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Design and Simulation for Comparison of Three-Phase AC Motor and DC Motor Used in Solar Water Pumping System

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Abstract— *The main aim of this paper is to design and simulations for comparison of three- phase AC motor and DC motor used in solar water pumping system that can provide water for irrigation without the use of batteries, utility power or diesel engines. This research has designed the system such that necessary power can be obtained from solar panel arrangement to run the water pumps which pumps water from underground and distributed to plantation fields. In this paper, deals with basics of solar powered water pumping system and the comparison of performance between AC motor and PMD motor pumping system for irrigation of various crops plantation in Southern Shan State is presented. The detail study for drip irrigation system and water requirement is carried out at Heho PRIME Farms Myanmar Ltd, Shan State. Currently, this farm is operated by diesel engine pumping system. Thus, running cost for water supply is high. In this paper, the use of solar water pumping and supply system is presented to replace diesel engine-based system. The daily water requirements for the various crops were determined and the pumping system was simulated using MATLAB/Simulink software. According to the results, the water demand for crops plantation can be fulfilled by the designed system. From the simulation results, it is found that the direct current motor is best suitable for photovoltaic water pumping than the three – phase AC induction motor in pumping applications.*

Keywords— *DC Motor, Drip irrigation system, Solar Water pumping, Three- Phase AC motor, Water requirement.*

I. Introduction

In this paper, solar power drip irrigation system using three phase pump motors is presented. Drip irrigation is the system that can take better advantage of photovoltaic pumping. Over the past few decades, drip irrigation systems have been developed which deliver drops of water directly to the soil at the plant roots, requiring a small fraction of the water needed to grow the same crops by conventional irrigation techniques. Drip irrigation has efficiency (water savings) of 90%, and because of its target, the plant roots, evapotranspiration and percolation water losses are minimized [1]. Depending on the crop cycle, drip irrigation could allow up to three crops per year to be harvested instead of only a single crop in the rainy season of many tropical locations. This means that when it rains or is cloudy, irrigation is not needed because there is less evapotranspiration due to the irradiation decrease. This is convenient because under the same rainy and cloudy conditions, the solar pumping would not generate as much energy. The same applies to the opposite, on sunny clear days the water demand of the plant increase and at the same time there is more water pumped [2]. When such pumps are used, power conditioning or maximum power point tracking is commonly included between the solar panel the pump, so that the electrical energy can be converted into a more usable form. Just like varieties of water pumps, there is a huge variety of motor types used in water pumping systems with each other having its own advantages and disadvantages, and they result in the type of application they can be used for. If AC motors are used, an inverter should be placed between the solar panels and the motor which will add value to the cost of the system while comparing with DC motor-based water pumps. In this paper, PV fed single- phase induction motor and permanent magnet DC motors are simulated by using MATLAB and compared with the experimental results. It is found from the work that the AC motor water pumping system. The general block diagram of AC motor and PMDC motor water pumping systems are shown in Fig. 1 (a) and (b) respectively.

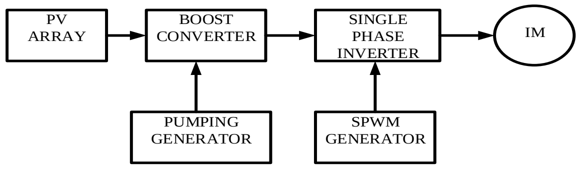

Fig. 1(a). Block diagram of the AC pumping system

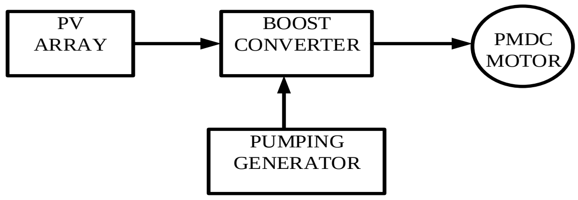

Fig. 1(b). Block diagram of the PMDC motor pumping system

II. Irrigation and Irrigation Methods

Irrigation is water artificially applied to farm, orchard, and horticultural crops [3]. This definition is very close to the one given by Oxford Advanced Learner’s Dictionary (7th edition) for which "to irrigate is to supply water to an area of land through pipes or channels so that crops will grow “Irrigation method or technique is the way water is supplied to crops. There are five basics methods of applying water to the soil:

- surface irrigation
- sprinkler irrigation

International Journal of Scientific Engineering and Science
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- subsurface irrigation
- micro-irrigation
- trickle/drip irrigation [4]

A. Surface irrigation: Surface irrigation methods are based on the principle of moving a water stream over the surface of the land in other to wet it, either completely or partially.

B. Sprinkler irrigation: It is the application and distribution of water over the field in the form of a spray, or jet, which breaks into drops or droplets created by expelling water under pressure from an orifice or nozzle.

C. Subsurface irrigation: Subsurface irrigation involves the application of water to crops via underground systems. In principle, two systems can be distinguished, a buried trickle irrigation system and a ditch water infiltration system.

D. Micro-irrigation: It is the slow application of water on, above or beneath the soil. It includes surface drip (SDI), subsurface drip (SSDI), micro-sprayers, or micro-sprinklers.

E. Drip (trickle irrigation): The principle of trickle irrigation is to water the plants by means of low flow pressure pipelines. Irrigation efficiency is high, since losses by evaporation are negligible and percolation losses are low [5].

III. Solar Energy for Pumping Application

A water pumping system needs a source of power to operate. In general, AC powered system is economic and takes minimum maintenance when AC power is available from the nearby power grid. However, in many rural areas, water sources are spread over many miles of land and power lines are scarce. Installation of a new transmission line and a transformer to the location is often prohibitively expensive. Windmills have been installed traditionally in such areas; many of them are, however in operative now due to lack of proper maintenance and age. Today, many stand- alone type water pumping systems use internal combustion engines especially diesel engines. These systems are portable and easy to install. The consumption of fossil fuels also has an environmental impact, in particular the release of carbon dioxide (CO_2) into the atmosphere.CO_2 emissions can be greatly reduced through the application of renewable energy technologies, which are already cost competitive with fossil fuels in many situations [6]. The use of renewable energy for water pumping systems is, therefore, a very attractive proposition. Windmills are a long-established method of using renewable energy; however, they are quickly phasing out from the scene despite success of large-scale grid-tied wind turbines [7]. PV systems are highly reliable and are often chosen because they offer the lowest lifecycle cost, especially for applications requiring less than 10 kW, where grid electricity is not available and where internal-combustion engines are expensive to operate. If the water source is 1/3 mile (app. 0.53 km) or more from the power line, PV is a favorable economic choice.

IV. Water Requirement with Drip Irrigation System

Water Requirement with Drip Irrigation System In general, the daily maximum power (Hydraulic energy) required to lift water is; $E= \eta QHg$ (1)

Where;

Q= mass of water delivered per day in ton/day or m3/day. (1kg = 1 liter, Q = V)

H = Static head in (m)

G = acceleration due to gravity ($9.81 m/s^2$)

η= total system efficiency at maximum flow Provided those units, the result will be in kJ. To convert in MJ, 'E' is multiplied by 10^{-3} Formula (1) can be rewritten as follows: $E = 10^{-3} \times 9.81$ VH (in = kJ) (2) Since 1kWh = 3.6 MJ, to get the energy in kWh, 'E' in equation (2) is simply divided by 3.6 $E = 10^{-3} \times 9.81$ VH/ 3.6 = 2.725 $x10^{-3}$ VH (in kWh) (3) Equation (3) can rewrite in the following form: E = VH/ 367 (in kWh) (4) The hydraulic energy needed to lift a certain amount of water is proportional to the product of the amount of water to be lifted and the height through which it is lifted, the so-called volume- Head product. Only a small fraction of the available solar radiation is converted to hydraulic energy. Only about 10-15% of solar energy input is converted to electrical energy. Perhaps the most promising future PV cells will consist of thin films [8]. These films are not single crystal device, so there are limitations to carrier mobility and subsequent device performance. However, in spite of the non- single- crystals structures, laboratory conversion efficiencies exceeding 17% have been achieved [9]. Due to the relatively low efficiency of solar cells, solar cells, solar pumping is recommended only under some circumstances or conditions as follow: Village water supply: volume- head product VH< $800m^4$ and daily insolation> 2.8 kWh/m^2 Irrigation: volume head product VH < $250m^4$ and daily insolation > 3.0 kWh/m^2 [10]

V. Design Calculation for Solar Power Drip Irrigation System

For this research study, the detail study is carried out at Heho Prime Farms Myanmar Ltd. It is located in Heho Township, Southern Shan State. The specific location is North latitude 21. 27 degree and East Longitude 96. 38 degree. The location map of selected area is shown in Figure 2. The important data for selected farm is as follow:

Total area = 5 acres

Head = 30m

Water requirement per acre = $18m^3$/acre

Total water requirement = $90m^3$

Flow rate = $90m^3$/hr.

The water requirement is for summer.

Fig. 2. Map of Heho Prime Farms

International Journal of Scientific Engineering and Science
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Presently, this farm is operated by diesel engine pumps for irrigation. For application of solar power drip irrigation system using three phase pump motors, the system block diagram in figure 3.

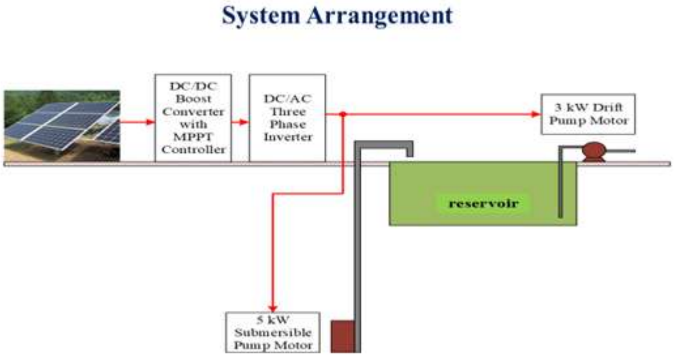

Fig. 3. System arrangement

A. Design calculation for Submersible Pump Motor

For the pumping of water from the deep well, a submersible pump motor is selected

The required power rating of submersible pump is calculated as follow

Water Requirements = 90 m^3/ day.

Head = 30 m

Time = 5 hr.

Flow Rate (Q) = $90m^3/5hr = 18m^3/hr. \times 1/3600s$

$= 0.005m^3/s$

$$P_{pump} = \frac{\rho g\, Q\, h}{\eta pump} = \frac{1000 \times 9.81 \times 0.005 \times 30}{0.4} = 3678.75W$$

For power rating of pump motor, motor efficiency is assumed as 80 %. Then motor power rating is calculated as follow:

$$P_{motor} = \frac{P\ pump}{\eta motor} = \frac{3678.75}{0.8} = 4598\ W$$

Thus, 5 kW motor is selected for submersible pump

B. Selection for PV module

For the selection of PV power rating, the daily average energy demand (Ed) is obtained as follow:

Ed = 5kW x 5hr = 25 kWh

The required daily average energy demand (Erd) is obtained as follow;

$$Erd = \frac{Ed}{\eta inv\ \eta c} = \frac{25}{0.95 \times 0.95} = 27.7\ kWh$$

Then, the average peak power of PV module is calculated

$$P\ aver,\ peak = \frac{Erd}{Tsh}$$

Where, T_{sh} = the peak sun hours (5 hrs./day for selected location)

$$P\ aver,\ peak = \frac{Erd}{Tsh} = \frac{27.7}{5\ hr} = 5.54\ kW$$

The power rating of PV module is selected as 6.2 kW. To obtain the required PV power, "Sun Power SPR – 200 – BLK – U" PV module is selected. The important parameters of the selected modules are as follow

(Pmp = 200W, Vmp = 40 V, Imp = 5A, Vdc = 600V)

In this case, the derating factor of PV system is taken as 90%. Then the series and parallel numbers of modules are obtained as follow

$$I_{DC} = \frac{P\ avg,peak}{vdc} = \frac{6.0k \times 0.9}{600} = 9.0A$$

$$N_{sm} = \frac{Vdc}{Vmp} = \frac{600}{40} = 15 \text{ nos of series modules}$$

$$N_{pm} = \frac{Idc}{Imp} = \frac{9.0}{5} = 1.86 \approx 2 \text{ numbers of parallel strings.}$$

Thus total number of 200 W PV modules is as follow N_{tm} = Nsm x Npm = 30 nos of total modules

VI. Modeling of System

As mentioned in the last section, "Sun Power SPR – 200 – BLK – U" PV module is selected for modeling of the system. There are 15 numbers in series and 2 parallel strings. The power versus voltage characteristic curves for the selected PV system is shown in Figure 4(a) and 4(b).

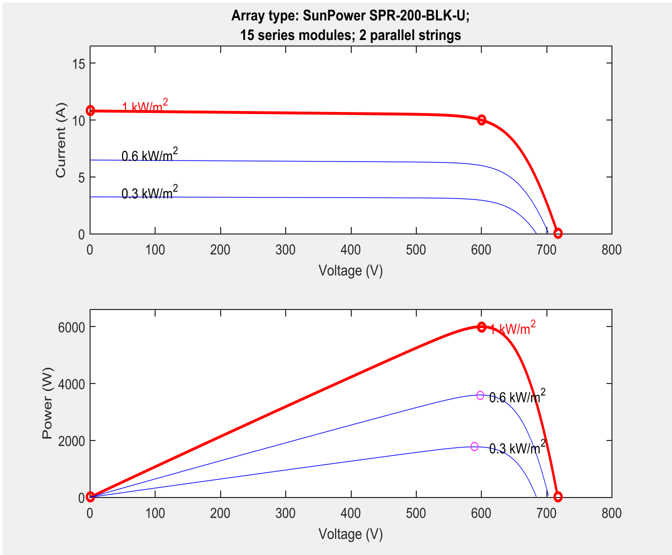

Fig. 4(a). Power versus Voltage Characteristics of PV array for Different Temperature and Constant 1000W/m^2 Irradiation

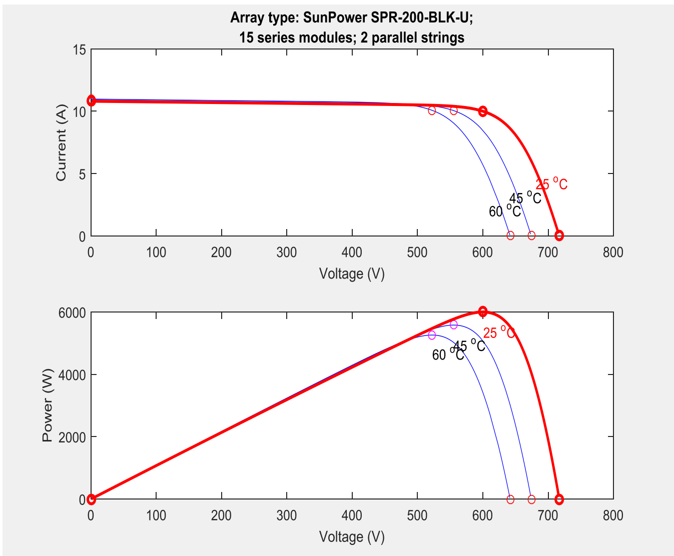

Fig. 4(b). Power versus Voltage Characteristics of PV Array for Different Irradiations and Constant 25° C Temperature

For the modeling of system, three phase AC motor and DC motor are selected for 5 kW rating. The parameters for the selected 5 kW motors are shown in Table 1 and Table 2.

TABLE 1. Rating of 5kW Three- Phase AC Motor

S. No	Parameters	Value
1	Nominal Power [Pn (VA)]	5000
2	Voltage (line- line) [Vn (Vrms)]	400
3	Frequency [fn (Hz)]	50
4	Stator Resistance [Rs (ohm)]	1.2145
5	Stator Inductance [Lls(H)]	0.005041
6	Mutual Inductance [lm(H)]	0.15846
7	Rotor Resistance [Rr (ohm)]	0.02079
8	Rotor Inductance [Llr(H)]	0.005041
9	Initial [J (kg.m2)]	0.01916
10	Friction factor [F (N.m.s)]	0.002276
11	Pole pairs	2

TABLE 2. Rating of 5kW DC Motor

S.No	Parameters	Value
1	Armature Resistance [Ra (ohms)]	11.2
2	Armature Inductance [La (H)]	0.1215
3	Field Resistance [Rf (ohms)]	281.3
4	Field Inductance [Lf (H)]	156
5	Field armature mutual inductance [Laf (H)]	1.976
6	Total inertia [J(kg.m2)]	0.02215
7	Viscous friction coefficient Bm (N.m.s)	0.002953
8	Coulomb friction torque [Tf (N.m)]	0.5161
9	Initial Speed (rad/s)	1
10	Initial field current	1

After selection of PV modules and motors, the modeling is carried out by using MATLAB/Simulink software. Figure 5 shows Simulink model for PV water pumping system with AC motor Figure 6 shows Simulink model for PV water pumping system with DC Motor. In both models, the output terminals from PV modules are connected to DC/ DC boost converter controlled by Perturb and Observed algorithm for maximum power point tracking.

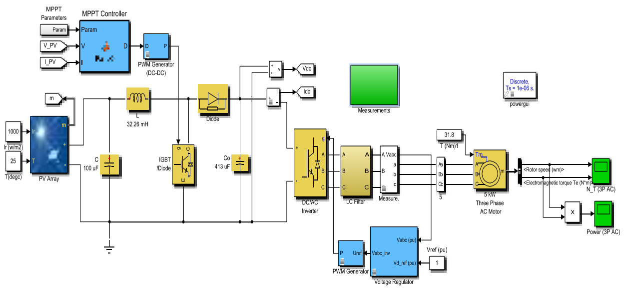

Fig. 5. Simulink Model for PV Water Pumping System with AC Motor

In water pumping with AC motor, DC/AC inverter is connected to boost converter output for conversion of DC to three- phase AC system. For smoothing of inverter output, LC filter is added between inverter and three- phase AC motor as shown in figure 5. The inverter output is connected by voltage regulator.

In water pumping with DC motor, the output of boost converter is directly connected to armature winding of separated excited DC motor. The field winding of motor is supplied by 300 V DC source as shown in figure 6. To compare and analyze the performance of the two systems, the measurements are carried out at DC link a motor output terminal IN case of AC motor, the inverter output voltages and current with their RMS values and active/ reactive powers are also measured using scopes.

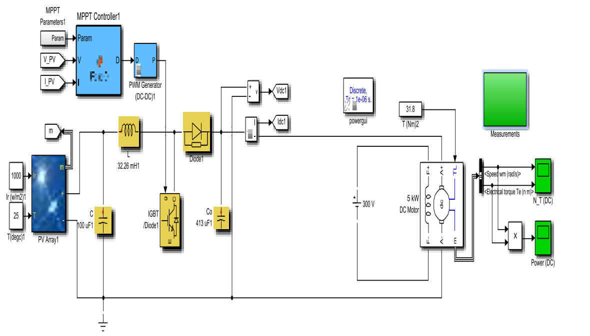

Fig. 6. Simulink Model for PV Water Pumping System with DC motor

VII. SIMULATION RESULTS AND ANALYSIS

In simulation of the two pumping systems, the simulation time is set as 1 second and sampling time is set as 1u second. The inputs to PV modules are set as 1000W/m^2 irradiation and 25° C temperature. These values are the standard irradiation and temperature for PV modules. The load torque of 5kW motor at 1500 rpm (157.1 rad/sec) speed. The simulation results for the two pumping systems are illustrated in the following figures.

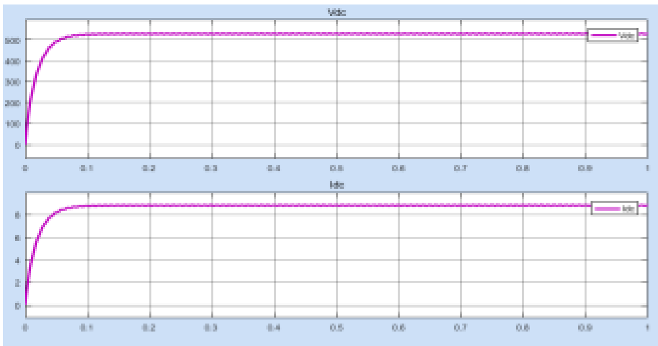

Fig. 7. Simulation Results for output Voltage and Current at DC/DC Boost Converter

Figure 7 shows simulation results for output voltage and current at DC/DC boost converter. Thee value are the same for both pumping systems. DC link voltage is about 540V and current is about 9A as shown in figure.

A. Pumping with Three- Phase AC Motor

The simulation results for pumping with three phase AC motor are shown in figure 8 through figure 11

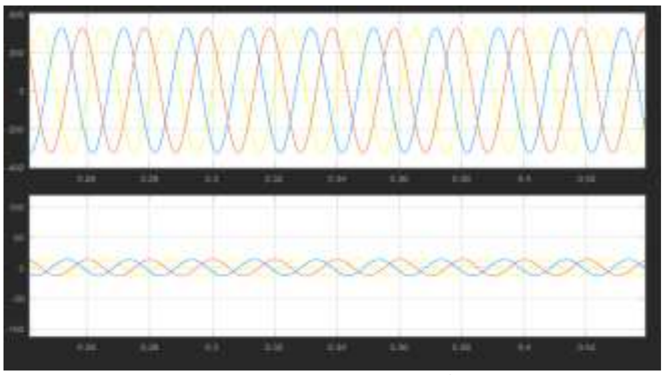

Fig. 8. Output Voltage and Current of LC Filter

Volume 3, Issue 11, pp. 76-81, 2019. ISSN (Online): 2456-7361

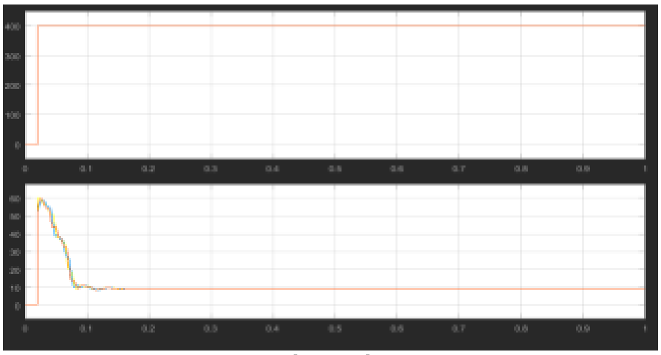

Fig. 9. Input RMS Voltage and Current to AC Motor

Figure 8 shows output voltage and current of LC filter and fed to AC motor. With the application of LC filter, the input to AC motor are nearly sinusoidal waveform. Figure 9 shows input RMS voltage and current to AC motor. The input line to line voltage is 400V and line current is nearly 10A

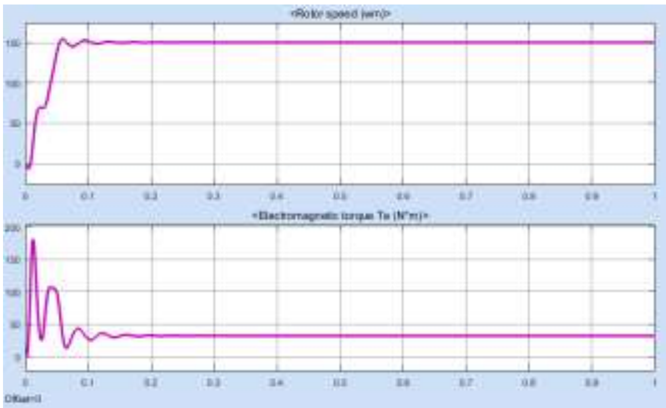

Fig. 10. AC motor Output Speed and Torque

Figure 10 shows AC motor output speed and torque. The speed is formerly overshoot and oscillated until 0.15 second. Then it is constant at 150 rad/sec (1432 rpm). Thus, the slip speed is about 18rpm. Similarly, the starting torque of AC motor is also large as shown in figure 10. After 0.15 second, the output torque is constant at set value.

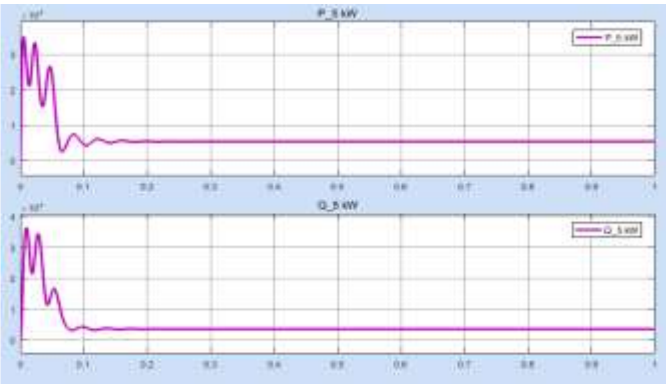

Fig. 11. Active and Reactive Power Consumed by AC Motor

Figure 11 shows the active and reactive power consumed by AC motor. At starting both active and reactive powers are large and reach steady values after 0.15 second. Under steady state condition, the active power consumption is about 5kW and reactive power consumption is about 3kVAR. Thus power factor is about 0.85 (lagging)

B. Pumping with DC Motor

The simulation results for pumping with DC motor are shown in figure 12 through figure 13.

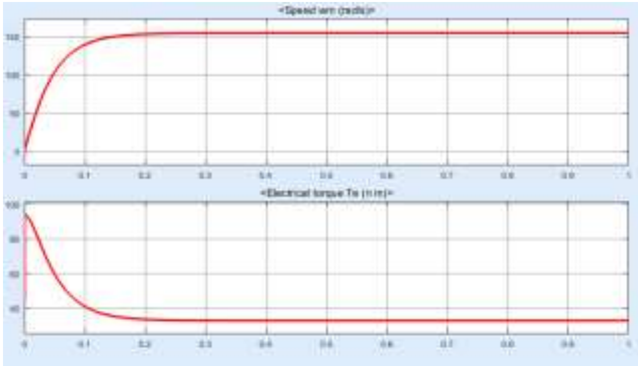

Fig. 12. DC Motor Output Speed and Torque

Figure 12 shows DC motor output speed and torque. The speed is gradually increased to the rated value without overshoot and oscillation. The steady rated value is reached at about 0.2 second. Under steady condition, the speed is about 157 rad/sec (1500 rpm) and there is no speed reduction as compared to AC motor. Similarly, the starting torque of DC motor is about 95 Nm. It is smaller compared to Ac motor when starting torque is about 180 Nm. There is no oscillation and the operation smooth as shown in figure 12.

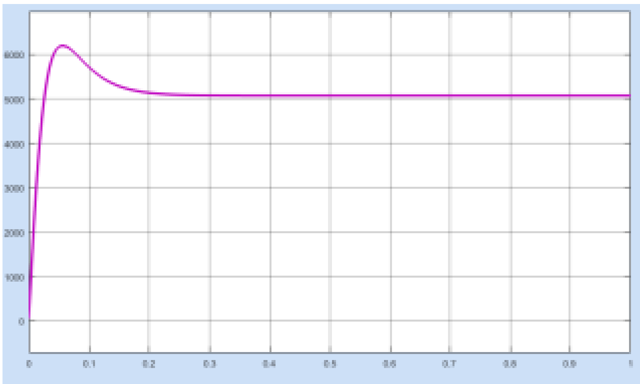

Fig. 13. Power consumed by DC Motor

Figure 13 shows the power consumed by DC motor. At starting, power is large and reach steady values after 0.2 second. Under steady state condition, the power consumption is about 5.11 kW.

C. Comparison of Simulation Results

According to the simulation results, the output torque and speed performance of DC motor is better than AC motor. There is no oscillation and overshoots with DC motor. The starting torque is smaller and speed regulation is better with DC motor. In case of power consumption, it is about 5.1 kW in DC motor and 5.85 KVA in AC motor. Thus, power requirement and current draw is lesser with DC motor.

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In AC motor operation DC/AC inverter and LC filter are needed whilst in DC motor only separately excited DC source is required. This DC source can be eliminated by using shunt or permanent magnet DC motor. Thus, the additional circuitry required is more for AC motor

VIII. Conclusion

In this paper, the application of solar PV system for irrigation is designed and simulated with three- phase AC motor and DC motor. The irrigation system was used and the requisite daily water requirement for Heho Prime Farms Myanmar Ltd was computed. Then MATLAB/Simulink software was used to simulate the solar- powered pump for the irrigation system. The modeling and simulations are carried out with three- phase Ac motor and DC motor. Design calculations are carried out based on water requirement and available solar power. In all, the pumping system is able to supply the required water for all the months with AC as well as DC motor. In performance comparison, the DC motor can exhibit better performance compared to AC motor. Again, the additional circuitry requirement by DC motor is less and this will lead to lower system initial cost and better system efficiency. Thought the initial costs of this solar panels and the pump are comparatively high, in the long run it is a simple, good investment. In future, panel efficiency will have a considerable improvement with increased research work and the cost will significantly decrease with the growth in demand and the usage of PV technology. In further study, the cost analysis for PV based irrigation systems with AC motor and DC motor should be executed for the selected case.

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