Solar Powered Automatic Drip Irrigation System (SPADIS) using Wireless Sensor Network Technology

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Abstract - *The farmers working in the farmlands are dependent on the rains, river, pond and bore wells. Even if the farm land has a water-pump, most of the time it is being kept stand-still due to non-availability of grid power in the remote areas where the potential of sun light availability is tremendous throughout the year. Increase in agricultural production depends to a large extent on the availability of water and power. If the solar power is harnessed, an agricultural pump can run during day hours without depending on grid power. It is observed that in addition to water and power shortage, the farmers are not aware of the scientific method of irrigating the agricultural land. By adopting a proper scientific method, the farmers can save water, energy, labouring time and production cost. The main objective of this paper is to establish an automatic solar powered drip irrigation system by adopting wireless sensor network technology (WSNT) by integrating Solar Photovoltaic System (SPV), Arduino Microcontroller, Soil Moisture Sensor, Mobile Bluetooth, Water Tank, Pump etc. WSNT employed in this work contributes not only to save energy, water, fertilizers but also ensure uniform watering at right time without manual intervention leading to enhance the quality and quantity of agricultural yields.*

Key Words: Automated drip irrigation, Solar panel, Soil moisture sensor, Microcontroller, Wireless network, Energy saving.

1. INTRODUCTION

Irrigation is an artificial and an essential application of water historically followed to overcome the deficiencies in rainfall for the purpose of growing crops. Irrigation is the method in which controlled amount of water is supplied to the plants at regular intervals to maintain the soil moisture which is necessary for the germination of seeds. In many countries irrigation is an old art, as much as the civilization, but for humanity it is a science, the one to survive [1]. Water scarcity is a critical constraint to farming in many parts of the world. As per worldometers, the world population clock shows the current world population as 7517.80 million (i.e., as on 12th July, 2017 at 03:00p.m), India with 1342 million, holds second place after China which has 1388 million. Every one minute the world population is increasing by 160-175. Due to this tremendous increase in population India is expected to overtake China by 2025. After 25-30 years there will be a serious problem for food. In order to meet this food problem, there is a need for producing more agriculture yields using the available limited resources and by adopting the best techniques. The available traditional irrigation techniques are: ditch irrigation; terraced irrigation; drip irrigation and sprinkler system [2]. The global irrigation scenario is categorized based on increased demand for higher agricultural productivity and decreased availability of water and power. These problems can be appropriately rectified by adopting an automated solar power based drip irrigation system which is linked to soil moisture sensor through Android mobile. Mobile phones in present times have become an essential and integral part of human beings; serving multiple needs arises in their day to day life. Sensors can be used for remote monitoring and controlling of the devices via short message service (SMS) and global system for mobile (GSM).

Conventional agricultural practices can cause a wide range of negative impacts on the environment [3]. Agricultural production can substantially affect the functioning of ecosystems, both positively and negatively. Some of the negative impacts of conventional agriculture include the high and inefficient use of water, large land requirements, high concentrations of nutrients and pesticides in runoff, and soil degradation accompanied by erosion [4]. In conventional pumping, diesel and electric motors are employed to pump ground water out of major aquifers to irrigate crops. Unfortunately, the rate of depletion was often faster than its natural recharge by rainwater. This can lead to permanent loss of aquifer capacity, decreased water quality, ground subsidence and other problems [5]. The future of food production in the plain areas is threatened by this phenomenon. At the global scale 689 million acres of fertile land is equipped with irrigation infrastructure. About 68 % of the area equipped for the irrigation is located in Asia, 17 % in America, 9 % in Europe, 5 % in Africa and 1 % in Oceania [6]. Efficient utilization of available water resources is crucial for a country like India, which shares 15-17 % of the global population with only 2.4 % of land and 4 % of the water resources [7]. India receives annual average rainfall of about 1190 mm, which is highly variable temporally and spatially [8]. It has been assessed that there is potentiality of bringing around 45 million hectares land under micro irrigation in India [9]. Out of which 30 million hectares are suitable for sprinkler irrigation for crops like cereals, pulses, fodder, oilseeds etc. Around 12 million hectares are suitable for drip irrigation for crops like cotton, sugarcane, fruits, vegetables, spices, condiments, pulses etc. Apart from this two, around 2.8 million hectares are suitable for mini sprinkler crops like potato, onion, garlic, groundnut, short stature vegetable crops like cabbage, cauliflower etc.

Drip irrigation is a form of irrigation that saves water and fertilizer by allowing water to drip slowly to the roots of many different plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing and emitters [10]. It is done through narrow tubes that deliver water directly to the base of the plant. Solar powered automated drip irrigation system (SPADIS) can be used for efficient drip irrigation. Android mobile is used to check the temperature and moisture of the soil at on specified interval time so that to retain the soil condition and the nutrients composition for better growth of the crops. SPADIS supports efficient drip irrigation; water management practices; increases yields; improve crop quality; conserve water and energy and decreases fertilizer requirements.

According to the survey conducted by the Bureau of Electrical Energy in India in 2011 there are around 18 million agricultural pump sets and around 0.5 million new connections per year is installed with an average pump capacity 5 HP. The total electricity generation in India for the fiscal year 2015-16 was 1352TWh [11, 12]. India is the world's third largest producer and fourth largest consumer of electricity [13, 14]. Electric energy consumption in agriculture was 241.87TWh recorded highest (17.89%) in 2015-16 among all countries. Over 70 % of the rural households in India depend on agriculture as their principal means of livelihood [15]. In India still, the General Packets Radio Service (GPRS) based Irrigation systems are not economically affordable for many farmers.

2. METHODOLOGY

To explore the feasibility of functional testing of SPADIS and based on the design, the methodology involved in procuring and assembling of Solar Photovoltaic System (SPV) for the purpose of automatic watering of testing field selected in CSIR Chennai, Taramani, campus.

Land area selected for this study (6mx3m) = 18m^2
Land area ratio (Drip to Conventional) = 1:1
Quantity of water required for cultivation
considering annual avg. rainfall, 1190mm = 300 lit/m2
Total water requirement for irrigation = 300 x 18
= 5400 liters

The land selected for solar powered automatic drip irrigation system is shown below in Figure 1.

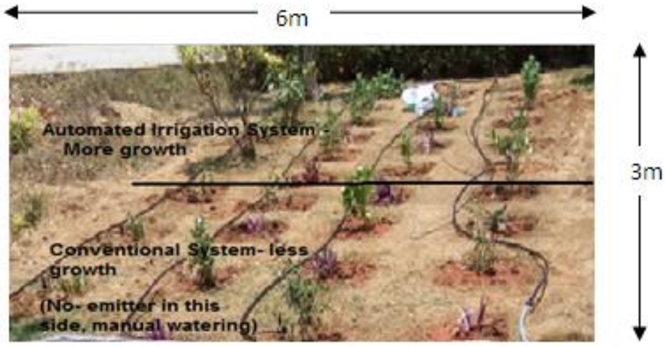

Figure-1: Land selected for SPADIS

The specifications of SPADIS components such as pump, batteries, solar panel, solar charge controller, inverter, soil moisture sensor, Arduino mega 2560 micro controller are described below:

2.1 Design of Pump and Batteries

It was decided to keep a water tank nearer to this land and watering to be done to this selected land by using a small submersible AC pump which is expected to run for about 7-9hours/day with the help of solar panel and battery. A 50W (AC) submersible pump which can supply 600lph @ 6ft head (400lph @ 8ft head) was identified from the market. Figure 2 illustrates the specification and model of procured submersible pump for SPADIS application.

	Specifications AC Voltage range :220-240V Current range :280-330mA Operating freq. : 50Hz Power consumption : 50W Capacity @ 8ft :400lph

Figure-2: Submersible pump used for SPADIS

Since, the pump was chosen to run at 6ft head, it was delivering 600lph and it was meeting the quantity of water needed to be supplied into the selected area (i.e., 18m^2 if the pump is kept in operation for 9hours, it will deliver 5400 liters). Energy requirement for this pump would be (9hr x 50W) 450Wh. In order to meet this power, it is required to design the battery and solar panel capacity. Lead acid battery with 7Ah, 12V capacity which will deliver maximum voltage 12-14.4V and maximum current 1.4A has been selected.

For trouble free operation, the capacity of battery should be 30-40% higher than the capacity of pump; hence 4nos of the said batteries were chosen and connected parallel to get higher rating than 50W pump. Capacity of batteries connected in parallel is 67W (i.e., 1.4A x 4 x 12 = 67.2W which is 35% higher than pump power). Figure 3 shows the photo image of 4 batteries connected in parallel.

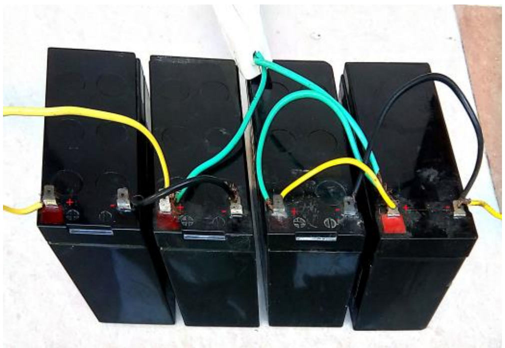

Figure-3: Batteries (7Ah, 12V batteries -4Nos) connected in parallel

2.2 Design of Solar Panel

Photovoltaic cell use sun light to generate electricity, the generated power is the product of voltage times the current (i.e., P = V x I). The amount of electrical power generated by an individual photovoltaic cell at its output terminals depends upon the amount of solar radiation that hits its PN junction as well as the percentage of solar radiation it actually converts into electricity, in other words its efficiency. It is known that the optimum operating voltage of a PV cell under load is about 0.46 volts, generating a 3A current in full sunlight. Hence, the power output of typical solar photovoltaic cell is 1.38W. The power generated by a single cell is not enough to do any useful work. In our case, the battery theoretical capacity is 67.2W, hence we need more power. Considering the solar radiation in Chennai, 1kW solar panel can produce about 6kWh per day. As it has been worked out that the per day energy consumption of submersible pump selected for SPADIS was 450Wh and to generate this required capacity of the solar panel would be 75W. For trouble free operation, 2nos of 75W solar panel were connected in parallel. Figure 4 shows the photo image of solar panel used in this present study.

Specifications
Rated Power : 75W±5%
Rated Voltage : 17.2V
Rated Current : 4.36A
Open Circuit V : 21.5V
Short Circuit I : 4.8A
Total capacity : 150W
Rated total current: 8.72A

Figure-4: Solar Panel (75W, 2Nos) used for SPADIS

The details of solar charge controller and its specification is shown in Figure 5.

Specifications
Input range : 90-300V±20V
Max. PV voltage:
Voc ≤ 25V
Battery low warning
Voltage : 10.7±2%
Operating temperature
: 0 to 55°C
Max. PV panel rating 260W, Imp≤ 16A
Power conversion eff. ≥95%

Figure-5: Solar Charge Controller

The following Figure 6 shows the photo image of 250VA Inverter used to convert the DC power obtained from the battery to AC power need to be given for submersible pump.

Specifications

Output Frequency: 50 ±0.1Hz
Output Voltage : 200-220V ±25V
Maximum charging
Current : 4.5±1A
Open Circuit V : 21.5V
Short Circuit I : 4.8A

Figure-6: Inverter (250VA/12V) used for SPADIS

The complete schematic diagram SPV system is shown in Figure 7. Solar panel is connected to battery thorough charge controller. Charge controller is connected with battery, inverter and AC main supply. The solar panel will be disconnected from the circuit if its voltage goes below battery voltage and the battery will be only source to run the pump. If grid power is available then the SPV will be disconnected from the circuit and only AC power from main will be drawn to run the pump.

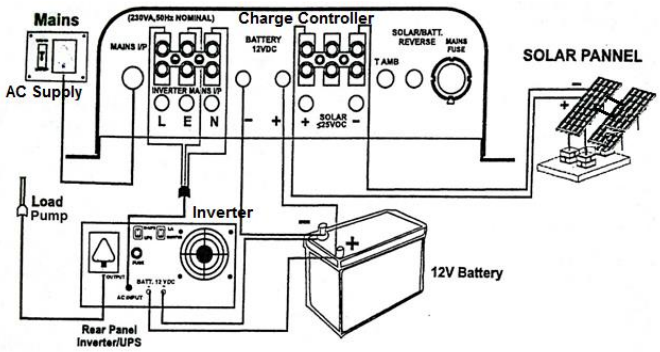

Figure-7: Schematic layout of Solar Photovoltaic System

2.3 Soil Moisture Sensor

Soil is nonconductive by nature but presence of water in soil increases its conductivity due to the presence of conduction ions in water. Soil resistivity is a measure of a soil's ability to retard the conduction of an electric current. Normally, the soil resistivity varies from 0 to 5 kilo-ohms. The soil moisture sensor, shown in Figure 8 has probes to be inserted into soil.

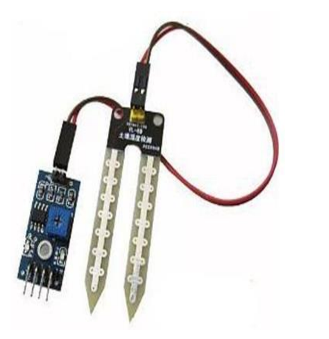	Specifications Operating voltage : 3.3V-5V Dual output, 4 wire interface. Panel PCB dimension : 3cm x 1.5cm Soil Probe dimension : 6cm x 3cm Cable length : 21cm DO : Digital output (0 and 1) AO : Analog output interface

Figure-8: Soil Moisture Sensor

Voltage will be developed between the PIN AO and GND, the development of voltage is depends upon the moisture condition of the soil and the sensor length kept inside the soil.

The sensor will produce high voltage say 4.5 to 5V when the soil is completely dry. Voltage level will decrease w.r.t increase in moisture content. When the soil is completely wet, the output voltage will be 0.88 to 1.0V.

The position and depth of the moisture sensor used in the developed automated drip irrigation system, is shown in the Figure 9. In fruit trees, moisture sensor should be placed on the sunny side of the tree at 30-45 cm from the emitter. In vegetable crops, moisture sensor should be placed at 10-15 cm depth [16]. For trees, thumb rule is to irrigate 60 % of the shaded area [16].

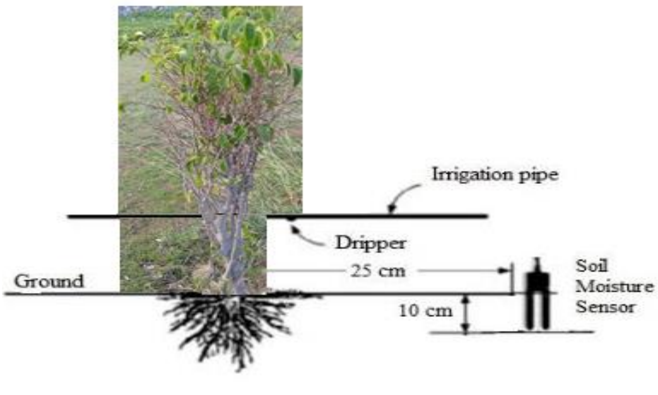

Figure-9: Placement of moisture sensor

2.4 Arduino Mega 2560 Microcontroller

In this present study, Arduino mega 2560 micro controller has been used. The different pins (digital, analog and power supply) of Arduino is illustrated in the following Figure 10.

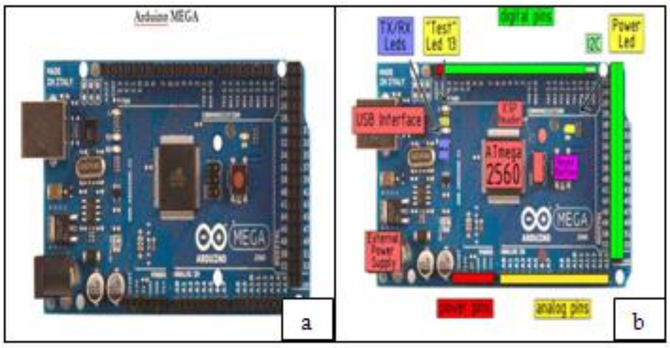

Figure-10: Arduino mega 2560 (a:pin diagram, b: pin description)

Specifications of Arduino ATmega 2560 is given below:

Operating voltage	: 5V
Input voltage	: 7-12V
Input voltage limit	: 6-20V
Digital I/O pins	: 54
Analog input pins	: 16
DC current per I/O pin	: 40mA
DC current for 3.3V pin	: 50mA
Flash memory	: 256kB
SRAM	: 8kB
EEPROM	: 4kB
Clock speed	: 16Mhz

Plants to grow it requires specific amount moisture in the soil in which it has been planted. The amount of moisture varies from crop to crop. Out of supplied water, plants will absorb fraction of water and remaining will be hold in the soil itself and excess water if any applied it will get evaporated. For better irrigation management one has to do the water balance and it can be done by Evapotranspiration (ET) method. In this method Class A pan, by integrating climatic factors, is commonly used to measure the quantity of water getting evaporated.

The main objective of irrigation is to provide strength to the plant to prevent stress which is the main factor for reduction in yields. New irrigation system, design and selection techniques are continually being developed and tested to obtain the highest practically attainable efficiency in water irrigation. The irrigation scheduling frequency and quantity of water to be supplied depends upon the local climatic conditions; type of crops; its growth stage and soil characteristics. Irrigation time can be estimated without the knowledge of ET rates. A laymen way is to observe crop indicators such as change of color in the color of leaf or leaf twisting angle, but this information may appear to be late and it is not going to indicate the exact moisture content in the soil and due to which watering will not be done at right time which causes reduction in crop yields. Though the basic information on weather data is available, ET estimate based on weather data has not been made in India. Presently, in India, irrigation is done based on plant water stress, soil moisture status or soil water potential measurement. Because of its simplicity soil moisture measurement can be the most preferred option. Hence, in our investigation it has been decided to go for automatic solar power drip irrigation based on soil moisture measurement. Water content by gravimetric and volumetric in the soil can be calculated using the following formula [17].

$$Gravimentric\ water\ content\ (\%) = \frac{\text{Mass of wet soil} - \text{Mass of dry soil}}{\text{Mass of dry soil}} X100$$

Volumetric water content is commonly used to express the soil water content, is obtained by multiplying the bulk density of the soil by the gravimetric water content.

$$Volumetric\ water\ content\ (\%) = \frac{\text{Bulk density of soil X Gravimetric water content } (\%)}{\text{Density of water}}$$

Bulk density is the expression of mass of dry soil per unit volume of soil.

$$Bulk\ density = \frac{\text{Mass of dry soil}}{\text{Volume of soil}}$$

Based on the detected moisture content in the soil, in this study it has been decided to focus on automated drip irrigation system. Automated irrigation system can control water wastage in the field due to excess water supply, evapotranspiration, leakages etc. This technique can also be used for finding the exact field condition and for selecting the right crops. Traditional irrigation method has drawbacks like under irrigation, over irrigation which in turn causes leaching and loss of nutrient content of soil. Automated Irrigation can remove all these drawbacks.

Soil moisture sensor based Automated Irrigation systems are the most feasible solution in the present time. Soil moisture sensor can be used at multiple places in the field for getting the better accuracy. This system has ability to apply site-specific irrigation management to match spatially and temporally variable conditions, which can increase application efficiencies, reduce environmental impacts, and can improve yields. Global System for Mobile (GSM) technology can be used for communication purpose to inform farmers about the exact field condition. In addition to an automated drip irrigation system, implementing of mobile communication can also help the farmers to have full remote access on their field cultivation activities which includes watering the crops at right time by operating the pump remotely. GSM based motor control board is shown in Figure 11. GSM contains a Subscriber Identity Module (SIM), farmers can communicate with this SIM-Number. Simple commands such as STN9444728563 for storing the mobile number 9444728563; STS for getting the status; OWN for accept command from registered number only; ANY for accept command message from any number; ON for Pump ON or 1st missed call Pump ON); OFF for Pump OFF or 2nd missed call for Pump OFF.

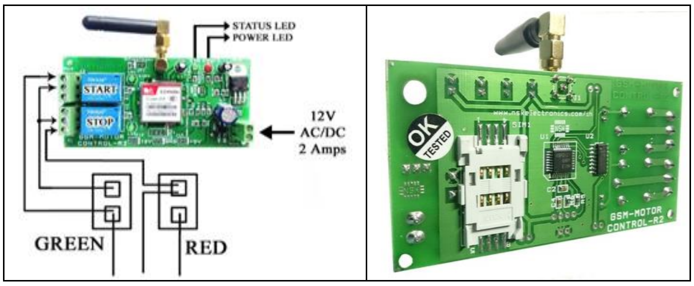

Figure-11: GSM based SPADIS Motor Controller

By adding some more features into the developed SPADIS, it can also be used for monitoring other field parameters like soil temperature, air temperature, pH, nutrients etc. The data related to micrometeorological information in and around the field, i.e., air temperature, relative humidity, precipitation, wind speed, wind direction, and solar radiation can also be obtained from nearby weather station for knowing environmental parameters and plan farming activities accordingly. This type of system can also be used at Cricket stadiums or Golf stadiums and in public garden area for proper irrigation purpose [18].

Bluetooth module connected with Arduino UNO. Four pins of Bluetooth module (+5V, GND, TX, RX) is connected with the Arduino UNO, with the help of two resistors as shown in the following Figure 12.

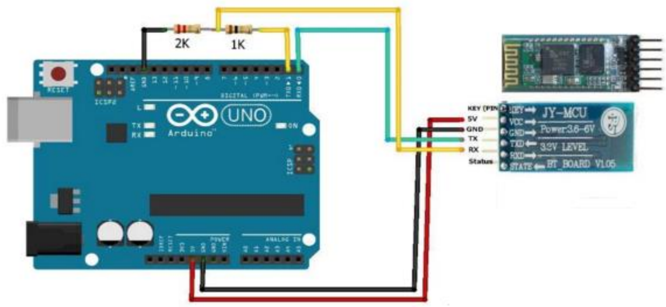

Figure-12: Bluetooth module connected with Arduino

GSM and Bluetooth modules connected with Arduino microcontroller which is inturn connected with the relay can control the operation of submersible using wireless technologies i.e. by sending SMS through GSM network. If the farmer wants to control the pump, he has to send the SMS indicating the operation of the pump, what he wants to do. The modulator-demodulator (MODEM) embedded microcontroller receives SMS. Based on the received SMS, microcontroller gives the command to the connected pump through relay.

Although the microcontroller used in this project was appropriately programmed to control only the water pump. The system can also be used for transferring fertilizer and the other agricultural chemicals (calcium, sodium, ammonium, zinc) to the field by adding new sensors and valves. It discourages weeds, saves water and time, and statistical data can also be used to control diseases and fungal growth. Field was equipped with wireless communication techniques Bluetooth and GSM, that avails better facilitated sensor communication and covers wider field area. Android Application ArduDroid can be used for getting data on mobile from Arduino through Bluetooth for shorter distance. For long distance, GSM technology can be used for getting the pump status and moisture condition as a text message on mobile phone. Pump status and moisture content can be displayed with the help of display in the field or on the mobile phone with the help of android application.

The various components used for the developing GSM and Bluetooth based Solar Powered Automated Drip Irrigation System is shown in the following Figure 13.

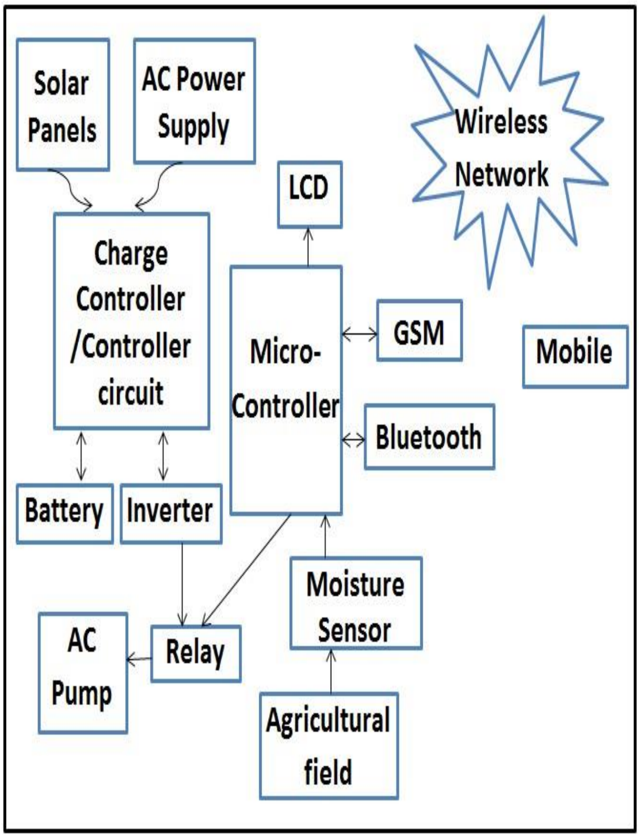

Figure-13: Block Diagram of Solar Powered Automatic Drip Irrigation system using GSM-Bluetooth Technology

3. EXPERIMENTS

Based on the created setup, many experiments were conducted to understand the functional behavior of soil moisture sensors, batteries charging voltage, batteries discharging voltage while running the pump by drawing the power from battery alone (i.e., keeping solar panel disconnected from the circuit) and batteries discharging voltage while running the pump drawing power from batteries and simultaneously it is also kept in charged condition from SPV. The following Table 1 illustrates the voltage developed by the moisture sensor w.r.t addition of water. It was observed that when the soil was completely try it was developing 4.5V and when 60ml water added, the soil turned into completely wet as shown in Figure 14. For this complete wet, the voltage developed from the soil sensor was 0.88V.

Table -1: Moisture sensor voltage w.r.t water content in the soil

Soil Cup No.	Weight of soil, (g)	Added water quantity, (ml)	Moisture sensor output voltage, (V)	Soil moisture, (%)
1	200(dry)	0	4.5	0
2	200	12	3.1	38.67
3	200	24	2.6	52.48
4	200	36	2.1	66.29
5	200	48	1.4	85.63
6	200(wet)	60	0.88	100

Figure-14; Complete wet soil

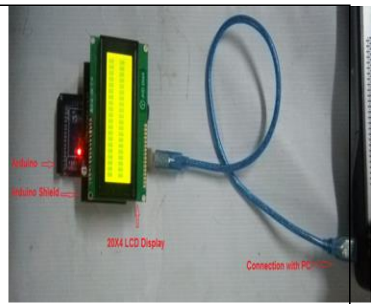

Figure-15: LCD display connected with Arduino

Arduino mega 2560 micro-controller receives the incoming voltage signal from the moisture sensor and gives the command to the pump based on the moisture condition in the soil. A LCD was also connected (Figure 15) with the micro-controller to display the moisture value and pump ON/OFF status. Completely developed and installed SPADIS is shown in the following Figure 16.

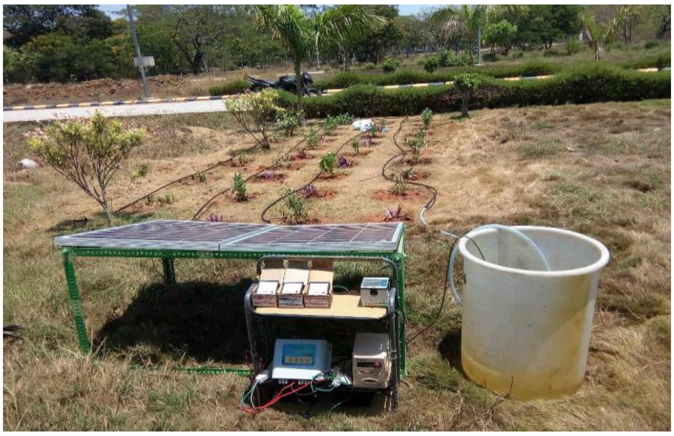

Figure-16: Solar Powered Automated Drip Irrigation System

This system can run either with electricity or solar power. The pump can without battery also (i.e., receiving the DC power directly from solar panel and then converting it into AC power by Inverter). It is suggested to use SPADIS with batteries to get longer life to the pumps. The cost of AC pump is much cheaper than DC pump and that is the reason why in this experiments AC pump has been chosen.

4. RESULTS AND DISCUSSION

From the Table 1, the moisture sensor which will give voltage output w.r.t the water content in soil can be used as online soil moisture measurement. If the soil is completely dry, the voltage output from the sensor would be 4.5V and if the soil is completely wet then the voltage output would be 0.88V. Hence, this 4.5V relates 0% moisture and 0.88V relates to 100% moisture. The following Figure 17 shows the calibration curve prepared for sensor output voltage versus % of moisture.

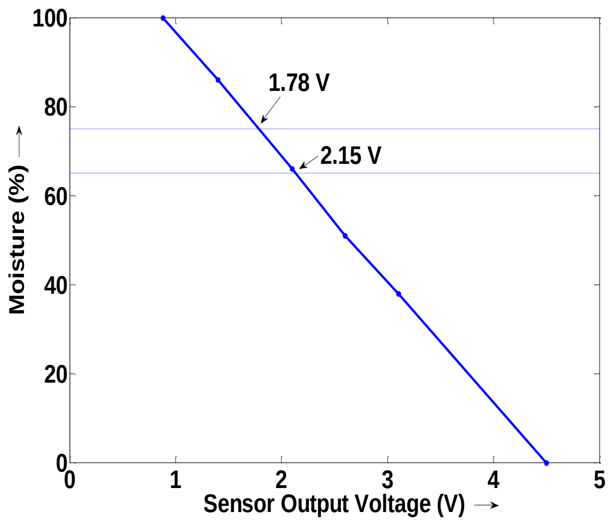

Figure-17: Sensor output voltage Vs Soil Moisture

Based on the experiments, it has been decided to switch ON the submercible pump whenever the soil moisture goes down to 65% (i.e., at sensor output voltage at 2.15V) and swich OFF the pump when the moisture level reaches to 75% (i.e. sensor output voltage at 1.78V). The simulated irrigation done manually is compared with the solar powered automated irrigation system as shown in Figure 18.

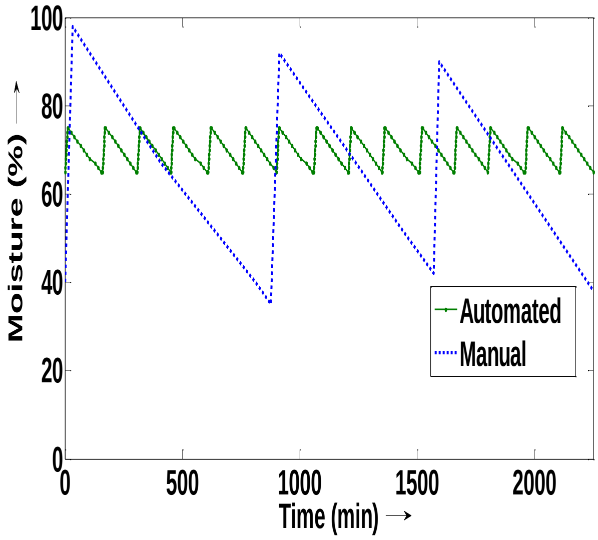

Figure-18: Comparison of manual irrigation with SPADIS

In manual irrigation the pump switch ON was done at soil moisture at 45, 35, 40 and 38. The pump was switched OFF at soil moisture at 98, 92 and 90. In case of SPADIS, the pump was always switched ON at soil moisture at 65% and always switched OFF at soil moisture at 75%. The pump takes about 10 minute to increase the soil moisture from 65% to 75%. With little change in the program, it is possible to maintain the moisture condition in the field at different ranges of values. By running the pump based on moisture measurement and drip irrigation system, about 30 to 70% irrigation water can be saved.

The results of battery voltage as shown in the following Figure 19, indicates that the connected batteries (i.e., four batteries, each 7 Ah capacity, connected in parallel) gets fully charged in 1 hour and 55 minutes with the help of two 75W solar panels. The experiment was started at 10.15a.m and at that time solar panel voltage was 14.59V and the battery voltage was 12.91V. The peak voltage recorded 15.36V and 16.02V for battery and solar panel respectively at 11.38a.m was due to higher solar irradiation 1020W/m^2 and the immediate drop for 5 minutes was again due to increased wind which changes i.e., reduces the solar irradiation to 750W/m^2. At fully charged condition the recorded voltage in the battery was 15.36V.

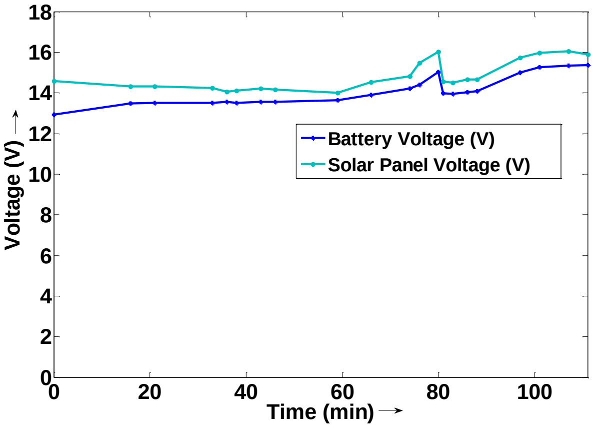

Figure-19: Batteries charging voltage with two solar panels

Once, the battery is charged the pump can be run without the solar power or external supply; only with the help of battery and inverter. From the following Figure 20 which illustrates the drop in battery voltage recorded when the pump draws power from battery alone and at the same time the battery was not getting charged from the solar panel. Under this condition the pump can run maximum for 1hr 15min.

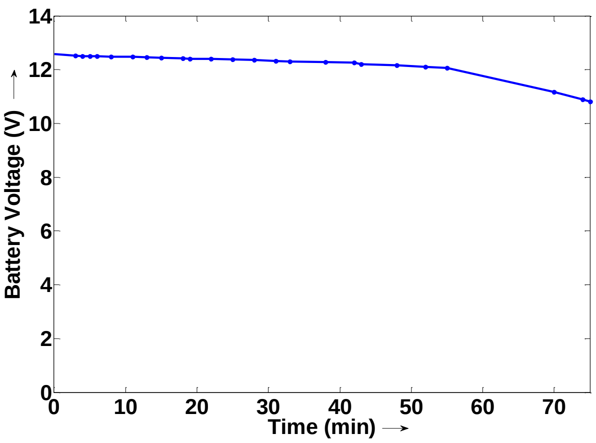

Figure-20: Pump operation with battery and inverter without solar panel

The battery voltage continuously decreases with the pump operation, and the pump stops if the battery voltage goes below 10.7 V.

The following Figure 21 illustrates that the pump can be kept in operation continuously for 7 hour 50 minutes when it was drawing the power from battery and at the same time the battery is also getting charged from solar panel.

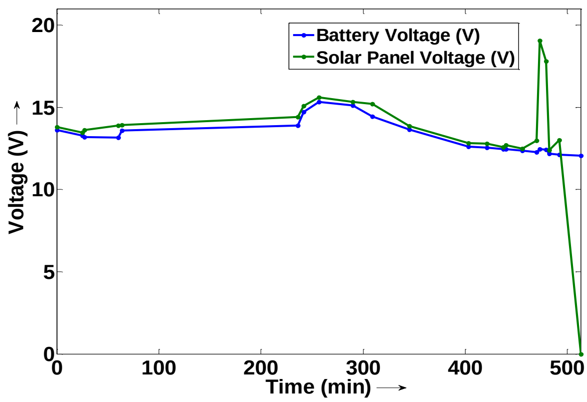

Figure-21: Pump operation with battery and solar panel

The battery initial voltage was 13.62 V and final voltage after 7 hour 50 min was 12.27 V. After this point (i.e., at 6.0 p.m) solar panel voltage goes below than the battery voltage. Hence, the solar panel was automatically disconnected from the circuit by the charge controller. Pump was found running 43 minutes extra without solar panel. The total running hours of pump was recorded was 8 hours 33 min, without any interruption with the help of solar panel and battery.

5. CONCLUSIONS

In this present investigation, Solar Powered Automatic Drip Irrigation System (SPADIS) was developed for irrigating the farm land by measuring the soil moisture. The subcomponents of SPADIS consists i) Arduino micro-controller, Bluetooth module, GSM module, Solar Panel, Battery, Charge controller, Inverter and other accessories such as submersible pump, water tank and drip irrigation kit. It is established in this present investigation that SPADIS will be an effective tool for the formers those who wants to conserve water and who also faces power shortage at their places where sufficient sunlight is available. With the help SPADIS, the pump can run maximum for 7-9 hour per day with the help of solar panel and battery and 5-7 hours per day without battery taking power directly from the solar panel. Pump status and moisture value was obtained on mobile phone with the help of Bluetooth module HC-05 or GSM module. Pump can also be controlled by digital pins of Arduino through some Android application via mobile phone. The automated irrigation system is a feasible and cost effective technique for optimizing water resources for increased agricultural production. Studies show that SPADIS can save the irrigation water about 30-70 %.

In future, this SPADIS can also be used for monitoring the water soluble fertilizers such as Urea, Potassium, Nitrate, Ammonium Sulfate, Ammonium Nitrate, Mono Ammonium Phosphate, Calcium Nitrate, Magnesium Nitrate etc by introducing the suitable sensors.

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