Grid Connected Photovoltaic System with SVPWM Inverter Base on Voltage-Oriented Control at the Distribution System

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Abstract - *Growing energy demand and proportionately increasing use of the fossil fuels has led to the problem of air pollution, global warming concerns. Also, high usage of fossil fuels may create a crisis for power in near future as they are in a stage of depletion. As an impact of this, renewable energy resources (RES) are being considered as an alternative source of energy all over the world. In this paper, the topology and the control scheme of the photovoltaic three-phase grid connected SVPWM inverter based on voltage-oriented control (VOC) connected distribution system is analyzed. In VOC, a current control loop is used. The currents are controlled in a synchronous rotating dq-frame using a decoupled feedback control. The simulations of the system based on Matlab/Simulink environment are presented too.*

***Key Words*: Micro Grid, Renewable Energy Sources, voltage-oriented control, SVPWM ,Nonlinear Loads**

1.INTRODUCTION

Presently, fulfilling the rising power requirement of the customers is a challenging task for electricity providers. As of now, about 75% of total global power is obtained by burning fossil fuels. Considerable usage of fossil fuels may create crisis for power in the near future as they are in a stage of depletion. Consequently, their cost is also getting high. Also, these conventional energy sources lead to large pollution, increase in greenhouse gasses(GHG).To overcome these disadvantages non-conventional energy resources are considered as an upcoming energy solution. As a result a strong research on renewable power generation has started and emphasizing on the power generation through renewable sources is been priority for many industries.

Among the RES, hydropower and wind energy have the largest utilization nowadays. In countries with hydropower potential, small hydro turbines are used at the distribution level to sustain the utility network in dispersed or remote locations. The wind power potential in many countries around the world has led to a large interest and fast development of wind turbine (WT) technology in the last decade.

Another renewable energy technology that gains acceptance as a way of maintaining and improving living standards without harming the environment is the photovoltaic (PV) technology. As of to-days situation we are not in a stage to use RES to their maximum utility, so we introduced the concept of Distribution generation. Injecting output of renewable energy sources at distribution point can be called as distributed or discrete generation.

Not all the power which is produced by the non-renewable plant are utilized by the loads, but a part of the power is injected by the distributed generation systems at certain locations of the transmission. These sources inject active and reactive powers into the system using voltage source inverter (VSI) which converts DC into AC as all the transmission systems are in AC. Thus, distributed generation meets the portion of the power demand. VSI includes power electronic devices such as IGBTS, MOSFETS. Frequent switching of these devices for getting AC from DC may cause the problem of harmonics in the system. By implementing SVPWM control topology for inverter; output of distributed generation systems is regulated for suppressing harmonics at point of common coupling (PCC). SVPWM for power converters is suggested here which helps in reduction of harmonics of the system. In this modulating signals from input side are summed up to the fixed voltage. Later they are differentiated with carriers for producing gating pulses for inverter.

The topology and the control scheme of the photovoltaic three-phase grid connected svpwm inverter based on voltage-oriented control (VOC) is analysed. In VOC, a current control loop is used. The currents are controlled in a synchronous rotating DQ-frame using a decoupled feedback control. The reference current of d-axis controller is extracted from instruction which comes from the former system. the simulation of the system based on Matlab/Simulink environment are presented too.

2. PHOTOVOLTAIC

A solar cell is basically a p-n junction fabricated in a thin wafer of semiconductor. The electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor creates some electron-hole pairs proportional to the incident irradiation. To find the model of the photovoltaic generator, we must start by identifying the electrical equivalent circuit to that source. Many mathematical models have been developed to represent their highly nonlinear characteristics resulting from that of semiconductor junctions that are the major constituents of PV modules. There are several models of photovoltaic generators which have a certain number of parameters involved in the calculation of voltage and current output. In this study, we will present the model of single diodes (Fig.2.3) taking into account the internal shunt and series resistances of the PV cell.

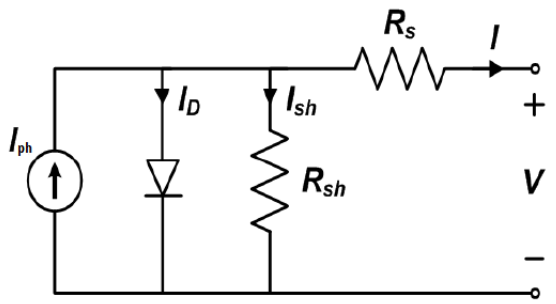

Fig-1: Model of a photovoltaic cell

The current source I_{ph} represents the cell photocurrent. R_{sh} and R_s are the intrinsic shunt and series resistances of the cell, respectively. Usually the value of R_{sh} is very large and that of R_{sh} is very small, hence they may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules which are further interconnected in a parallel-series configuration to form PV arrays. The photovoltaic panel can be modelled mathematically as given in equations

Module photo-current:

$$I_{ph} = [I_{SCR} + K_i(T - 298)] * \frac{\lambda}{100}$$

Module reverse saturation current :

$$I_{rs}=I_{sc}/[\exp(qv_{oc}/N_skAT)-1]$$

The module saturation current I_S varies with the cell temperature, which is given by

$$I_s=I_{rs}[T/T_r]^3\exp[q*E_g/Ak(1/T_r-1/T)]$$

The current output of PV module is

$$I_{PV}=N_p*I_{Ph}-N_p*I_0[\exp\{q*(V_{pv}+I_{pv}R_s)/N_sAkT\}-1$$

Where V_{pv} and I_{pv} represent the output voltage and current of the PV, I_{ph} is the photocurrent; IO are diode saturation current; q is coulomb constant (1.602 e-19C); T_r is the reference temperature is 298 K;K is Boltzmann's constant (1.381e-23 J/K); T is cell temperature (K); N_S are P-N junction duality factor; R_{sh} and R_s are the intrinsic shunt and series resistance of the cell respectively;N_s is the number of cells connected in series is 36 ;N_p is the number of cells connected in parallel is 1 .

3.SPACE VECTOR PULSE WIDTH MODULATION TECHNIQUE

The circuit model of a typical three-phase voltage source PWM inverter. S1 to S6 are the six power switches that shape the output, which are controlled by the switching variables a, a^1, b, b^1, c and c^1. When an upper transistor is switched on i.e., when a, b or c is 1, the corresponding lower transistor is switched off i.e., the corresponding a^1, $b^1c^1$is 0. Therefore, the on and off states of the upper transistors S1, S3andS5 can be used to determine the output voltage.

In conventional method of space vector modulation, voltage space vectors are extracted from the grid 3phase voltages. Later these vectors are mapped into *d* – *q* axis frame And a resultant voltage vector is obtained. Whole space of (2π) has to be divided into 6 sectors. For each instantaneous voltage vector extraction, positions of resultant vector with Respect to the sector have to be determined. Subsequently, switching time calculations for active vectors as well as null vectors needs to be done. These calculations decide the On/off timings for the inverter switches such as IGBTS or MOSFETS.As shown in fig.2 eight voltage space vectors divide the entire vector space into six sectors, namely 1 -6. Except two zero vectors, V0 and V7, all other active space vectors have the same magnitude. there are eight possible combinations of on and off patterns for the three upper power switches. The on and off states of the lower power devices are opposite to the upper one and so are easily determined once the states of the upper power transistors are determined.

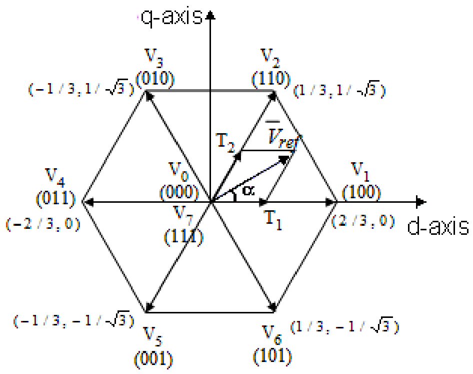

Fig-2: Switching vector and Sectors

SVPWM technique is accomplished by the rotating reference vector around the state diagram consisting of six basic non zero vector forming an Hexagon. The angle made by d-q quantity is compared with the reference angle which lies between 0° to 360°. This concept is implemented to find the angle of reference voltage vector which frames the different sector of the reference voltage. With this the reference voltage is made to work in different sectors with different angle which covers throughout the entire 360° of operation.

4 VOLTAGE ORIENTED CONTROL

The Voltage Oriented Control (*VOC*), which guarantees high dynamics and static performance via an internal current control loops, has become very popular and has constantly been developed and improved. Consequently, the final configuration and performance of the *VOC* system largely depends on the quality of the applied current control strategy.

Fig.3 shows the system structure of three-phase SVPWM grid-connected inverter studied in this paper. This system consists of an input filter capacitor *C*, a three-phase VSI, an output filter. The three-phase VSI with a filter inductor converts a DC input voltage U_d into an AC sinusoidal voltage by means of appropriate switch signal to make the output current in phase with the utility voltage..

To simplify the analysis and design of controller, the space-phase variables of VSI are projected on a synchronously rotating *dq*-frame. The Fig.3 is the system vector diagram based on the grid voltage orientation.

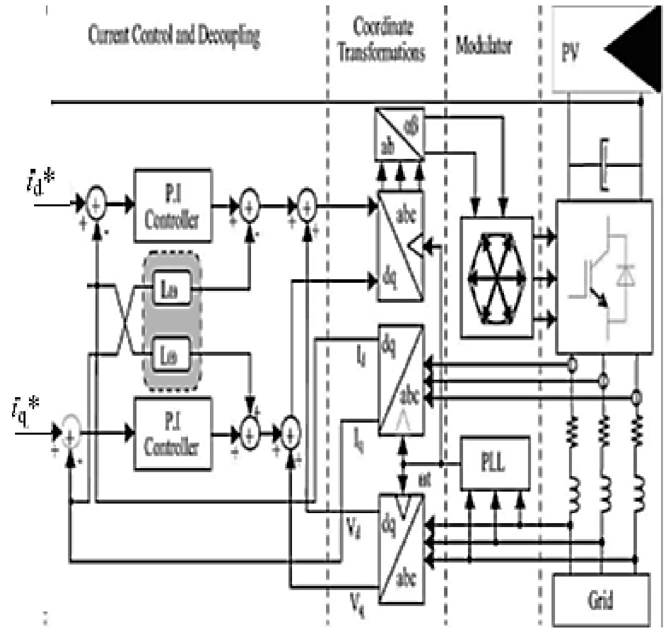

Fig-3: The system block diagram of three-phase SVPWM inverter base on voltage-oriented control

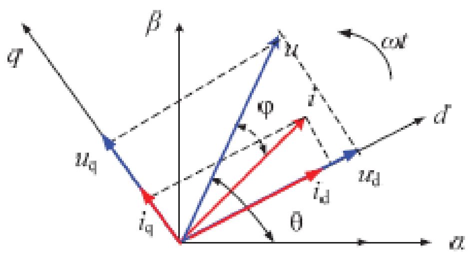

Fig-4: System vector diagram based on the grid voltage orientation

Where ω the angular speed that equals to the angular frequency of grid;

i_d ,i_q *d*- and *q*-axis currents, respectively;

u_d u_q d-and *q*-axis voltages, respectively.

According to the Fig.4, the system quantities can be transformed become time-invariant in steady-state, the output voltages of three-phase VSI in the synchronous *dq*-frame based on the grid voltage orientation can be described by the following equations:

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \begin{bmatrix} u_{gd} \\ u_{gq} \end{bmatrix} + \begin{bmatrix} R & -\omega L \\ \omega L & R \end{bmatrix} \begin{bmatrix} i_{gd} \\ i_{gq} \end{bmatrix} + \begin{bmatrix} \frac{di_{gd}}{dt} \\ \frac{di_{gq}}{dt} \end{bmatrix}$$

Where R equivalent resistance of inductor;
L inverter filter inductor;
i_{gd}, i_{gq} *d*- and *q*-axis grid current, respectively;
u_{gd},u_{gq} *d*- and *q*-axis grid voltage, respectively.

In the synchronous rotating *dq*-frame, the active and reactive powers of a three-phase grid-connected VSI are given by

$$\begin{cases} p = \frac{3}{2}\left(u_d i_d + u_q i_q\right) \\ q = \frac{3}{2}\left(u_d i_q - u_q i_d\right) \end{cases}$$

Because the *dq*-frame angular speed is adjusted to the grid angular frequency, the transformed quantities become time-invariant in steady-state, simplifying the controller design. This is achieved by means of a PLL whose block diagram is given in Fig.5.4 . The input to the PLL block is the sinusoidal varying voltage and the output is the angle for *abc*-to-*dq* transformation,

In Fig.3, the voltage is regulated to zero using a PI controller. Regulating the q-axis component of the voltage to zero, consequently. Its active power depends on the *d*-axis current, that is proportional to and can be controlled by the *d*-axis current, and the reactive power depends on the *q*-axis current.

$$\begin{cases} p = \frac{3}{2} u_d i_d \\ q = \frac{3}{2} u_d i_q \end{cases}$$

Furthermore, in order to achieve unity power factor fundamental current flow, the *q*-axis component of the command current vector is set to zero. The cross-coupling can be decoupled by. Hence, the *d*-axis currents *i*d and *q*-axis currents i_q can be controlled independently by reference current i_d * and i_q^*, respectively.

According to, VOC strategy guarantees fast transient response and high static performance via current control loop. As shown in Fig.5.4, the input to the PLL block is the sinusoidal varying grid voltage detected by voltage sensor, and the output is the grid voltage vector rotating angle for *abc*-to-*dq* and *dq*-to-*abc* transformations, *ɵ*. i_d*and i_q* are reference current of *d*- and *q*-axis, respectively.

There is cross-coupling between *d*–axis and *q*-axis components. However, cross-coupling can affect the dynamic performance of the controller. Therefore, it is very important to decouple the two axes for better dynamic performance. The feedward compensation decoupling control method can be adopted. The control diagram of decoupling method is shown in Fig. 5

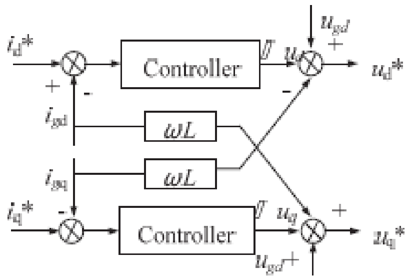

Fig-5: Control block of current decoupling.

In Fig.4, i_{gd}*and i_{gq}* are reference current of *d*-axis and q-axis, respectively, Δu_d and Δu_q are output of the *d*-axis and the *q*-axis current controller, respectively.

According to the, the decoupling control equation are given by:

$$\begin{cases} u_d *= \Delta u_d + u_{gd} - \omega L i_{gq} \\ u_q *= \Delta u_g + u_{gq} + \omega L i_{gd} \end{cases}$$

5. SIMULATION RESULTS

Case-1 :DISTRIBUTION SYSTEM WITHOUT PV BASE INVERTER

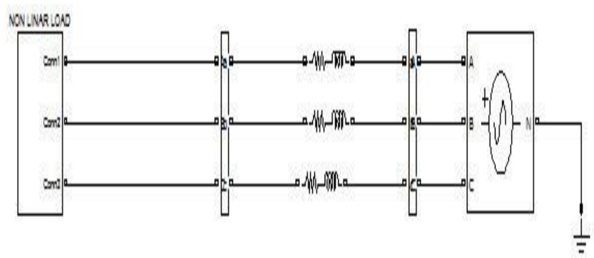

Fig-6: distribution system without pv base inverter

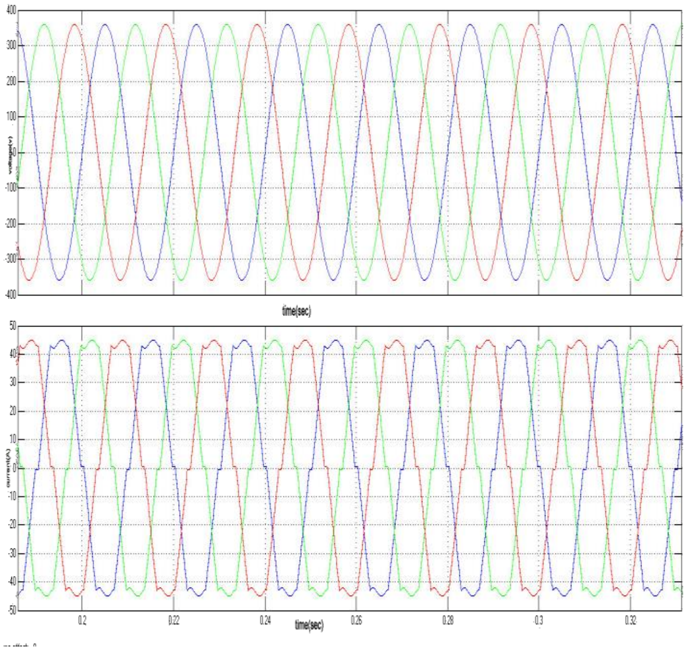

Fig7-: voltage and current wave from at load

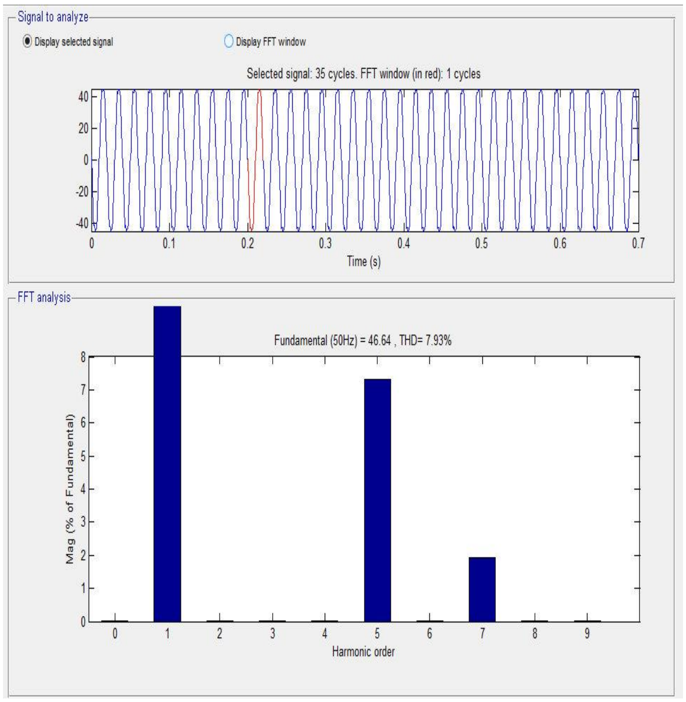

Fig-8: FFT analysis current wave from at load

Case-2 :DISTRIBUTION SYSTEM WITH PV BASE INVERTER

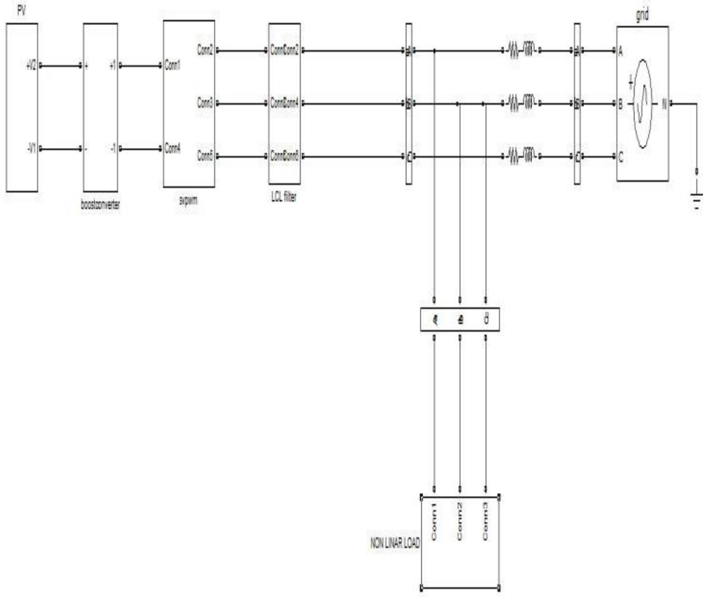

Fig-9: Distribution system with pv base inverter

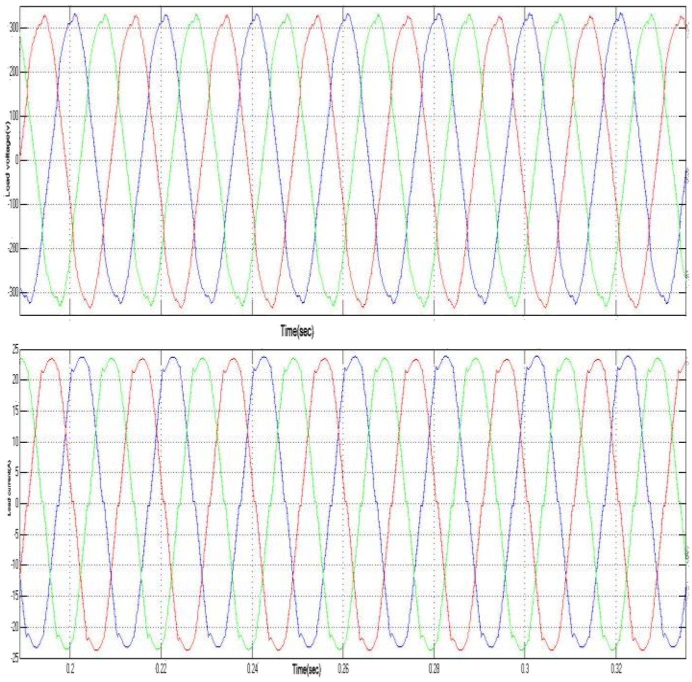

Fig-10: voltage and current wave from at load

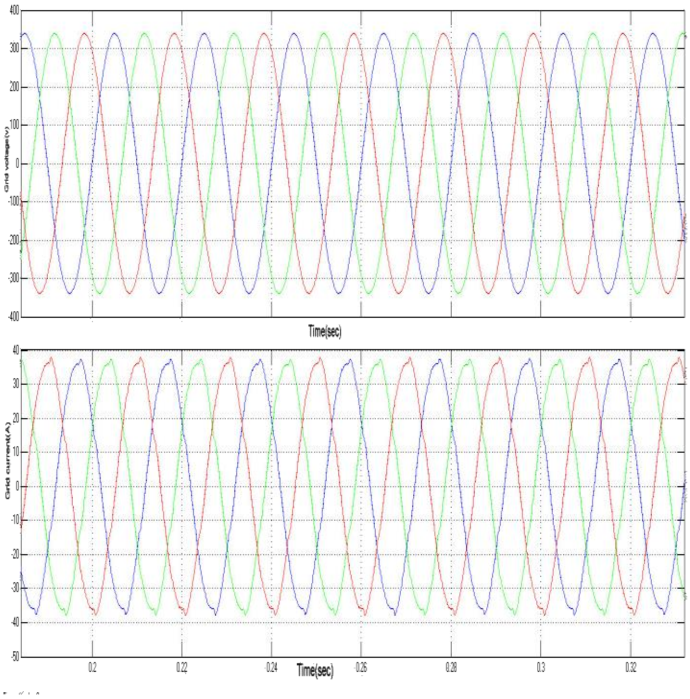

Fig-5: voltage and current wave from at grid

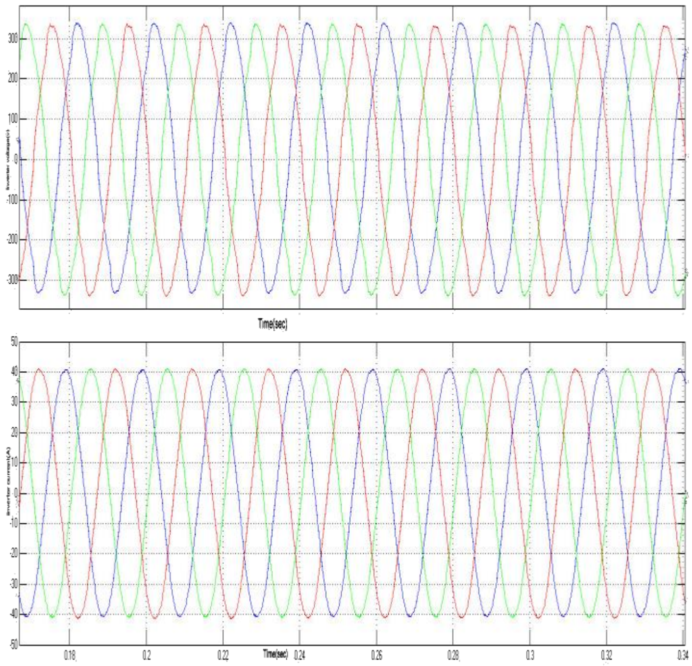

Fig-5: voltage and current wave from at inverter output

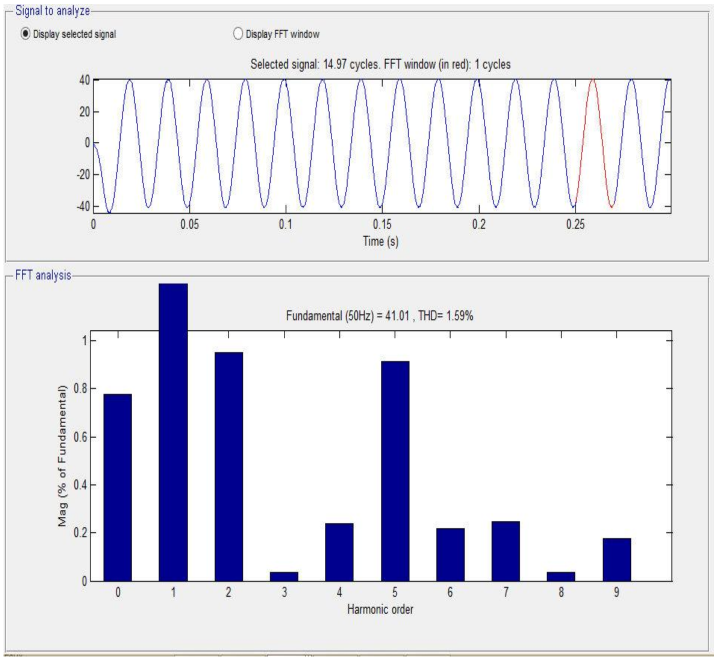

Fig-5: FFT analysis current wave from at inverter output

Table 1 - Comparison of THD-I(current)

Before connecting inverter connect to system	After connecting VOC base SVPWM inverter connect to system
7.9	1.6

6. CONCLUSION

The efficiency and the performance of renewable energy sources can be increased by the development of the control structures of the grid-connected inverter. In this paper a three-phase grid connected VSI has been presented. The comparison distribution system with out SVPWM inverter and Voltage-Oriented Control base SVPWM inverter when connected to distribution system. We observed that THD is reduced with Voltage-Oriented Control base SVPWM inverter when connected to distribution system because VOC control can eliminated harmonics from taken reference voltage and current at distribution system

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