2016 1st International Electrical Engineering Congress (IEEC 2016)
May. 13-14, 2016 in IEP Centre, Karachi, Pakistan

Application of smart solar system for irrigation purposes

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Abstract: Scarcity of water for irrigation purposes is one of the major problems in our country. Every year, a huge amount of water is wasted in agriculture due to over-watering. To address this problem, a solar powered smart irrigation system is presented in this paper. The system will harness power from the sun and will be independent of grid power; the method we are applying is drip irrigation, so only a concise amount of water would be consumed during irrigation, resulting in water optimization, and thereby increasing crop productivity. The hardware is composed of microcontrollers which control the flow of water to the concerned soil, based on the present level of soil moisture. A database management system is used that will keep track of system parameters like moisture values and water level, the concerned person will also be notified about the system status via GSM. The system will prevent water wastage and will save electric power, employing lower fabrication cost and requiring less human effort.

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Keywords: Soil Moisture Sensor (SMS); Smart-Irrigation System (SIS); Photovoltaic Array; Global System for Mobile Communication(GSM);

I. INTRODUCTION

Pakistan is basically an agrarian country. The largest economic sector in Pakistan is the agricultural sector, which contributes 20.9% to the Gross Domestic Product (as of 2014-15). Also, 43.5% of the labour force in Pakistan is employed in the agricultural sector.[1]

In every system and process, problems are encountered. Agriculture is no exception. Our country faces various problems, a few of which will be discussed here. One problem is that water supply is scarce in the arable lands of Pakistan where irrigation takes place, usually these areas are remote. Also, electric power is unreliable in such areas. Another problem encountered is the wastage of human effort; a poor farmer has to work all day in the scorching heat of the sun to meet the agricultural demands of the country. This leads to our next problem; the wastage of solar energy. Sun is the largest source of Energy on Earth; in one minute, it radiates enough energy to cater for the demands of the earth's entire population for a whole year. Now, keeping this in mind, we are presenting a solution in the form of a solar powered auto-irrigation system which is meant to address these problems.

Our intention in presenting this system is to reduce water wastage, reduce human effort and dependency on grid-connected system and to increase the efficiency in irrigation methods by presenting a small-scale prototype automated system for irrigation. The process we have employed is drip irrigation[2], which is an efficient method of irrigation for many crops. It applies precise amount of water to the roots of the crops through a distribution network of tubes and pipes. Doing so, water usage is optimized. Water consumption is about 45% less (refer to Eq. 1), providing efficiency and healthier growth of crops.

II. DESIGN METHODOLOGY

The proposed design is an independent solar-based automated system that performs drip irrigation using sensors, pump, reservoir and other components.

The block diagram for the complete system is shown below:

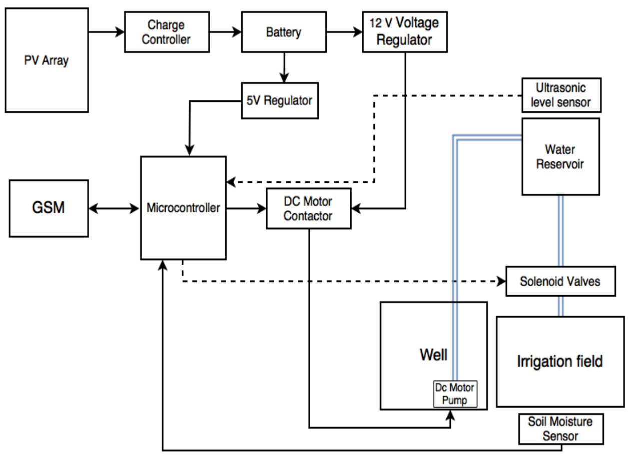


Fig.1: Complete Block diagram

The system is provided electrical power by the photovoltaic array, which is connected to the battery via a charge controller. A voltage regulator is also used with the battery.

The heart of the system is a Microcontroller, which is connected to various components; other components connected to the microcontroller are DC Motor (via a contactor) and a solenoid valve which allows the flow of water from the reservoir, which in turn is filled using a DC pump motor assembly; a level sensor detects the water level in the reservoir. Moisture sensors are connected to the microcontroller, which continuously send signals to the controller. A system for data management is also connected that informs the concerned person about the various performance parameters via GSM module.

The complete methodology of the proposed system is described in the forthcoming paragraphs.

For the sake of simplicity, this system is divided into three modules.

A. Source Module

This module supplies electric power to the entire system, it consists of PV array, charge controller and a battery.

Photovoltaic panels used around the world can be classified into monocrystalline and polycrystalline. Both have their merits and drawbacks. For our system, polycrystalline is the preferred choice, considering the relatively small scale of the system. Also, in areas having continuously high temperatures, polycrystalline is the preferred choice because its efficiency is not considerably affected upon exposure to high temperatures (>38ºC). [3]

The photovoltaic array is connected to the battery via a charge controller. Based on our needs we have opted for PWM charge controller.

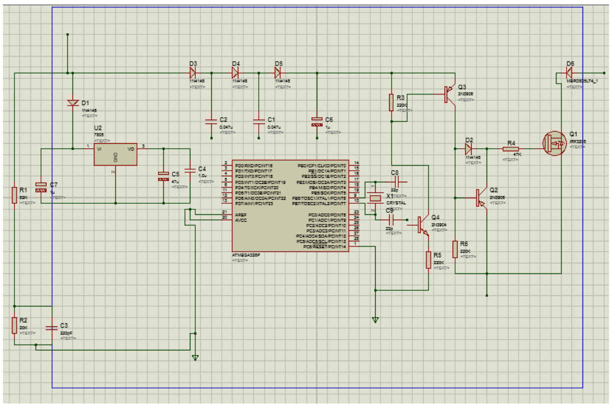


Fig.2: PWM Charge controller simulation

Compared to MPPT, PWM is more economical and suitable for relatively smaller systems. The purpose of this charge controller is to monitor and stabilize the current flow to the battery, in order to prevent damage of the battery due to overcharging. The battery is included in order to continue the irrigation process throughout the night or during times of low sunlight intensity, e.g. cloudy or foggy weather. This is done in order to reduce dependency on sunlight.

B. Controlling Module

This module controls the entire working of the system. In the Controlling module, sensors and actuators are interfaced with the microcontroller. This module is the core of this system consisting of Atmel ATmega16 Microcontroller which is connected to various components and peripherals.

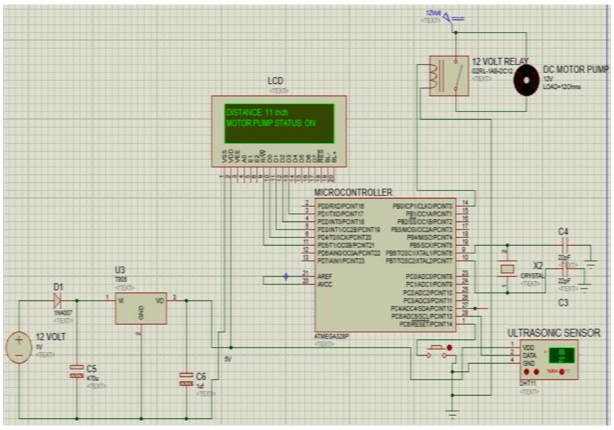


Fig.3: Microcontroller, motor pump and sensor simulation

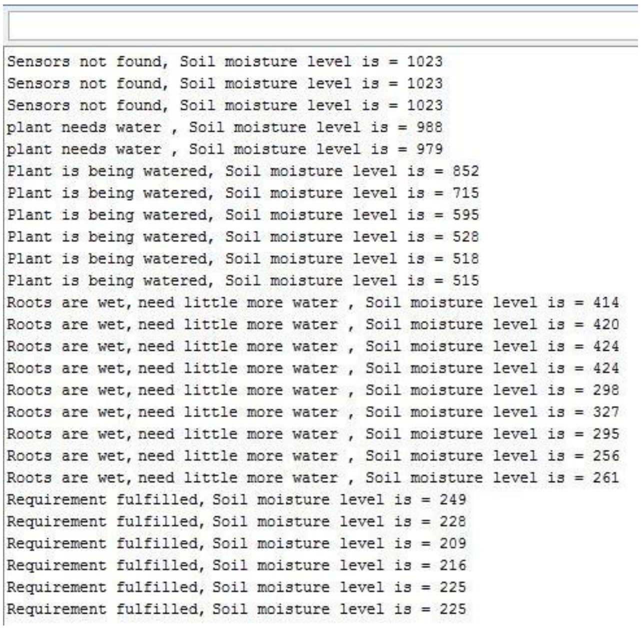
It is divided into three sub-modules, each of which is described below:

B.1: Soil Moisture Sensors

Soil Moisture Sensors (SMS) will sense the water content in the soil; a pre-defined threshold value of water content will be set in the microcontroller programming.

When the water content falls below that pre-defined value, the microcontroller will send signals to the solenoid valve attached with the overhead reservoir, causing it to open a fixed amount, resulting in the flow of water to the intended area. When the water content of the soil crosses the threshold value, the sensors will transmit signals to the microcontroller, which in turn causes the solenoid valve to close, hence stopping the flow.

Fig.4: Testing of soil moisture sensor



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Sensors not found, Soil moisture level is = 1023
Sensors not found, Soil moisture level is = 1023
Sensors not found, Soil moisture level is = 1023
plant needs water , Soil moisture level is = 988
plant needs water , Soil moisture level is = 979
Plant is being watered, Soil moisture level is = 852
Plant is being watered, Soil moisture level is = 715
Plant is being watered, Soil moisture level is = 595
Plant is being watered, Soil moisture level is = 528
Plant is being watered, Soil moisture level is = 518
Plant is being watered, Soil moisture level is = 515
Roots are wet, need little more water , Soil moisture level is = 414
Roots are wet, need little more water , Soil moisture level is = 420
Roots are wet, need little more water , Soil moisture level is = 424
Roots are wet, need little more water , Soil moisture level is = 424
Roots are wet, need little more water , Soil moisture level is = 298
Roots are wet, need little more water , Soil moisture level is = 327
Roots are wet, need little more water , Soil moisture level is = 295
Roots are wet, need little more water , Soil moisture level is = 256
Roots are wet, need little more water , Soil moisture level is = 261
Requirement fulfilled, Soil moisture level is = 249
Requirement fulfilled, Soil moisture level is = 228
Requirement fulfilled, Soil moisture level is = 209
Requirement fulfilled, Soil moisture level is = 216
Requirement fulfilled, Soil moisture level is = 225
Requirement fulfilled, Soil moisture level is = 225
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Fig.5: Results of soil moisture sensor

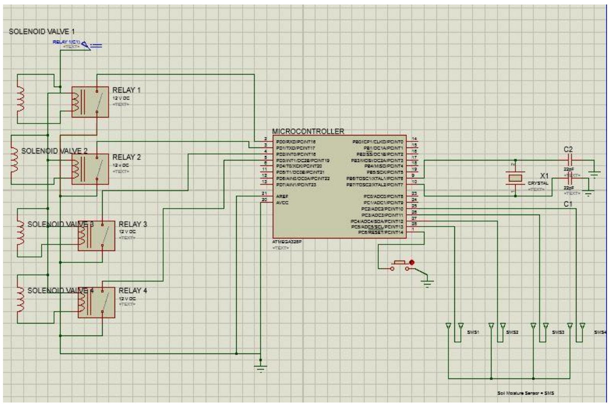

Fig.6: Microcontroller with sensors, valves and distribution network

B.2: Tube well, pump and reservoir

In the overhead reservoir, level sensors would be installed, which will detect the level of water in the reservoir. When the water level falls below the threshold value, the microcontroller turns on the DC motor pump which draws water from the tube well and fill the overhead reservoir until the threshold value is reached. As the threshold value is crossed, the pump is turned off.

B.3: GSM module

The GSM module we are employing for the system is SIM900 quad band modem. A GSM module offers the flexibility of remotely monitoring the SIS, this provides ease to the farmer or concerned person who can monitor and accordingly manage the process. Once the irrigation process is complete, the Microcontroller will cause the GSM Module to send notification to a pre-defined SIM Card, which may be operated by the concerned person. Also, in case the Soil Moisture Sensor malfunctions, a notification will be sent to that SIM Card.[4]

C. Distribution Module

This is the final module of the system which consists of water distribution system using a network of tubes and pipes which are responsible for the precise delivery of water to the roots of the plants using drip irrigation system.

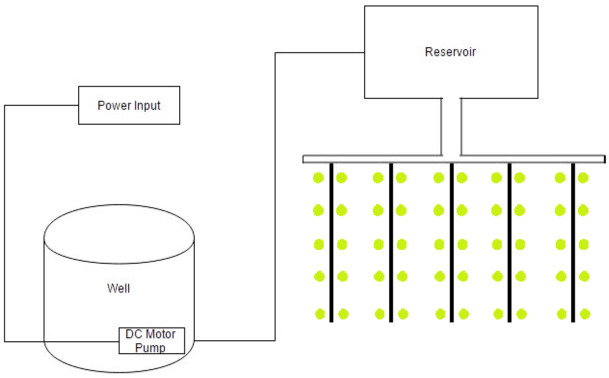

Fig.7: Distribution module Block diagram

Water flows to the sub-main pipe from the overhead reservoir, and then channels to several connected lateral pipes parallel to each other. There are several pores on the sides at certain points along the length of the pipes, which supply the water directly to the root of the plants (in Fig.4, the green dots represent plants). A submersible DC motor pump is fitted inside the tube well, the sole purpose of which is to fill the overhead water reservoir when it empties.

The flow of water from the reservoir is controlled by solenoid valves connected to the parallel pipes connected to a common pipe; the solenoid valves are operated by the microcontroller; when the moisture sensors detect a low level of moisture in the soil, the respective solenoid valves open to let the water flow; as soon as the desired level of moisture is detected by the sensors, this information is sent back to the microcontroller, which closes the respective valves.

III. FLOWCHART

The flowchart shown below describes the complete automation process of the entire smart irrigation system.

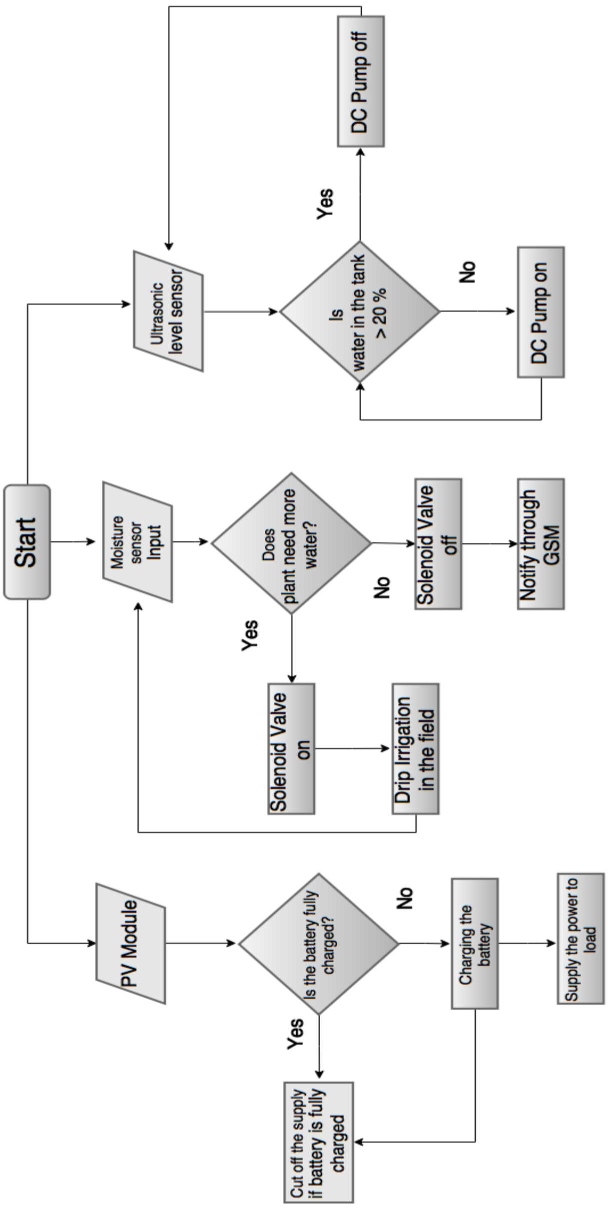

Fig.8: Complete Flowchart

IV. MATHEMATICAL ANALYSIS

A. Drip Irrigation Calculation:

As opposed to conventional irrigation systems that are common throughout our country, drip irrigation system makes less use of water, significantly reduces water wastage and directs the flow of water directly to the required areas, i.e. roots of the crops.

Volume of water required for irrigation of reference crop is calculated as follows:

The irrigation area for the following calculations is taken to be 300 ft^2, although any area can be considered.

The reference crop considered is Tomato, however the calculations can be done for other crops as well.[5]

Formula for Crop Water Requirement (CWR)[6]:

$$CWR = (E_{To} \times K_C \times \rho \times EF \times AP \times 0.623) / \eta_e \qquad \text{(Eq. 1)}$$

Where,
CWRD: Crop Water Requirement for Drip irrigation
E_{To}: Amount of water needed by the crop (mm/day)
K_C: Crop coefficient
ρ: Plant Density (plant/ft2)
EF: Exposure Factor
AP: Planted Area (ft2)
η_e: Irrigation Efficiency

(Here E_{To} and K_C are average values from sowing to harvesting)

$$CWR = (5.8 \times 0.8 \times 1 \times 0.8 \times 300 \times 0.623) / 0.9$$
$$CWR = 25 \text{ Gallon/day.}$$

In a conventional irrigation system, most of the water supplied to the concerned area is wasted and only a little part is utilized by the crops, due to this the irrigation efficiency is much less compared with that of drip irrigation (for simplification, we have assumed this value to be 0.5).

B. Load Calculation:

In drip irrigation the requirement of water was obtained to be 25 gallons/day. On this basis, we calculate the ratings of motor pump.[7]

$$P_H = (Q \times \rho \times g \times \Delta h) / (3.6 \times 106) \qquad \text{(Eq. 2)}$$

$$P_S = P_H / \eta_P \qquad \text{(Eq. 3)}$$

$$P_M = P_S / \eta_M \qquad \text{(Eq. 4)}$$

Where,

P_H: Hydraulic Power (kW)

P_S: Shaft Power (kW)

P_M: Motor Power (kW)

Q: Flow Rate (m3/h)

ρ: Density of Water (kg/m3)

Δh: Head (m)

g: Gravitational acceleration (m/s2)

η_P: Pump Efficiency

η_M: Motor Efficiency

Applying the above values of parameters to Eq. 2, we get the value of Hydraulic Power (PH) equal to 217.7 W;

P_H = (4 x 1000 x 9.8 x 20) / (3.6 x 106) = 0.2177 kW

Now, using Eq. 3, we get the value of Shaft Power equal to 271.25 W;

P_S = 217.7 / 0.8 = 271.25 W

We use Eq. 4 to get the value of Motor Power equal to 387.5W (approx. 0.5 hp);

P_M = 217.7 / 0.7 = 0.3875 kW

It can be concluded from the above calculations that for the considered area and crop parameters, the motor rating will be around half horsepower (0.5 hp).

C. Source Module Rating Calculation:

On the basis of Motor ratings, the ratings for PV panel and battery are determined here [8]:

Motor Wattage = 387.5 W

Motor Load Current = 387.5 W / 12 V = 32.92 A

Flow rate = 4 m3/h or 1056.9 gallon/h (from Eq. 2)

Reservoir capacity = 200 gallons (Excess amount of volume is considered)

Operational time/day = 200 gallon / 1056.9 = 0.189 h / day

Daily Energy Requirement = Load current x Op. time/day

Daily Energy Requirement = 6.22 Ah

Losses are assumed to be 25 % due to Charge Controller and Battery. Hence:

Daily Energy Requirement = 6.22 Ah x 1.25 = 7.77 Ah

Battery Requirements:

Daily Energy Requirement = 7.77 Ah / 0.8 = 9.7125 Ah

(To prolong the battery life it is advisable to use the battery at 80% of its capacity)

The Photovoltaic array to meet requirements for this system has the following parameters:

Rated Voltage = 18.02 V

Rated Current = 11.5 A

Rated Power = Rated Current x Rated Voltage

Rated Power comes out to be 207W

Keeping these values in mind, it is decided to use a PV panel rated at more than the calculated value (200Watt), i.e. 250W.

V. INPUTS AND OUTPUTS

The table below shows the inputs and outputs and their states; the soil moisture sensor gives different values based on the water content in the soil. The motor pump turns on and off based on the value of ultrasonic level sensor, when the reservoir is full, the motor will turn off, and when the water level reaches 20% in the reservoir, the motor will be turned on.

Inputs/Outputs	Variable	State 1	State 2
Soil moisture sensor	S1	>250	<250
Solenoid valve	V1	1 (ON)	0 (OFF)
Soil moisture sensor	S2	>250	<250
Solenoid valve	V2	1 (ON)	0 (OFF)
Soil moisture sensor	S3	>250	<250
Solenoid valve	V3	1 (ON)	0 (OFF)
Soil moisture sensor	S4	>250	<250
Solenoid valve	V4	1 (ON)	0 (OFF)
Ultrasonic level sensor	U	20%	1 (full)
DC Motor pump	MP	1 (ON)	0 (OFF)

Table.1: Inputs/Outputs and their states

VII. COMPARISON

Based on observations and calculations, we can do comparison and contrast with conventional irrigation systems.

Our proposed system is independent of grid power, as it runs solely on self-generated power from solar panels; it prevents a huge problem prevalent in our society, namely the wastage of water (refer to Graph. 1), as our system is automated using soil moisture sensors. It also reduces the human effort involved in conventional irrigation methods. Unlike conventional systems, our proposed system causes no atmospheric pollution. On the other hand, conventional irrigation systems are dependent on power from grid, which may be unreliable in remote areas. Although the installation cost of the proposed system is quite high, the economic benefit after installation will be worthwhile. Overall, the cost of our system will turn out to be much less than the cost of conventional systems, resulting in increased production of crops and consequently increasing the GDP of our country.

VIII. CONCLUSION

The auto-irrigation system we have described in this paper holds the practical answer to many problems, the largest of which is the availability of water. The system, being self-reliant, is not dependent on grid power; the use of soil moisture sensors will greatly reduce the amount of water wasted in irrigation, and it will also significantly save human effort and detailed calculations for crop water requirements. The concerned person will also be notified about any problem that occurs in the system.

In short, this automated system addresses and rectifies many problems regarding irrigation in our country at a much lower cost, with efficient utilization of solar energy, no wastage of water and no atmospheric pollution.

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