DEVELOPMENT OF CONTROL CIRCUIT FOR PARABOLIC DISH SOLAR WATER HEATER

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ABSTRACT

This research work focuses on the development of an electronic control circuit for the tracking mechanism of a solar water heater, and assessing the effectiveness of this control circuit by assessing the thermal performance of the heater. A 10-litre capacity parabolic dish solar water heater was designed and constructed for use in Kaduna. The heater was designed to heat water from ambient temperature up to 100 ^oC. For effective performance the heater had to track the sun, and an electronic control circuit using two light-dependent resistors was designed and developed for this purpose. The control circuit uses two modes of control, manual mode and automatic mode. Both modes of control use a Superjack, a widely used tracking device in the satellite dish industry. The manual mode uses two switches to track the sun at intervals of time and requires the physical presence of an operator to carry out the operation. Analysis of series of experimental results using the plant indicates that the overall thermal performance of the system under automatic mode is superior to the performance under the manual mode. Improved thermal efficiency of more than 2% and time reduction of about 4% were achieved with the automatic mode of control over the manual mode. These two advantages, together with another advantage that it does not require the physical presence of an operator to track the sun, make the automatic mode have more economic potentials than the manual mode.

KEYWORDS: *Development, control-circuit, parabolic-dish, solar, water-heater, light-dependent resistor (LDR)*

I. INTRODUCTION

Solar concentrators are optical devices which increase the amount of incident energy on the absorber surface as compared to that on the concentrator aperture. The increase is achieved by the use of reflecting or refracting surfaces which concentrate the incident radiation onto a suitable absorber. A solar concentrator generally consists mainly of (i) a focusing device (ii) an absorber provided with or without a transparent cover, and (iii) a tracking device. Solar concentrators are used for thermal as well as photovoltaic conversion of solar energy. Solar concentrators have the following advantages [1].

1. Reduced losses due to reduced heat loss area.
2. Higher delivery temperatures resulting in better thermodynamic efficiency
3. Storing heat at higher temperatures results in reducing the storage cost
4. Reduced cost due to less material requirement compared to flat plate solar collector systems.

Concentration of radiation by optical means is possible only if the projected solid angle of the radiation is increased [2]. This requirement is the direct consequence of the law of the etendue, which is the phase space of radiation [3]. Solar concentrators which achieve high concentration must track the sun, that is continuously reorient, in order to compensate for the apparent movement of the sun in an earth centred coordinate system. Such concentrators can achieve very high concentrations of about 45000 in air [4]. Even higher concentrations have been achieved inside transparent media [5], [6].

A variety of tracking mechanisms have been designed for this purpose, either the reflector or the absorber or both may be moved. The motions required to accomplish tracking vary with the design of the optical system and a particular resultant motion may be accomplished by more than one system of component motions.

For surfaces of revolution systems such as parabolic dishes, orientation is complex because the arrangement must be such that the vertex, focus and the sun should remain in a line. Angle of incidence beam radiation determines the amount of energy collection on such a focusing collector system. Energy collection is maximum if it is oriented in such a manner that the surface normal at the centre coincides with solar beam all the time. This will be possible only with the continuous tracking of the sun about two perpendicular axes. Energy collection will be minimum if no tracking is done. Further classification of orientation systems may be made on the basis of manual and mechanised operations [7], [8].

1. *Manual systems*: In this type of operation, tracking of the sun is dependent upon the observation and skill of the operator and is adequate if concentration ratios are not so high. Such a system is obviously out of consideration in industrialised or developing economies.

2. *Mechanised systems*: the mechanised orienting system can be divided into (a) sun seeking systems and (b) programmed systems.

(a) *Sun seeking systems* use detectors to determine system misalignment and, through controls, make necessary corrections.

(b) *Programmed systems* make use of special computer programs to track the sun on a predetermined path and, therefore, needs only occasional checks. Zimmerman reviewed a number of such sun-seeking computer programs and evaluated their accuracy [9]. Some of the programs are applicable to small computers and hand-held programmable calculators [10].

Closed-loop types of sun-tracking systems are based on feedback control principles. In these systems, a number of inputs are transferred to a controller from sensors which detect relevant parameters induced by the sun, manipulated in the controller and then yield outputs. In 1998, Khalifa and Al-Mutawalli [11] developed a two-axis sun tracking system to enhance the thermal performance of a compound parabolic concentrator. The system was designed to track the sun's position every three to four minutes in the horizontal plane and every four to five minutes in the vertical plane. Brown and Stone [12] developed a tracking system for solar concentrators in which a neural network was applied to an error model in order to compensate for tracking errors. The test data showed that the resulting system was capable of reducing the tracking error to a value of less than 0.01^o. Kalogirou [13] presented a one-axis sun tracking system utilizing three light-dependent resistors (LDRs). The first LDR detected the focus state of the collector, while the second and third LDRs were designed to establish the presence (or absence) of cloud cover and to discriminate between day and night, respectively. The output signals from the three LDRs were fed to an electronic control system which actuated a low-speed 12V DC motor in such a way as to rotate the collector such that it remained pointed toward the sun. Arasu and Somakumar [14] also designed and developed an electronic embedded system to control a one-axis solar tracking parabolic trough collector for hot water generation. The electronic control circuit determined the position of the sun using LDRs, with an accuracy of 0.1^o. The tracking mechanism's maximum error was found to be 0.18^o, and the overall performance of the system was found to be satisfactory. A twenty-year review on solar tracking system designs and models assessing the performance of specific solar energy systems is presented by Lee et al [15].

Solar tracking is technically demanding because solar collectors are commonly fairly large, and designing these systems for orientational mobility may add significantly to their cost. A combination of manual and mechanised arrangement may be best and most economical.

II. RESEARCH METHODOLOGY

The methods adopted in undertaking the research include a review of existing literature on solar concentrators and their tracking systems, description of the experimental setup, development of the electronic control circuit, experimental investigation of the behaviour of the solar water heater in manual and automatic modes of control, results obtained, their analysis, and research findings.

III. System Description

A 10-litre capacity parabolic dish solar water heater was designed and constructed for use in Kaduna. The heater was designed to heat water from ambient temperature up to 100 ^oC. The aperture diameter of the dish is 167 cm and the focal length is 57.9 cm from the vertex. The surface of the dish is covered with small glass mirrors of dimension 7 cm length × 4.5 cm width × 2 mm thick. The shape of the absorber is cylindrical and is made from aluminium sheet. The external diameter of the absorber is 23.8 cm and the height is also 23.8 cm. The designed concentration ratio of the plant is 10. For effective performance the heater has to track the sun continuously [16], and a Superjack (linear actuator) is adopted for this purpose. The Superjack consists of a hydraulic arm, and an electric motor. The hydraulic arm of the Superjack consists of two cylinders, one fitted into the other in a telescopic manner as shown in Fig.1. The diameter of the inner cylinder is 14cm and its length is approximately 30cm. When fully extended the total length of the two cylinders is approximately 95.5cm. The elongation and contraction of the inner cylinder within the outer cylinder gives the dish its movement from east to west. The outer surface of the inner cylinder and the inner surface of the outer cylinder are separated by an extremely thin film of lubricating oil, which make the relative movement of the two cylinders smooth. An oil seal provided at the top end of the outer cylinder prevents the lubricating oil from leaking outside. The Superjack is connected to the body of the parabolic dish through a hole on a piece of metal at the top of the inner cylinder. The hydraulic arm is controlled by a 12-36V motor fitted at one end of the outer cylinder. Electric current is supplied to the motor by a 12 volt, 12AH rechargeable dry cell of trade mark GASTON model MH19926.

Initially, the control circuit of the parabolic dish was adopted from a *positioner*, a widely used device in the satellite dish industry for adjusting the orientation of dishes to receive good TV signals. The *positioner* uses manual mode of control only, because it is only being used once in a while to adjust the direction of the dish. This was found to be unsatisfactory for the control of the solar dish where continuous tracking of the sun is required.

IV. Development of Electronic Control Circuit for the Tracking Mechanism

The original control circuit of the *positioner* used two switches to control the movement of the dish. One of the switches turned the dish in clockwise direction while the other one turned it anticlockwise. It required the physical presence of the operator to carry out these operations. To eliminate this requirement, a new circuit using solar photo-sensors was developed. The new circuit has two control switches, just like the *positioner*, and at the same time, introduced a third switch for the automatic control of the dish using the solar photo-sensors. This is shown in Fig.2. Thus when the switch is in the automatic position, the control of the dish is automatic, using the two solar sensors while when the switch is turned to the manual mode, the control of the dish is manual, using the two switches. The two photo-sensors of the control system are attached to two sides of an equilateral triangle stand. Each of the sensors is attached to one side of the triangle, facing directions opposite to each other. During operation, the entire unit is placed at the aperture of the dish to receive direct sunlight which then triggers the control mechanism of the Superjack.

The solar tracking system circuit diagram shown in Fig.3 has two relays, which are interconnected such that the motor which is mechanically coupled to the jack system could push up or pull down the dish attached to it. The operation of the motor (d.c motor) depends on the polarity of the supply [14], [17]. Thus, reversing the polarity of the supply to the d.c motor reverses the direction of the drive (rotation).

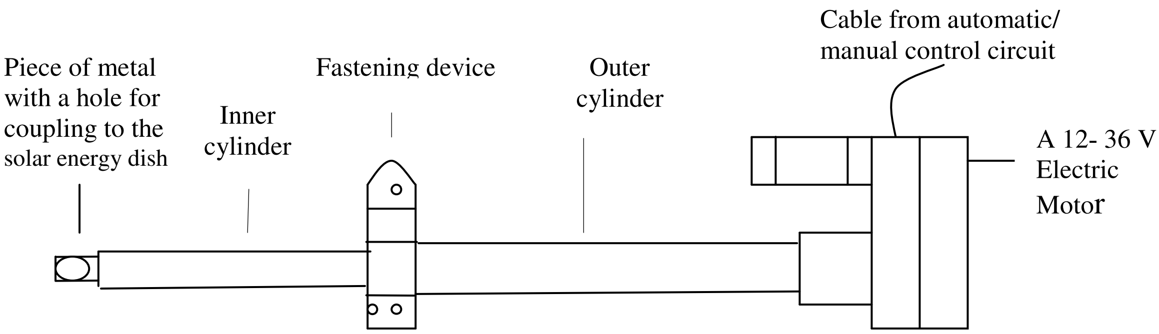

Figure 1: Front view of superjack for the control of the solar water heater

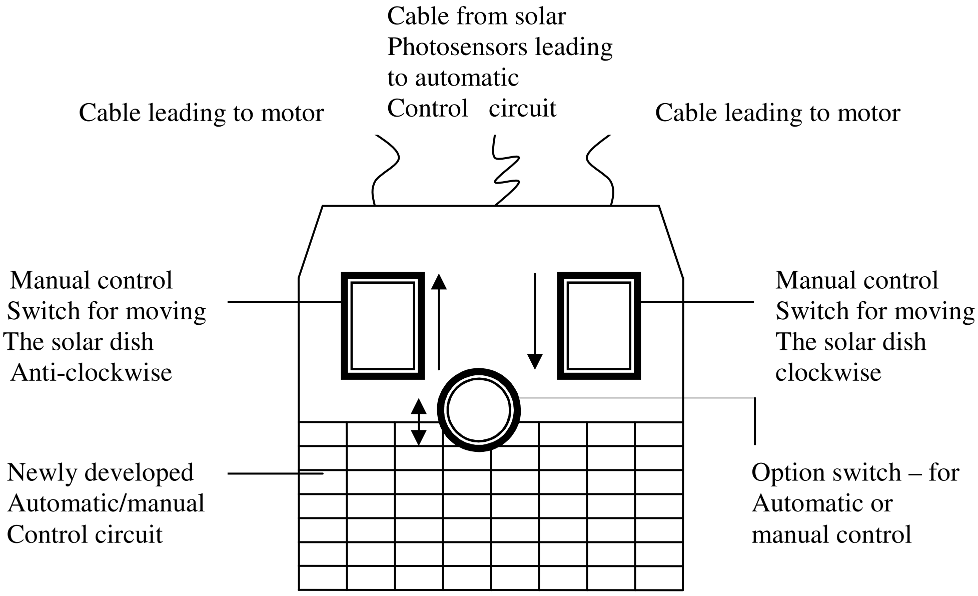

Figure 2: Sketch of automatic/ manual control switch for moving the solar energy dish clockwise or anti-clockwise

The polarity of the supply is here controlled by the activations of the relays RLy_1 and Rly_2, such that only one of the relays could be activated at any point in time, based on the design of the window comparator circuit controlling it.

The window comparator circuit is an electronically designed system which operates by comparing the signals available at two (window) inputs. In this design the circuit is based on the use of the light dependent resistors (LDR_1 and LDR_2) which are semiconductor devices sensitive to light variation, and produce an inverse proportional change in resistance as the light intensity varies [18].

The fact that there exist a simple law (ohm's law): that the voltage drop, V, across a resistor, is directly proportional to the resistance, R, and from the operational characteristic of the LDR's, the design of this window comparator is aimed at ensuring that as the light intensity increases in a particular direction, the resistance of the LDR placed in that direction decreases. Thus in the reverse direction the resistance will increase, hence leading to a decrease and an increase in voltage in the two directions respectively, based on the ohm's law:

$$V=IR \quad \text{or} \quad \frac{V}{R}=I \tag{1}$$

The operational amplifiers commonly referred to as OP amps are devices which could be used to compare two signals and to produce an output of 1 or 0, true or false, ON or OFF, etc depending on which signal is being compared with the other (reference). It comes with a dual input, known as the inverting (-ve) and the non-inverting input (+ve). The operation is such that when the positive input (+ve) is greater than the negative input (-ve) the output goes high, while when the –ve is greater then the +ve the output goes low. Using this device requires that there must always be a reference point (level), and in this work the reference is provided using a potential divider method, as shown in Fig 3 using R_1, R_2 and R_3. The reason for using voltage dividers is to ensure that the reference voltages are independent of the variation in the light intensity. Hence the comparator IC_1, compares the voltage at its reference terminal provided by R_1 and R_2 with the window signal (voltage) provided by LDR_1, and switch its output to a high only when the voltage
at LDR_1 (+ve) is higher than that provided by R_1 and R_2 (-ve). This, in turn, activates the

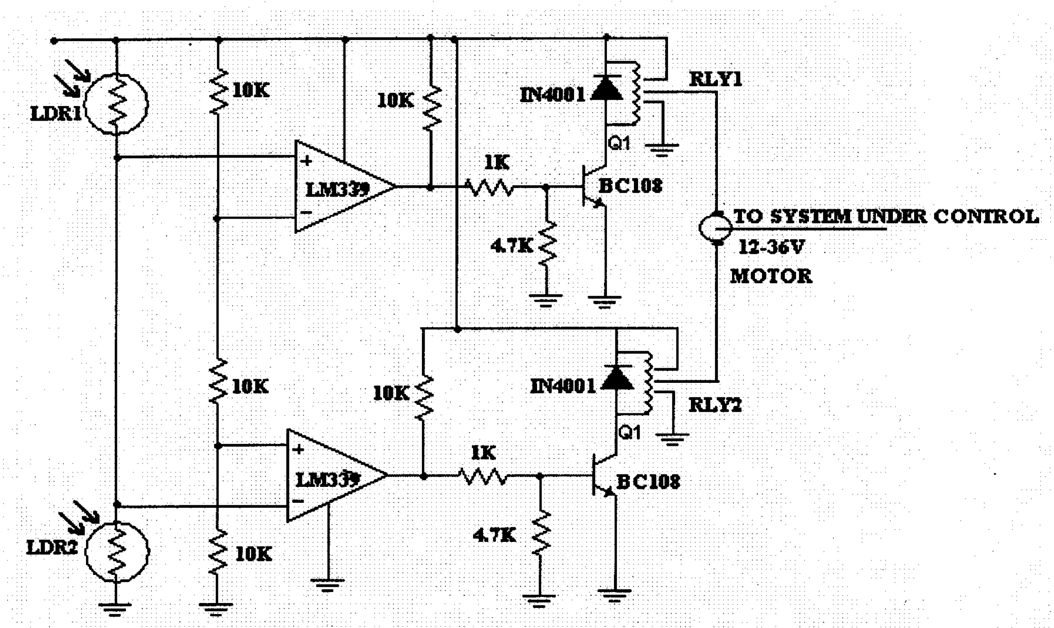

Figure 3: Circuit diagram for the automatic control of the parabolic dish solar water heater

Relay 1 via T_1, while Relay 2 is similarly triggered via T_2 based on a similar operation by IC_2, with a reference obtained at R_2, R_3 and window signal coming from LDR_2.
The operational amplifier used in this work LM339 is an open collector type and requires that a pull up resistor be applied, for the output of such device to effectively switch to its high state (ibid). Hence the resistors R_4 and R_5 were introduced to handle this.
Output produced by the operational amplifier is used to switch on the relays via a transistor as a switch. A transistor is simply a semiconductor with three terminal PN junction devices capable of operating as a switch or as an amplifier. When used as a switch it requires that a simple voltage above the base, emitter junction voltage (V_b) be applied. Hence to ensure that the transistor operates as a switch which allows only a sufficient current to flow through the collector 'IC', the base current I_B must be controlled [19] so that :

$$I_C = \beta I_B \text{ and } I_B = \frac{V - V_b}{R_b}. \tag{2}$$

Thus a base resistance, R_b, is required to allow for safe operation. However, a pull down resistance is also required to ensure that the transistor is completely cut off (switched off) when the output of the operational amplifier is switched low, and this is provided using R_6 and R_7 as shown in Fig. 3.

A relay coil, though seen as an electromechanical switch which has a common, normally closed (N_C) and a normally open (N_O) terminals, requires that it must be powered. Being inductive it also obeys the law of induction, storing charges and producing reverse current when switched off, and this requires that a free wheeling diode be used to handle this, and hence prevent the reversed current from flowing through the transistors [20]. The relays as earlier stated are interconnected such that the N_O are connected to the +ve (positive supply) while their N_C are connected to the –ve (ground supply), so that when activated as a result of sun rays falling on any of the LDR, a power supply to the motor will drive the load (dish) in the direction of higher intensity.

This method as applied here provides the window to see using the LDRs, and to track using the motor drive, and allows for threshold (difference of intensity) to be chosen by varying the variable resistor R_2.

V. EXPERIMENTS AND RESULTS

Monthly series of experiments were carried out using the parabolic dish solar water heater (as shown in Fig.4) which consists of the concentrator, the absorber, the tracking device (Superjack), the vertical support, and the base support mounted on wheels. The wheels make the base support (and hence the entire dish system) mobile and allowed it to make a complete turn (360^o) on the ground. Thus, seasonal tracking of the sun was carried out by rotating the dish system in the right direction. The experiments were carried out with the aid of a compass, thermometer, solarimeter, and a stopwatch. The whole assembled plant was pushed into open space and the dish turned away from the direction of the sun. The compass was used to align the base of the plant so that it gave the dish a N-S horizontal axis E-W tracking. The thermometer was inserted in the absorber through a hole on the cover of the absorber. The initial temperature, T_{w1}, of the water in the absorber (10 litres) was then noted. The dish was then turned in the direction of the sun by the arm of the Super jack until maximum beam radiation intensity was received by the absorber. Almost at the same time the stopwatch was started, to record time, *t*. For the *manual mode* of control of the plant, the position of the dish was adjusted, at an interval of about 12 minutes, to keep track of the sun and to maintain maximum radiation intensity on the absorber. This was done manually using the two switches provided (one for clockwise, the other for anticlockwise movements). For the *automatic mode* of control of the plant, the position of the dish was adjusted automatically using the solar radiation sensors, to keep track of the sun and to maintain maximum radiation intensity on the absorber

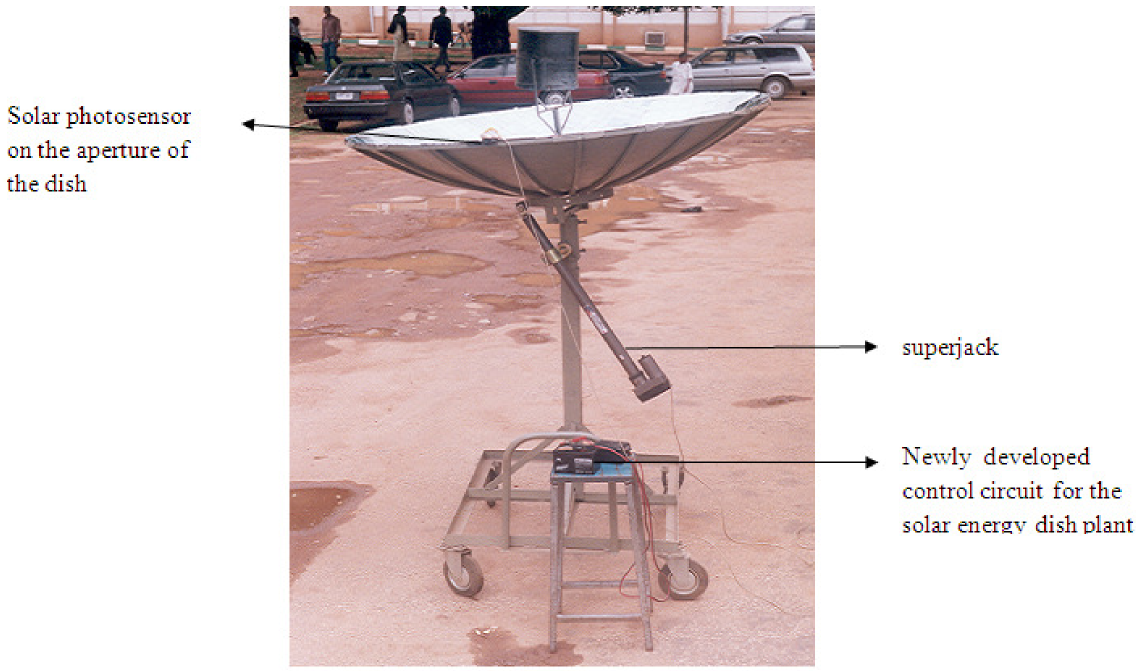

Figure 4: side photograph of the parabolic dish solar water heater

Readings of the radiation intensity, I_b, of the sun on the solarimeter were taken at intervals, as the sun was heating the water in the absorber. Final temperature, T_{w2}, of water was noted when the water almost reached the boiling point. Final reading of the solarimeter was noted and the average value determined. Stopwatch was stopped and the time recorded. The results of the experiments are summarised in Table 1, and are graphically shown in Figs. 5 and 6. The thermal efficiency η is given as [21]:

$$\eta = \frac{\rho_w V_w c_{pw} (T_{w2} - T_{w1})}{I_b A_a t} \times 100 \tag{3}$$

where:
ρ_w – density of water
V_w - volume of water
c_{pw} – specific heat capacity at constant pressure of water
A_a – aperture area

Table 1: Summary of Results of Experiments with the Parabolic Dish Solar Water Heater

Exp	T_{w1} (°C)	T_{w2} (°C)	I_b (W/m^2)	Manual			Automatic			% red. of time
				Month	*t* (min.)	η (%)	Month	*t*(min.)	η (%)	
1	25	100	600	Sep 2007	77	51.6	Nov 2007	74	53.7	3.90
2	26	100	620	Jul 2007	75	50.5	Oct 2007	72	52.6	4.00
3	26	100	650	Oct 2007	66	54.8	Aug 2007	65	55.6	1.52
4	27	100	580	Dec 2007	76	52.6	Nov 2007	75	53.3	1.32
5	27	100	700	Sep 2007	62	53.4	Aug 2007	60	55.2	3.23
6	28	100	670	Sep 2007	64	53.3	Dec 2007	62	55.0	3.13

VI. ANALYSIS OF RESULTS

The analysis is done by comparing the thermal performance of the solar energy plant under *manual mode* of control to the performance under *automatic mode* (Table 1). The variable parameters which affect the thermal efficiency of the system are the initial temperature of the water (T_{w1}) the solar radiation intensity (I_b), and the time taken (*t*). The fixed variables are the volume of water (10 litres) and the final temperature of water (T_{w2}= 100° C). To make comparison on equal basis between the two modes of control, it is necessary that the system operate on the same basis of equal initial temperature of water and the solar radiation intensity. Due to the intermittent and uncontrollable nature of solar energy radiation, it was not possible to design outdoor experiments such that the two modes of control will have the same value of T_{w1} and I_b at a time. Instead, series of experiments for the two modes were carried out over a relatively long period of time (six months) and the values of T_{w1}, I_b, *t*,, and the months were recorded. Experiments for *manual* and *automatic* controls whose values of T_{w1} and I_b accidentally matched each other were then compared for evaluation of their thermal performance. Thus it will be seen from Table 1 that each set of experiments has the same value of T_{w1}, T_{w2}, and I_b for the two modes of control. What vary are the month, time, and the thermal efficiency (η). The values of I_b shown in the table only represent the mean values during the period of operation of the water heater and, therefore, do not represent the mean values for the possible sunshine hours of the representative day of the month.

For set of Experiments 1, both *manual* and *automatic* modes have the same values of T_{w1}= 25° C, T_{w2}= 100° C, and I_b= 600 W/m^2. For the manual mode, the efficiency is 51.6% while for the automatic mode the efficiency is 53.7%. There is an efficiency difference of 2.1% in favour of the automatic mode. The time taken by the manual mode is 77 minutes while the time for the automatic mode is 74 minutes. There is a difference of 3 minutes in favour of the automatic mode of control. The percentage reduction of time gained by the automatic mode of control over the manual mode is 3.90%. Similar trend of improved efficiency (Fig. 5) and time reduction (Fig.6) by the automatic mode compared to the manual mode is exhibited in the remaining Experiments 2 – 6. The highest efficiency recorded for the automatic mode is 55.6%, while the corresponding and also the highest efficiency for the manual mode is 54.8%. The lowest efficiency for the automatic mode is 52.6% which, also, corresponds to the lowest efficiency of 50.5% for the manual mode. The highest percentage reduction of time is 4.00% which occur at the lowest efficiencies.

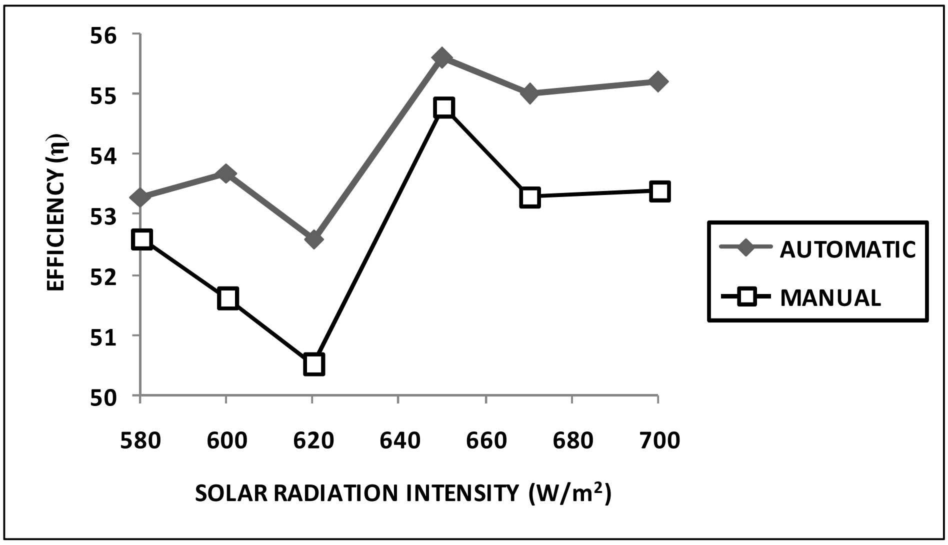

Figure 5: Variation of efficiency with solar radiation intensity

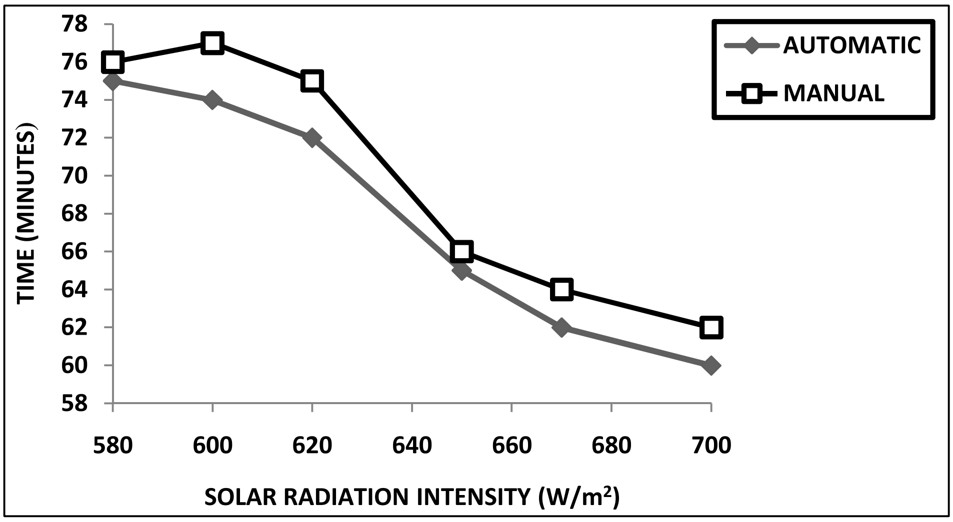

Figure 6: Variation of time with solar radiation Intensity

VII. RESEARCH FINDINGS

What the results demonstrate is that the overall performance of the automatic mode of control is better than the manual mode. This is because the tracking of the sun in the automatic mode is instantaneous and continuous, whereas in the manual mode, tracking of the sun is at intervals of time. Hence, the automatic mode has higher ability to maintain maximum solar radiation intensity on the absorber compared to the manual mode. This superiority is manifested in improved efficiency and time reduction of the overall energy conversion system.

VIII. CONCLUSION

From the results and their analysis, it is clear that the overall performance of the parabolic dish solar water heater under automatic mode of control is superior to the performance of the system under the manual mode. Improved thermal efficiency of more than 2% can be achieved with the incorporation of the automatic control using solar photo-sensors. Time reduction of about 4% can be achieved by the automatic mode over the manual mode. The manual mode requires the physical presence of an operator to carry out the tracking operation. This has the tendency to increase the total cost of labour and, hence, increase in the overall cost of operating the plant. This inconvenience is eliminated in the automatic mode. The automatic mode, therefore, has the potential to make substantial economic gains over the manual mode.

REFERENCES

[1]. Marthur S.S. and Kandpal T.C. (1984) "Solar Concentrators". *Reviews of Renewable Energy Sources*, vol.2. Wiley Eastern Ltd., New Delhi.
[2]. Ries H. (1982) "Thermodynamic Limitations of the Concentration of Electromagnetic Radiation". *J. Opt. Soc. Am* **72**, 380 – 385.
[3]. Welford W.T. and Winston R. (1989) *High Collection NonImaging Optics*. Academic Press, New York.
[4]. Spirkl W., Ries H., Muschawock J., and Winston R. (1998) "Nontracking Solar Concentrators". *Solar Energy*, Vol. 62, No. 2, 113-120.
[5]. Cooke D., Gleckman P., Krebs H., Sagie D., and Winston R. (1990) "Sunlight Brighter than the Sun". *Nature* **346**, 802.
[6]. Jenkins D., Winston R., Bliss J., O' Gallagher J., Lewandowski A. And Bingham C. (1996) "Solar Concentration of 50000 Achieved with Output Power Approaching 1 kW". *J. Sol Energy Engg Trans* ASME **118**, 141 – 145.
[7]. Rai G.D. (2005) *Solar Energy Utilisation*. 5th edn. Khanna publishers, Delhi, India.
[8]. Magal B.S. (1993) *Solar Power Engineering*. Tata McGraw Hill Publishing Company Limited, New Delhi.
[9]. Zimmerman J.C. (1981) "Sun Pointing Programs and their Accuracy". Sandia National Laboratories, Report SAND81 – 0761, September.
[10]. Stine W.B. and Harrigan R.W. (1985) *Solar Energy Fundamentals and Design*. John Wiley and Sons Inc., New York.
[11]. Khalifa A.N., Al-Mutawalli S.S. (1998) "Effect of two-axis sun tracking on the performance of compound parabolic concentrators". *Energy. Convers. Manage.* **39**, 1073-1079.
[12]. Brown, D.G.; Stone, K.W. (1993} "High accuracy/low cost tracking system for solar concentrators using a neural network". In *Proceedings of the 28th Intersociety Energy Conversion Engineering Conference*, Atlanta, GA, USA, Aug. 8-13.
[13]. Kalogirou, S.A. (1996) "Design and construction of a one-axis sun-tracking system". *Solar Energy*, **57**, 465-469.
[14]. Arasu A. V. and Sornakumar T. (2007) "Design, Development and Performance Studies of Embedded Electronic Controlled One Axis Solar Tracking System". *Asian Journal of Control,* Vol. 9, No. 2. 163-169.
[15]. Lee C.Y., Chou P.C., Chiang C.M., and Lin C.F. (2009) "Sun Tracking Systems: A Review". *Sensors*, **9**, 3875-3890.
[16]. Rai G.D. (2006) *Non-Conventional Energy Sources*, 4th edn. Khanna publishers, Delhi, India.
[17]. Tudorache T. and Kreindler L. (2010) "Design of a Solar Tracker System for PV Power Plant". *Acta Polytechnica Hungarica*, Vol. 7, No. 1.
[18]. Bolyestad R.L. and Nashelsky L.R. (2002) *Electronic Devices and Circuit Theory*, 8th edn. Pearson Education Inc., Delhi, India.
[19]. Evans L.P. and Long E.W. (1974) *Electronic Principles and Circuits – An Introduction to Electronics for the Technician.* John Wiley and Sons Inc., Canada.
[20]. Senturia D.S. and Wedlock D.B. (1975). *Electronic Circuits and Applications.* Wiley International Edition, John Wiley & Sons. Inc. Canada.
[21]. Mohammed I.L. (2009) "Development and Performance Analysis of a Solar Tracking Parabolic Collector". PhD Thesis, Bayero University Kano, Nigeria, 184 pp.

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