Simulation of Micro Grid Connected Solar PV Array

HARIOM RAWAL
Under the Guidance of: **Mr. Rakesh Kumar,**
Department of Electrical Engineering Noida International University.

ABSTRACT

The sale of electric energy generated by photovoltaic plants has attracted much attention in recent years. The installation of PV plants aims to obtain the maximum benefit of captured solar energy. The different techniques of modeling and control of grid connected photovoltaic system with objective to help intensive penetration of photovoltaic (PV) production into the grid have been proposed so far in different papers. The current methodologies for planning the design of the different components of a PV plant are not completely efficient. Therefore lot of research work is required for overall configuration of the grid connected PV system, the MPP tracking algorithm, the synchronization of the inverter and the connection to the grid. This paper focuses on the solar energy, grid connected photovoltaic system, modeling of photovoltaic array, maximum power point tracking, and grid connected inverter. This paper helps the researchers to know about the different methods presented so far for modeling and control of grid connected photovoltaic system so that further work on integration of solar energy with grid can be carried out for better results.

1. INTRODUCTION

The conventional energy sources, obtained from our environment, tend to exhaust with relative rapidity due to its irrational utilization by the humanity. Renewable energy offers a promising alternative source. Solar energy seems to be most attractive now days. The quantity of energy from the sun that arrives on the earth surface in a day is ten times more than the total energy consumed by all people of our planet during a year. Photovoltaic (PV) energy has great potential to supply energy with minimum impact on the environment, since it is clean and pollution free. The grid integration of Renewable Energy Sources (RES) applications based on photovoltaic systems is becoming today the most important applications of PV systems, gaining interest over traditional stand-alone systems. Four different system configurations are widely developed in grid-connected PV power applications: the centralized inverter system, the string inverter system, the multi string inverter system and the module-integrated inverter system.

In the grid-connected PV system, power electronic inverters are needed to realize the power conversion, grid interconnection, and control optimization. Generally, grid-connected pulse width modulation (PWM) voltage source inverters (VSI) are widely applied in PV systems. For 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 strict regulations have been applied to the equipment connected to the utility lines to maintain the grid security. Some of these regulations relate to harmonic distortion and power factor. The growing use of power electronics has tendency of the harmonic distortion levels to increase. Therefore the increasing integration of photovoltaic energy with electric transmission and distribution network has been a challenge for planners and researchers. This paper presents a review of modeling and control of grid connected photovoltaic system.

2.Model Formulation and Structure

Typically, grid-connected PV system consists of solar panels, DC–DC converter, MPPT controller, inverter and grid connection equipment. It has no energy storage losses since there are no batteries used as it is not a standalone system. The system's components are modeled in Matlab/Simulink software environment. Matlab/Simulink is selected, due to its reusability, extendibility, and flexibility in such systems. It is a dynamic model where the simulation time is 3s, sampling time is 10−5s, since the time step has to be lower than the propagation time. The model can predict the performance of the system and assess it by comparing the set up to new introduced set ups with added components, solving a set of non-linear equations. A schematic of the Simulink model is shown in Fig.1

Photovoltaic Array: Solar cells exhibit a non-linear current voltage characteristic (Eq. (1) that depend on solar radiation and temperature (Figs.2 and 3).

$$I = I_{ph} - I_0(e^{q(V+IRs)/nkT} - 1) - (V+IR_s)/R_{sh} \qquad (1)$$

Where Iph is the photo current, Io is the saturation current of the diode, Rs is the series resistance, Rsh is the shunt resistance, n is the diode ideality factor, k is Boltzmann's constant (1.4 × 10−23), q is the electron charge (1.6 × 10−19), T is the absolute temperature in Kelvin.

Inverter: All photovoltaic systems interface the utility grid through a boost converter and a voltage source inverter. The DC–DC converters are used to balance the system. Inverters are responsible for converting DC power to AC power. This is done by switching the DC input voltage (or current) in a pre-determined sequence so as to generate AC voltage (or current) output. Three-phase inverters consist of one, two, or three arms of power switching devices. Each arm consists of four switching devices along with their anti parallel diodes and two neutral clamping diodes. The control signal generated by any MPPT method, feed the boost converter switch.

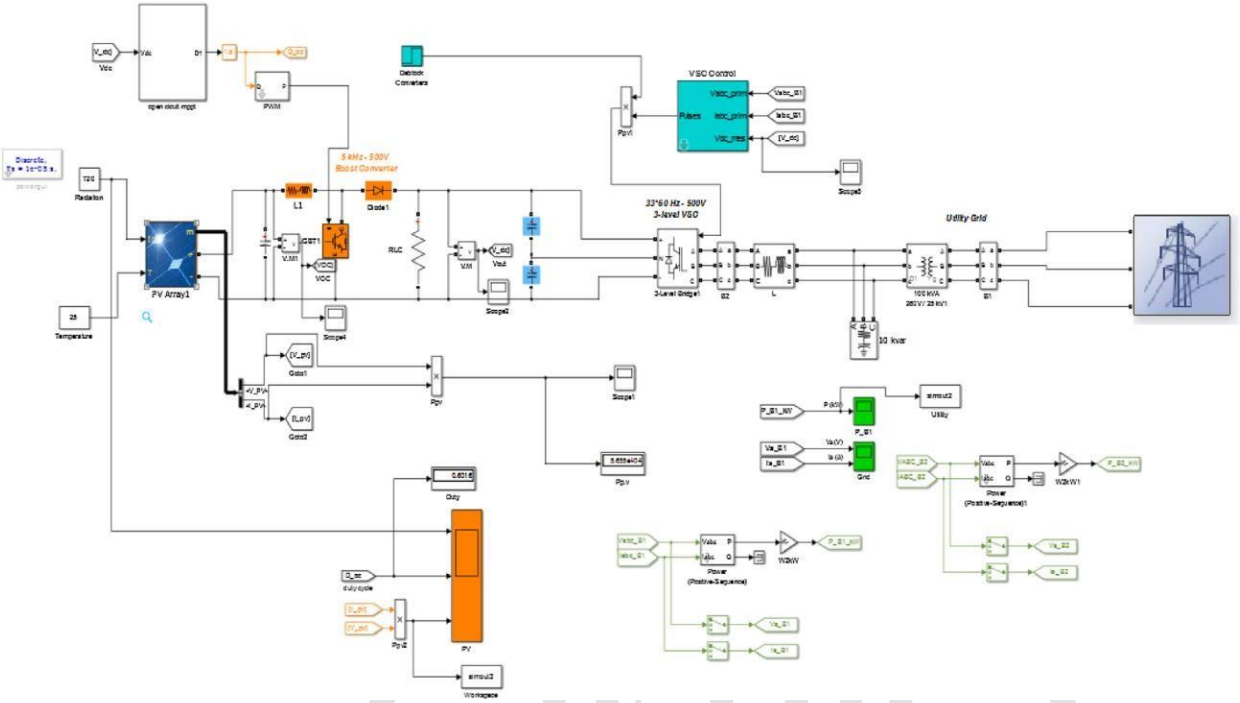

Fig. 1 Schematic of Simulink model Fig.

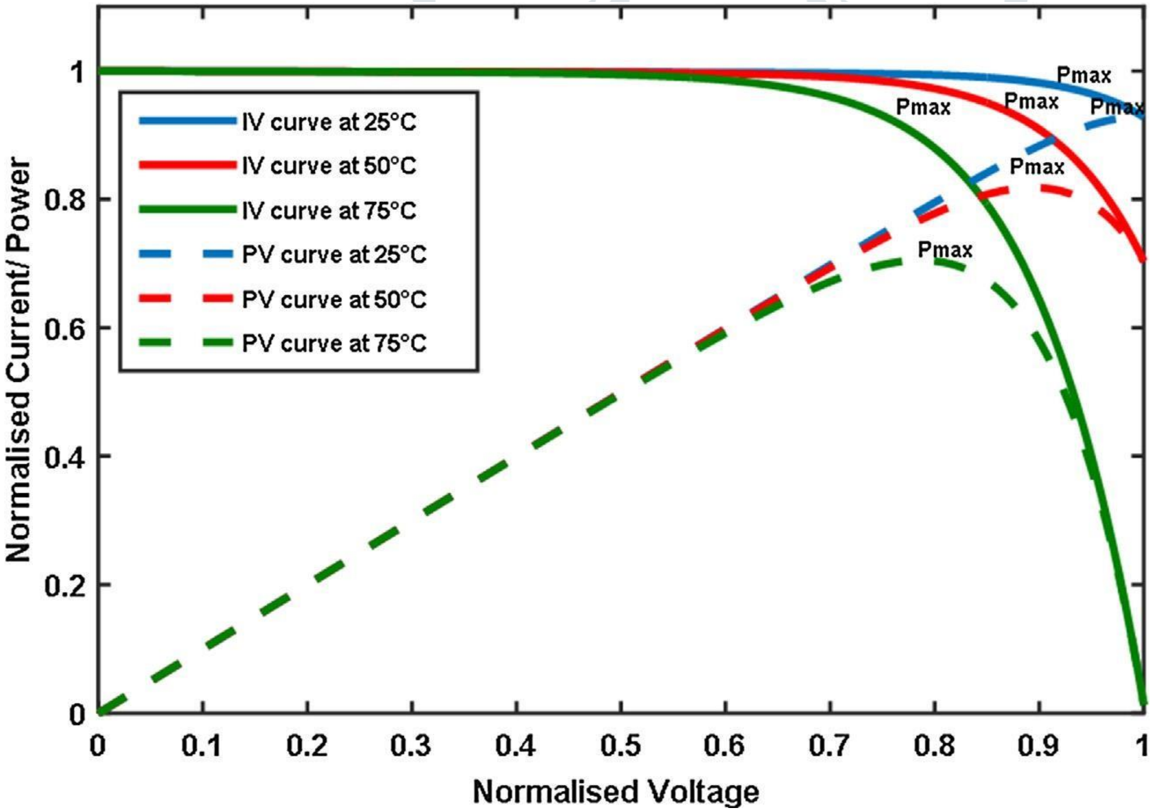

Fig.2 Typical IV/PV characteristic of a solar cell at 1 kW/m2 and different temperatures.

MPPT Control: There is a point where the output power from the array (a string of panels) has a maximum value. In order to ensure efficient operation of the solar array the MPP of the array has to be tracked. MPPT, in addition to raise the power

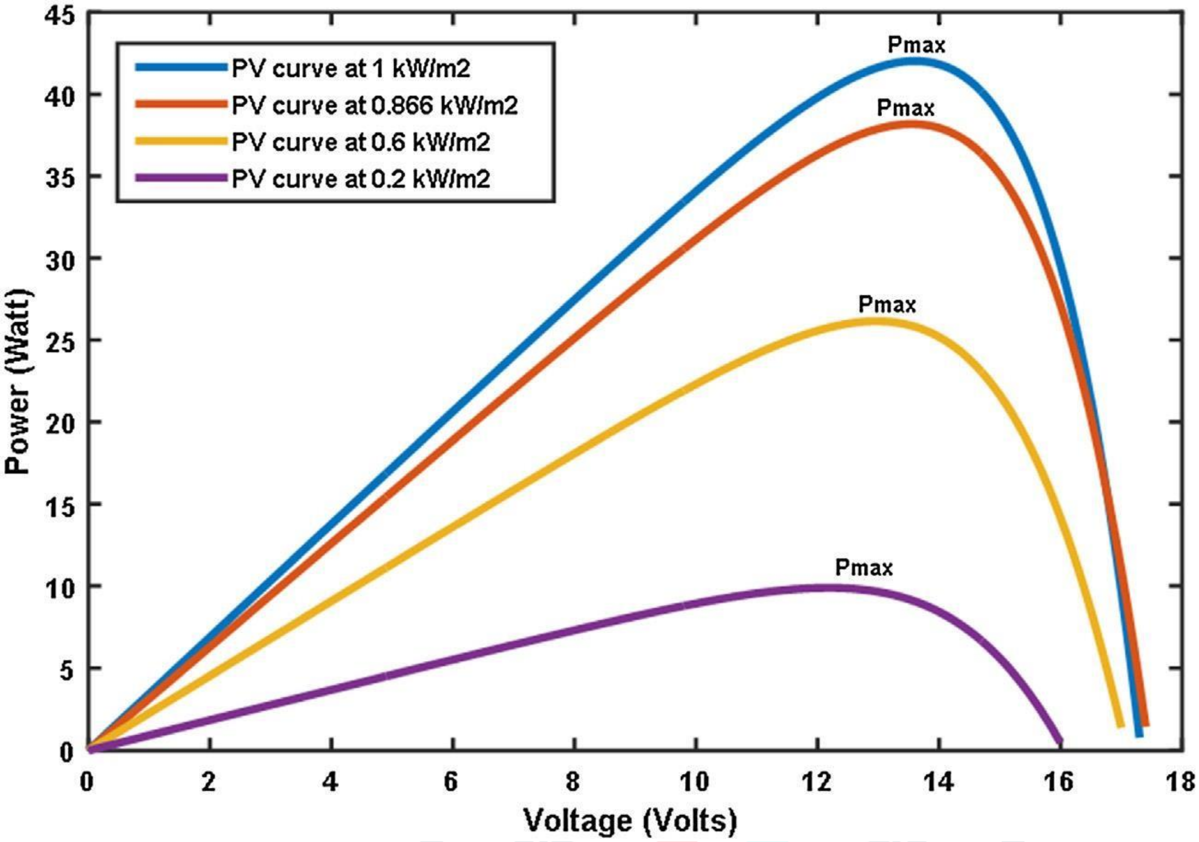

Fig. 3 PV characteristic of a solar cell at 75 ◦ C and different illumination levels.

delivered from the PV module to the load, is considered as a PV system lifetime booster. There are many control strategies and controller types. These methods can be grouped based on different features. In essence, MPPT methods are categorized into: offline methods which are dependent on solar cell models, online methods which are usually referred to as the model-free method. The MPPT technique that generates the control signal which feeds the boost converter is assumed to be fractional OCV technique. This technique is under the MPPT offline methods which generally require the knowledge of one or more of the solar panel parameters values; here the open circuit voltage (V_{OC}). These values generate the control signal necessary for driving the solar cell to its MPP. In the tracking operation, this control signal remains constant if ambient conditions can be regarded as fixed and there are no attempts to regulate the output power of the PV system. The OCV technique is chosen because it is one of the most straight forward off line methods. It uses the almost linear relationship between the open circuit voltage (V_{OC}) and the MPP voltage (V_{MPP}) under changed climatic circumstances as described by the following equation:

$$V_{MPP} = k * V_{OC} \tag{2}$$

Where k is a constant, depending on the solar cell characteristics. The constant k is derived empirically after measuring several V_{OC} and V_{MPP} for any specific cell under different climatic conditions. Values for the constant k, in general, vary between 0.73 to 0.80, herein our specific case, the constant k is assumed to be 0.8.The efficiency was calculated of the technique by the following formula shown in Eq. (3), to validate it:

$$\eta = (P_{max.Tracked} / P_{max.}) \times 100 \tag{3}$$

Where η is the efficiency of the tracking method, *P*max .tracked is the MPP tracked and *P*max. is the actual MPP of the array derived by the following equation:

$$P_{max.} = V_{MPP} * \text{ No. of series modules } * I_{MPP} * \text{ No. of parallel strings} \quad (4)$$

Where *V*MPP is the voltage of the solar cell at MPP and *I*MPP is the current of the solar cell at MPP, bearing in mind that these two parameters vary according to radiation and temperature.

Transformer: To connect the PV system to the national high voltage grid, a transformer (Fig. 4) is added to the system. Its function is to change the ratio of voltage to current delivered from a voltage source to meet the characteristics of the load, keeping the power constant. Transformers consist of primary coil which receives energy from the AC source (here the inverter), secondary coil which receives energy from the primary winding and delivers it to the load (here the national grid) and the core which makes a path for the magnetic flux. Transformers are either step-up (deliver higher voltage to the load) or step down (deliver lower voltage to the load) according to the ratio of the number of turns of the secondary to the primary.

$$V_2 = (n_2 / n_1) V_1, \quad I_2 = (n_1 / n_2) I_1, \quad P = V_1 I_1 = V_2 I_2 \quad (5)$$

Where: V_1, I_1 are the voltage and current received from the source to the primary coil; V_2, I_2 are the voltage and current delivered to the load from the secondary coil; n_1, n_2 are the number of turns of the primary and secondary coils. As for the high voltage assumed grid, it consists of a distribution feeder and a transmission system

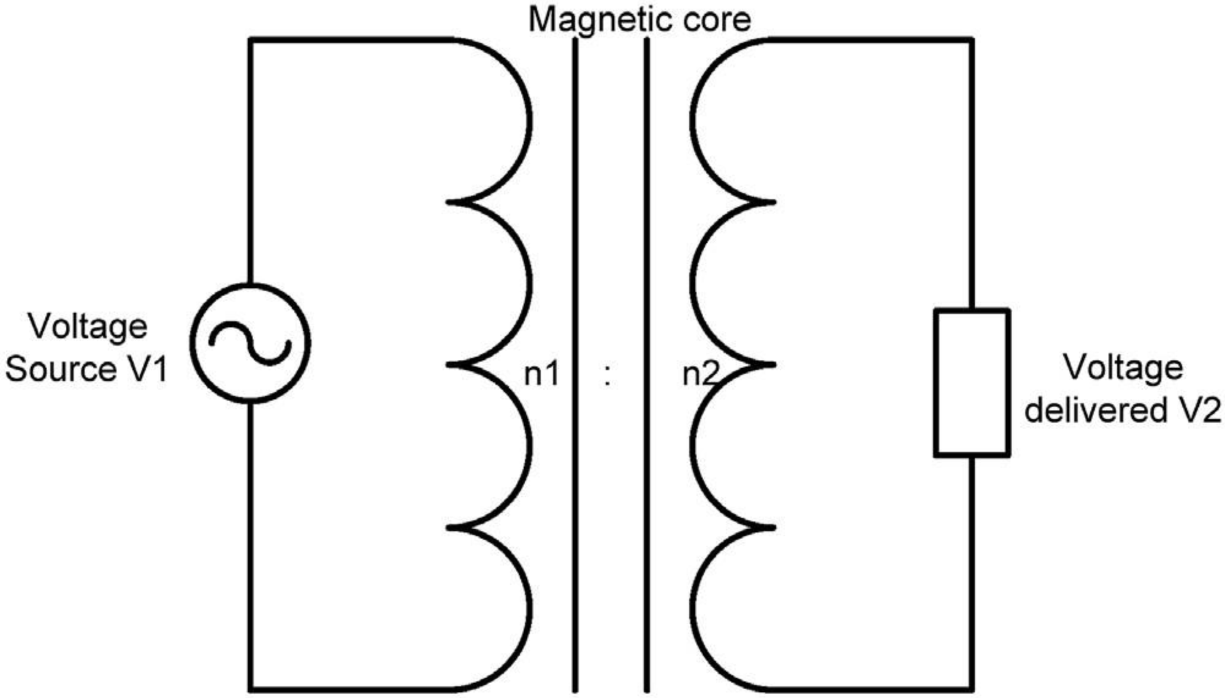

Fig.4 Ideal Transformer

3.System Configuration

The 90 kW photovoltaic system is located in Qanatir at 30.19 latitude and 31.14 longitude with an elevation 20m above mean sea level on the roofs of one of the buildings of NWRC campus with a total area of 900 m2, 5 m height. NWRC set a plan to provide all the roofs of its premises with photovoltaic generated systems, and this location is one of them. Qanatir receives an average radiation of 720 W/m2, while the average temperature of the site all over the year is 25.8◦. NWRC PV system supplies power to the local low voltage grid and the difference in demand and generated power is supplied from the national grid.

PV system: NWRC PV system consists of 255 W polycrystalline solar module of type SUNTECH STP255-20/Wd. It comprises 51 parallel strings with 7 series connected modules per string tilted at 30◦ towards the south. Array is kept as equal to the latitude of the corresponding location to get maximum solar radiation.

MPPT control: As stated above, the MPPT technique that generates the control signal which feeds the boost converter is assumed to be fractional OCV technique. The V_{OC} generates the control signal necessary for driving the solar cell to its MPP. Solar cell's electrical characteristics at radiation 1000 W/m2 and temperature 25◦C are available from the solar cell data sheet.

Inverter: Four inverters of power rating 20 kW and one of rate 10 kW is used. The DC voltage supplied to the inverter is 500 V and the output range is 160–300 V at 45–65 Hz. Power switching device used is of IGBT type and the number of arms formulating the bridge is three.

Transformer: The rated power of the transformer is 100 kVA. The primary voltage of the transformer is 260 V and the output to the grid is 25 kV since, the high voltage assumed grid consists of a 25-kV distribution feeder and a 120 kV equivalent transmission system.

4.Energy and Economic calculations

Local grid tied system: PV systems only generate energy during day hours.The monthly energy generated from the system is shown in Eq. (6):

$$E_{month} = P_{month} * \text{Daylight hours}_{month} * \text{no. of month days} * 10^{-3} \tag{6}$$

Where Emonth is the energy generated monthly in MWhr, P_{month} is the monthly power delivered from the inverter in kW. The annual energy is the sum of the energy generated from the twelve months which differs according to the monthly temperature and radiation and the sunlight hours of that month but for NWRC the energy will only be generated at working hours (assumed to be 7 h from 8 am – 3 pm) and 5 days a week discarding all official holidays. The net consumed energy by NWRC is evaluated as shown in Eq. (7):

$$E_{NET} = E_{WOPV} - E_{PV} \tag{7}$$

Where E_{WOPV} is total annual energy consumed in by NWRC in 2015 without the PV system (568.571 MWh/year), E_{PV} is the total annual energy produced by the PV system when connected to the local grid and E_{NET} is the net consumed annual energy the National Utility charges NWRC for:

$$\text{Elect Ch}_{NWRC} = E_{NET} \times 1000 \times 96/100 \tag{8}$$

Where Elect Ch_{NWRC} is the electricity charges for NWRC.

National grid tied system: Due to the limited work hours and the weekends an amount of energy is lost, Another alternative is connecting the system to the national grid and thus all the generated power is balanced with NWRC's consumed energy charging the generated using the feed-in tariff 90.1 pt/kWh, while the utilization tariff for NWRC is 96 pt/kWh since our yearly consumption is more than 1000 kWh/month. When the system is connected to the national grid all the generated power is balanced with NWRC's consumed energy. So the National Utility will charge NWRC according to Eq. (9).

$$\text{ElectCh}_{NWRC} = E_{WOPV} \times 1000 \times 96/100 - E_{PVNatgr.} \times 1000 \times 90.1/100 \tag{9}$$

Where $E_{PVNatgr.}$ is the total energy generated from the PV system when connected to the national high voltage grid.

5. RESULTS

Validation of the model: The model is first tested under standard temperature conditions (STC): radiation 1000 W/m2 and temperature 25◦for validation and testing of the MPPT technique and compared with the maximum power of the array computed from Eq. (4) (90 kW), where *V*MPP and *I*MPP are 30.8 V, 8.28 A respectively. Fluctuations exist since the simulation duration is 3 s and the sampling time is 10−5s.The median of the simulated results is deduced so that the outliers do not affect the results, the *P*max Tracked is 78.87 kW making the overall efficiency of the technique 86.67% (Eq. (3)). Fig. 6 shows the output of the inverter peak to peak voltage is 300 V, note the output of the inverter is modified sine wave. The output of the transformer is shown in Fig. 7; note that the output voltage is 20 kV and the current decreased as the energy transmitted from the primary to the secondary coils should remain constant. The model is also validated by comparing the average output AC power from the inverter to the real time data measured over one year.

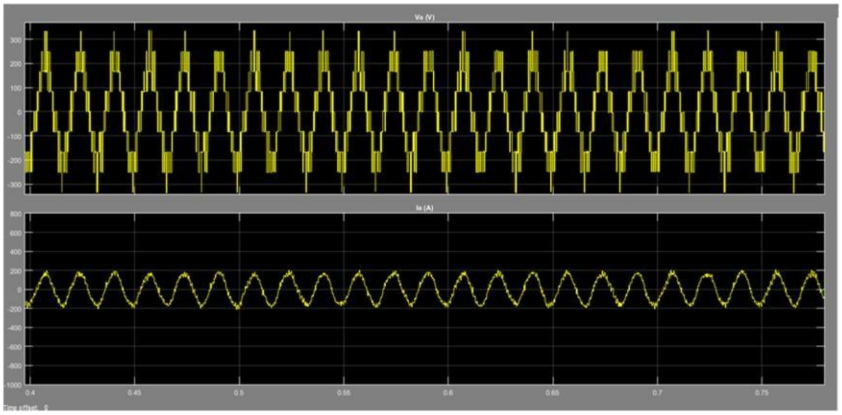

Fig. 6. Output of the inverter from simulation model.

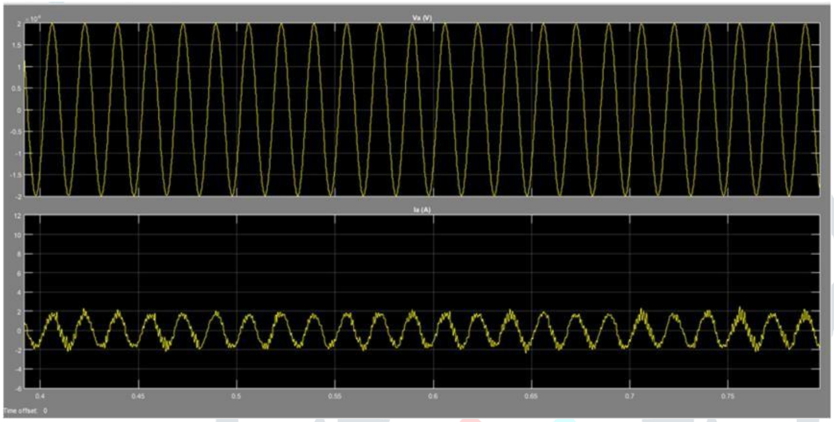

Fig. 7 Output of the transformer from simulation model.

CONCLUSION

In this manuscript a MATLAB Simulink model is constructed mimicking a detailed representation of a PV system, mounted on NWRC's roof. This model simulates two scenarios: local grid tied system (present situation) and national grid tied system (introduced option). The economical savings when system is connected to the national grid are exponentially higher compared to the saving of the real system when feeding the local grid. Therefore, to encourage private and governmental agencies expanding on solar energy production Electricity Distribution Company have to be truly committed to 'Feed-in Tariff' billing system. A more precise tracking method (online or hybrid) can be used to track the MPP rather than the OCV that has an efficiency of 85%.Later, before the execution of NWRC's plan, to provide all the roofs of its premises with photovoltaic generated systems, It is recommended that a complete design and a Cost Benefit Analysis (CBA) has to be carried out. Also, this model could be reused and modified to provide an early evaluation of any introduced system and setting severalscenarios to choose the most efficient one taking into consideration transmission and cabling besides the saving in NWRC's electrical bill.

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