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Modelling And Investigations Effect on The Grid of Photovoltaic Power Systems

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Abstract: *In this study, the effects of PV systems on grid were researched and these effects were discussed by modeling on- grid photovoltaic systems in MATLAB/Simulink environment. Through the performed simulation, frequency, .phase and stress measurements were carried out by investigating the synchronization process between PV system .and grid. Additionally, harmonics due to inverters in photovoltaic systems were measured and they were .minimized via a designed filter. Changes and harmonics before and after the synchronization were investigated in .the_simulation_and_necessary_evaluations_were_performed.*

Keywords: *Photovoltaic Power Systems, Harmonics, Synchronization.*

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I. Introduction

The industry whose use rapidly increases today in the world is photovoltaic industry. The use of on-grid PV system in places where the electricity is not enough or its commercial use has recently become common. Solar cells (photovoltaic batteries) are electronic devices which transform luminous energy into electrical energy, they directly transforms the energy of sun into electrical energy as a result of inner photoelectric reactions [1]. The first solar cells were developed by Schottky, Lange and Grondahl and they were made of copper oxide (Cu_2O) and selenium (Se) [2]. Most commonly used materials in the production of photovoltaic batteries are silicium (Si), Gallium Arsenide (GaAs), Cadmium sulphide (CdS) and Cadmium tellurium (CdTe) [3]. Solar energy can be transformed into electrical energy between 5% to 20% efficiency depending on the structure of solar cells [4]. Solar panels constitute photovoltaic systems by being used with inverters, accumulators, solar control devices and various electronic support circuits away from settlement areas where there are no electrical grid, hours of sunshine are long, and in situations when it is difficult and expensive to bring fuel for the generator. If the system is used during the time when the sunshine is low or during the night, there should be an accumulator in the system. In this way, electric generated in photovoltaic modules is stored in accumulators and energy is provided via accumulators when necessary. Charge regulator which prevents discharging and over charging of accumulator and is also a control unit, cuts off the current from solar cells or load in line with the condition of the accumulator. In the applications where alternative grid synchronized current is used, an inverter is added to the system and DC voltage in accumulators are transformed into AC voltage. After DC voltage generated by photovoltaic power plant is transformed into alternative current wave, synchronization should be provided in order to connect the system to the grid directly. When the synchronization is ensured, connection with the grid can be performed. If the synchronization can not be performed, big circulation currents may occur or the inverter may get damaged during the first connection. Another demanding condition which is needed for synchronization is to determine the synchronism moment. Synchronism moment (Synchronization) means the overlapping of PV system –which is to be connected in parallel – and grid phases. However, just to provide synchronization is not enough for on-grid photovoltaic systems. It is also necessary to reduce harmonics, which are caused by inverters in photovoltaic system, by designing a filter.

We can define a harmonic wave as the multiple of fundamental frequency [5]. If the current and voltage are not clear in terms of harmonics, various degrees of harmonics occur. The possibility of resonance as a result of the interaction of harmonics generated by PV inverters with the grid is detected, if the filters are not added to the system harmonics can not be suppressed and various damages may occur in the system [6-7].

n this study, an on-grid photovoltaic system was modeled in MATLAB/Simulink environment in order to monitor aforementioned synchronization situation and harmonics effect. Frequency, phase, voltage, power and harmonics measurements were done in this study carried out in a simulation environment and the effects of photovoltaic system on grid were analyzed.

II. Equivalent Circuit Model and General Mathematical Model for PV Solar Cell

As it can be seen in Fig.1, an ideal solar cell can be modeled with a radiation connected current source, a parallel connected diode and a resistor on this source of current and a serial connected resistor to all these [8]. Since the ideal model as in the figure just generates current, it includes one source of current, and it also includes one diode since it consists of p-n joint. Since the parameters in this model depend on the intensity of light and temperature, the levels of intensity of light and temperature should e known for each output value. Circuit model given in the figure can be represented mathematically by Equation [9]. I_D voltage is an inner flow flowing from the P-N juncture of the semiconductor materials which constitute PV battery; it changes as a function of the absolute temperature of the battery, terminal voltage and load current. This current is represented by Equation 2 [9].

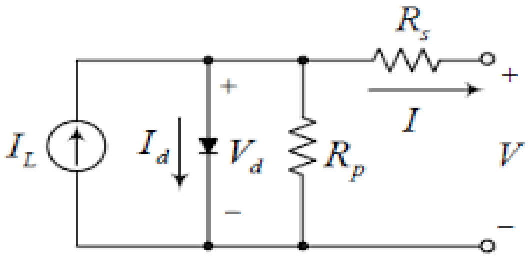

Figure 1. Equivalent circuit model for ideal PV solar cell [10].

$$I = I_L - I_0\left[\exp\left(\frac{e}{kT_{pil}}(V+R_S \times I)\right)-1\right] - \frac{V+(R_S \times I)}{R_p} \quad (1)$$

$$I_D = I_0 \cdot \left[\exp\left(\frac{e}{A.k.T_{pil}}(V+R_S \times I)\right)\right] \quad (2)$$

The representation of the letters is given below;

I: Output current of OV battery (A)

I_L: Intensity of light and function of P-N joint temperature, photocurrent (A)

I_o: Reverse saturation current for D diode (A)

V: Output voltage for PV battery (V)

R_s: Serial resistance of equivalent circuit (Ohm)

R_p: Parallel resistance of equivalent circuit (Ohm)

e: Electron charge (1.6021917 x 10^{-9} C)

k: Boltzmann constant (1380622 x 10^{-23} J/°K)

$T_{battery}$: Reference operating temperature (°K)

On-Grid Photovoltaic Systems

The energy generated by photovoltaic system is used in intra-network usage, the rest is directly transferred to the grid. For instance, the need of electricity of a household is met and extra generated electric is sold to the grid and when enough energy can not be generated, energy is transferred from the grid in this system. Therefore, there is no need of using accumulator or similar devices in on-grid systems [11]. Therefore initial investment cost reduces and the cost of the electricity obtained from the sun is also decreases.

Additionally, junction point in photovoltaic systems, which are used as energy generation plant, changes depending on the installed power of the system [12]. Systems with up to 50 MVA installed power are connected to the grid on 34,5 kV distribution line voltage level, others with over 50 MVA are connected to the grid on 154 kV or 380 kV transmission line voltage level.

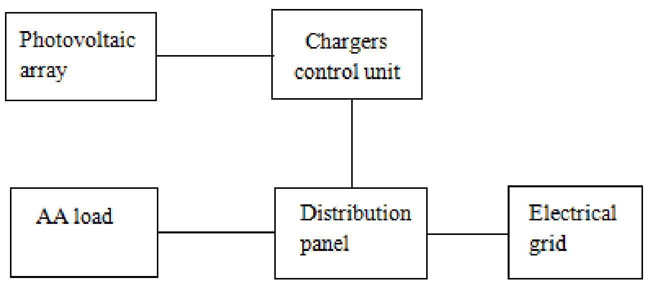

Figure 2. On-Grid Photovoltaic System [13].

III. Simulation of On-Grid PV System on Matlab/Simulink Program

On-grid photovoltaic system was modeled on Matlab/Simulink environment. Solar panel in the photovoltaic systems in simulation was carried out on the basis of Villalva and friends [14] study and the effects of photovoltaic system on grid and the harmonics they created are analyzed in the simulation. Harmonics were tried to be reduced as much as possible through the designed filter. Additionally, the synchronization of photovoltaic system with the grid was monitored and a breaker, which is going to turn of when the synchronization was performed, was added to the simulation. Block diagram of the system is shown in Fig. 3.

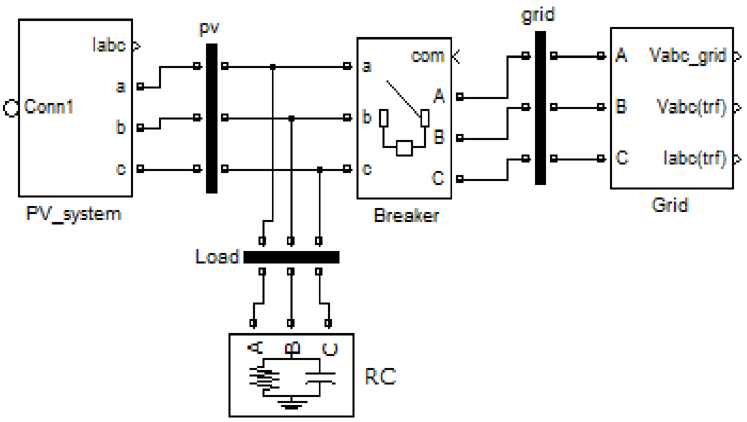

Figure 3. Block diagram of on-grid PV system.

Fig. 3 is the block diagram of the system and the model where the measurements were performed and the system was analyzed in the simulation is shown in Fig. 4. A solar panel, a DC/DC converter (boost converter), a DC/AC converter, a voltage regulator and filters to reduce harmonics were used in the inner structure of the PV system. A star-delta transformer with 0.4/34.5 kV voltage value, a 15 km of pi type energy line and 500 KVA source are used in the inner structure of grid system.

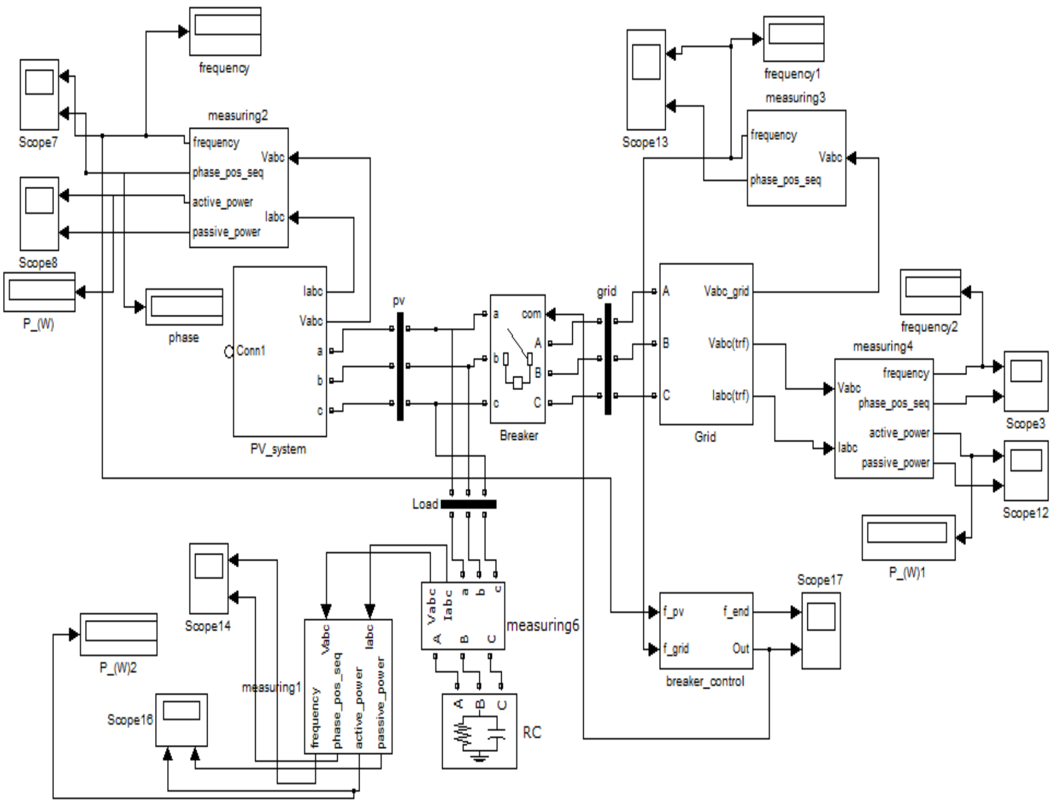

Figure 4. On-grid PV system simulation.

IV. Simulation Results

First the synchronization of PV system and the grid was monitored in the simulation and frequencies, phase levels and voltage values of both PV system and the grid were measured. Frequency-time and phase –time graphics of PV system can be seen in Fig. 5. It is seen in Fig. 5 that frequency was stabilized at 50 Hz and phase level was stabilized at 0 degrees respectively. When frequency and phase level started to be stabilized at the same time, this time was 0.25th second and it was constantly stable after 0.25th second.

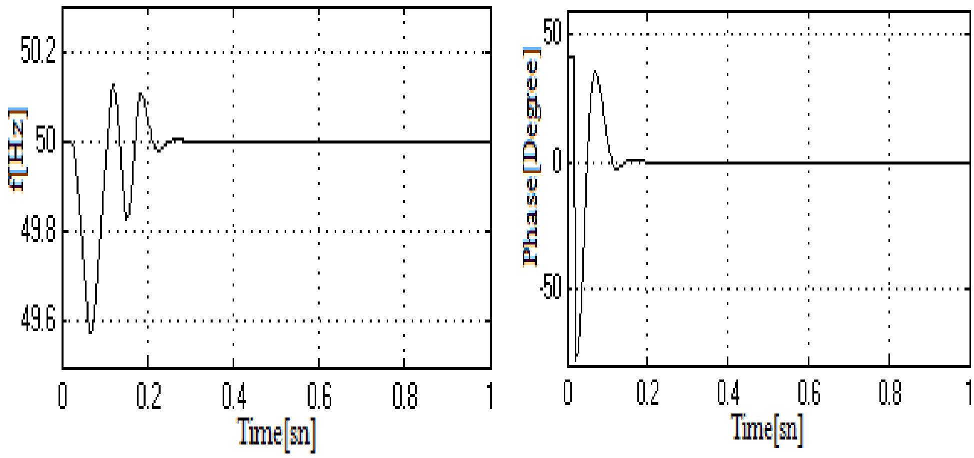

Figure 5. Frequency – time and phase –time graphics of PV system respectively.

Frequency – time and phase –time graphics of grid side is seen in Fig. 6. It is seen in Fig. 6 that, frequency is stabilized at 50 Hz and phase level is stabilized at 0 degrees as it was in PV system. When frequency and phase level started to be stabilized at the same time in grid side, this time was also 0.25th second and it was constantly stable after 0.25th second.

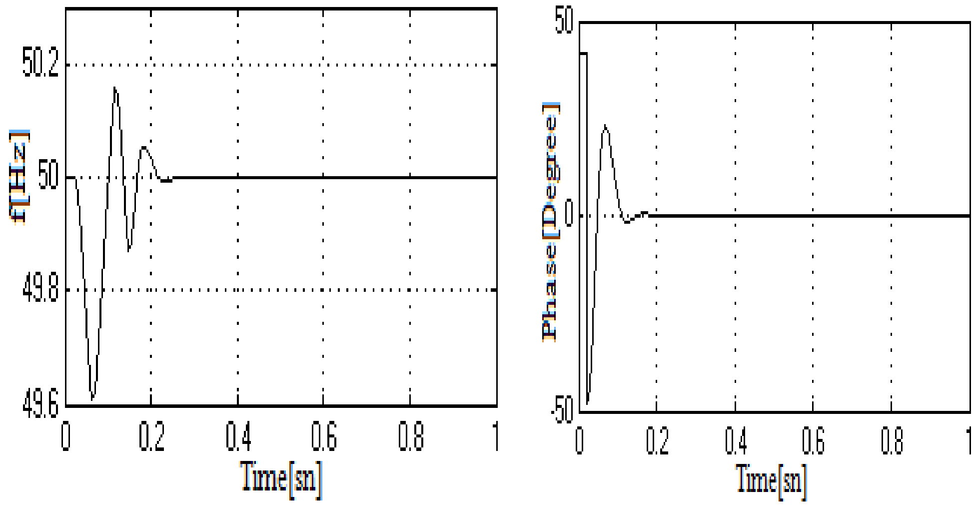

Figure 6. Frequency – time and phase –time graphics of grid respectively.

Since frequency, phase and voltage values in on-grid system were stabilized as from 0.25th second, the synchronization of the system was provided from 0.25th second. Therefore, the breaker which was like an open key at first, was closed at 0.25th second after being programmed. Voltage at pre-filter DC/AC converter output is shown in Fig. 7. Since the breaker was closed at 0.25th second, the voltage up to that point was 0 and after that point it obtained a wave with a lot of harmonics. Harmonic values of the waves shown in Fig. 7 are given Fig. 8. This value was measured as 58.59% (for 50 cycles). Since this value constitutes a high rate of harmonic, a filter was designed and the rate of harmonics was reduced. Pre-filter voltage is shown in Fig. 7, and harmonic value of pre-filter voltage is shown in Fig. 8.

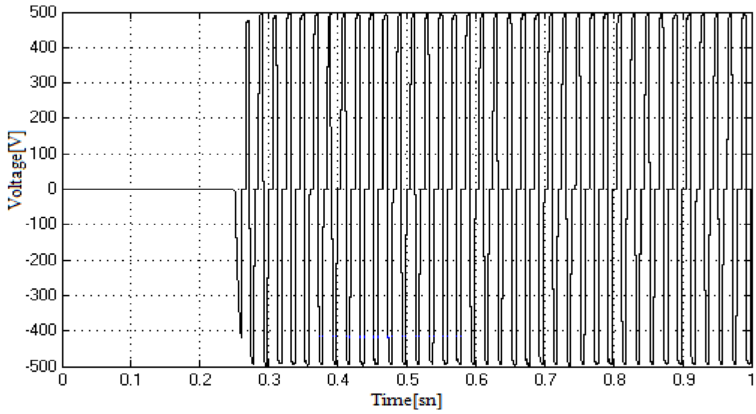

Figure 7. Pre-filter voltage at DC/AC converter output.

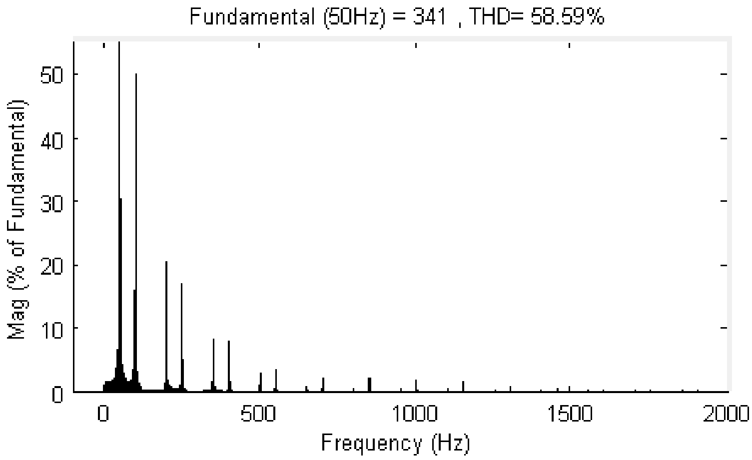

Figure 8. Harmonic value of pre-filter voltage.

Post-filter voltage wave obtained after being reduced of harmonics is given in Fig. 9. Since the breaker was shut down as from 0.25^{th} second, after that point in time, the wave was stabilized at 566.08V at maximum. Since maximum voltage value is $\sqrt{2}$ times bigger than effective voltage, effective value of post-filter voltage wave is 566.08 / $\sqrt{2}$ = 400.02 V.

Harmonic values of voltage wave post-filter are given in Fig. 10, and this value was measured as 7.73 % (for 50 cycles)

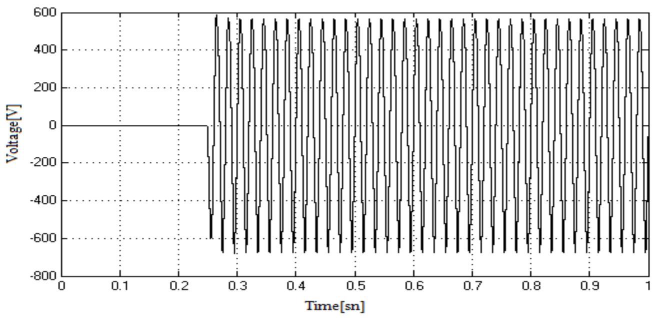

Figure 9. Post-filter voltage wave obtained after being reduced of harmonics.

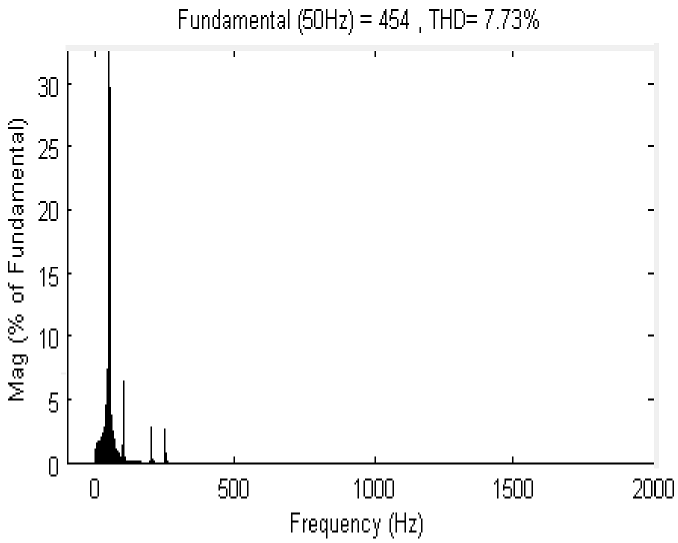

Figure 10. Harmonic value of post-filter voltage wave.

Voltage wave obtained after breaker is given in Fig. 11 and since the synchronization occurred as from 0.25th second, voltage wave was stabilized at 566.26V at maximum. Since maximum voltage value is $\sqrt{2}$ times bigger than effective voltage, effective value of voltage wave after breaker is 566.26 / $\sqrt{2}$ = 400.4. Since the breaker was open until 0.25th second (because the synchronization occurred at that point in time) load was added to the system at 0.25th second. Since there had been no load in the system until 0.25th second, there was a slight voltage increase after breaker.

Effective value of voltage wave after breaker, after the load was added to the system, was stabilized at 400.4 V as it can be seen in Fig. 11.

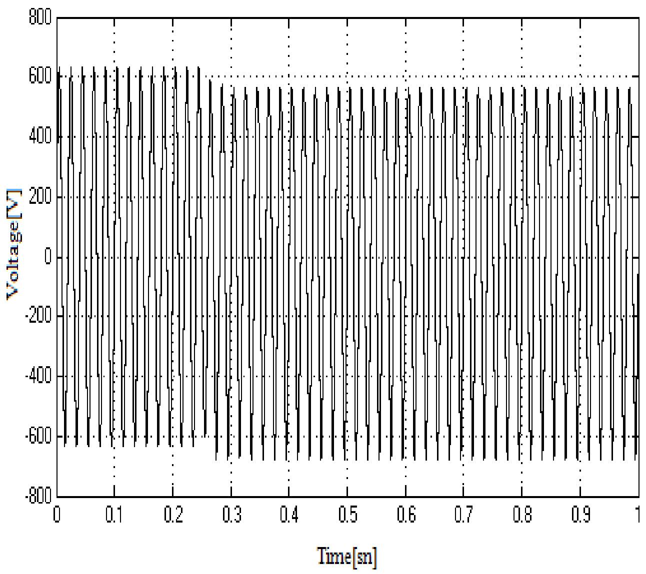

Figure 11. Voltage wave after breaker.

Effective value of voltage wave at transformer output was measured as 48.84 / $\sqrt{2}$ = 34.5 kV. As it was told in Fig. 11, since there had been no load in the system until 0.25th second, there was a slight voltage increase at transformer output until 0.25th second. Voltage wave at transformer output is given in Fig. 12. Since the synchronization again occurred as from 0.25th second, voltage wave was stabilized at 48.84kV at maximum since the 0.25th second.

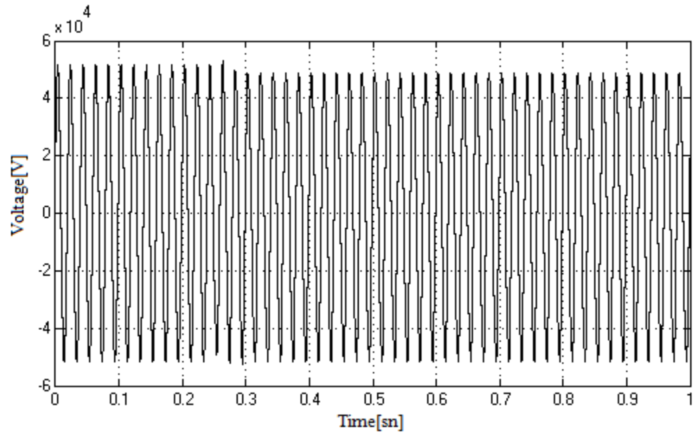

Figure 12. Voltage wave at transformer output.

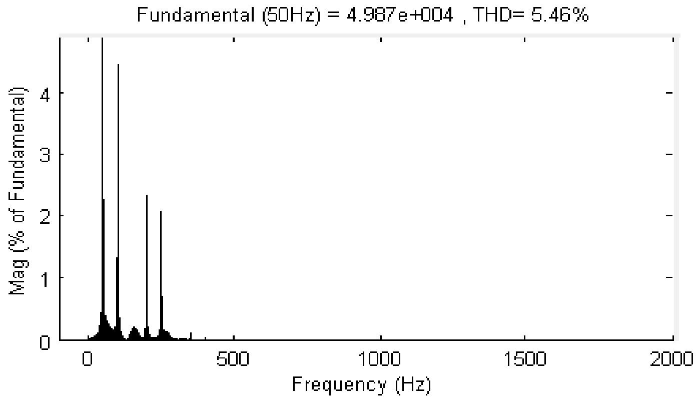

Figure 13. Harmonic value of voltage wave in the beginning of line

Harmonic rate occurring in voltage wave in the beginning of 15 km of pi type energy line is given in Fig. 13 and this value is 5.46%. A harmonic measurement was also performed in the end of the same line, and it can be seen in Fig. 14, this was measured as 5.45 %. As it can be seen in the figures, the harmonic value decreased 0.01% from the beginning to the end of the line.

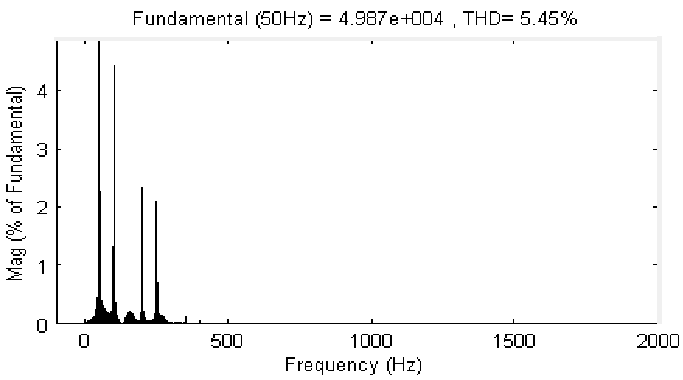

Figure 14. Harmonic value of voltage wave in the end of line.

Active power-time and reactive power-time graphics of PV system is given Fig. 15 respectively. After the breaker was shut down, the power of PV system was measured 59.31 W and it was stabilized at this value. Reactive power, after the breaker was shut down, was measured as 42.18 Var and it was stabilized at this value. Active power-time and reactive power-time graphics of load is given in Fig. 16 respectively. The power in load after the breaker had been shut down was measured 94.71 W and it was stabilized at this value. Reactive power after the breaker had been shut down was measured as 3.01 Var and it was stabilized at this value.

Active power-time and reactive power-time graphics of grid side is given in Fig. 17. The power occurring on the power side after the breaker had been shut down was measured as 154.1 W and it was stabilized at this value. Reactive power, again, after the breaker had been shut down was measured as 39.1 Var and it was stabilized at this value. Voltage of DC/DC converter (boost converter) output is shown in Fig. 18.

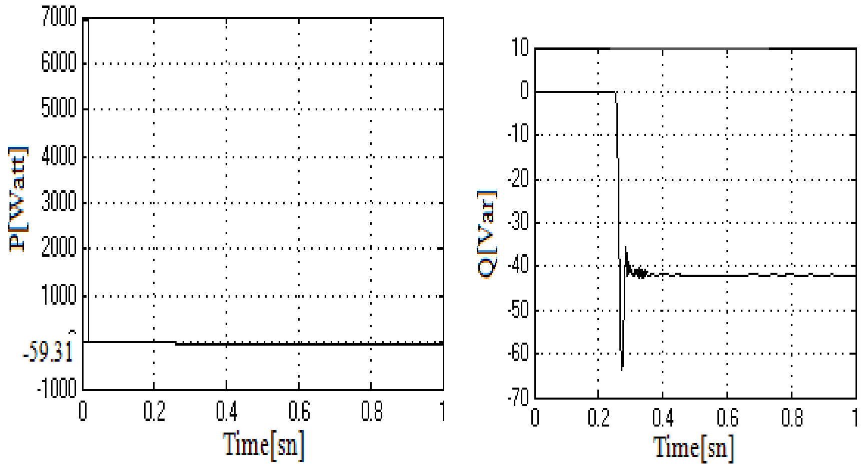

Figure 15. Active power-time and reactive power- time graphics of PV system respectively.

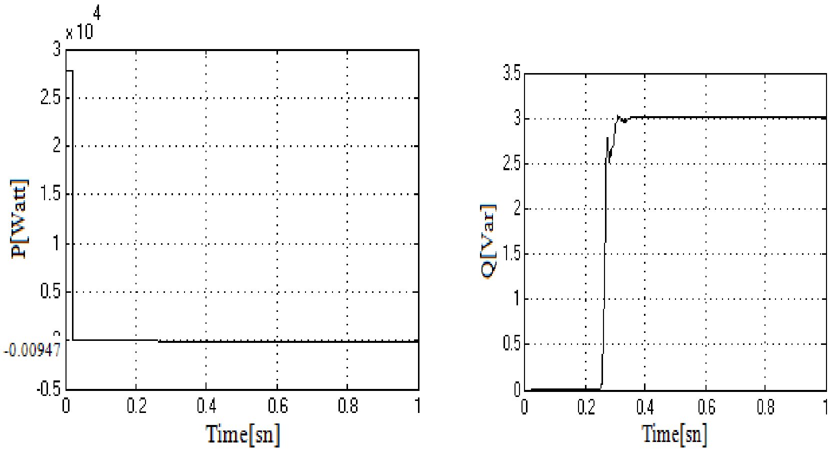

Figure 16. Active power-time and reactive power- time graphics of load respectively.

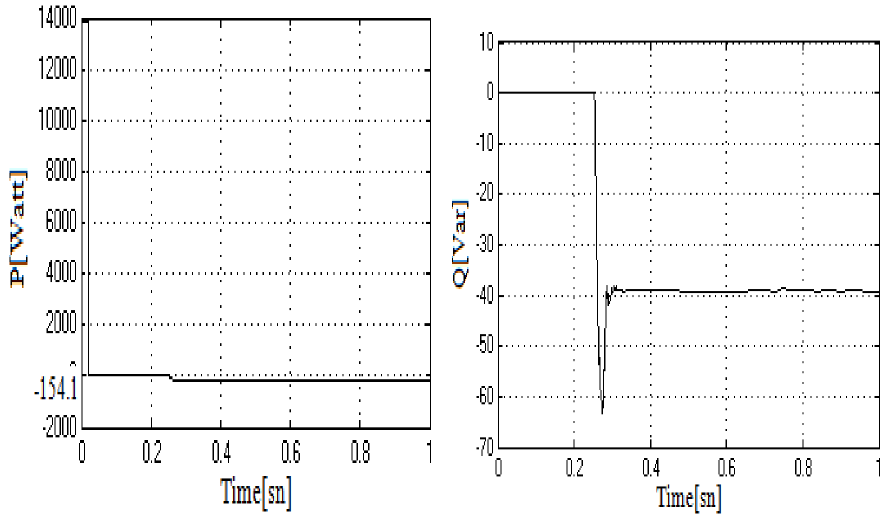

Figure 17. Active power-time and reactive power- time graphics of grid side respectively.

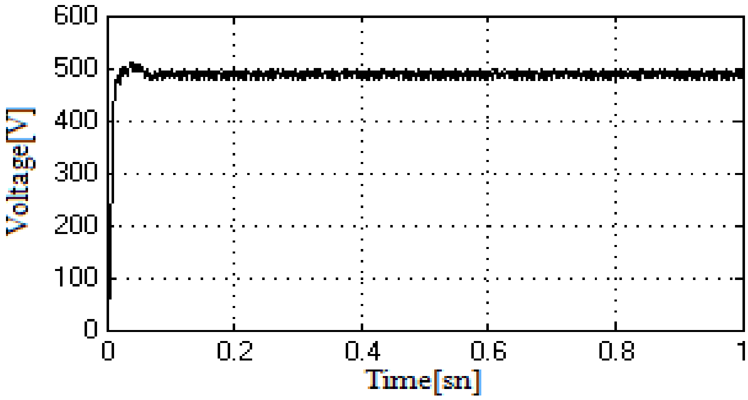

Figure 18. Voltage of DC/DC converter (boost converter) output.

V. Conclusion

Simulation of on-grid photovoltaic system was performed on Matlab/Simulink environment and the effects of photovoltaic system on the grid were analyzed. Synchronization process between PV system and grid was monitored, phase and voltage measurements were performed and the performance of the system was analyzed. Additionally, harmonics due to inverters in photovoltaic systems were measured and it was observed that through the designed filter harmonics were reduced to minimum in accordance with international standards.

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