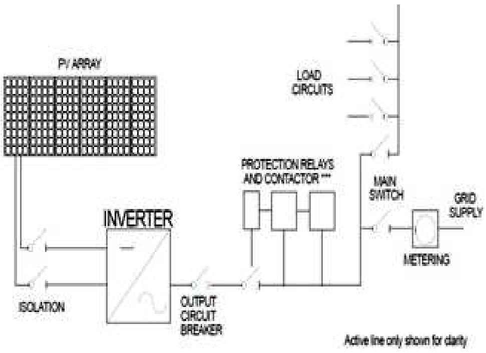

Fig.3. A grid connected system with basic main components of the system.

III. PROPOSED GRID-CONNECTED PV POWER SYSTEM

A) Steady-State Model of High Step-Up ZVT-Interleaved Boost Converter:

Fig.3.1 shows the proposed grid-connected PV power system with the ZVT-interleaved boost converter with winding-coupled inductors and active-clamp circuits. The winding-coupled inductors offer the voltage-gain extension. The active clamp circuits realize the ZVT commutation of the main switches and the auxiliary switches. As shown in Figure 4, *S*1 and *S*2 are the main switches; *S*c1 and *S*c2 are the active lamp switches; *D*o1 and *D*o2 are the output diodes. The coupling method of the winding-coupled inductors is marked by open circles and asterisks. Each coupled inductor is modeled as the combination of a magnetizing inductor, an ideal transformer with corresponding turns ratio and a leakage inductor in series with the magnetizing inductor. The proposed converter, the full-bridge dc–dc converter is employed commonly as a similar first stage in the PV system. However, for the high step-up gain applications, the large current ripples of the primary side.

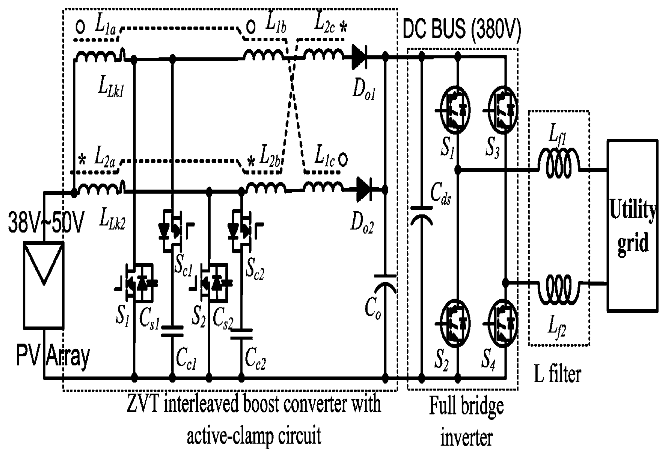

Fig. 4. Proposed grid-connected PV power system.

The ZVT-interleaved boost converter has the following three main advantages.

1. Voltage gain is extended greatly by using a proper turns ratio design. As the turns ratio increases, the voltage gain increases without the extreme duty ratio, which can reduces the input and output current ripples. Omitting the effect of the leakage inductance and applying the voltage

second balance to the magnetizing inductor, the voltage gain is given by

$$M = \frac{Vout}{Vin} = \frac{N+1}{1-D} \quad (1)$$

2. Voltage stress of the main switches is reduced, as the turns ratio increases. Therefore, the low-voltage and high performance devices can be used to reduce the switching and conduction losses. And the voltage spikes are clamped effectively and the leakage energy is recovered. If the clamp capacitance is assumed large enough and the voltage ripple on the switches can be ignored when they turn off, the normalized voltage stress of the main switches is given by

$$Vds = \frac{Vout}{N+1.} \quad (2)$$

3. ZVT soft switching is achieved for both main switches and auxiliary switches during the whole switching transition, which means the switching losses are reduced greatly. Diode reverse-recovery loss is greatly reduced because the d*i*/d*t* of the diode current is controlled by the inherent leakage inductor of a coupled boost inductor.

B) Control Strategy of Full-Bridge Inverter with Bidirectional Power Flow:

The full-bridge inverter works as a voltage-source PWM (VS-PWM) converter in this paper, which implements the bidirectional power flow. By using a direct-current-control strategy, the VS-PWM converter can force the instantaneous load current to accurately follow the sinusoidal reference, which synchronizes with the utility grid voltage. And the high power factor, the low THD and the fast dynamic response are achieved. Furthermore, the bidirectional flow of power facilitates the compensation of the dc-bus and the ac-side voltage variations, which helps to stabilize the dc-bus voltage in startup and cloudy situations and improves the stability of overall system. Fig. 5 shows the control block of the two-stage grid-connected PV system. Fig. 6 shows the control block of the full-bridge inverter with bidirectional power flow.

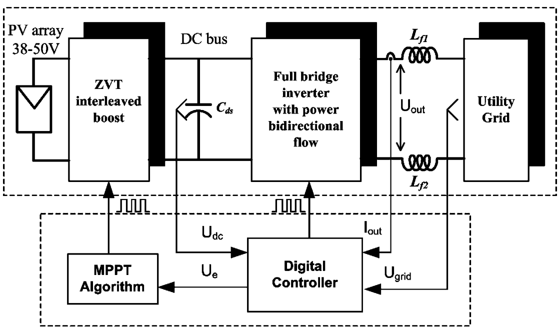

Fig. 5. Control block of two-stage grid-connected PV system.

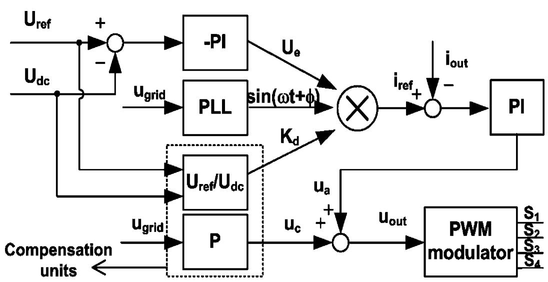

Fig. 6. Control block of full-bridge inverter with bidirectional power flow.

C) Maximum Power Point Tracking (MPPT):

The rapid increase in the demand for electricity and the recent change in the environmental conditions such as global warming led to a need for a new source of energy that is cheaper and sustainable with less carbon emissions. Solar energy has offered promising results in the quest of finding the solution to the problem. The harnessing of solar energy using PV modules comes with its own problems that arise from the change in insulation conditions. These changes in insulation conditions severely affect the efficiency and output power of the PV modules. A great deal of research has been done to improve the efficiency of the PV modules. A number of methods of how to track the maximum power point of a PV module have been proposed to solve the problem of efficiency and products using these methods have been manufactured and are now commercially available for consumers. As the market is now flooded with varieties of these MPPT that are meant to improve the efficiency of PV modules under various insulation conditions it is not known how many of these can really deliver on their promise under a variety of field conditions. This research then looks at how a different type of converter affects the output power of the module and also investigates if the MPPT that are said to be highly efficient and do track the true maximum power point under the various conditions.

A MPPT is used for extracting the maximum power from the solar PV module and transferring that power to the load. A dc/dc converter (step up/ step down) serves the purpose of transferring maximum power from the solar PV module to the load. A dc/dc converter acts as an interface between the load and the module Figure. By changing the duty cycle the load impedance as seen by the source is varied and matched at the point of the peak power with the source so as to transfer the maximum power.

Therefore MPPT techniques are needed to maintain the PV array's operating at its MPPT. Many MPPT techniques have been proposed in the literature; examples are the Perturb and Observe (P&O) methods, Incremental Conductance (IC) methods, Hill climb search (HCS) etc.

The problem considered by MPPT techniques is to automatically find the voltage V_{MPP} or current I_{MPP} at which a PV array should operate to obtain the maximum power output P_{MPP} under a given temperature and irradiance. It is noted that under partial shading conditions, in some cases it is possible to have multiple local maxima, but overall there is still only one true MPP. Most techniques respond to changes in both irradiance and temperature, but some are specifically more useful if temperature is approximately constant. Most techniques would automatically respond to changes in the array due to aging, though some are open-loop and would require periodic fine tuning. In our context, the array will typically be connected to a power converter that can vary the current coming from the PV array.

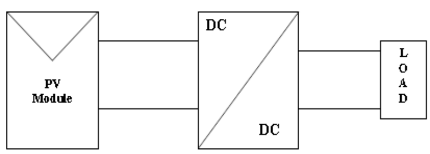

Figure: 7. Block diagram of Typical MPPT system.

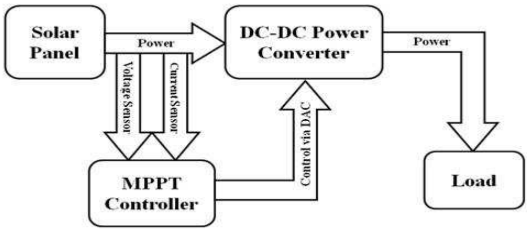

Figure 8. DC – DC converter for operation at the MPPT.

The location of the MPP in the *I–V* plane is not known beforehand and always changes dynamically depending on irradiance and temperature. For example, fig 19 shows a set of PV *I –V* curves under increasing irradiance at the constant temperature (25^{o}C), there are observable voltage shifts where the MPP occurs. Therefore, the MPP needs to be located by tracking algorithm, which is the heart of MPPT controller.

D) Benefits of Grid-Connected PV Systems:

By reducing the need for fossil-fuel generation, grid-connected PV cuts greenhouse gas emissions (and other air pollution), because no emissions are produced during PV operation. In the past there has been concern about the green house gases emitted ('embodied') in the manufacture of PV systems, particularly in the production of ultra-pure semiconductors. With current production techniques, these embodied greenhouse gases are saved within two to four years of use of grid-connected operation, depending on the amount of sunlight.

PV is the easiest renewable electricity source to incorporate into buildings. The electricity is supplied at the point of use, thus avoiding the losses which occur in electricity distribution. It can be easily installed on large public buildings, It is simple and reliable. Because of this, it is a valuable way to raise awareness of electricity supply and use, and helps highlight the potential for renewable energy. Several schools and colleges are installed PV, to supply part of their electricity and as an education aid.

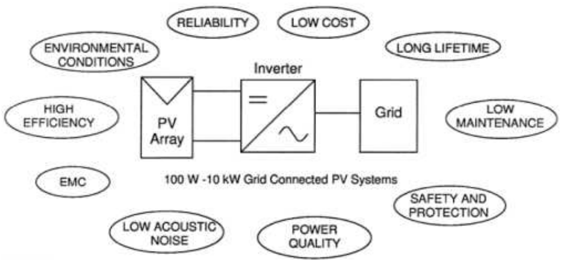

Fig. 9. Issues regarding grid connected PV systems.

IV. SIMULATION RESULTS

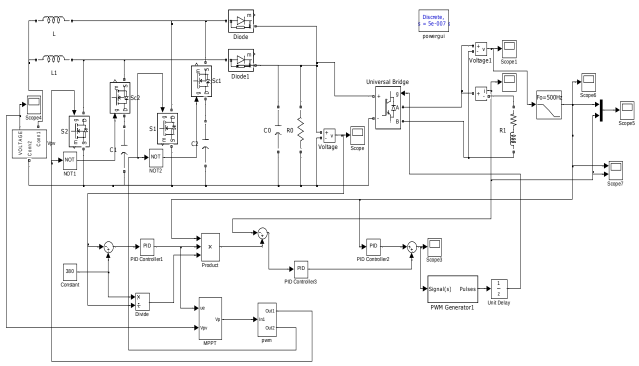

Figure 10. Simulation for Closed Loop System.

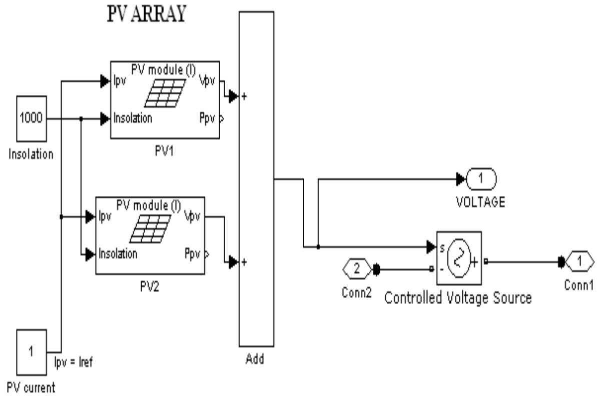

Figure 11. PV Array.

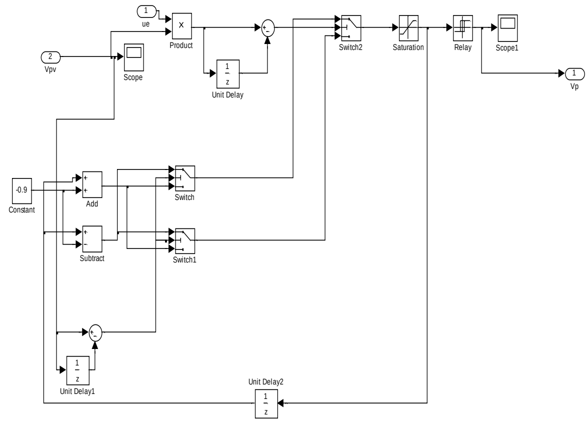

Figure 12. Sub-System for MPPT.

A) Simulation:

To confirm the theoretical analysis in the previous sections, a 2-kW prototype of the proposed grid-connected PV power system was built. Two ZVT-interleaved boost converters of 1 kW are connected in parallel via a dc bus through a central inverter of 2 kW to the grid. The lower power dc–dc converters are connected respectively to the individual PV arrays, and the central inverter can expand the power rate and reduce the system cost.

If suppose single block is designed for 50v grid voltage is 500 we need to connect 500/50v = 10 blocks in cascaded connection. If suppose another customer required 1000 v we need to connect 20 blocks in cascade. 1000/50. So we need not to re design our system for different grid voltage. From the figure 9 by selecting the Harmonic Order we can find the Total Harmonic Distortion (THD). With this proposed system the Total Harmonic Distortion (THD) has been reduced to 3.7%.

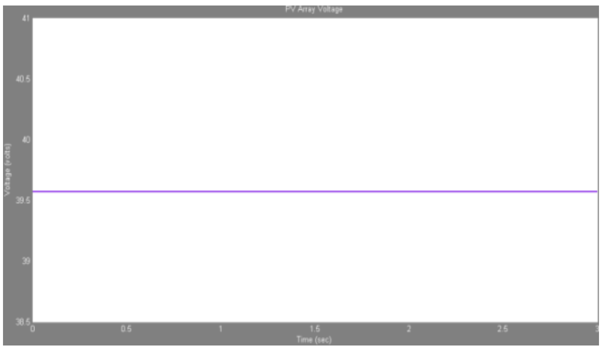

Figure 13. PV Array Input Voltage.

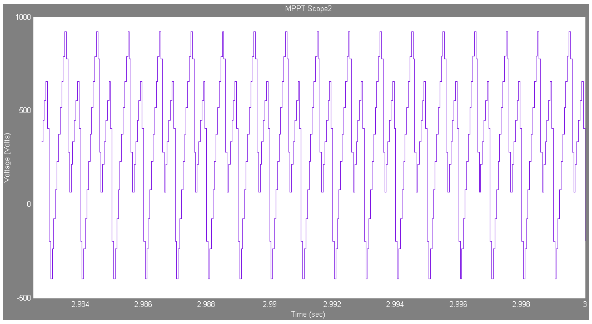

Figure 14. Output of the Solar Unit (or) MPPT Voltage.

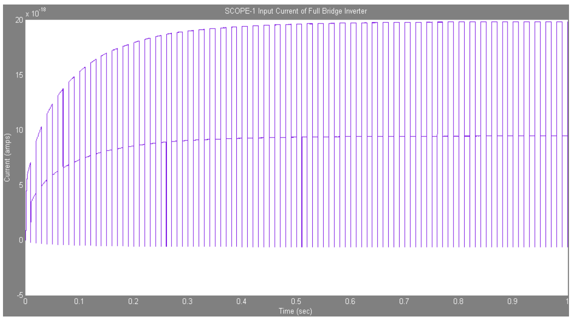

Figure 15. Scope-1 Input current measurement 1.

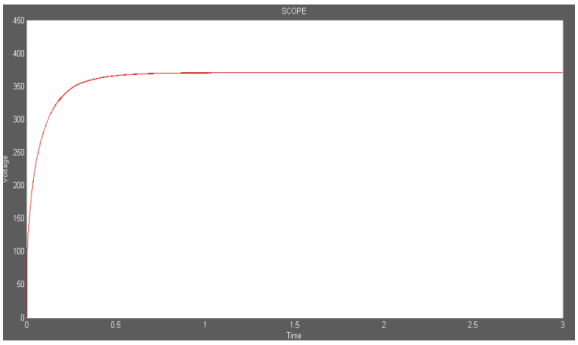

Figure 16. Output of the DC – DC Boost Converter.

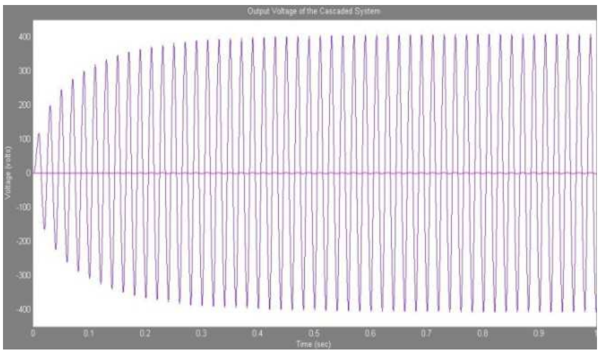

Figure 17. Output of the cascaded system.

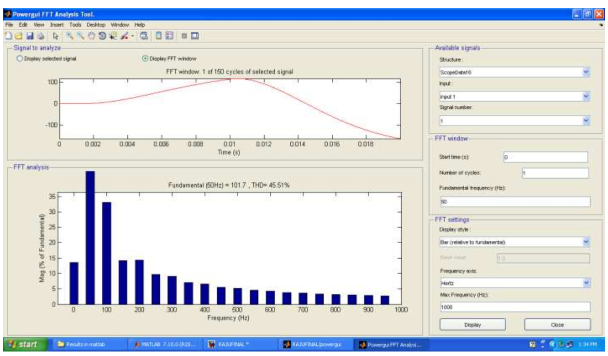

Figure 18. FFT Analysis Tool-THD.

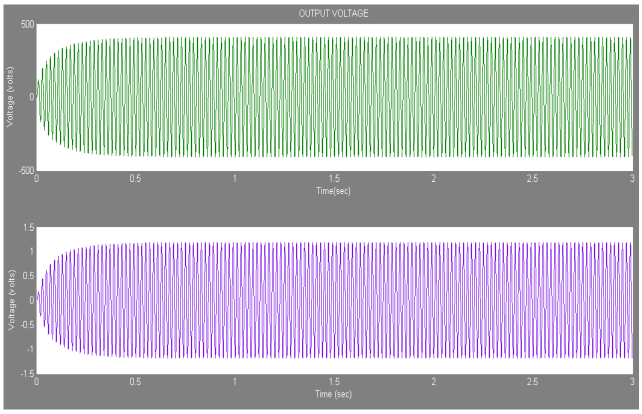

Figure 19. Final Result (Scope 12) Output Voltage & Current.

V. CONCLUSIONS

This paper presented a grid-connected PV power system with high voltage gain. The proposed PV system employs a high Step-up ZVT-interleaved boost converter with winding-coupled inductors and active-clamp circuits as the first power-processing stage, and high voltage gain is obtained by the turns ratio selection of winding-coupled inductors. In conventional system a single PV cell is connected to a dc - dc converter and the output of the dc – dc converter is connected to the inverter finally inverter feeds the power into the grid.

DC - DC converter are rated for grid voltage, so the cost of the whole system is high and reliability is low. Another problem is the inverter output is not a pure AC so we need to use large size filter.

The Proposed system eliminates all above disadvantages. In this system DC - DC coverer and inverter are rated for lower voltage and such blocks are connected in cascade to meet the grid voltage. Since we are using low voltage components the overall cost of the system is less and reliability is high. As by using this cascaded inverter, the requirement of high rated filter is reduced this will further reduces cost, complexity of the system and THD.

An accurate steady-state model of the converter is obtained and verified by the simulation results. A full-bridge inverter with bidirectional power flow is used as the second power-processing stage, to stabilize the dc-bus voltage and shape the output current. Two compensation units are added to the system control loops, and the low current THD and the high dynamic performance are achieved. Furthermore, a simple MPPT method based on power balance is applied in the PV system and represents a good performance.

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