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Research Article

Modeling of PV System Supported Intelligent Irrigation System in Iraq-Mosul Region

Karam Wadhah Hameed Alhilo[a,*], *Metin Kaya*[a]

[a]Department of Energy Systems Engineering, Faculty of Technology, Karabük University, Karabük, Türkiye.
[*]**Corresponding Author:** 2128132021@ogrenci.karabuk.edu.tr

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ABSTRACT

In this study, Matlab/Simulink software was used to create a smart irrigation system that utilizes the electricity produced by photovoltaic cells. The system setup will be carried out considering that the farm needs 90,000 liters of water during its periodic irrigation period. The designed irrigation system will be installed in the rural area of Mosul, Iraq. According to our calculations, a submersible pump compatible with a 1400 W power BLDC model and capable of a 200 m water lifting height is sufficient. It has been observed that using a smart irrigation system is more efficient and economical compared to traditional irrigation systems. Approximately 36% savings were achieved from the design of the 1400 W power BLDC model submersible pump and about 67% savings from the design of the photovoltaic array. Due to its location, Iraq is one of the countries with high annual solar radiation values. We believe that using smart irrigation system models in regions with high electricity energy needs but low coverage rates will contribute positively to national economies.

Keywords: *BLDC Motor, DC-DC Boost Converter, MPPT Technique, PV array, Smart Irrigation, Water Flow.*

Irak-Musul Bölgesinde PV sistem Destekli Akıllı Sulama Sisteminin Modellenmesi

ÖZET

Bu çalışmada, fotovoltaik hücrelerin ürettiği elektriği kullanan akıllı bir sulama sistemi oluşturmak için Matlab/Simulink programı kullanılmıştır. Çiftliğin periyodik sulama döneminde 90.000 litre su ihtiyacı olduğu düşünülerek sistem kurulumu gerçekleştirilecektir. Tasarımı gerçekleştirilecek olan sulama sistemi Irak'ın Musul kırsal kesiminde kurulumu gerçekleştirilecektir. Yapmış olduğumuz hesaplamalara göre 1400 W gücünde BLDC model fotovoltaik sisteme uyumlu, 200 m su basma yüksekliğine sahip dalgıç pompa yeterli olmaktadır. Akıllı sulama sistemi kullanılmasının geleneksel sulama sistemlerine göre daha verimli ve ekonomik olduğu gözlemlenmiştir. 1400 W gücünde BLDC model dalgıç pompa tasarımından yaklaşık %36, fotovoltaik dizi tasarımından %67'lik bir tasarruf sağlanmıştır. Irak, konumu gereği yıllık güneş ışınım değeri yüksel olan ülkelerden biridir. Biz bu çalışmamızda elektrik enerji ihtiyacı fazla olan fakat ihtiyacı karşılama oranı düşük olan bölgeler için akıllı sulama sistem modelinin kullanılmasının ülke ekonomilerine katkı sağlayacağını düşünüyoruz.

Anahtar Kelimeler: *Akıllı sulama, BLDC Motor, DA-DA Dönüştürücü, MPPT tekniği, PV dizi, Sulama.*

I. INTRODUCTION

This study aims to develop an intelligent irrigation system that utilizes a photovoltaic power system to extract power efficiently. The proposed PV system comprises a pumping system, a tank, a Photovoltaic Array (PV array), a sensing system, and a DC-to-DC converter with an incremental conductance MPPT control algorithm.

The primary objective of this study is to create a sustainable irrigation system using solar power instead of diesel-powered pumps. This approach will eliminate fuel costs and reduce the carbon emissions these engines produce.

A secondary objective is to manage groundwater withdrawal and consumption more effectively. Irregular and inefficient drainage depletes groundwater resources and can damage wheat plants by over-saturating them, even though they require a specific amount of water. Thus, controlling drainage practices will enhance and improve agricultural production.

Solar-powered irrigation systems ought to emphasize efficiency, optimizing the use of the solar energy provided by the panels. PVsyst result was used to get optimal results, followed by Matlab to verify these outcomes.

II. MATERIAL AND METHOD

A. Irrigation System Description

The irrigation system consists of PV array MPPT (Maximum Power Point Tracking) boost converter, two DC pumps (one for pumping water from the well to the tank and the other one for pumping water from the tank to the farm), tank, piping net, solenoid valves, sprinklers and control system (solar radiation sensor, moisture sensors, water level sensors for water level of the well and the tank and controller) as shown in Figure 1

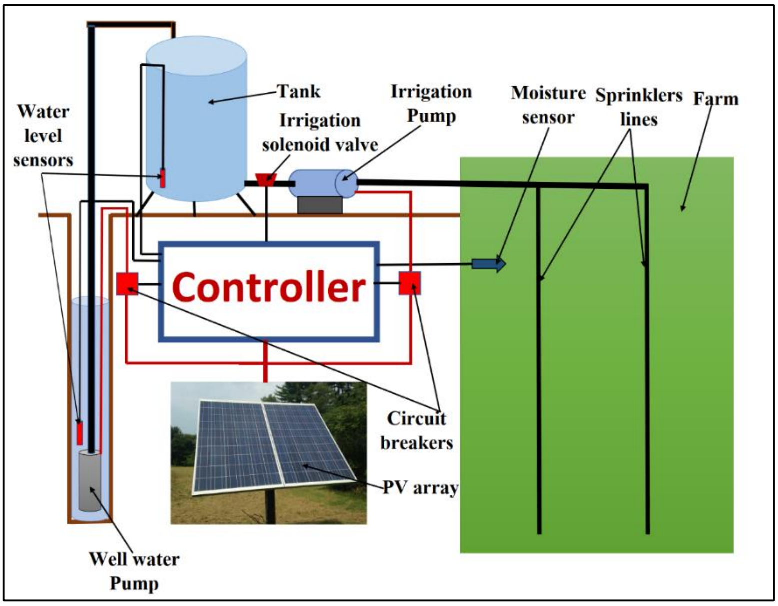


Figure 1. Intelligent irrigation system.

B. Theoretical Calculations of the System

The size of the irrigation system is primarily determined by the monthly energy output of the PV system and the daily water requirements. The monthly energy output of a 1 kWp PV system at the Al-Ayadiya location is shown in Figure 2 (Europa, 2024).

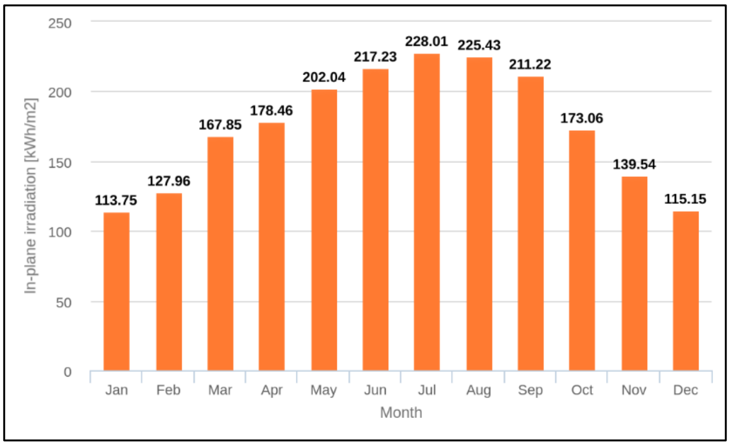


Figure 2 The monthly energy output

Using the Peak Sun Hour (PSH) principle in conjunction with a simple deterministic algorithm, one can quickly determine the size of a PV system. In such cases, the PSH value from the Global Sun Map can be used, as this approach is effective in locations where daily solar radiation data is unavailable. PSH represents the number of hours a day when the average solar energy is 1,000 W/m^2. As shown in Table 1. (Al Riza et al., 2024;Markvart and Castañer, 2003; Al Riza, 2011; Sen, 2008), the Peak Sun Hour (PSH) is calculated by dividing the monthly average irradiation by the number of days.

Table 1 Irradiation and Peak Sun Hours

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Irradiation kW/m2	113.75	127.96	167.85	178.46	202.04	217.23	228.01	225.43	211.22	173.06	139.54	11.15
PSH	3.67	4.47	5.41	5.95	6.52	7.24	7.36	7.27	7.04	5.85	4.65	3.74
Average PSH	5.0325											

The average depth of wells in the area ranges from 30 to 50 meters; therefore, the deepest well was used for this study. A 10-acre wheat farm requires 90,000 liters of water per irrigation period, which occurs six times a month, based on data gathered from farmers. The average water requirement of the crop is calculated as follows:

$$Daily\ water\ requipment = \frac{Monthly\ water\ requirement}{month\ days} = 18\ \mathrm{m}^3/\mathrm{day} \tag{1}$$

Equation (2) is used to calculate the flow rate in cubic meters per hour (m^3/h) based on the PSH and daily water needs.

$$Flow\ rate\ = \frac{Daily\ water\ requirement}{PSH} = \frac{18}{5.0325} = 3.576 \tag{2}$$

Since the system is intended to operate during the winter and spring, the tilt angle in Mosul is typically selected to be between 14 and 60 degrees. The plane tilt was adjusted to 55 degrees, which corresponds to minimal loss concerning the optimal angle (Hassan et al., 2021; Ali, 2018; Morad et al., 2018).

For the solar PV water pumping system, the following calculations are part of the theoretical analysis: hydraulic power, PV array sizing, motor sizing, and system efficiency.

a. Hydraulic power requirement

Equation (3) is used to determine the system’s hydraulic power requirements (Sharma et al., 2020):

$$P_H(kW) = \frac{\rho.g.Q.H}{3.6{*}10^6{*}\eta} \tag{3}$$

where
Water density = 1000 kg/m^3,
g: Acceleration due to gravity (9.81 m/s^2),
Q: Water discharge = 3.576 (m^3/h)
H: Head = 50 m
η: Pump efficiency

P_H (kW) =1.2Kw

b. Sizing of Motor

The pump is driven by a DC motor. The motor's power consumption is determined by the efficiency of the pump (Sharma et al., 2020; Yahyaoui et al., 2015):

$$Power\ required\ by\ motor\ = \frac{Hydraulic\ power\ required\ by\ pump}{Efficecny\ of\ motor} \tag{4}$$

Power required by motor= 1.5 kW

c. Sizing of PV Array

The size of the PV array is determined by the power requirements of the system. The system's efficiency affects the overall power requirements (Sen, 2008):

$$Total\ power\ required\ from\ PV\ array\ = \frac{Power\ required\ by\ motor}{Efficiency\ of\ the\ system} \tag{5}$$

Total power required from PV array = 1.666 kW

d. System Sizing Calculation

Number of modules required in the PV array:

$$\text{The total no. of modules} = \frac{\text{Power output required from PV array}}{\text{Power rating of the unit module}} \tag{6}$$

Total no.of modules = 2.38 ≃ 2 Modules

C. 4. Matlab/Simulink Modeling

As shown in Figure 3, the solar PV irrigation system consists of a PV array, an MPPT-DC converter, energy storage, and a control system.

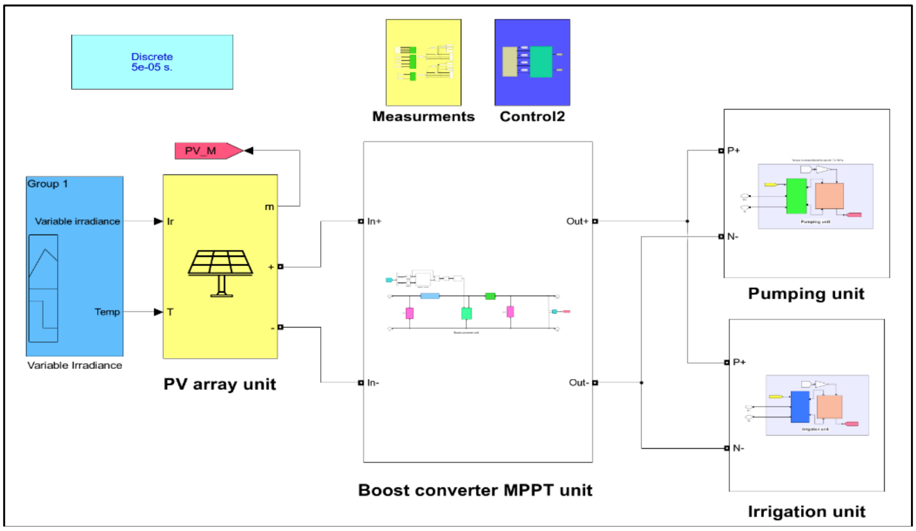


Figure 3. Grid-connected PV power plant

The PV array consists of two 700 Wp Risen modules (Riseenergy, 2024), which are configured as a 2x1 array. These two modules are connected in series to form a 1.4 kW PV array. Additionally, the system includes a 1.4 kW permanent magnet DC motor (BLCD), a 1.4 kW MPPT-DC converter with an incremental conductance MPPT technique (Grundfos, 2024), and a smart control system.

a. PV Array Specifications

The PV array has a Maximum Power Point (MPP) voltage of 83.56 V and an MPP current of 16.77 A at Standard Test Conditions (STC). These values represent the input voltage and current for the MPPT-DC converter, based on the electrical data of the module and the pump requirements.

b. MPPT Modeling

The control technique employed in this solar power system is the incremental conductance MPPT (Maximum Power Point Tracking) method, implemented using Matlab code. This control approach adjusts and monitors the operating point to maximize power output from the PV array. The Matlab function utilized in this approach optimizes PV power production by continuously tracking the maximum power point.

The incremental conductance MPPT control method is detailed in Figure 4, which shows the simulation model. In this model, the PV current and voltage serve as the input signals, while the PWM triggering signal is the output.

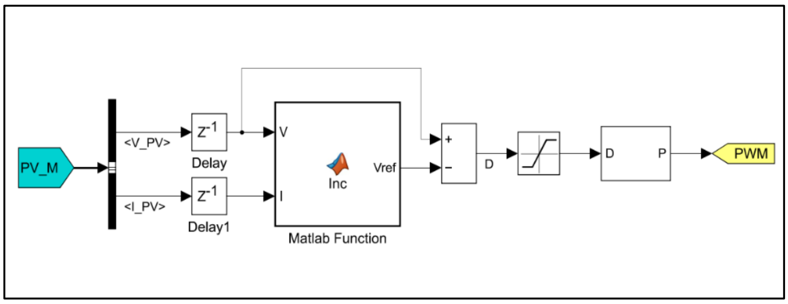


Figure 4. Incremental conductance MPPT control model

c. MPPT-DC Converter

An incremental conductance boost converter is used to achieve a fixed output voltage at maximum power. The Incremental Conductance (IC) MPPT approach was applied to this end. The simulation model of the boost converter is illustrated in Figure 5.

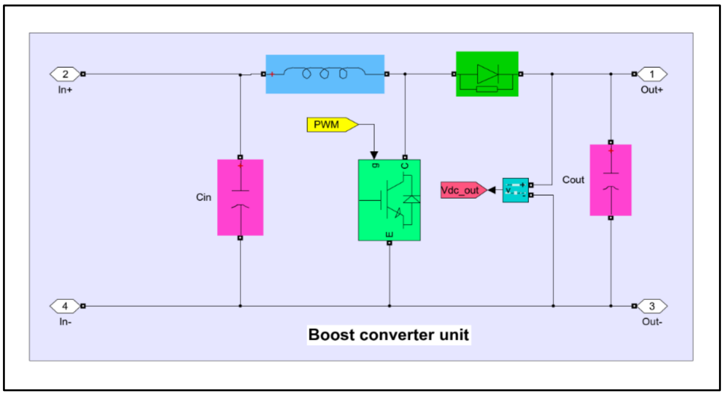


Figure 5. Boost converter model

The parameters of the boost (Sen, 2008);

The parameters of the boost converter were calculated as follows (Hasaneen and Mohammed, 2008; Shaikh et al., 2023; Rashid, 2017):

P= 700 x 2 = 1400 W.

The input voltage is the PV array at maximum power point

Vin = 41.77 x 2 = 83.56 V.

The switching frequency was 5000 Hz.

The motor nominal voltage which is the boost converter output voltage is 170 V.

Vout = 170 V.

The maximum output current is the maximum motor current which is calculated as follows;

$$I_{\ out_{max}} = \frac{P}{V_{out}} = 8.235\ A \tag{7}$$

The maximum current ripple is calculated as follows;

$$\Delta I_L = 0.01\ x\ I_{\ out_{max}} x\ \frac{V_{out}}{V_{in}} = 0.167\ A \tag{8}$$

The maximum voltage ripple is calculated as follows;

$$\Delta V_{out} = 0.01\ x\ V_{out} = 1.7\ V \tag{9}$$

The Inductor value is calculated as follows;

$$L = \frac{V_{in} x (V_{out} - V_{in})}{\Delta I_L x F_S x V_{out}} = 51\ mH \tag{10}$$

The Capacitor value is calculated as follows;

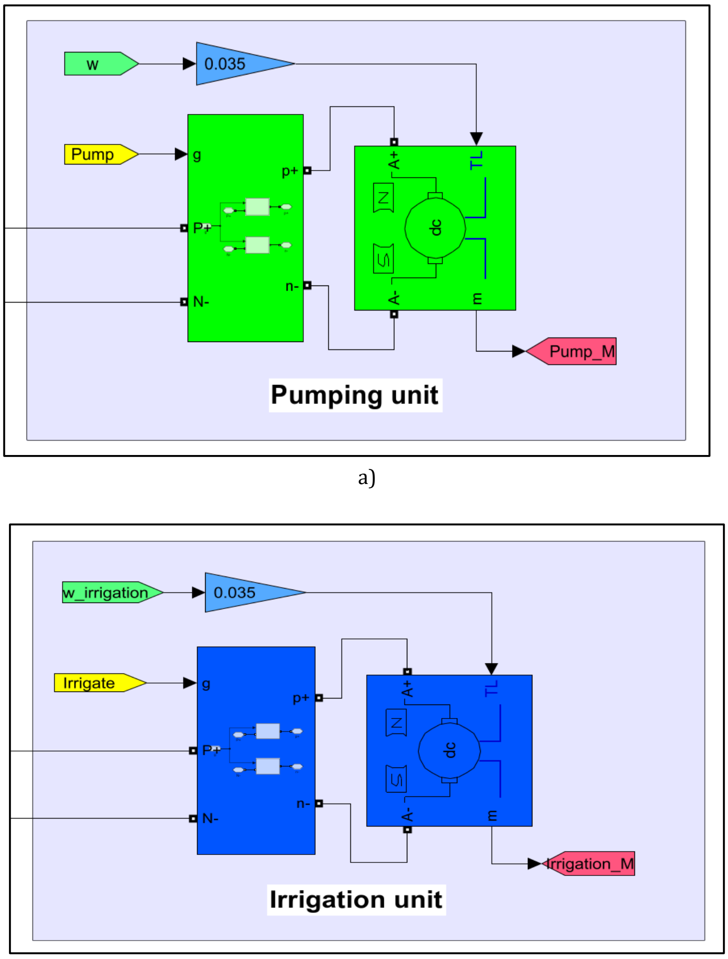
$$C = \frac{I_{out\_max}\ x\ \frac{V_{in}}{V_{out}}}{F_S\ x\ \Delta V_{out}} = 493\ \mu H \tag{11}$$

The duty cycle is calculated as follows;

$$Duty\ cycle = \frac{V_{out} - V_{in}}{V_{out}} = 0.51 \tag{12}$$

d. Pump Modeling

A 1.4 kW permanent magnet DC motor (BLCD), which serves as the pump, is connected to the boost converter via a circuit breaker. The input torque of the motor has been calibrated based on the nominal head and flow rate. As shown in Figure 6, the smart irrigation system control manages the circuit breaker to connect or disconnect the pump as needed.



a)

b)

Figure 6. a) Pumping unit & b) Irrigation unit

D. Operation Strategy

The operation strategy is determined by four parameters: radiation level, soil moisture content, water level in the tank, and water level in the well. The flowchart in Figure 7 illustrates this process. The controller will activate the irrigation pump when radiation is available, the soil moisture level is below the minimum threshold, and the water level in the tank is above the minimum threshold. Additionally, if the water level in the well is above the minimum threshold, the controller will turn on the pumping pump.

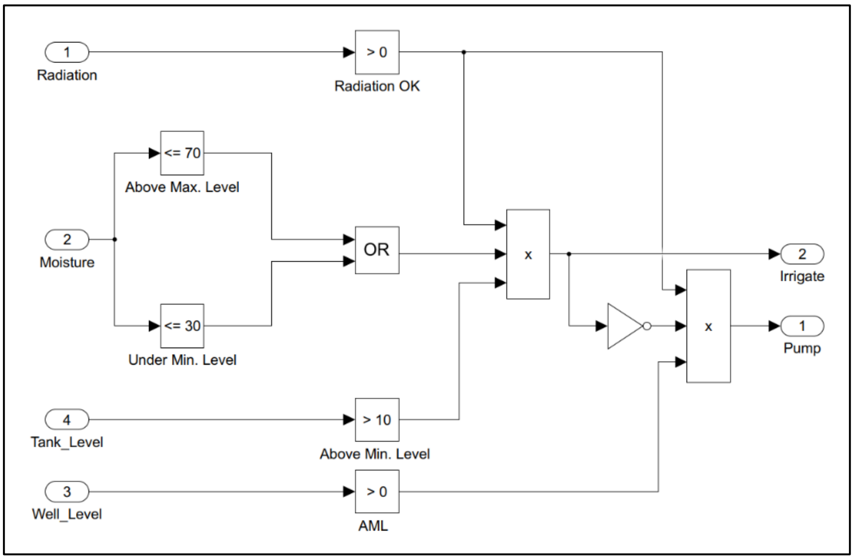


Figure 7 Matlab/Simulink control circuit.

The flowchart of the system is shown in Figure 8

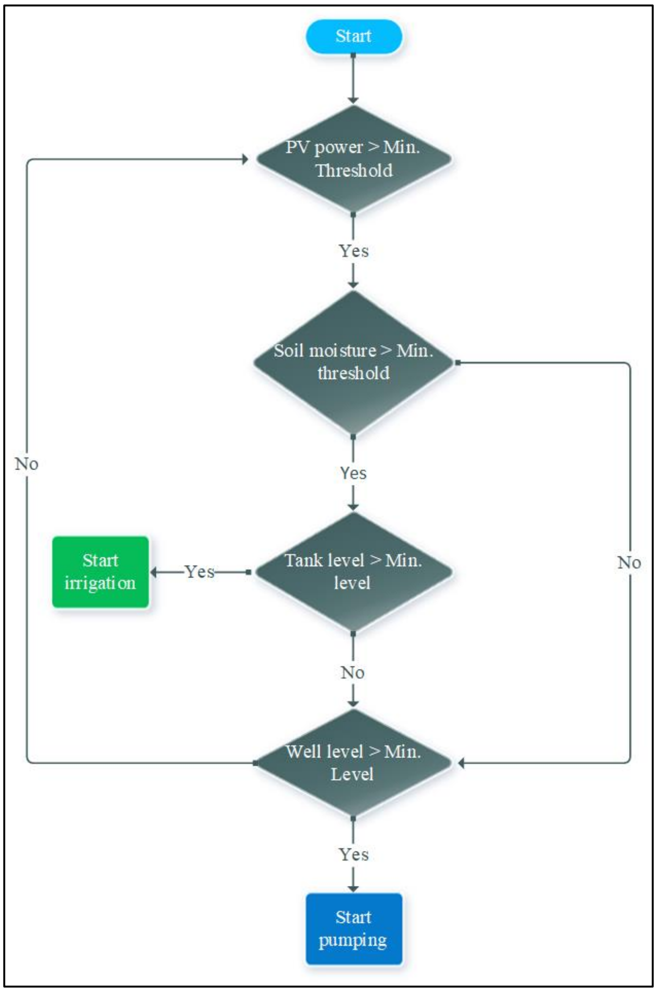


Figure 8. Operation strategy flowchart

III. RESULTS AND DISCUSSIONS

A. Matlab/Simulink Simulation

The 1.4 kWp nominal capacity PV array designed using PVsyst software consists of two 700 W solar panels, an incremental conductance MPPT DC-DC converter, and two permanent magnet DC motors—one for pumping water from the well to the tank and the other for pumping water from the tank to the farm. The two panels are connected in series to form a 2x1 array, as depicted by the PVsyst system, and this configuration serves as the basis for the MATLAB design.

As shown in Figure 9, various radiation and temperature levels were used to cover all possible climatic scenarios.

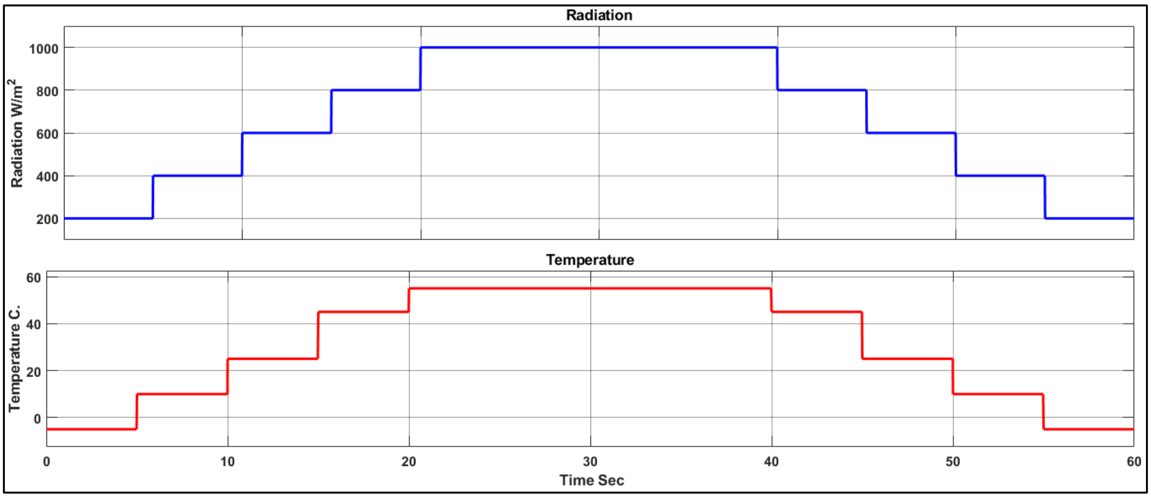


Figure 9. Different Irradiances and Temperature Levels

The chart displays a range of temperatures from -5 to 55 degrees Celsius and irradiance levels from 200 to 1000 W/m^2.

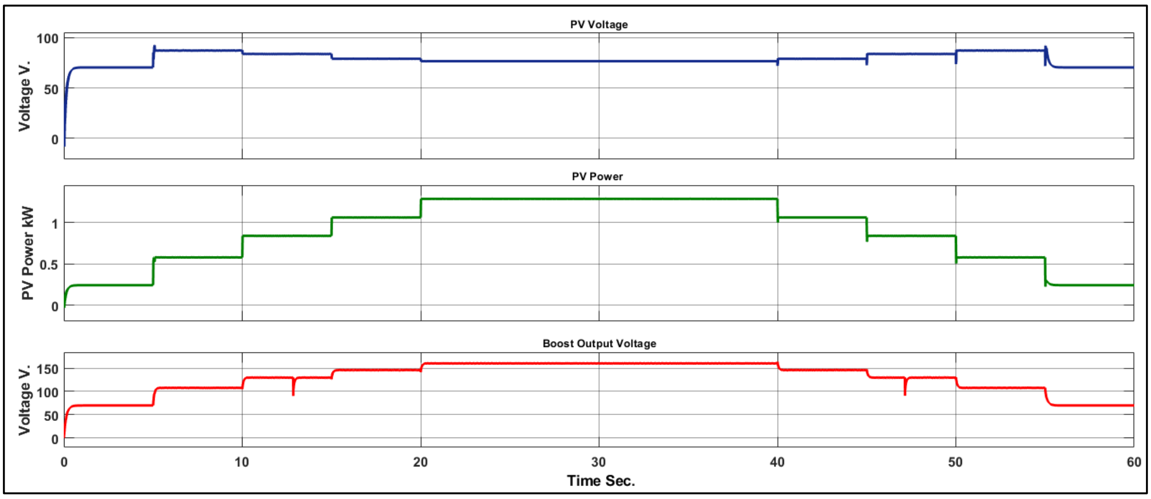


Figure 10. System voltages and power.

The graphic demonstrates that while voltage and power increase with rising radiation levels, voltage decreases due to the effect of increasing temperatures.

The process of pumping water from the well to the tank or from the tank to the farm depends on the availability of PV power, soil moisture, and the water levels in the tank and well. To test the system's operation, these parameters were simulated. The priority is irrigation. If PV power is available and the tank level is above the minimum level, the irrigation pump will start. If not, the pumping pump will start if PV power is available, the well level is above the minimum level, and the tank level is below the maximum level.

The following conditions were replicated:

- PV power is zero, no pumping and no irrigation.
- PV power > minimum threshold, moisture < minimum level, well level is normal and tank < minimum level, start pumping and no irrigation.
- PV power > minimum threshold, moisture < minimum threshold, well level is normal and tank is full, no pumping and start irrigation.
- PV power > minimum threshold, moisture < minimum threshold, well level is under minimum level and tank is normal, no pumping and start irrigation.
- PV power > minimum threshold, moisture > minimum threshold, well level is normal and tank < minimum level, start pumping and no irrigation.
- PV power > minimum threshold, moisture > minimum threshold, well level < minimum level and tank is full, no pumping and no irrigation.
- PV power > minimum threshold, moisture > minimum threshold, well level is normal and tank level is normal, start pumping and no irrigation.
- PV power > minimum threshold, moisture > minimum threshold, well level is normal and tank is full, no pumping and no irrigation.

Figure 11 shows the system control signals for the system parameters.

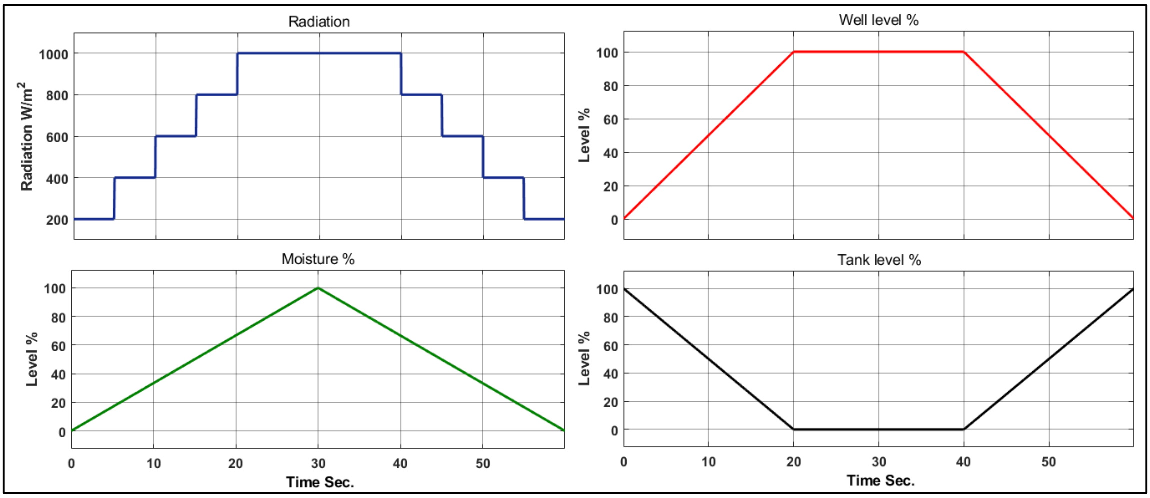


Figure 11. PV System control signals.

The system was operated according to the control signals. As illustrated in Figure 12, when the moisture level falls below the minimum threshold and the water level in the tank is above the minimum level, irrigation takes precedence. If the water level in the well is above the minimum level, the pump will run to fill the water tank.

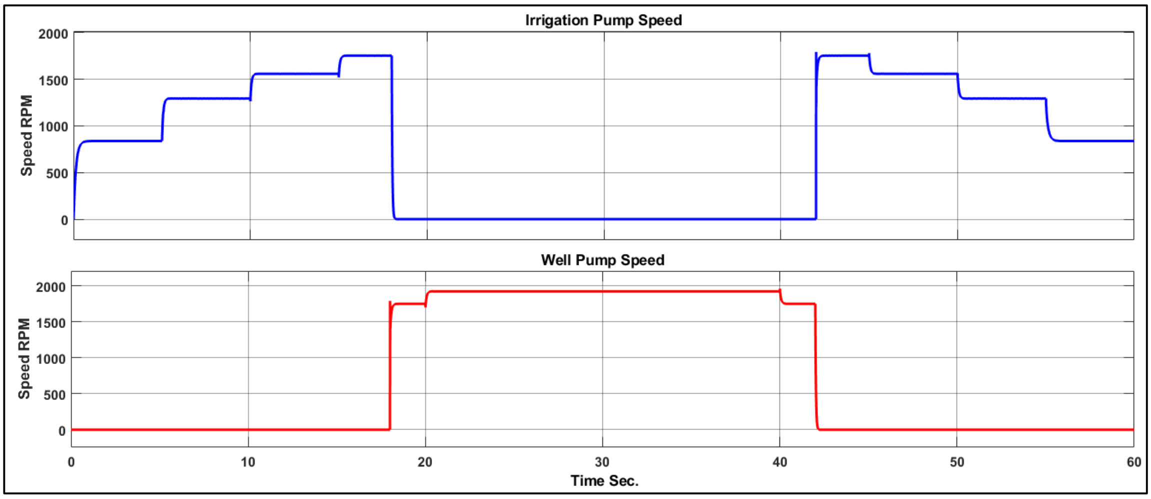


Figure 12. System operation.

The operation of the irrigation pump is illustrated in the figure above. When the radiation level was higher than zero, the motor's speed increased in accordance with the radiation level. The irrigation pump continued to operate until the moisture level reached its maximum value at eighteen seconds. At this point, the irrigation pump stopped, and the well pump began transferring water from the well to the tank. The well pump ceased operation when the moisture level fell below the minimum threshold at forty-two seconds, and the irrigation pump restarted.

IV. CONCLUSIONS

The simulation performance of the proposed smart irrigation system demonstrates that the theoretical calculations and Matlab/Simulink results align reasonably well. Farmers, especially those in the agriculture sector, will ultimately benefit from the implementation of this system. By monitoring soil and weather conditions on the farm, this method provides an alternative means of controlling overwatering and underwatering issues during the irrigation process.

However, due to the occurrence of rainfall during the rainy season, the smart irrigation system cannot prevent overwatering on its own. To address this, the soil moisture level should be continuously measured to adjust the irrigation schedule accordingly. High soil moisture levels can inhibit the irrigation mechanism, thereby preventing unnecessary irrigation.

Overall, the smart irrigation system can significantly conserve resources such as money, labor, and water usage by automating the irrigation process with an effective schedule. It is expected that this system will substantially transform the agriculture sector. For future work, incorporating a weather forecasting system could help predict the onset of the rainy season and further optimize irrigation management.

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