

Simulation and Analysis of Control System for a Solar Desalination System

R. Prakash, B. Meenakshipriya, R. Kumaravelan

Abstract—Fresh water is one of the resources which is getting depleted day by day. A wise method to address this issue is by the application of renewable energy-sun irradiation and by means of decentralized, cheap, energetically self-sufficient, robust and simple to operate plants, distillates can be obtained from sea, river or even sewage. Solar desalination is a technique used to desalinate water using solar energy. The present work deals with the comprehensive design and simulation of solar tracking system using LabVIEW, temperature and mass flow rate control of the solar desalination plant using LabVIEW and also analysis of single phase inverter circuit with LC filters for solar pumping system in MATLAB. The main objective of this work is to improve the performance of solar desalination system using automatic tracking system, output control using temperature and mass flow rate control system and also to reduce the harmonic distortion in the solar pumping system by means of LC filters. The simulation of single phase inverter was carried out using MATLAB and the output waveforms were analyzed. Simulations were performed for optimum output temperature control, which in turn controls the mass flow rate of water in the thermal collectors. Solar tracking system was accomplished using LABVIEW and was tested successfully. The thermal collectors are tracked in accordance with the sun's irradiance levels, thereby increasing the efficiency of the thermal collectors.

Keywords—Desalination, Electro dialysis, LabVIEW, MATLAB, PWM inverter, Reverse osmosis.

I. INTRODUCTION

ABOUT thirty percent of the world's population lives in countries suffering from moderate-to-high water stress. They are dependent on renewable freshwater resources that constitute more than ten percent of overall potable water supplies in these countries. About eighty countries with forty percent of the world's population, were suffering from serious water shortages by the mid-1990s and it is estimated that in less than 25 years two-thirds of the worlds' people will be living in water-stressed countries.

A wise solution to this problem would be to desalinate the sea water. Desalination may be exhibited using various techniques, which have been discussed by [1]. Various methods such as distillation [3], reverse osmosis [4], electro dialysis [5], etc., may be used to obtain fresh water from saline

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water. However, these techniques generally require huge capital and use of energy from fossil sources or require waste heat from large power stations. In addition, an infrastructure is indispensable for the distribution of the produced water. Solar desalination [6] is one such technique of thermal evaporation, where the thermal energy is obtained from the sun. It is based on evaporation of sea water or brackish water and consecutive condensation of the generated humid air, mostly at ambient pressure. This process mimics the natural water cycle, but over a much shorter time frame.

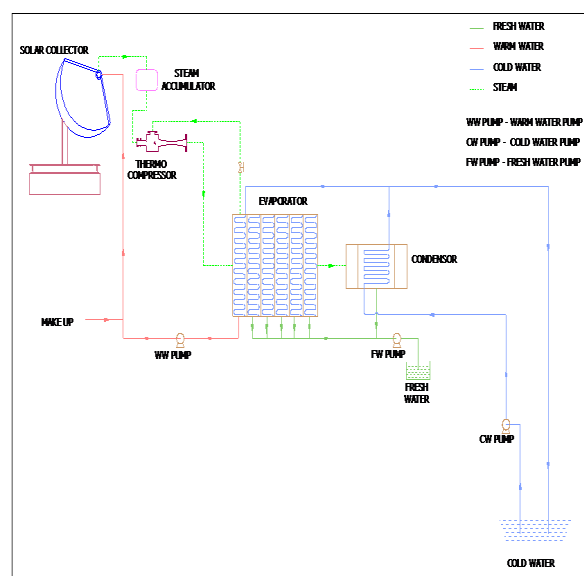


Fig. 1 Layout of the Proposed Solar Desalination Plant

A scheme for large scale desalination of sea water by solar energy was proposed by Anil K. Rajvanshi for Thar desert on an area of 4.5 miles [7]. The plant was designed to operate based on Multi stage flash distillation principle with 20 stages and had a capacity to produce 5.25×10^7 m³ of fresh water every year. Pumping power was proposed from 415 wind machines each of 200 kW capacities. The present work is a similar solar desalination system proposed for coastal areas in Chennai. The layout of the proposed desalination plant is shown in Fig. 1. The plant is designed to operate based on multiple effect evaporation with 6 stages. Previous literature models focused on the usage of various sources of electricity for pumping water in the solar desalination plant. Here, the water for desalination is pumped to the system by the use of solar energy from PV modules. The power conversion from PV modules is done using inverter with properly designed LC filters [8]. For effective utilisation of thermal energy, tracking

[9] of collectors has been proposed using LabVIEW. Output control of thermal collectors by control of temperature and mass flow rate of water has been proposed using LabVIEW.

II. DESIGN AND SIMULATION OF LC FILTER

Solar PV water pumping systems are reliable and very cost-effective and can replace manual pumps, if used in the right location. A solar water pumping system may be employed with a single phase inverter to supply the load. Output voltage from an inverter can be adjusted or maintained at a desired level by exercising a control within the inverter itself. The most efficient method of doing this is by pulse-width modulation control used within an inverter. In this method, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. This is the most popular method of controlling the output voltage in an electrical system. The circuit diagram of single phase inverter is shown in Fig. 2.

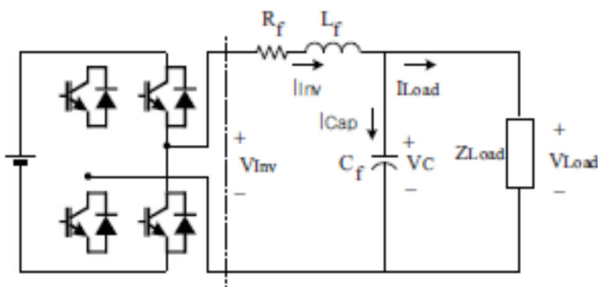


Fig. 2 Single Phase PWM Inverter Equivalent Circuit

A. PWM Inverter with LC Filter

To design an inverter, many power circuit topologies and voltage control methods are used. The most important aspect of the Inverter technology is the output waveform. To filter the waveform, capacitors and inductors are used. Low pass filters, are used to reduce the harmonic components. The design procedure is discussed below.

1) Design Procedure

The design procedure of the LC filter can be divided into the following steps:

Step1. Based on the nominal dc source voltage E_d and nominal load voltage V_o , we can calculate the nominal modulation index. Since the voltage drop across the filter inductor cannot be determined before the parameters of the filters are specified, this voltage drop can be assumed to be negligible [2]. This assumption is justified because voltage drop across the inductor is compensated in part by the filter capacitor. In order to calculate the nominal modulation index, therefore, the rms value of the output voltage of the inverter can be assumed equal to the rms value of the load voltage, that is,

$$k = \sqrt{2} \frac{V_o}{E_d} \quad (1)$$

The result is then used to calculate the factor K by using

$$K = \left[\frac{k^2 - \frac{15}{4}k^4 + \frac{64}{5\pi}k^5 - \frac{5}{4}k^6}{1440} \right]^{\frac{1}{2}} \quad (2)$$

Step2. Based on the nominal load current, I_o , fundamental output frequency, f_r , switching frequency, f_s , and the specified values of the total harmonic of the load voltage, $V_{o(av)}$, the optimum mean value of the inductance of the filter can be calculated using

$$L_f = \frac{V_o}{I_o * f_s} \left\{ k \frac{E_d}{V_{o,ac}} \left[1 + 4\pi^2 \left(\frac{f_r}{f_s} \right)^2 K \frac{E_d}{V_{o,ac}} \right]^{\frac{1}{2}} \right\} \quad (3)$$

Step3. The capacitance of the filter can be calculated by using,

$$C_f = K \frac{E_d}{L_f * f_s^2 * V_{o,av}} \quad (4)$$

2) Experimental Results

The output rms voltage from the circuit without filter is 17 V. The input voltage E_d to the inverter circuit is 24V. The triangular carrier wave frequency is 1000 Hz. The reference sinusoidal wave frequency is 50 Hz. Here sinusoidal PWM technique is used. The modulation index is obtained from (1) as $k = 1.0017$, from (2), $k = 7.186 * 10^{-3}$.

The total harmonics of the output voltage of the inverter without filter is calculated as 0.6784 (67.84%).

The nominal load current is calculated as 1.708A.

The optimum value of the inductance is obtained using (3) as

$$L_f = 5.0809 \text{ mH}$$

From the inductance value, optimum value of the capacitance is obtained using (4) as

$$C_f = 50 \mu\text{F}$$

The condition to be satisfied is

$$\sqrt{L_f / C_f} > Z_{load}$$

Hence, Z_{load} can be greater than 10 Ω .

3) Simulation Results

A stochastic simulation software (MATLAB) is implemented to accomplish design simulation studies of the plant for various objectives like minimization of total harmonic distortion and maintaining a constant load voltage. The circuit diagrams for single phase PWM inverter with and without filter were drawn using simulink in MATLAB and the corresponding output waveforms were simulated. The results of the simulation are given below along with their respective circuits and design values. Fig. 3 shows the circuit diagram of single phase inverter without filter and Fig. 4 shows the corresponding output voltage and current waveforms.

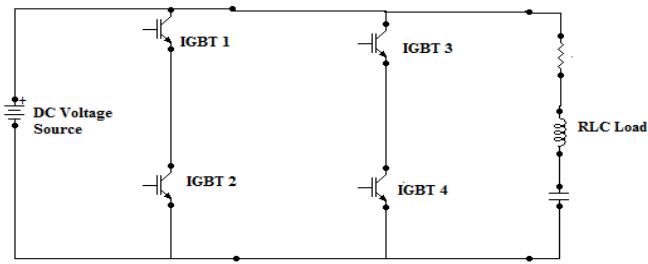


Fig. 3 Single Phase PWM Inverter without Filter

TABLE I
 DESIGN VALUES OF PWM INVERTER WITHOUT FILTER

Parameters	Range
Input DC voltage	24 V
Resistive load	10 Ω
Obtained output voltage	17.08 V
Obtained output current	1.708 A
Switching frequency	1000 KHz
Frequency	50 Hz

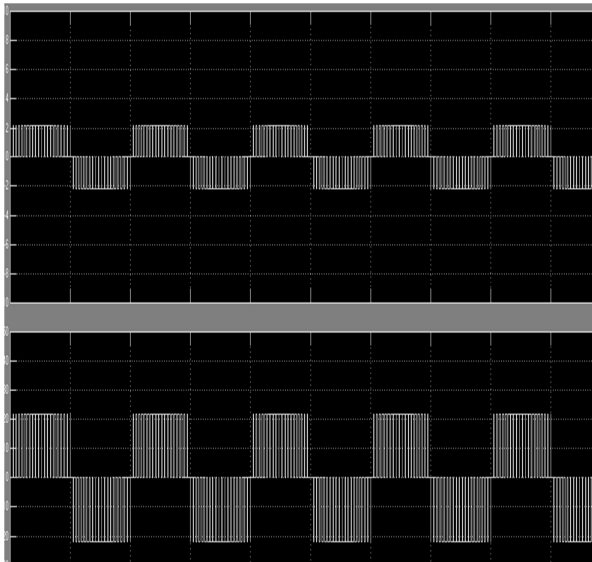


Fig. 4 Output Voltage and Current Waveforms

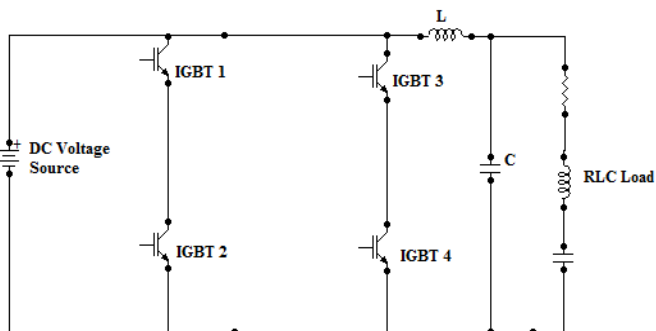


Fig. 5 Single Phase PWM Inverter with Filter

Figs. 5 & 6 show the circuit diagram of single phase PWM inverter with LC filter and the output voltage and current waveforms respectively. It can be seen from the results that

the performance of the PWM inverter with filter is improved in terms of output voltage and harmonic distortion.

TABLE II
 DESIGN VALUES OF PWM INVERTER WITH FILTER

Parameters	Range
Input DC voltage	24 V
R load	10 Ω
L value	5.08 mH
Obtained output voltage	18.92 V
C value	50 μ F
Frequency	50 Hz

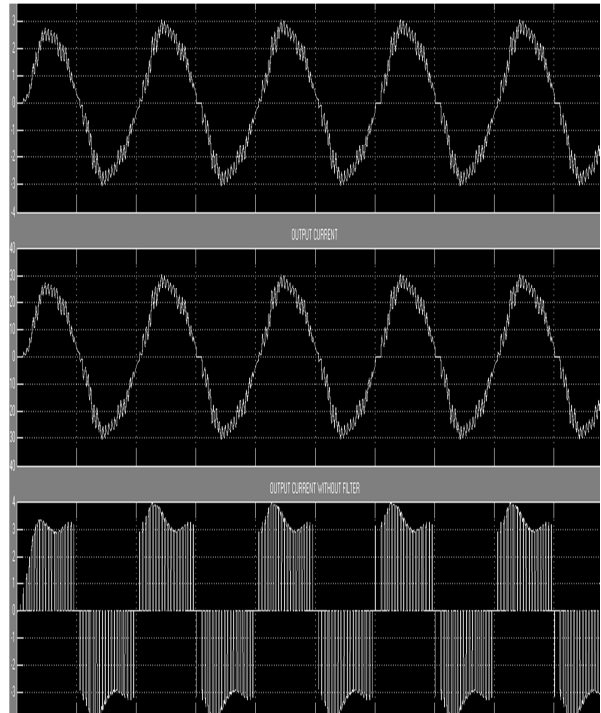


Fig. 6 Output Waveforms of Single Phase Inverter with LC Filter

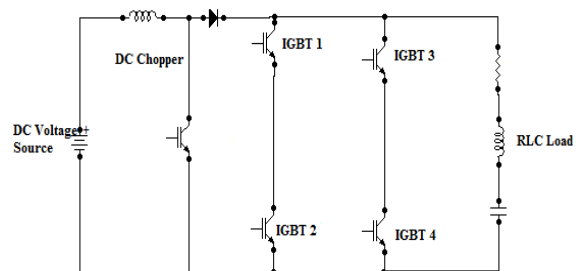


Fig. 7 Single Phase Inverter with DC Chopper

TABLE III
 DESIGN VALUES OF INVERTER WITH DC CHOPPER

Parameters	Range
Input voltage	24 V
R load	20 Ω
L value	5.08 mH
C value	50 μ F

Figs. 7 & 8 show the circuit diagram and the obtained output voltage and current waveforms using a DC chopper in a single phase inverter circuit. The design values are mentioned above.

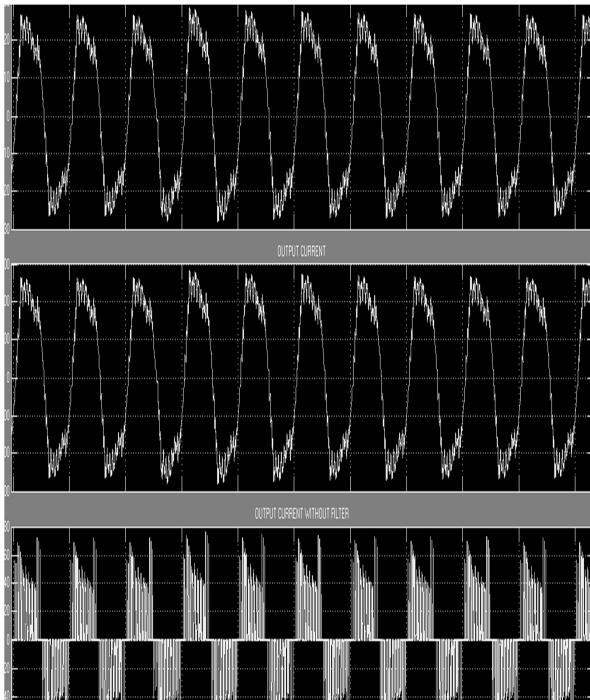


Fig. 8 Output Voltage & Current Waveforms with DC Chopper

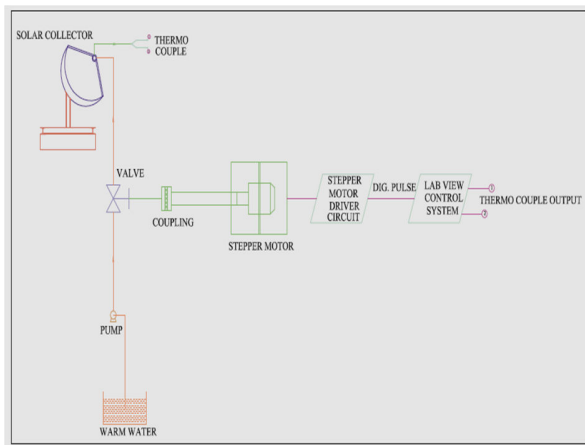


Fig. 9 Layout of Temperature and Mass Flow Rate Control System

The DC chopper helps in boosting the output voltage the use of LC filter in the output side also helps in reducing the harmonic distortions.

III. DESIGN AND SIMULATION OF TEMPERATURE AND MASS FLOW RATE CONTROL SYSTEM

In solar collector, the solar field outlet temperature can be controlled inside solar collectors by using water flow as a manipulated variable. Higher temperature could form scale in heat exchanger but lower temperature reduce distillate production. The solar radiation is the only energy source of the

system operation which deterministically affects all the performances. Because the solar radiation profile is not known beforehand in practical operation, a control system instead of an optimizer is a feasible for better system. In order to fulfill the requirements for optimal operation of MED distillation plants, a specific water temperature range must be reached and maintained in the heat exchanger of the first effect of MED plant. Fig. 9 shows the layout of temperature and mass flow rate control system.

A. Reasons for Temperature Control

There are two main reasons for control of temperature in the solar desalination plant. The first one is that solar collector output temperature must be less than 90°C to prevent water evaporation inside the collector absorber tubes. Next the temperature difference in water between outlet and inlet. To avoid stress in absorber tubes material, the difference may be no more than 20°C. Hence, the solar field control system must maintain the desired outlet temperature, despite disturbance in radiation, inlet temperature, ambient temperature and system uncertainties using inlet water flow rate as a manipulated variable.

B. Modes of Operation

The control system utilizes Temperature sensors, LabVIEW software, Data Acquisition System and Stepper Motor along with the Driver Circuit. There are two modes namely, automatic mode and manual mode.

- 1) Automatic Mode: In order to maintain constant temperature of steam from the solar collector, the control system must be employed with closed loop system. In automatic mode, LabVIEW software along with stepper motor is used for the control system. The valve is connected to the rotor part of the stepper motor. This valve is adjusted to control the mass flow rate of water entering the solar collector which in turn controls the output temperature from the varying solar radiation. When the solar radiation is high, then the output temperature varies and it means that more heat is available and so the flow rate must be increased to utilize the available heat until the temperature remains constant. If the solar radiation is low, then the output temperatures decreases and so the flow rate must be decreased in order to maintain the constant temperature. The control system diagram is shown in Fig. 10

Control Limits are:

- 1) High temperature limit: 90 ° C
- 2) Low temperature limit: 80 ° C
- 3) High level limit: 0.32 litres
- 4) Low level limit: 0.14 litres

The automatic control system was programmed in LabVIEW for the specified temperature limits (90°C and 80°C) and the simulation was performed. The panel diagrams of temperature control are shown in Figs. 11 (a) and (b).

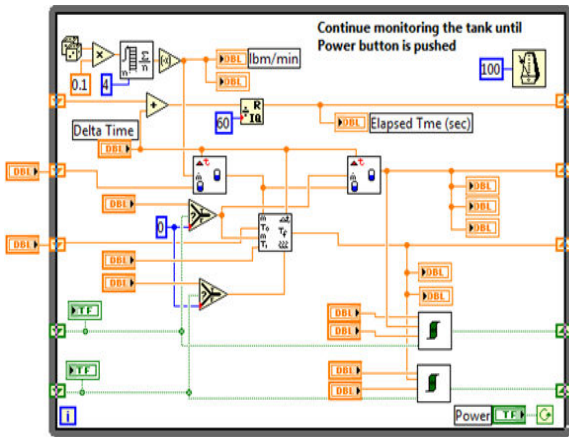


Fig. 10 Temperature Control System Diagram

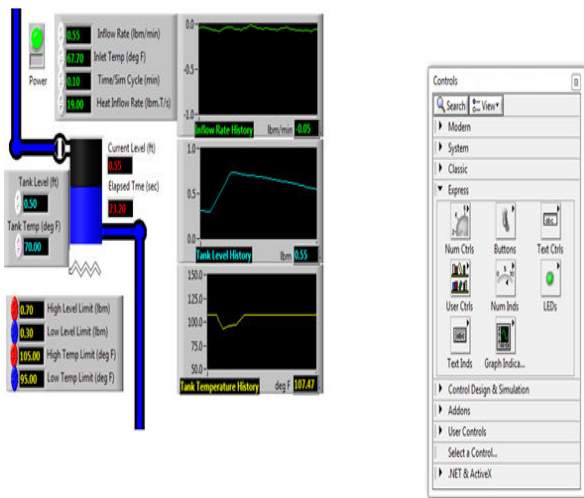


Fig. 11 (a) When temperature varies

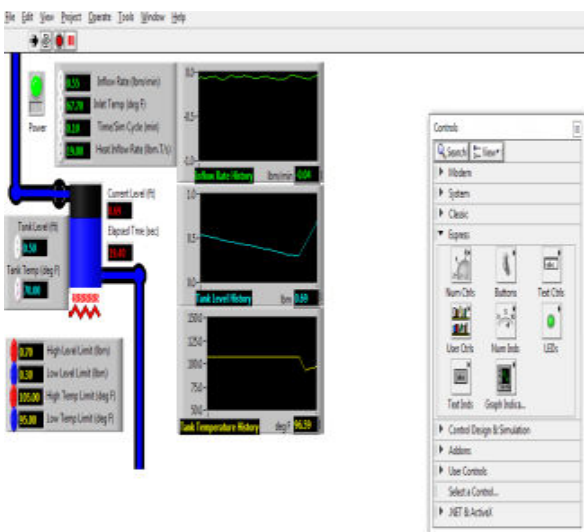


Fig. 11 (b) For constant temperature

that the water temperature is outside the set value. Hence, the pulses are generated for the stepper motor as shown below, thereby opening the valve for flow of water.

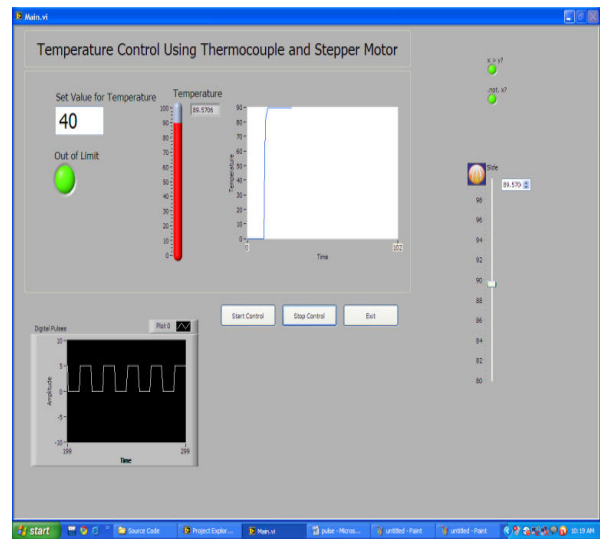


Fig. 12 Panel Diagram during execution of Automatic Control

- Manual mode: The opening /closing of the valve can also be controlled manually using LabVIEW and stepper motor. The valve is connected to the rotor part of stepper motor. We must enter the number of steps or rotation the valve takes for opening/closing in LabVIEW. Based on this, the software will generate pulses for the stepper motor for the desired level of opening/closing. Therefore, we can control the valve opening/closing which in turn controls the mass flow rate and total output of the solar desalination system. Fig. 13 (a) shows the provision for entry of the desired number of valve rotations for manual control and Fig. 13 (b) shows the manual control front panel diagram during execution.

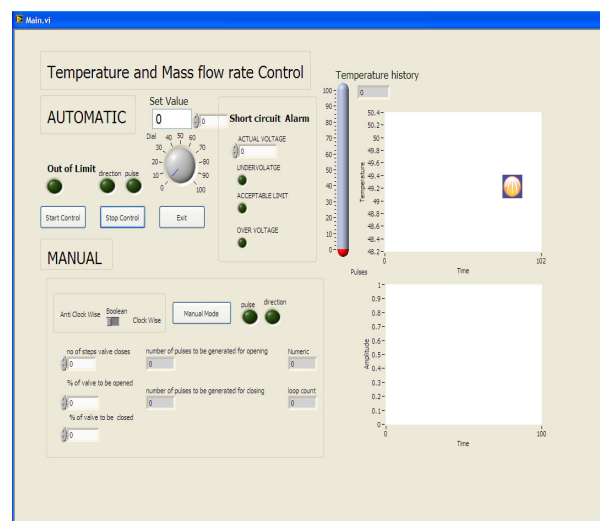


Fig. 13 (a) Provision for manual entry of number of steps

Fig. 12 shows the front panel diagram during execution. Here, the temperature value is set as 40°C. However, the water temperature is around 90°C. The green light glows indicating

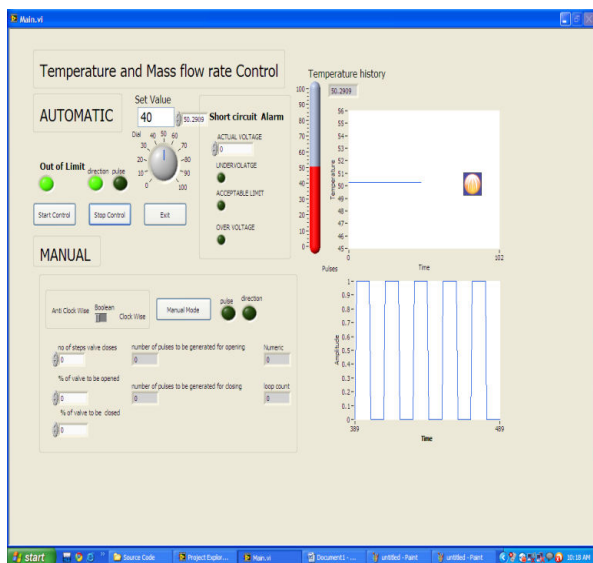


Fig. 13 (b) Front Panel Diagram during execution of Manual Control

IV. DESIGN AND SIMULATION OF SOLAR TRACKING SYSTEM FOR THERMAL COLLECTORS

Since the sun moves across the sky, in order to receive the best angle of exposure to sunlight for collection energy, a tracking mechanism is often incorporated into the solar arrays to keep the array pointed towards the sun. Here, the tracking mechanism is used for solar collectors [10] to utilize the naturally available solar radiation more efficiently and effectively so that output of the solar collectors can be increased with respect to solar radiation [2].

A. Proposed Solar Tracking Mechanism

The control system utilizes LDR sensors, Stepper motor and driver circuit, Data acquisition Card and LabVIEW Software. LDR sensors are placed exactly at the centre of the solar collector and their output depends upon the intensity of light falling on it. The layout of solar tracking system is given in Fig. 14.

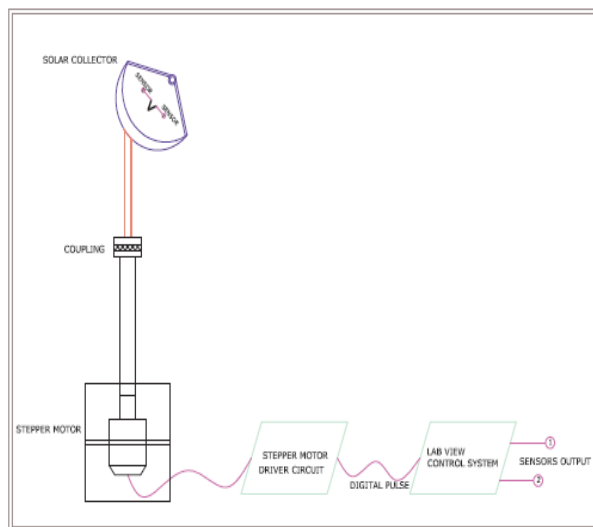


Fig. 14 Layout of Solar Tracking System

The tracking system is accomplished according to the following conditions.

- 1) When the sensors are getting the same amount of sunlight, it means that collector is perpendicular to the sun and so tracking system never operates.
- 2) After sometime as sun moves, the sensors will get the difference in their incident solar radiation. The differences between the outputs of the sensors are monitored and if the difference is positive the motor will rotate in clockwise direction until the difference between the sensors output is zero.
- 3) But if the difference between the sensors output is negative then the motor will rotate in anti-clockwise direction to make the position of collector in perpendicular with the sun.

Thus, the solar collector is adjusted according to variation of solar radiation and the utilization of solar energy increases so that the overall efficiency of solar desalination system increases. A program for solar tracking has been written in LabVIEW and simulations were performed. The results of simulation are given in Figs. 15 (a) and (b).

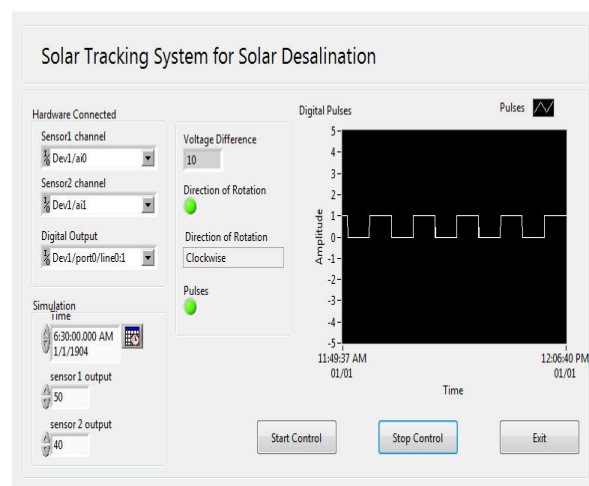


Fig. 15 (a) Front Panel Diagram for Positive Voltage Difference

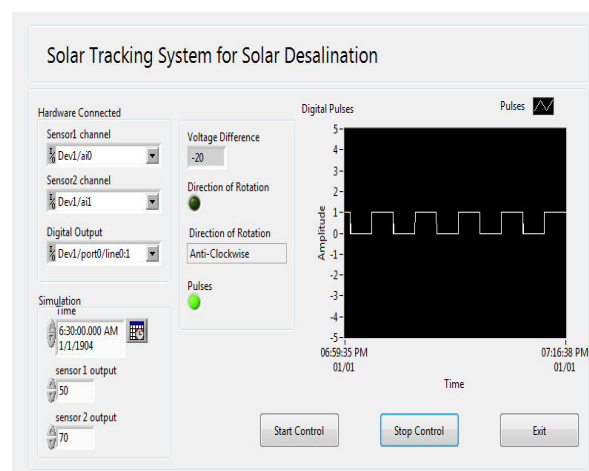


Fig. 15 (b) Front Panel Diagram for Negative Voltage Difference

The output from the two sensors is monitored by LabVIEW software and the difference between the outputs is visible in the front panel as shown above. Based on the difference, the pulses will be generated and direction for the stepper motor to rotate is also decided by the LabVIEW. The digital pulse will move to the driver of the stepper motor which controls the operation of the stepper motor.

V. CONCLUSION

Solar desalination offers a promising prospect for covering the fundamental needs of water in remote regions, where the water scarcity is severe. A new scheme for solar desalination has been proposed in all areas, to meet the water requirements. The plant is proposed in such a way that there are neither emissions nor other environmental hazards. Hence, the power requirements for the operation of the plant have been decided to be obtained from photovoltaic modules. The power conversion from PV modules is performed by single phase inverters. In order to reduce the harmonic distortion and to boost the output voltage, filters and choppers have been designed. The output voltage and current waveforms have been analyzed and the harmonic distortion levels have been reduced consecutively. The output of the solar desalination plant is being maintained at an optimum level by means of the proposed temperature and mass flow control system. Programs have been written in LabVIEW and the simulation results were obtained. The tracking system for collectors has been proposed using LabVIEW and simulations have been performed.

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