Design and analysis of a solar water pumping system for two hectares farm in India

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***Abstract*—This paper is about the design of a solar water pumping system for a two hectare wheat farm in Amritsar, Punjab India. After collecting the site data and farm water requirements a system was designed and simulated in HOMER software. The designed system consists of a 4.14kW photovoltaic panel network, 20 12V Trojan SAGM batteries and a 1.58kW power converter. Steady state system simulation results show that design system can meet the farm water requirements. The dynamic simulation of the designed system was performed in MATLAB and the overall characteristics of the system was improved by incorporating a control system based on Perturb and Observe maximum power point tracking algorithm. Designed system details and simulation results are included in the paper.**

Keywords—Solar water pump, HOMER, Dynamic Modeling, MATLAB,

I. INTRODUCTION

This report represents solar water pumping system for use on two hectares of farmland in Amritsar, Punjab India. The design process include site selection, gathering of solar data, sizing and modeling of the solar water pumping system. The modeling include modeling of a water pump, photovoltaic panel network, a power converter, a storage system in shape of a battery bank, its dynamic modeling and implementation of a maximum power point tracking system which will act as its control system. The work can be split evenly into three sections.

- Project sizing, modeling, and analysis
- System dynamic simulations
- System control design and analysis.

II. PROJECT SIZING, MODELING, AND ANALYSIS

A. Site Selection and Data

For site selection of a 2-hectare farm, the site selected is located in Punjab, India. The Indian, Punjab is divided into six agro climate zones, as can be seen in figure 1[1].

1. Sub-Mountain Undulating Region
2. Undulating Plain Region
3. Central Plain Region
4. Western Plain Region
5. Western Region
6. Flood Plain Region

For our project, Amritsar city was selected, which lies in Central plain zone (Zone 3). Based on data in paper [2], a 2-hectare farm for wheat requires a water pump to operate for 8 hours, which have a flow rate of 6.26 l/s (liters/sec). The average water depth in the area is 13m, and the total head is 18.6m.

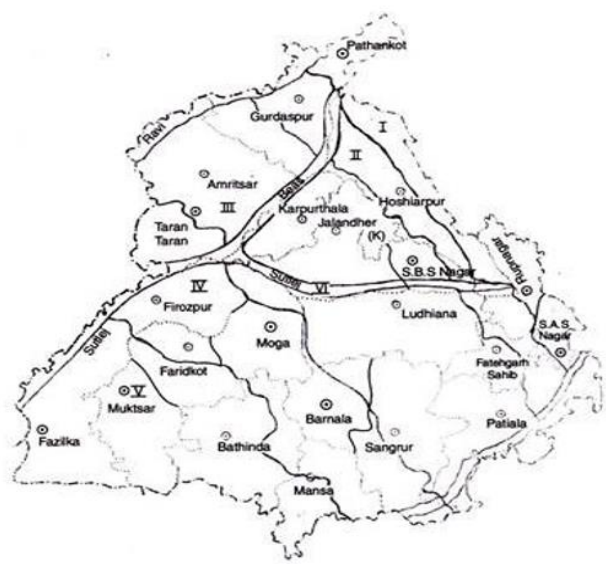

Fig. 1. Punjab Agro-Climate Zone

B. Load Calculation

In Amritsar, the best time for solar throughout the year is 8 AM to 4 PM, which makes it 8 hours. Our solar pump will be working throughout the year for those 8 hours. For the calculation of load, equation 1 is used. As the output from the pump will be 6.26l/s → 22.536 m3/hr.

$$P_h = \rho * g * TDH * Q/3600 \quad (1)\ [3]$$

$$P_h = 997*9.81*18.6*22.536/3600$$

P_h = 1138.8 W

Typical efficiency of water pump is 80%

So, 1138.8/0.8 = 1423.5 W

Load is 1.424kW

The load calculated above was plotted in HOMER, as can be seen in figure 2. It can be seen in the figure 2, that maximum load is 1.42 kW and average load is 0.47kW with minimum possible load being 0kW. The daily profile for the solar water pump can be seen in figure 3. It can be seen in figure 3, that the load is 1.42 kW for 8 hours from 8 AM to 4 PM.

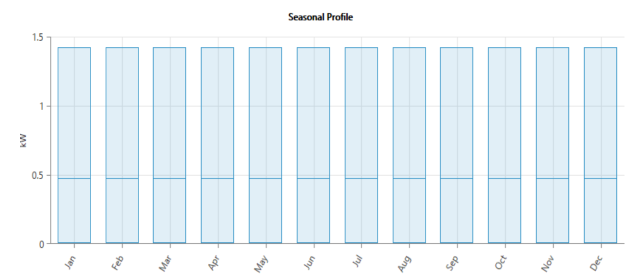

Fig. 2. Load Profile of Solar water pump in HOMER

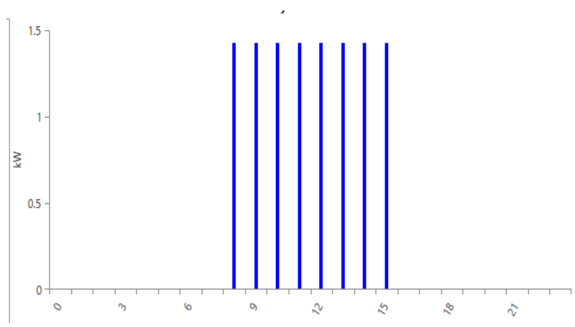

Fig. 3. Daily Profile of Solar Water Pump

C. *Solar Irradiance Availability (Solar GHI)*

The typical Solar Global horizontal Index for Amritsar can be seen in figure 4. It can be seen in figure 4, that the solar irradiance varies from 2.938 kWh/m2/day to 6.957 kWh/m2/day throughout the year. The clearness index varies from 0.537 to 0.638 throughout the year. The overall stats show that Amritsar is an excellent location for implementation of a solar water pumping system.

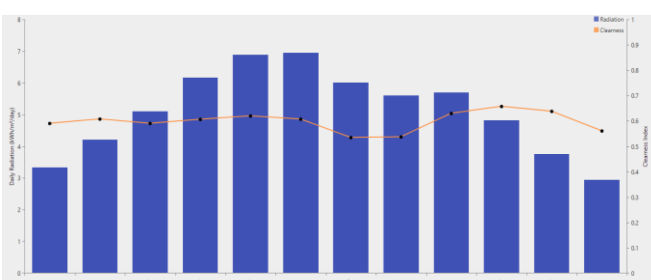

Fig. 4. Solar GHI as in HOMER

D. *Simulation in HOMER*

The schematic in the HOMER for the proposed design can be seen in figure 5. The system consists of a network of Astronergy Solarmodule305ASM6612P 305 solar panels [4] connected to a DC bus of 120V with a battery bank consisting of Trojan SAGM 12 105 [5]. The load is 11.39kWh/day and 1.42 kW at its peak and is connected to the AC bus. In between AC and DC buses, there is a 2kW SMA America SB2000HFUS-30 (240V) [6] power converter, which is connected to take care of the conversion from DC to AC.

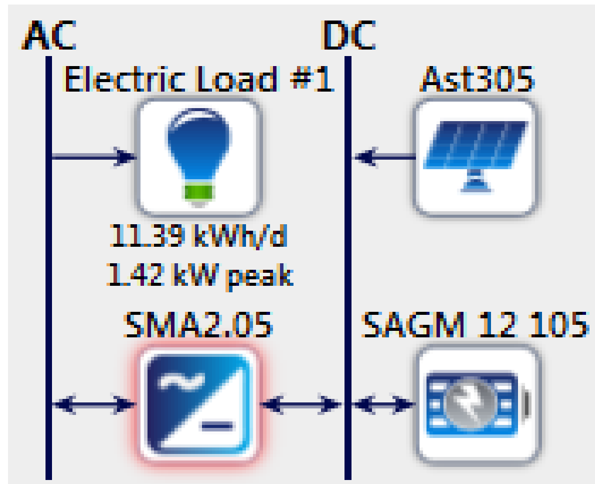

Fig. 5. Schematic of Proposed design

1) Simulation Results in HOMER: After simulation of the whole network in HOMER, the result can be seen in Tables 1 and 2. The PV resource requirement came out to be 4.142kW, which is equal to 14 panels. Since our bus voltage is 120V, we will go with 15 panels with 5 connected in series consisting of 3 strings. The batteries requirement came out to be 20, which makes it only 2 strings of batteries. This proposed system can be seen in Figure 6.

Table 1. Simulation results in HOMER

Architecture				Ast305	
Ast305 (kW)	SAGM 12 105	SMA2.05 (kW)	Dispatch	Capital Cost ($)	Production (kWh/yr)
4.142	20	1.58	CC	2607	6648

Table 2 Simulation results in HOMER

SAGM 12 105				SMA2.05
Autonomy (hr)	Annual Throughput (kWh/yr)	Nominal Capacity (kWh)	Usable Nominal Capacity (kWh)	Inverter Mean Output (kW)
46.9	496	27.9	22.3	0.47

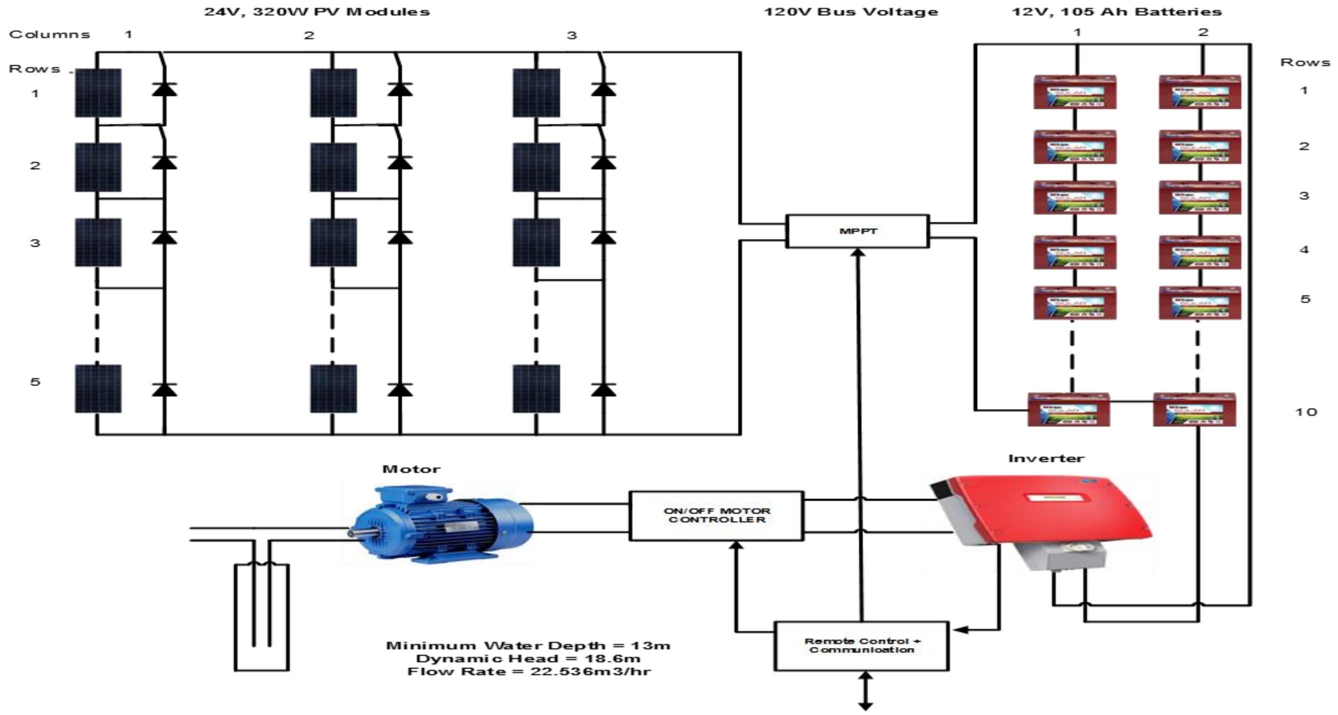

Fig.6. Layout of proposed system

After the simulation, the electrical production results for a whole year can be seen in figure 7. The figure shows that the electrical production from PV source per month varies from 0.5 to 0.6 kW throughout the year.

2) Cost Analysis using HOMER: The cost analysis of the proposed system in HOMER as can be seen in figures 8 and 9. In figure 8, cost summary of the entire system is summarised as the total net present cost $13,850, levelized cost of energy is $0.26, and operating cost of the system is $155. In figure 9, the cash flow for the 25 years cycle of operation of the proposed system is summarized. The upfront capital cost is $11,841. After 15 years, a replacement cost of $2,233 will incur. At the end of 25 years cycle, a salvage amount of $2,894 can be gained from the system.

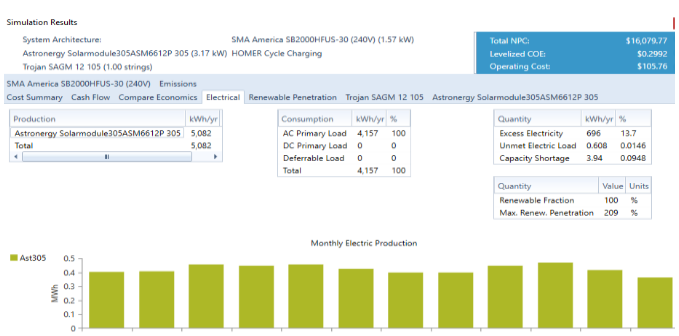

Fig.7. Power Output Results from PV Source

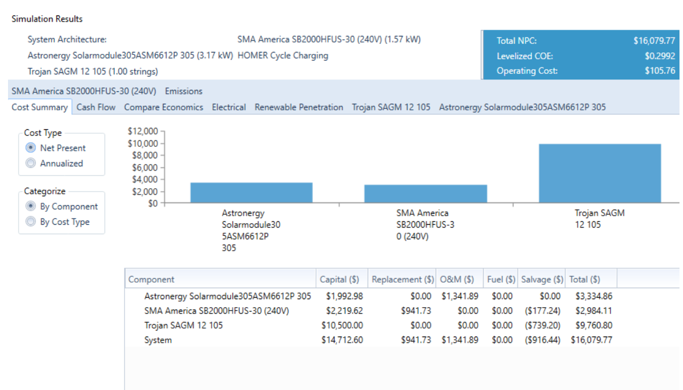

Fig.8. Cost summary of the entire proposed system

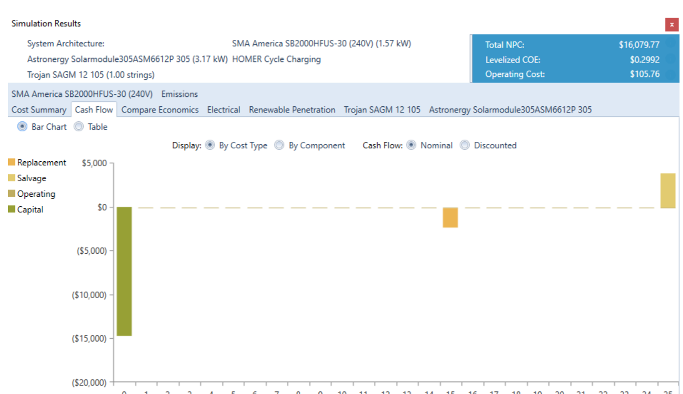

Fig.9. Cash flow of the entire proposed system

III. SYSTEM DYNAMIC SIMULATIONS

The load of the pumping system is a constant of 1.424 kW for 8 hours each day (from 8 AM to 4 PM). The motor is modeled as an RL load with P=1.424 kW at a 0.9 lagging power factor. The system consists of a PV array, followed by a boost converter, which is connected with a Trojan battery bank on its way to the inverter. At this instant, the bus voltage is 120V as the bus voltage of battery bank is 120V. After the inverter stage, the voltage is stepped up using a transformer from 120V to 240V as per Indian standards.

In the end, termination of the whole network is at the load, which is 1.424kW with 0.9 lagging power factor.

1) Test Conditions: The test conditions for the dynamic model and control design of the system can be seen in figure 10. The first curve is of the Irradiance, and the second curve is of the temperature to simulate the situation between 8 AM to 4 PM during which load is operating and constant.

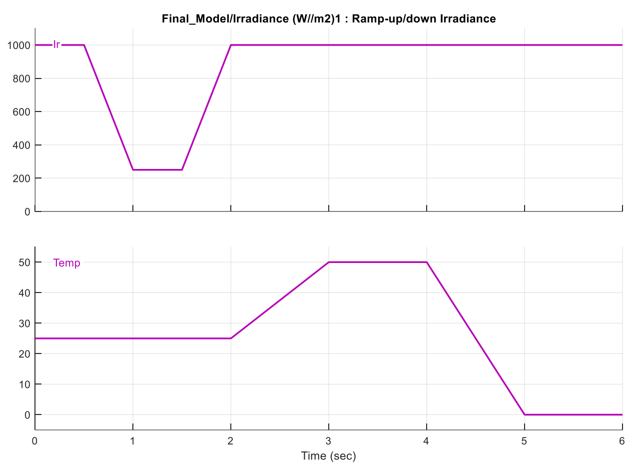

Fig.10. Irradiance and Temperature to PV Array

2) Simulation Results: The simulation results of the dynamic model at a constant duty cycle of 0.8 to boost converter can be seen in figures 11, 12, and 13. In figure 11, the simulation results related to PV array parameters can be seen. In figure 12, the simulation results related to battery parameters can be seen. In figure 13, the simulation results related to motor load parameters can be seen.

IV. SYSTEM CONTROL DESIGN AND ANALYSIS

For the control system design of the setup, a block of Perturb and Observe maximum power point tracking was connected to boost converter to control duty cycle of power converter instead of a constant duty cycle.

1) Test Conditions: Test conditions are the same as were for the dynamic model.

2) Simulation Results: The simulation results after the boost converter are fed with the P&O algorithm can be seen in figures 14, 15, and 16

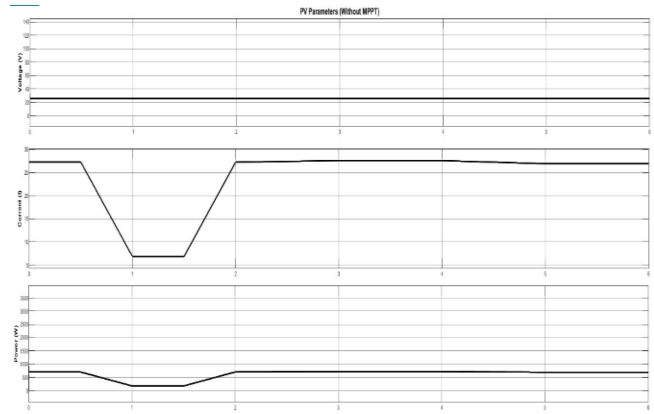

Fig.11. Simulation results for PV array parameters at constant duty cycle of 0.8

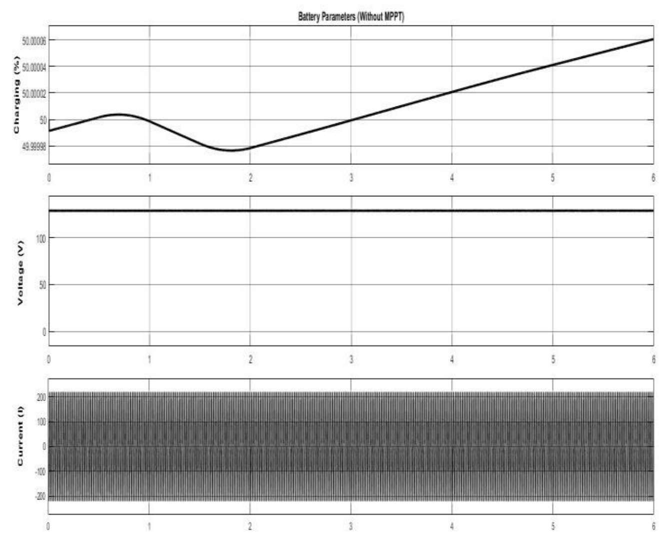

Fig.12. Simulation results for battery parameters at constant duty cycle of 0.8

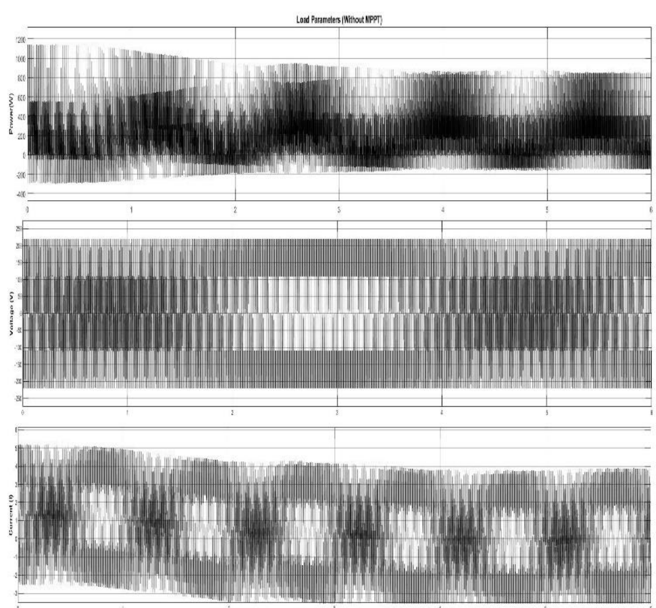

Fig.13.Simulation results for motor load parameters at a constant duty cycle of 0.8

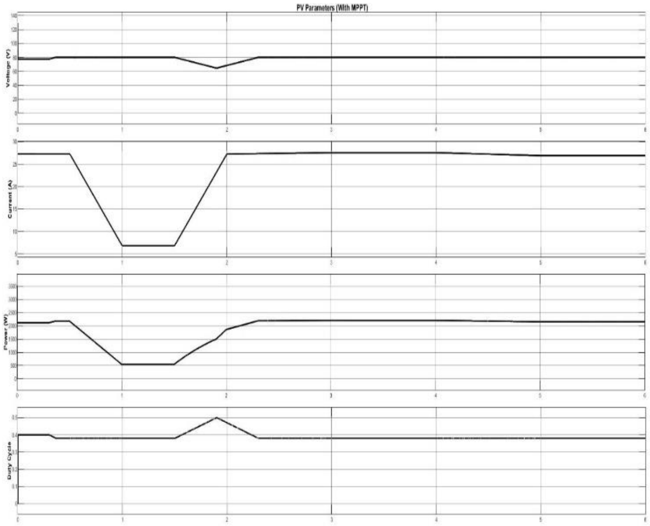

Fig.14. Simulation results for PV array parameters with P&O implemented

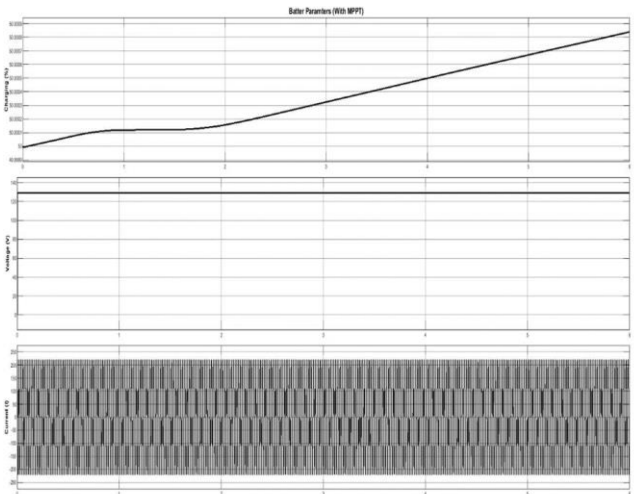

Fig.15. Simulation results for battery parameters with P&O implemented

V. CONCLUSION

In this section, the improvements will be discussed, which happened in the overall system with the addition of Perturb & Observe maximum power point tracking block as compared to a constant duty cycle block as in the dynamic model.

Photovoltaic characteristics have improved. If figures 11 and 14 are seen, it can be seen that the voltage output of the PV array improved, the current rating maintains the same trend in both scenarios fluctuating from 27A to 8A and then to 27A. The most important parameter is the improvement of the overall power rating of the panel array that was oscillating from 250W to 750W initially, but after the implementation of the P&O MPPT algorithm jumped to 2500W for the larger portion of the simulation.

Battery parameters are shown. Results in figures 12 and 15 show that a voltage level of 129V is maintained as per the declared bus voltage of 120V in both figures. In figure 12 without MPPT, it can be seen that there was initially a discharging registered after which the charging of the battery can be seen, whereas in figure 15 it can be seen that after the MPPT implementation no discharge of battery was seen; whereas battery current characteristics remained around 200A. Keep in mind that the initial state of battery charging was 50%.

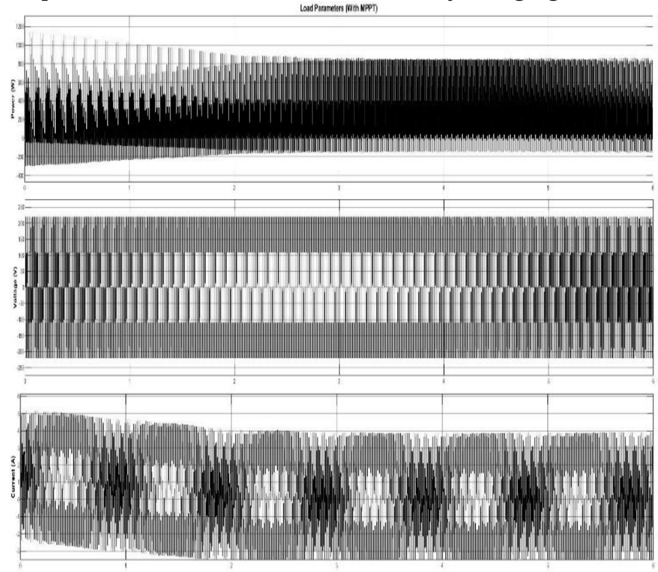

Fig.16. Simulation results for Motor load parameters with P&O implemented

Load parameters remained the same, as the rated load was a constant with 1.424kW with 0.9kW lagging. As can be seen in figures 13 and 16, the power of the load operating was between 1100 to 800W. The voltage can be seen as a constant oscillating around 220V as per standards in India and current varied around 5A.

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