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Usage of photovoltaics in an automated irrigation system

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Abstract

This study presents the usage of photovoltaic electricity in an automated irrigation system. The experimental setup consists of the controller, control valves, photovoltaic (PV) panels, back up batteries, and sensors. The system is capable of irrigating the fields at a pre-specified time, day/s of the week, and duration. It can also automatically irrigate the field if the soil is dried below a certain specified value. This type of automated system will optimize the quantity of water required for a particular crop and for a specified area. There are few natural springs of water used for irrigation purposes in the Kingdom. This system will also help in conserving water, besides its other advantages.

1. Introduction

The water needs of Saudi Arabia are met by desalination water plants, which are located in the coastal regions of the Kingdom. The cost of potable water is very high due to the costs of production and transportation. In major cities the water is transported through water pipelines. This water cannot be used for irrigation purposes due to the high costs. There are many fields in the eastern, central and northwestern parts of the Kingdom where farming is being encouraged by the administrations.

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The fields are developed and the water is either pumped from the ground or through scarcely available natural water streams.

One such natural source of water is being used in Al-Hassa for irrigating the farming fields. At present these fields are irrigated through a network of canals, which are operated manually to provide water to farmers according to their needs. Some times these fields are over irrigated and some times under irrigated. In this way, a lot of water, which is precious commodity for the Kingdom, is lost. Hence there is a need to optimize this source of water through the usage of affordable technology.

This study presents the design, implementation, and testing of an automatic irrigation system, which can optimize the usage of water and at the same time provide cost effective and efficient operation. This system utilizes photovoltaic cells to generate the electricity directly from the sun's rays to run the whole control system. The Kingdom of Saudi Arabia has a continuous source of abundant solar energy reaching the ground throughout the year. The daily average bright sunshine duration, as mentioned by Rehman and Halawani [1], is 8.89 h and the average daily value of global solar radiation on a horizontal surface is 5591 Whm^{-2}. Due to increasing awareness, technological development, and affordability new renewable means of producing electricity are being encouraged for a grid connected or an individual supply system. These sources include solar, wind, geothermal, small and large hydropower, biomass sources, tidal wave, etc. to name but a few.

Automation has become essential to provide optimal and efficient usage of the devices and systems, and to conserve resources. Masheleni and Carelse [2] used a microcontroller-based charge controller for stand alone photovoltaic systems to improve the efficiency of the system and to protect the storage batteries with special reference to automotive batteries. Koner [3] presented a design for a switching device for reconfiguration of photovoltaic modules used for the optimization of the photovoltaic modules. Recently Hammad [4] presented a study related to the usage of photovoltaic generated electricity for pumping water from 13 wells spread across the east and south east desert which is far from the national grid, as well as in the southern parts of the Jordan which has a complicated topographical situation. These pumps are capable of pumping 40–100 m^3 of water per day individually to meet the daily demands of individuals living in those areas. Hamerski et al. [5] presented the usage of solar energy through a photocatalytic process for the purification of contaminated soil. Other applications of photocatalytic processes are detoxification [6], water purification [7–12], decomposition of crude oil [13] etc. One of the most important applications of photovoltaic driven electricity is refrigeration for meeting health requirements [14] in developing countries.

Rehman and Halawani [1] presented a comprehensive review of the work done related to solar energy development and its application in Saudi Arabia. Their review did not find any application or development of solar energy usage for irrigation automation. Work has been carried out on the development of solar cookers for Mina and Arafat, street lighting, water heating, remotely located communication towers and meteorological stations. The objective of the present study is to test the irrigation automation system for optimal usage of water in farming, home and commercial lawns.

A description of the experimental setup, electrical connections, and ratings of all the components used is given in Section 2. Section 3 provides stepwise working of the whole system with different options that can be used to train the farmers and other users. The conclusions and observations are mentioned in Section 4.

2. Experimental setup

The experimental setup developed and used in this study consists of four major parts, viz.: solar power supply, controller, input devices, and output devices.

2.1. Solar power supply

The solar power supply used consists of two photovoltaic (PV) solar panels and two back up batteries. Each PV solar panel consists of 36 solar cells. The specifications of the solar panels are shown in Table 1 (http://www.solarex.com/products/vlx.htm). In Table 1, V_{pp} is the voltage at peak power, I_{pp} is the current at peak power, V_{cc} is open circuit voltage, I_{sc} is short circuit current, and L, W, T, are the length, width, and thickness of the PV panel, respectively. Each solar panel generates a maximum of 17.5 V DC. A regulator is used to adjust the cell output to 12 V DC. Two PV panels were connected in series to generate a total of 24 V DC that is required to supply the 24 V DC controller's power supply. The two 12 V batteries, which are used as backup supply in the absence of sunlight due to overcast skies or rain, are rechargeable, sealed, and lead–acid type. The batteries are charged from the PV cells. A blocking diode is used to safeguard the system from excessive voltage. Fig. 1 shows the basic block diagram of the solar power supply system that was used in the study. The load in the figure refers to the controller and the input/output devices.

2.2. Controller

The controller which is used in this study, is the new universal logic module from Siemens (also known as logo). It provides control functions, operating and display unit, power supply, 6 inputs and 4 outputs and interface capability with a personal

Table 1
Solar panel specifications

V_{pp} (V)	I_{pp} (mA)	V_{cc} (V)	I_{cc} (mA)	Dimensions (cm)			Weight kg (lb.)
				L	W	T	
17.2	1860	21.3	2010	60	50	5.0	3.5 (7.7)

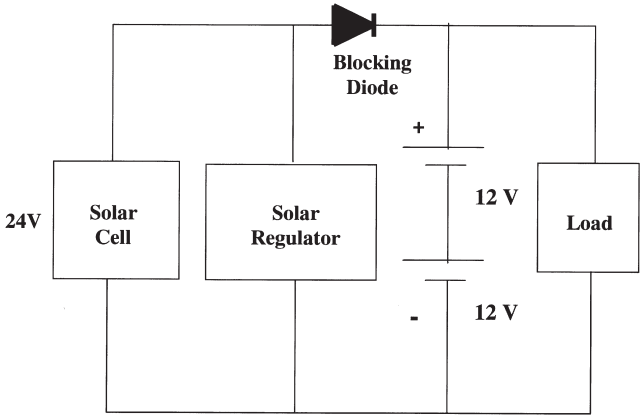

Fig. 1. Solar power supply layout.

computer (PC). The control functions that are utilized in this project are On/Off delay, real-time clock, counters, latching relays, and series/parallel functions. The most important function is the real-time clock, which is programmed to energize and de-energize any output at any time of the day or any day of the week based on the input from the field. The logo system is capable of accepting both the DC or AC supply. In this project, module 24RC is used. This module operates on 24 V DC. It has 6 digital inputs and 4 digital outputs, consumes 3 W of power, and switches up to 10 A load at 24 V DC rate [15].

2.3. Input and output devices

Table 2 shows the input/output assignments used in running the experimental setup. Fig. 2 shows the system hardware layout and connections used in the prototype built in the laboratory. The logo has provision for six inputs and four outputs and they have been utilized as follows (Table 2):

Table 2
Input/output assignments

Inputs assignments		Output assignments	
I-1	Manual mode	Q-1	Valve-1 (Field-1)
I-2	Auto mode	Q-2	Valve-2 (Field-2)
I-3	Sensor mode	Q-3	Emergency light
I-4	Level sensor No. 1 (from Field-1)	Q-4	Spare
I-5	Moisture senor (from Field-2)		
I-6	Level sensor No. 2 (from water tank)		

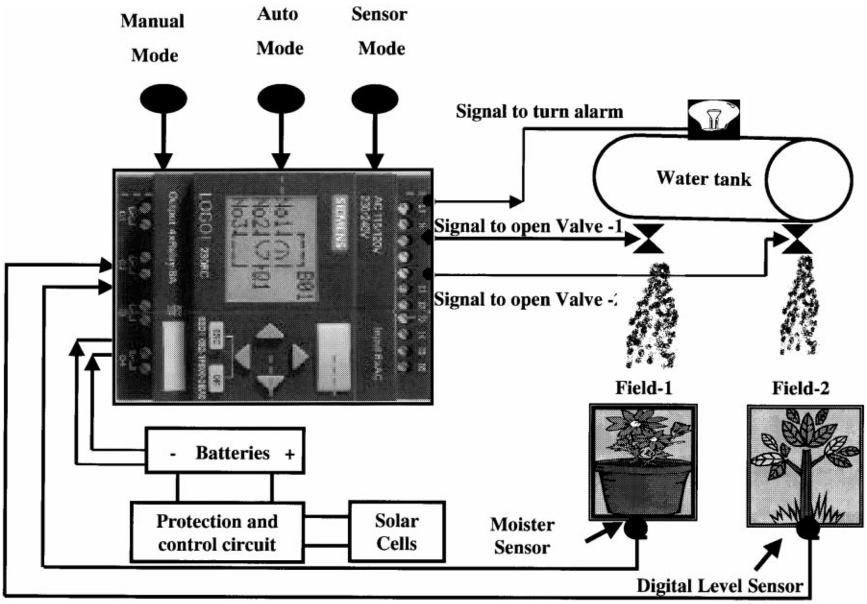

Fig. 2. System hardware configuration.

- Three input operation switches are used to operate the system in three different modes, viz. manual, auto and sensor mode.
- One digital level senor is used to feed the logo with the water level of Field-1 and operate as a digital sensor.
- One analog moisture sensor is used to feed the logo with the soil moisture of Field-2 and operate as an analog sensor.
- One digital level sensor is used to feed the logo with water level in the reservoir tank.
- Output number 1 is connected to the valve that irrigates Field-1
- Output number 2 is connected to the valve that irrigates Field-2
- Output number 3 is connected to the alarm lamp to indicate when the water level in the reservoir water tank becomes less than the pre-specified water level.

3. Discussion and working of the prototype

The system is designed and prototyped to irrigate two fields (Field-1 and Field-2). Field-1 is to be irrigated by opening valve-1 via the logo output No. 1 and the water level in the field is sensed by a digital level sensor that is connected to the logo input No. 1. Field-2 is to be irrigated by opening valve-2 via the logo output No. 2 and the water humidity in the field is sensed by the analog moisture sensor that is connected to the logo input No. 2. The analog moisture sensor is connected via a comparator circuit that can be adjusted manually for the required moisture level depending on the season by the farmer or user. The third output is used to indicate the water level in the reservoir tank, which flashes the light on/off when the water level in the tank goes below a predefined level. A feedback from the tank is sent via a digital level sensor to the logo input. The system has four modes of operations i.e. manual, auto, sensor and emergency modes. A brief description of operation in each mode is given below.

3.1. Manual mode

In this mode, the farmer or the user can irrigate both fields (Field-1 and Field-2) by switching on this input. The water valves of both fields will be activated as long as this switch is on. Turning this switch off manually will shut off both valves.

3.2. Auto mode

In this mode, the real-time clock of the logo, which is programmed to turn the water valves on/off at specific times and days, operates automatically with the real-time clock. It can also be programmed to turn any of the valves independent of each other. The built-in real-time clock is capable of working at any time of the day and any day of the week and for any desired period. For testing purposes, the system was programmed to irrigate Field-1 three times a week (Monday, Wednesday, and Friday) between 10:00 a.m. and 11:00 a.m. and Field-2 two times a week (Sunday and Thursday) between 3:30 p.m. and 5:00 p.m. The farmer or the user can change the time, period and day/s of the week using the built-in key-pad and display system. A short list of 1–2–3 steps can be supplied to the user as an operation manual to program the system.

3.3. Sensor mode

This mode has two feedback signals coming from the fields (Field-1 and Field-2). Field-1 is designed to operate based on the water level in the water storage tank and Field-2 is designed to operate using an analog sensor that measures the soil humidity. The water will flow to any field based on a signal from the correspond-

Table 3
Different irrigation operation modes

Operation mode	Field-1			Field-2	
Manual	Open at any time for any desired period by the user				
Auto	Sat.	Mon.	Wed.	Sun.	Thu.
	10–11 a.m.	10–11 a.m.	10–11 a.m.	3:30–5:00 p.m.	3:30–5:00 p.m.
Sensor	Based on the water level in the field			Based on soil humidity in the field	
Emergency	15 min every day until reset by the farmer or runs out of water				

ing sensor and stay on until the digital level sensor trips or the moisture sensor gets wet enough.

3.4. Emergency mode

The emergency mode operates based on the water level in the reservoir tank. If the water level falls below the predefined level, the lamp will start to flash on–off

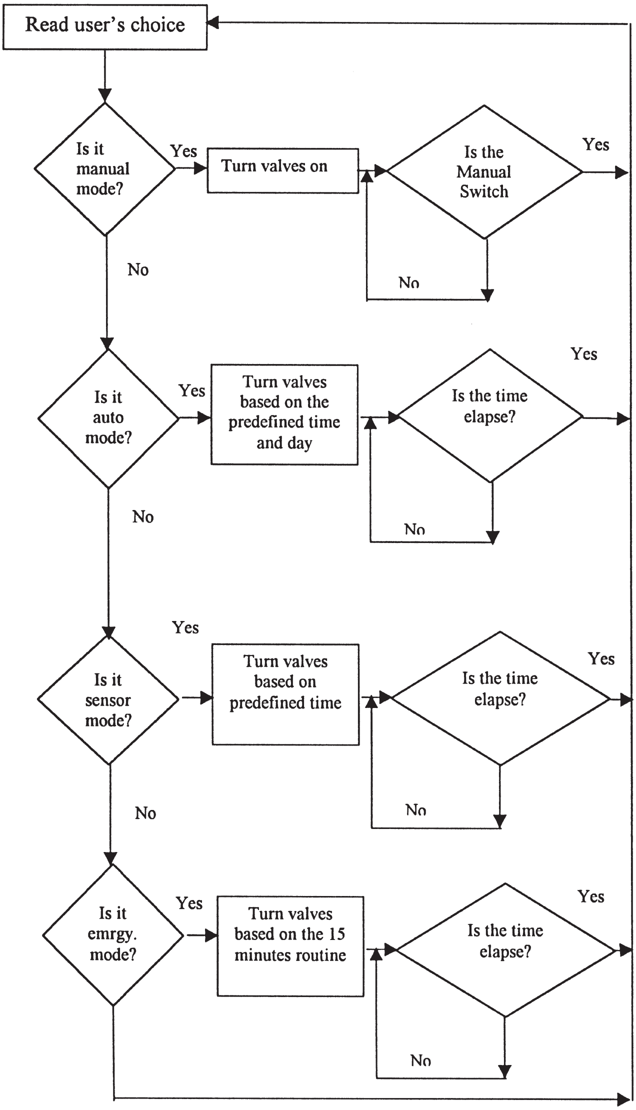

Fig. 3. System software flowchart.

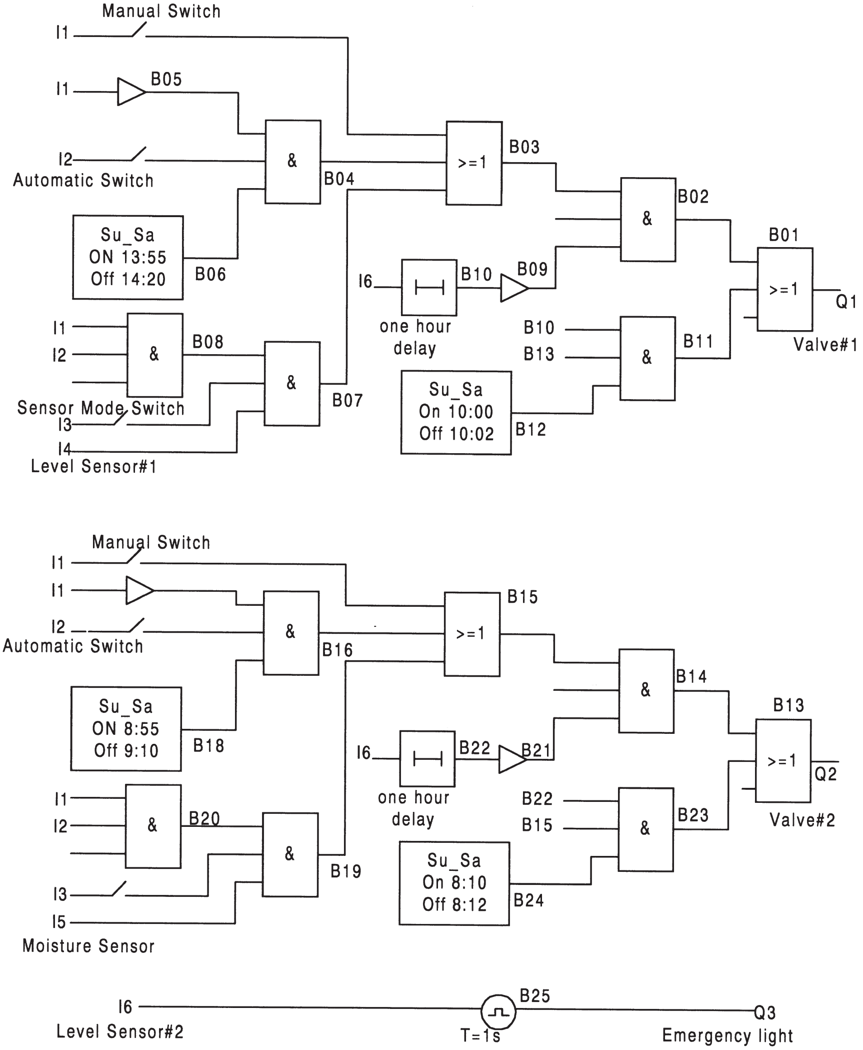

Fig. 4. System software ladder diagram.

and turn on the irrigation system for automation mode, but for 15 min only, rather than the predefined time which was programmed in the normal auto mode. Table 3 shows the operation modes summary.

It is worth mentioning that the above system hardware and software scenarios have been implemented in such a configuration for testing proposes that the system can be extended and modified to handle more inputs and outputs using different logo modules, sensors, and valves, as well as operation modes. Fig. 3 shows the system algorithm flowchart. The ladder diagram of the software program developed and

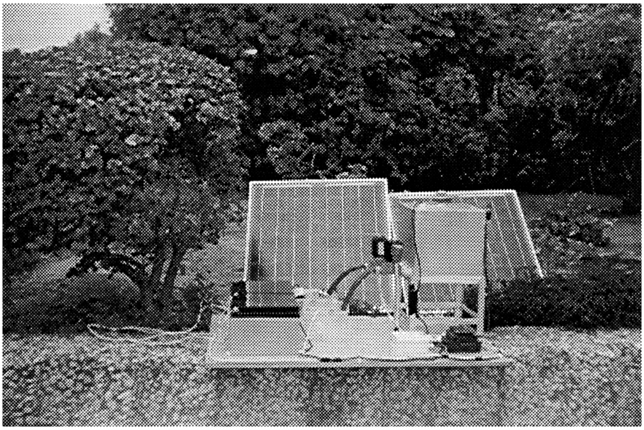

Fig. 5. Actual prototype system as built in the lab.

used in this prototype is shown in Fig. 4. Fig. 5 shows the actual prototype that was built in the laboratory.

4. Conclusions

A fully automated irrigation system is designed, built and tested using solar PV cells and a digital controller. The system is economical, reliable, portable, and compact. Savings in electricity bills and water bills can justify the initial cost, which may be a bit more than the conventional system, over a period of time. It causes less damage to the environment and releases the public utility from an extra load. It can be used in small or big farms, gardens, parks and lawns. Also, it can be used as a universal solar-based-controller to control building doors, water heaters, and air-conditioning control systems.

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