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Analysis of Induction Motor-pump System Supplied by a Photovoltaic Generator for Agricultural Irrigation in Southeastern Anatolian Region of Turkey

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Abstract – In agricultural systems, significant amount of energy is consumed during irrigation periods. Therefore operating irrigation systems with electrical energy produced by solar energy is very important. It is be possible to operate irrigation systems which have small-pump power like drip-irrigation with electrical energy produced by solar energy. Electrical energy produced by photovoltaic panels can vary from the estimated value due to environmental factors. Consequently analysis of a real system's performance is important. Thus, more correct projections can be made for the systems which will be designed. In this study, induction motor-pump mechanism for drip-irrigation system is operated with photovoltaic generator. Solar energy capacity of the established system is evaluated by measurements in irrigation periods. By means of simulations, power values produced by system and gained from the actual system are compared. Additionally the performance of induction motor is analyzed with the help of the driver system that increases the efficiency and controls the motor. As regards of results, design values of the drip-irrigation systems fed with solar energy in Southeastern Anatolian Regions of Turkey are obtained. Performance results of induction motor controlled with driver are also provided.

Key words: Solar energy, Photovoltaic generator, Speed control of induction motor, Simulation, Irrigation system with solar energy

1. Introduction

Producing energy from solar energy is an important research and development field recently. By using renewable energy resources not only supply and demand of energy required is provided but also it is produced by clean methods. Therefore it can be possible to prevent global climate change or at least to reduce it by this way [1]. Orienting towards renewable energy resources is necessity in actual conditions. It is necessary to obtain energy from renewable energy resources besides making use of it. In order to fulfill this, energy consumption should be made correctly. Studies show that Turkey has a significant solar potential. A little amount of this potential is used for gaining hot water in Southern and Western regions of Turkey, nevertheless this is not sufficient [1]. In addition to these, Turkey which is having 2640 sun hours per year is in second place among European countries in terms of solar electrical energy production potential. This solar energy capacity corresponds to 380 billion kWh energy production potential. The average solar irradiation intensity incident on the horizontal surface of Turkey is 1,303 kWh/m^2-year which means 3.6 kWh/m^2 energy per day. The average sun hours per day is 7.2 hours and the average sun days per year is 110 days. The studies indicate that 4600 km^2 of land area of Turkey is technically appropriate for utilization.

Some studies dealing with PV based induction motor irrigation systems have been made recently, but these were for different countries [2-6]. Solar energy is a very important renewable source for Turkey and Southeastern Anatolia. Thus local potential of it is investigated by an application in this study.

Southeastern Anatolia is an important agricultural region in Turkey because of its fertile lands. Irrigated agriculture is an important means for increasing efficiency and variety in agriculture. In order to make irrigated agriculture in this region, underground water is taken to surface from deep wells and used. Especially at Kiziltepe and Harran plains in Southeastern Anatolia of Turkey, there are more than 8000 wells. As flood irrigation technique requires high power pumps, a very big amount of energy is consumed. Pumping systems which are not designed accordingly with engineering techniques cause voltage dips and sags and losses in interconnected energy systems. By using agricultural irrigation systems a large amount of electrical energy is consumed; for that reason operating irrigation system by electrical energy produced by solar energy is very important. Because of their huge power, current irrigation systems are not economic and they cover big areas, so to feed them with solar energy seems impossible. However, by changing irrigation systems and optimizing it,

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systems having small pump powers like drip irrigation can be operated by electrical energy produced by solar energy.

In this study induction motor pump mechanism with driver system feeding drip irrigation system has been operated by solar energy. Solar energy capacity of the established system has been evaluated by measuring parameters in irrigation periods. With the help of simulations, power values produced by system and gained from the actual system have been compared. Electrical energy produced by photovoltaic panels can vary from estimated values with respect to environmental conditions. Therefore analysis of performance of real system is very important and consequently a more correct projection can be done.

With this study, design values of drop irrigation systems operated by solar energy for Southeastern Anatolia Region of Turkey have been gained by comparing simulated and experimented results.

2. Equivalent Circuit and Mathematical Model of Solar Cell and Simulation System

A mathematical model is developed in order to simulate solar cell [7-9]. Fig. 1 shows solar cell working models and ideal equivalent circuit. Under solar radiation a solar cell produces an I_g current from its joint system according to amount of radiation. Producing such an I_g current causes a potential voltage on the terminals of the cell. On the other hand, because of the fact that produced voltage awakens cell joint forward, an I_d diode current is composed, diverse to I_g current. This situation can be seen on Fig. 1 principally.

An I_g current produced relative to amount of solar radiation is a current source. Additionally the joint resistance which an I_d current passes trough and decreases I_d current is shown as diverse diode. Net current (I) which can be gained from cell for a load is the difference of those two currents [1].

$$I = I_g - I_d = I_g - I_o\left(e^{(qV)/(kT)} - 1\right) \quad (1)$$

In the Eq. (1);

I : Load current (Amper :A)

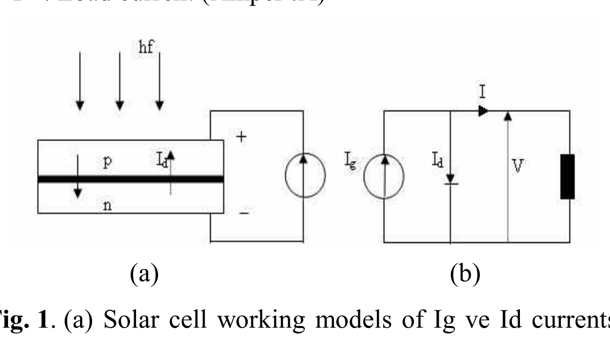


Fig. 1. (a) Solar cell working models of Ig ve Id currents. (b) Ideal equivalent circuit.

I_g : Current produced by photon (A)
I_o : Dark diverse leakage current (A)
q : Electron load ($1.6.10^{-19}$ C.)
V : Terminal voltage (Volt)
k : Boltzmann coefficient ($1.38.10^{-23}$ Ws/K)
T : Absolute temperature (Kelvin : K)

I_o leakage current is relative to structural features of cell and temperature. Therefore, this current rises with an increase in temperature.

Solar cell gives highest voltage (V_{oc}) in open circuit, highest current (I_{sc}) in short circuit. Under short circuit conditions, as current doesn't pass thorough joint resistance is considered I_{sc} can be assessed as I_g current ($I_g = I_{sc}$). In Eq. (1), term V that achieve value of I = 0 is equal to open circuit voltage (V_{oc}) Thus:

$$V_m = (kT / q).\ln[(I_g/I_o) + 1] \quad (2)$$

$$I_m = I_g - I_o(e^{(qVm)/(kT)} - 1) \quad (3)$$

can be defined. Here V_m is maximum voltage and I_m is maximum current. As can be seen from Eqs. (2), (3), direct calculation of current and voltage values at maximum power point is very difficult because of indirect joint resistance. Additionally even interior resistances of its cell is ignored, in consequence of electrical characteristic of joint maximum power (P_m) that can be taken is smaller than $V_{oc}.I_{sc}$ [1, 7-8]. Maximum efficiency proportion of I-V curve of cell power gaining part is defined by filling factor (FF).

$$FF = (V_m I_m) / (V_{oc} I_{sc}) \quad (4)$$

Cell efficiency (η) is defined by equation below;

$$\eta = P_m/(AP_g) = (V_m I_m)/(AP_g) = FF(V_{oc} I_{sc})/(AP_g) \quad (5)$$

Here A is area surface of cell, Pg is input power defined by W/area which is total solar radiation amount that may fall on this surface [9].

Due to its climate conditions and solar potential, Diyarbakir, a city in Southeastern Anatolian of Turkey has been chosen. An application which was established in Diyarbakir Solar House Education and Application Park has been simulated. Equations used in simulations are given Eqs. (1)-(5). Daily radiation data of Diyarbakir has been used in simulation. So, data of last 30 years have been taken from Diyarbakir Meteorology Centre. Additionally daily radiation data of NASA predicted according latitude and longitude has been used. Power used by implemented system has been input as regards of hourly data values for every single day in simulation model. So energy used by system was detected as regards of working periods. Characteristics and efficiency of inverter and batteries in system were used in simulation. As a result, a simulation closest to real values was gained. HOMER and MATLAB

Simulink softwares which are used for hybrid energy production simulations were used for simulation. Achievement of simulation was tested by comparing simulation results and real system.

3. General Structure of Implemented System

General structure of implemented system is given in block diagram in Fig. 2. Implemented system consist of photovoltaic panels, mppt (maximum power point tracker) charge regulator, batteries, induction motor driver, induction motor, centrifugal pump and drip irrigation system. A computer program is used in order to make connection between driver and induction motor. By means of this software feeding frequency and rotating direction of induction motor can be arranged. So, induction motor can be controlled. The reason of choosing induction motor in this system is wide spread use of this motor in irrigation systems. It is possible to choose more efficient and particular motors for systems that produce electrical energy from solar energy. However, according to the fact that motors used for irrigation are commonly used on land conditions, induction motors are more appropriate as regards of being more powerful and steady.

In system, twelve 80 Wp photovoltaic panel, one 1200 W DC-AC converter, one charge regulator, two 100 Ah battery, one induction motor driver were used. A computer in order to programming induction motor driver and an induction motor centrifugal pump system with drop irrigation mechanism were employed.

In established system twelve photovoltaic panels over the platform their configuration on it and joints between them are shown in Fig. 3. Properties photovoltaic panels and electrical characteristics of established system are presented in Table 1.

Current and voltage of photovoltaic array and charging current of battery can be given by Mppt charge regulator.

Table 1. Properties of PV panels and electrical characteristics of PV array used in system.

Cell type	Mono cristal
Maximum power	80 Wp
Maximum voltage	16.9 V
Current	4.73 A
Open circuit voltage	21.5 V
Short circuit current	4.97 A

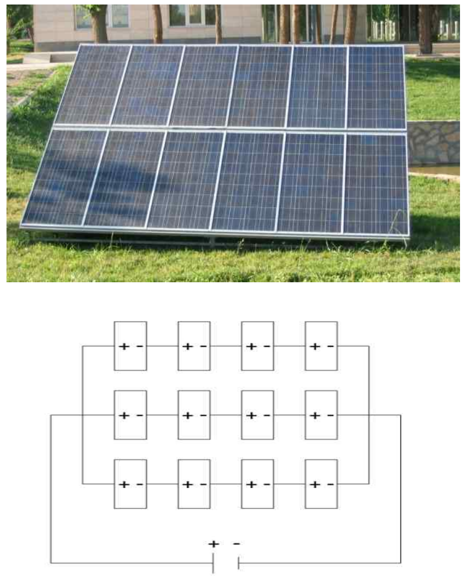


Fig. 3. Location of PV panels on platform and Circuit diagram of PV panels.

This operating data also keep in the charge regulator's data logger and daily consumed energy amount that produced by photovoltaic array can be stored in this data logger.

By the system established on a 4000 square meter of garden belonging to Solar House has been irrigated. An irrigation pipe system appropriate for drip irrigation has been allocated on the garden of the Solar House. Voltage and current data of PV arrays and battery system has been measured between hours 05:00 - 19:00. In solar systems PV's voltage is an indicator of electrical energy gained from the sun. On the other hand PV's current varies according to energy consumed and occupancy rate of battery at the moment. Current of the battery changes by amount of the load whereas voltage of the battery varies by occupancy rate of battery. When Mppt charge regulator is set up in system maximum battery voltage is arranged to 28.8 V, overflow voltage to 27.2 V, maximum current value to 60 A. Consequently maximum value of battery voltage doesn't exceed 28 V. Battery voltage remains at level 27.2 V when it is full occupied. Those levels are arranged as regards of limit levels. Established system has been operated averagely 4 hours every day between hours 07:00-09:00 in the morning and 17:00-19:00 in the afternoon. Additionally some days system has been operated more in order to measure analysis of system performance. Data have been taken from application system during an

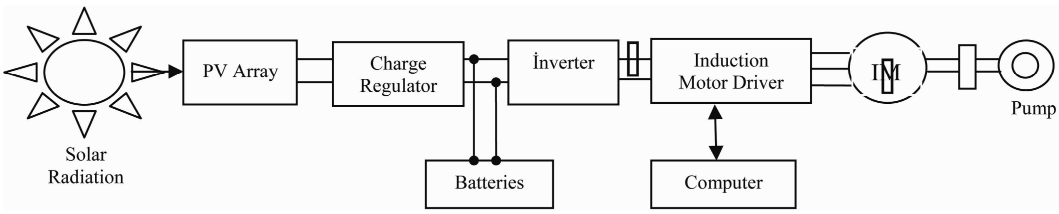


Fig. 2. Block diagram of the implemented system

irrigation season. The same conditions with the application system have been composed in simulation program. PV array, battery, converter, load at same values and daily radiation of local data have been applied to simulation one to one. Data from application system and simulation results at same conditions have been compared.

Speed control of induction motor has been managed by induction motor driver device by changing frequency. Induction motor has been controlled by sensorless flux vector control method. Thus, operating of induction motor in different frequencies and different speeds could be possible. Consequently managing of drip irrigation system in demanded amounts could be done without loss of valve.

4. Result Obtained by Implement System

In application system, data of photovoltaic panels and batteries were recorded between hours 05:00 - 19:00. Data were taken in July. As regards to irrigation season takes place in May-October, it is possible to take full value of solar energy during this period. So, by the help of measuring done in July, it can be possible to gain general results for irrigation season. Weekly average values of PV and battery current, voltage, power and consumed energy values by the loads taken from the system at every one hour of a day between 05:00-19:00 can be seen on Table 2. Average power values gained from PV system is shown in Fig. 4.

Table 2. Weekly average data of PV and battery system.

	PV			Battery			Energy
Hour	Current [A]	Voltage [V]	Power [W]	Current [A]	Voltage [V]	Power [W]	kWh
05:00	0.0	27.1	0.0	0.0	24.6	0.0	0.0
06:00	0.4	56.7	20.3	0.9	24.6	21.5	0.0
07:00	1.4	54.7	75.7	2.8	25.4	70.3	0.1
08:00	4.4	60.1	262.1	9.8	26.9	263.6	0.2
09:00	7.3	61.0	442.7	15.2	27.3	415.0	0.5
10:00	8.3	62.1	514.9	18.8	26.7	500.7	0.9
11:00	7.8	65.6	512.4	16.4	27.4	449.8	1.3
12:00	5.5	68.4	377.8	9.1	27.8	252.3	1.7
13:00	4.2	70.1	297.6	5.4	27.8	150.0	1.7
14:00	1.0	68.9	67.9	2.4	26.9	65.6	1.9
15:00	1.0	69.4	68.4	2.2	26.8	59.7	2.0
16:00	0.8	68.3	52.7	3.8	26.8	101.5	2.1
17:00	1.0	62.9	62.9	2.2	26.6	58.2	2.2
18:00	1.0	60.1	58.4	2.0	26.8	53.5	2.2
19:00	0.2	60.3	12.1	0.1	25.7	2.9	2.2

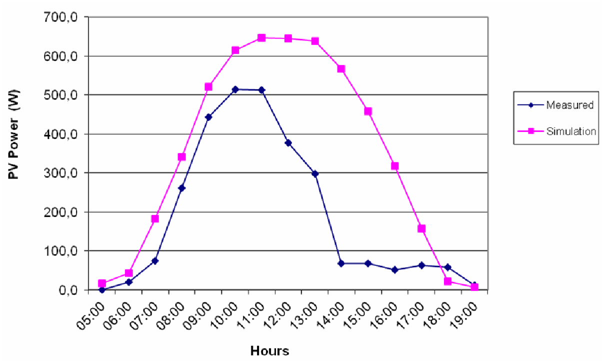


Fig. 4. Average power values gained from PV system

Gained values are relevant to load. Irrigation system was established on a land of 4000 m^2 in size. Energy value gained from system is larger than energy value required for irrigation. Consequently it couldn't be possible to benefit from current system maximally. PV power values calculated from gained results and data gained from simulation of system is shown in Fig. 5. When data is inspected it can be seen that measured results and simulation results were overlapped until 10 o'clock. Because of the fact that energy couldn't be drawn from system after batteries filled after 10 o'clock, measured results were smaller than simulation results. In case of demanding energy from system, curve gained from simulation results is expected to be close to measured results. Therefore after 10 o'clock the area left between simulation curve and measured curve shows potential of energy that system can produce. This potential hasn't been used on account of not being demanded by the load. Measured results gained by increasing of the load are justifying this prediction. In Fig. 6 results gained by means of increasing working hours of system and operating it maximally are compared with simulation results gained on same day. It can be seen that by means of increasing of the load, measuring and simulation results are compatible until 13 o'clock. After 13 o'clock, owing to the fact that system doesn't demand energy, diverge between simulation results

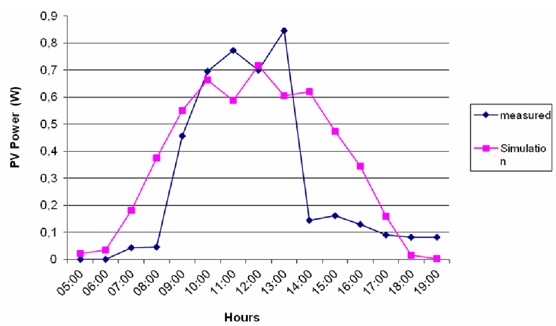


Fig. 5. Data of PV power at day which maximum power was demanded.

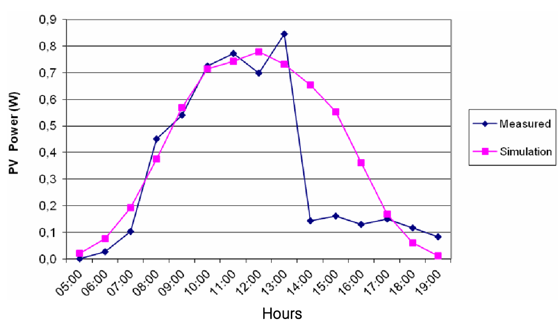


Fig. 6. Maximum PV power data gained from system.

and measured values began. Due to the fact that measured values depend on consumption energy, these results are expected. In Fig. 6 maximum power data gained by measuring from system and maximum values gained from simulation are given. It can be observed that, measured values at hours when power is drawn from application system and simulation values are overlapped. Differences between measured values and simulation values are observed during hours when application system doesn't demand power. This situation shows that simulation results are overlapped by real values. Differences between simulation and measured values in convergence time base on temperature of environment and/or real efficiency of PV system and/or average solar radiation values used in simulation. Thus, it can be said that simulation gives exact results for Diyarbakir and Southeastern Anatolian Region of Turkey by an acceptable error margin. When simulation results were compared with measured results the fact that simulation results contains maximum ±14% error have been detected.

5. Analyzing Results of Induction Motor

The performance of the induction motor fed by PV generator has been analyzed via the real system measurements and simulations. The system simulation has been generated with MATLAB Simulink (Fig. 7.). The PV panels have also been modeled in the simulation (Fig. 8). The sensorless vector control of induction motor has been simulated with the help of the generated simulation model. This induction motor's model also includes saturation of mutual flux that modeled by a polynomial nonlinear function. Furthermore, the measurements acquired from the real system and the simulation results have been compared. The results of the starting period of the motor for the torque reference ramp are shown in Fig. 9. Induction motor parameters used in system are shown in Table 3. The performance of the induction motor has been analyzed in frequencies 20, 25, 30, 35, 40, 45, 50, 55 and 60 Hz on the real and simulation system. Thank to driver system, current, voltage, power and torque values of motor

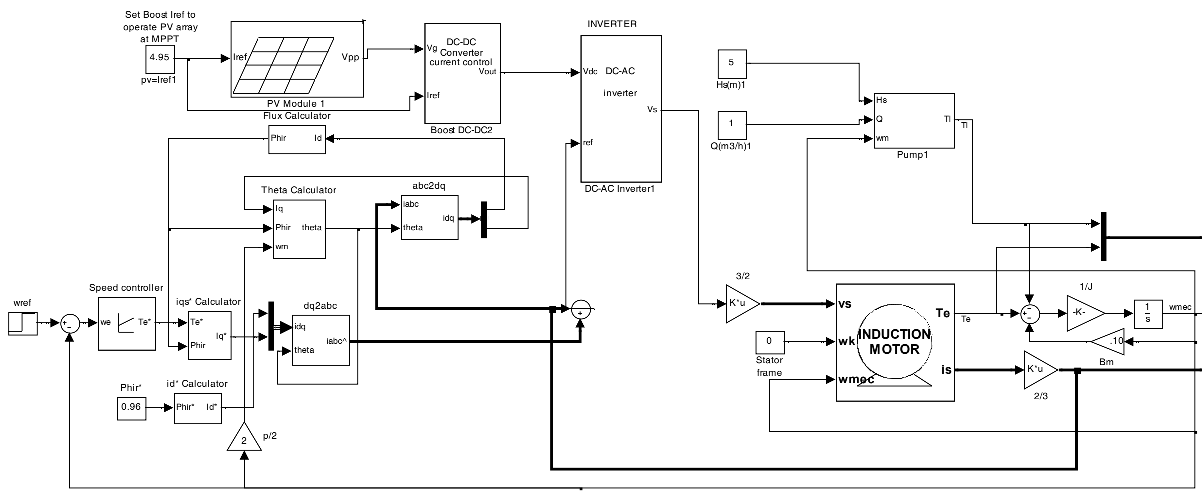


Fig. 7. MATLAB simulink simulation model of induction motor drive system

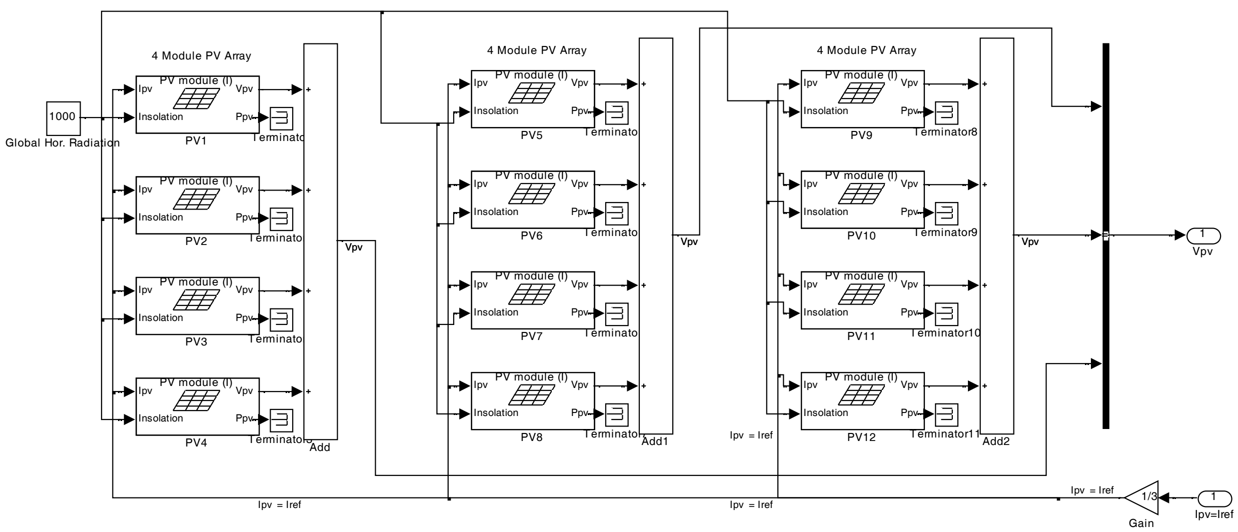


Fig. 8. Matlab simulink model of PV system.

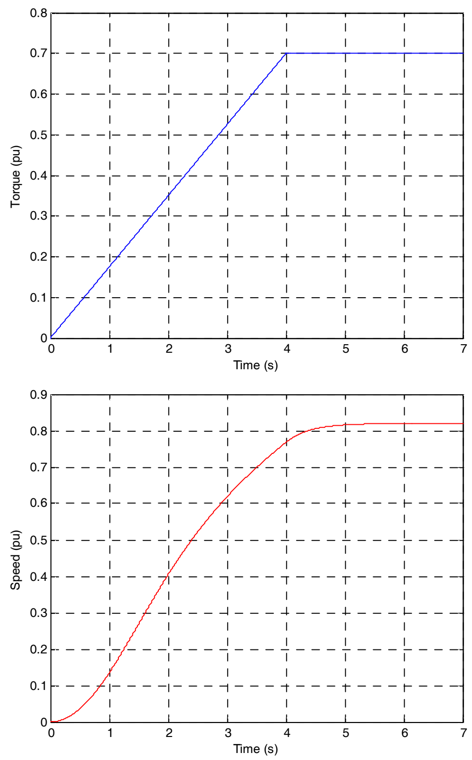


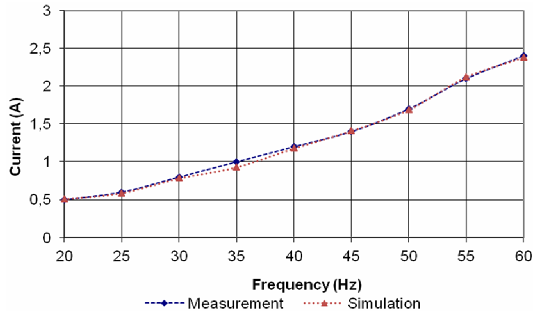
Fig. 9. Simulation results of sensorless vector controlled induction motor for reference torque ramp.

Table 3. Induction Motor's Parameters.

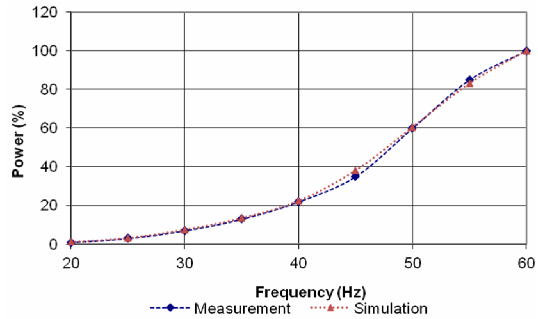
Power kW/HP	Voltage V	Current A	Power factor Cosφ
0.75/1	220-240 Δ/ 380-415 Y	3.7 / 2.2	0.8
Stator resistance (Ω)	Stator Inductance (mH)	Rotor resistance (Ω)	Rotor Inductance (mH)
3.353	6,94	1.99	6,94
Magnetizing Inductance (mH)	Moment of Inertia (kgm^2)	Pole pairs	Speed (min^{-1})
163.7	0.1	1	2900

could be recorded relevant to frequency. These recorded values have been compared with the values acquired from the simulation (Figs. 10-11).

It has been evaluated that the measurement values of the real system and the simulation results of the system match with each other. More and more, the maximum differences of the current, frequency, power and torque values of the measurement and simulation results are 5%, 0.22%, 3% and 2% respectively. All in all, these results show that the simulation models the real system with an acceptable accuracy. Power and torque of motor can be controlled by the help of driver. Motor reach to 100% torque value can be reached at 59 Hz. On the contrary at 35 Hz torque reach to 20%. At this value consumed power decreases to 18% of nominal value. Thus energy saving can be done as regards of decreasing torque necessity. This situation is very important for motors used in solar energy systems having limited energy production. Therefore in irrigation systems without loss of power in valves supply of water in



(a)



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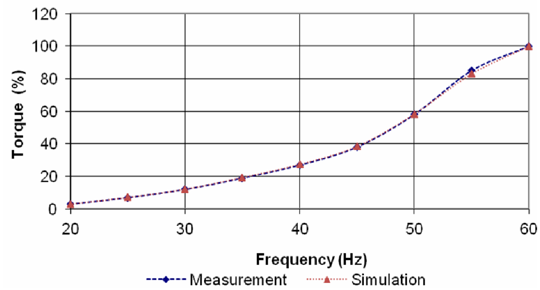

(c)

Fig. 10. Measurement and simulation results of induction motor: (a) Current versus frequency; (b) Power versusfreequency; (c) Torque versus freequency

demanded amount can be possible [11-18].

By results taken, it can be observed that power ascended with an increase in frequency. Similar when frequency in application system increased more torque could be gained from system.

With the help of induction motor's driver, attitude of motor can be controlled while starting process [19-21]. On the other hand by ramp function starting and stopping processes can be managed. Induction motor driver is controlled by ramp function in order to reach nominal speed in 5 seconds and stop in 5 seconds when system is stopped. As regards of exemplifying for starting performance values of induction motor current, phase voltage and frequency for a working period of 15 seconds are given in Fig. 8 at 50 Hz working frequency. On the other hand on account of ramp function system, frequency reaches to50 Hz from 0 Hz in 5 seconds. At the same time the value of current reaches from 0.7 A to 1.7 A in 4 seconds and

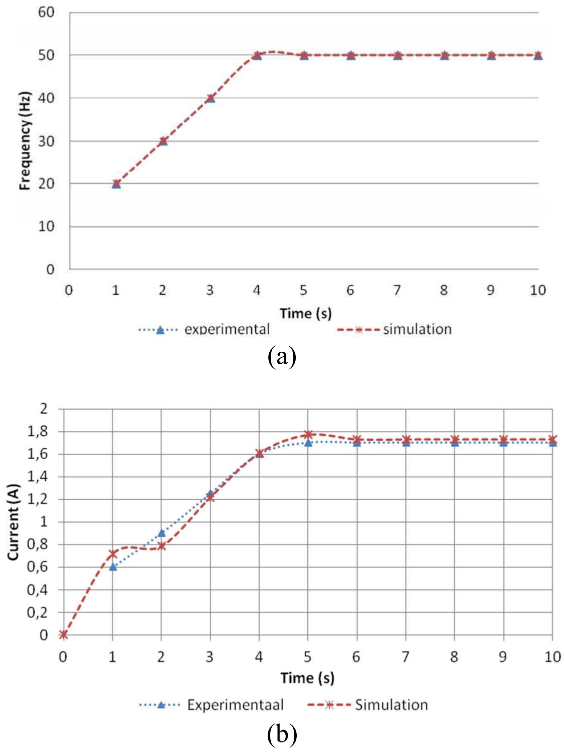

Fig. 11. Measurement and simulation results during starting time of induction motor: (a) Frequency versus time; (b) Current versus time

becomes constant.

Thus, reducing of starting current of induction motor is provided with induction motor driver.

6. Conslusion

In this study, application of electrical energy gaining from solar cells in a irrigation system and performance of induction motor used in this system is investigated. In order to do that, data taken from this application system were analyzed and compared with simulation results. In such solar irrigation systems generally brushless DC motors are preferred due to their high efficiency, but cost of these machines are higher than induction motors. However, induction motors are commonly used in conventional irrigation systems. Therefore, induction motor was preferred in application system on account of being able to work even in worse conditions, being cheaper and not requiring much maintenance. Induction motor and its driver system cost are one third of brushless motor and driver system. This led to decrease in high installation costs which were a great disadvantage of PV systems.

As regards of result gained from study, it can be seen that induction motor works efficiently. Electrical losses can be prevented by speed control techniques. In Turkey irrigation period is concentrated in summer season and at this time, solar radiation is widespread especially in south regions. When this situation is taken account, it can be said that implemented system is appropriate. According to study results, gaining electrical energy from solar system is efficient at irrigation period in Diyarbakir region. Thanks to controlling motor speed, water in demanded amount can be given into irrigation system by drip method. Due to eliminating valve losses energy is used more efficiently. In current system maximum power loss of driver system is 7% and this is an acceptable value.

By examining data, it can be seen that, system can work by electrical energy gained from PVs during the daytime without necessity of batteries. When night irrigation is needed, system can be operated by batteries and batteries can be charged quickly in day time. By implemented system that has 960 Wp power, 4000 m^2 area is irrigated. It can be seen from measured results that this system can irrigate larger area than 4000 m2. Average daily power needed for irrigation of 4000 m2 was measured as 1,89 kWh/day. Average power can be gained from system was calculated as 5.18 kWh/day by simulation results. By results measured from simulation ±14% errors have been investigated. Therefore, mentioned system can irrigate approximately an area of 11000 m^2. When some kind of plants that everyday irrigation is not needed for, is taken account, irrigation by current system can be possible on larger areas. For example for a kind of plant that should be irrigated every 5 days, with an appropriate irrigation system by current implemented system a four times bigger area can be irrigated. Irrigation necessities and water demanding of every kind of plant differs from each other.

The energy demand of the different plant species during an irrigation season in the Southeastern region of Turkey has been determined by a research study performed in Dicle University [22]. The required energy demand depends on the irrigation system and the plant specie. The energy demand of a drip irrigation system for 10 decares of land area is shown in Table 4. The irrigation area should be irrigated once every three days. Therefore, it is possible to irrigate a three times bigger area via a PV system. 10 kWp PV system will be enough to irrigate a 30 decares of area in the current climate conditions of the Southeastern region of Turkey in consequence of the evaluation of the measurement and simulation results. This value is a fundamental value that can be used for designing solar energy irrigation systems for Southeastern Anatolian Region of Turkey.

However electrical systems with solar energy are more costly than other energy resources by means setting up,

Table 4. Energy demand of different type plants for drip irrigation system at 10 decares areas for Southeast Region of Turkey.

Plant Type	Irrigation Times	Energy Demand to a irrigation (kWh)	Total Energy Demand (kWh)
Wheat	3	52,5	157,5
Corn	7	52.5	367.5
Cotton	8	52.5	420

they reduce installing energy costs like network lines, transformers in regions far away from network. Additionally they are preferred because of producing electricity at demanded amount and in demanded place, working without noise, not requiring much maintenance and being long lasting. In places where electrical energy is not available and difficult to access; or installing costs are high such systems are generally beneficial. To give place to renewable energy resources like solar energy in energy policies can reduce exterior energy purchasing besides decreasing environmental pollution resulted from fossil fuels.

Acknowledgements

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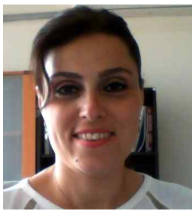

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