Romanian Reports in Physics, Vol. 59, No. 1, P. 101–111, 2007

PHYSICAL METHODS AND INSTRUMENTATION

ELECTRONIC CONTROL CIRCUIT FOR SOLAR BATTERY CHARGING

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(Received March 4, 2005)

Abstract. An electronic circuit is designed, built and tested. The circuit acts as a control circuit to regulate the process of photovoltaic solar panel battery charging process. The circuit is cheep and can be easily constructed from discrete electronic components. The circuit operation is based on matching the solar cell terminal load voltage to the appropriate number of battery cell units to be charged depending on the solar light intensity condition. Experimental results indicate that there is an increase of the overall charging current using the circuit over that using direct charging. Increase in the charge collection efficiency of the about of 10% is experimentally established.

Key words: control electric circuit, solar battery, charging.

INTRODUCTION

Enhanced interest in solar energy utilization was prompted after the world energy crisis associated with the 1973 Middle East war. This interest was further fueled by world apprehensions concerned with nuclear wastes and nuclear safety on one hand and green house gases and global warming on the other [1]. Apart from some unsystematic results concerning cold electrolytic nuclear fusion [2], nuclear fusion energy proper, still seems along way off. These considerations make solar energy the ultimate strategic choice as a source of world energy.

As a result of current day satellite technology, designers now have a more or less clear picture about solar energy intensity distribution world wide [3]. Solar energy research emphases over the past three decades were concentrated on two main aspects of this subject. The first is concerned with solar energy direct heat production. The second is involved with solar energy electricity production. The later involves research into many aspects of solar to electric power production processes. These processes are related to a wide spectrum of physics, chemistry and engineering disciplines. Much effort has been put on attempting to increase solar panel conversion efficiencies. Encouraging results have been obtained. However, and after thirty years, conversion efficiencies of about 20% are not up to the initial expectations on one hand and below economic considerations needed to make solar power an economically competitive source compared with conventional energy sources on the other hand [4].

Results from extensive researches in Storage batteries technology so far, fall short from producing new generations of practical electrical storage batteries which have a better (charge/Weight.cost) ratio than those of the good old lead acid battery or the nickel- cadmium battery.

Working on the assumption that we have a particular solar cell with some fixed conversion efficiency, we are concerned with the optimum conditions for extracting the maximum amount of electric charge from the panel that can be stored in the battery. Some works have been sited in literature concerning this mater [5, 6].

It is purpose of this work to introduce a relatively simple electronic control circuit that can automatically distribute the electric current produced by a photovoltaic solar panel in an optimum way to extract the maximum charging current at all times depending on the light intensity.

BASIC PRINCIPLE

For any particular solar cell panel, the open circuit voltage increases exponentially with the intensity of solar radiation, reaching a limiting value. The cell voltage will assume the value of the battery terminal voltage which is an approximately fixed quantity except for the case of a highly drained battery. It is common practice to design photovoltaic solar systems for battery charging with solar panel open circuit saturation voltage being 1.5 times the nominal emf of the battery to be charged. Even with such design, a good deal of sun energy under morning, after noon hours and cloudy weather may not be exploited properly due to the fact that the operating point will slip back into the exponential regions.

In order to gain more insight on the problem let us consider the simple equivalent circuit of the battery charging process shown in Fig. 1. The solar panel is represented by a voltage source E, an internal resistance r, and a diode D. When the electromotive force E exceeds that of the battery to be charged E_0, charging current i will flow

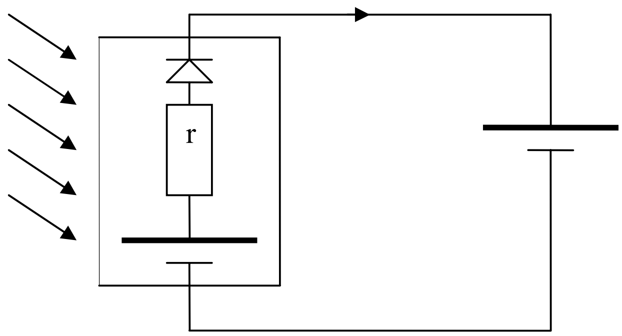

Fig. 1 – Solar charging equivalent circuit.

$$ir = E - E_0 . \tag{1}$$

The power stored in the battery will be $P = iE_0$. The solar panel internal resistance r is equal to the open circuit voltage E divided by the short circuit current I_0. For a typical solar panel, this current will be proportional to the radiation fallout ϕ. Thus, $I_0 = K\phi$, where K is a panel constant related to the charge conversion efficiency.

$$P = Ei - i^2 r . \tag{2}$$

For maximum power condition, we have

$$i = \frac{E}{2r} = \frac{I_0}{2} = \frac{K\phi}{2} . \tag{3}$$

For a particular fallout condition, it would be beneficial to try to adjust the charging current value in accordance with equation (3). The only way do this, is through the adjustment of the electromotive force of the battery being charged.

Let us assume that we have a solar panel that has been designed to charge a battery consisting of N cells each has an electromotive x under full radiation fallout condition. It is not unusual to make the electromotive for such panel equal to $(3/2)Nx$. We further assume that this panel is being used to charge a smaller number of series cells $n < N$.

The electromotive force solar fallout relation of a typical solar panel is usually of an exponential type. For such a case, equation (1) may be rewritten as

$$(\frac{3}{2})Nx(1 - e^{-K\phi}) - nx = ir , \tag{4}$$

where K is the conversion efficiency factor.

If one chooses to perform the charging process under maximum power condition, the current i will be that given by equation (3). If we further assume that the panel open circuit voltage is approximately equal to $\frac{3}{2}Nx(1-e^{-K\phi})$, equation (4) becomes

$$\frac{3}{2}Nx(1-e^{-K\phi})-nx=\frac{K\phi}{2}\frac{(\frac{3}{2})Nx(1-e^{-K\phi})}{K\phi}. \tag{5}$$

This gives

$$n=\frac{3N}{4}(1-e^{-K\phi}). \tag{6}$$

Equation (6) gives the number of unit cells that can be charged under maximum power condition as a function of the solar radiation fallout. Fig. 2 shows the optimum values of n plotted against ϕ for a typical solar panel of 10% conversion efficiency.

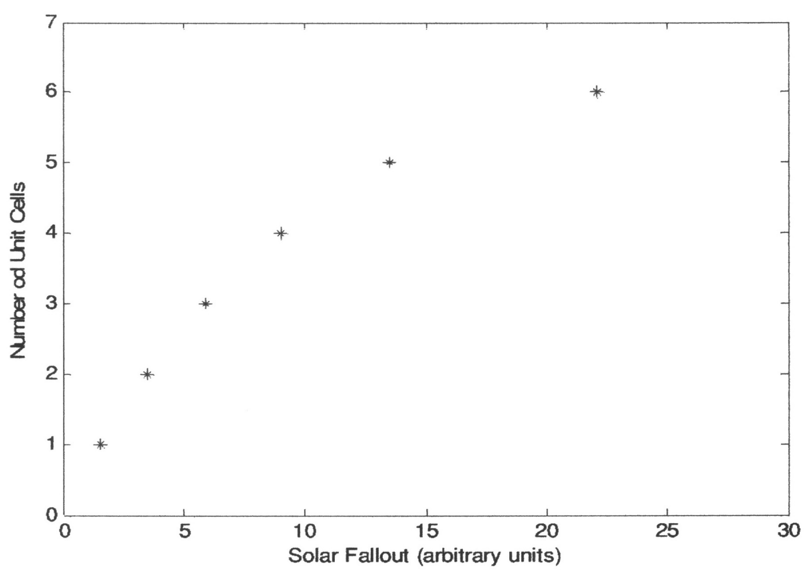

Fig. 2 – Number of optimum number of unit cells versus solar fall out.

One way to put the above argument into action is through the isolation of a certain number of unit cells from the battery, while charging only a proper number of series cells, in practice, such a process needs two things. The first continues monitoring of the solar panel electromotive force. The second is a reliable switching mechanism that can transfer the charging current to the appropriate number of series unit cells within the battery while excluding the remaining ones for the time being. For example and for 12V lead-acid battery consisting of 6 cells ×2V, the circuit and after monitoring the panel voltage, must direct the current to charge only the first cell when the solar panel voltage is between 2-4V. The charging current must be redirected to the series combination of the first and second cells for solar panel voltages fall in the range 4-6V, etc. If the monitored voltage is above 12V, the whole battery will be in a charging state. Finally and in order to avoid any over charging situation, the charging process must seize if the panel voltage exceed a certain limit 14.3V for example. A block diagram of such arrangement is shown in Fig. 3.

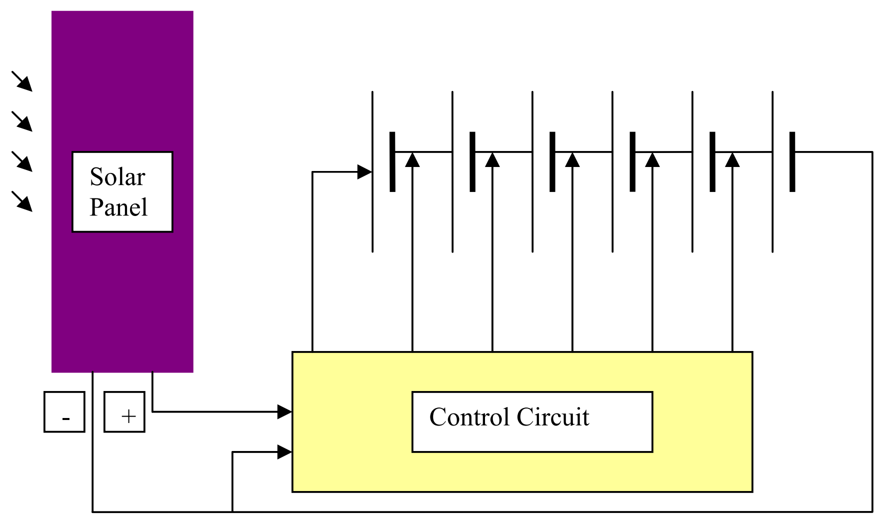

Fig. 3 – Block diagram of the controlled charging process.

The detailed circuit diagram of the control circuit and associated connections are shown in Fig. 4.The electronic circuit consists of six similar segments. Each segment comprises three transistors. All transistors can be of the general purpose type. The only constraint on these transistors is their power rating. The first transistor to the left can have a power rating as low as 0.1W. The second transistor must have a power rating of about 1W. The third transistor is a power transistor of the type 2N3055. Values of the zener voltages and the two resistors forming the potential divider to the zener are given Table 1 and 2 for Ni-Cd and lead acid batteries respectively. The base of the first transistor to the left is activated the zener diode. For low voltage values, the zener is in off mode. As the solar panel voltage starts to increase, zener current through the base of the PNP transistor will flow. Values of resistances connected to the two sides of the zener are chosen in conjunction with zener voltage such that the zener current is on when the solar panel voltage reaches 4V. At this point, the first transistor will switch to the on state. This will short circuit the second transistor biasing and results in bringing the second transistor and the third power transistor to the off mode. It may be worth mentioning that the second and third transistors are a Darlington pair and they can be replaced easily with a high gain Darlington transistor. Thus for solar panel voltage values between 2.2 – 4.4V, charging current will flow only through the first battery cell. No current flows through other cell because the cells voltages are all above the value of the solar panel voltage. As the solar panel voltage reaches the value of 4.4V, charging of the first cell is switched off and charging of the first and second cell series combination begins to take place through the second circuit. This process continues until the solar panel voltage reaches a value of 6.6V when the second circuit reaches its off condition. The process continues in the same way for all other cells. When the solar panel voltage becomes grater than 13.6V, the battery will be charging in the usual manner through circuit six. Circuit six can be set to switch off at any desired value to avoid over charging the battery. 14.3V is the custom value.

Table 1

Circuit values for 6.6 volt Nickel-Cadmium solar charging controller

Cut off voltage	Zener Voltage	R1 kΩ	R2 kΩ
1.3	1.2	1.0	1.0
2.6	3.3	120.0	1.0
3.9	3.3	1.2	2.2
5.2	5.1	2.2	2.0
6.5	6.2	2.2	2.0
7.8	6.8	1.2	2.2

Table 2

Circuit values for 12 volt lead acid battery solar charging controller

Cut off voltage	Zener Voltage	R1 kΩ	R2 kΩ
2.4	3.3	22.0	1.0
4.8	3.3	1.2	3.9
7.2	6.8	1.2	1.0
9.6	10.0	2.2	1.2
12.0	12.0	2.2	1.2
14.3	13.0	1.2	2.0

The circuit was designed using the WEWB electronic work bench simulation program. Resistances and zener voltage values were adjusted during the simulation process to get the desired out put switching off voltage for each circuit. Values obtained using the simulations are used to build the actual circuit. Further adjustments on the actual circuit were necessary to get the desired operating conditions. Two circuits were actually built. The first circuit was for charging a set of 6×1.1 series nickel- cadmium battery 1A·h battery. The second is for charging a 12V 60A·h lead acid car battery. This battery is of the uncovered all terminals type.

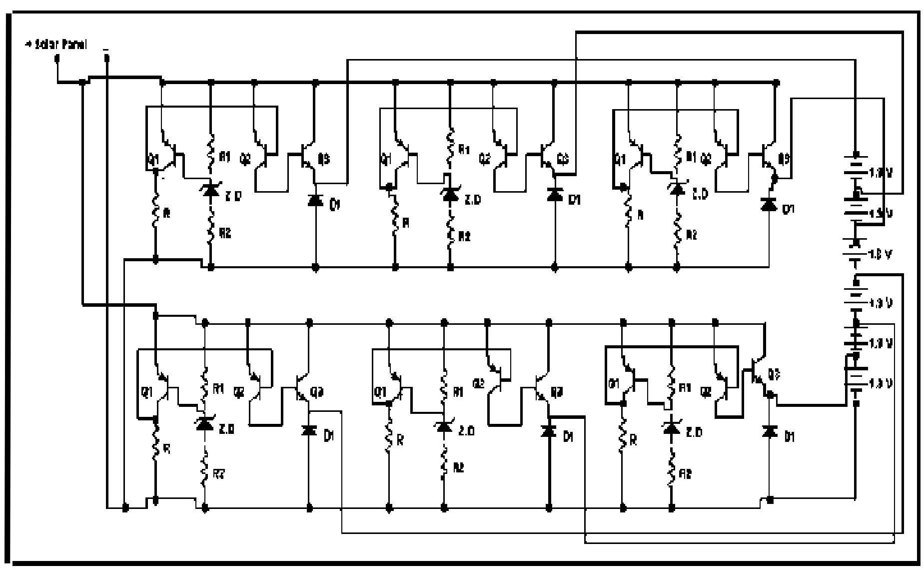

Fig. 4 – Schematic diagram of the positive current control circuit.

RESULTS AND DISCUSION

Two modules of the above circuit were constructed. The first one is for charging a set of six 1A·h nickel cadmium series battery. The over all voltage is 6.6V. The set of resistors and zener diode values are shown in Table 1. The second module is for charging a 12V 60A·h car battery consisting of 6 cells ×2V. The battery type chosen was one with accessible individual cells terminals to assist desired connections. The first module is connected to an 8V solar panel. A two way switch is used to make alternative connections of the solar panel to the nickel cadmium battery. The first connection is a direct connection. The second is through the control circuit. Alternative charging current reading were recorded every five minutes. Several experiments were carried out. All experiments produced similar results. One typical set of experimental results are shown in Fig. 5. The experiment was allowed to run for a whole day. The dark curve in Fig. 5 is the charging current through the control circuit. The lighter curve is the charging current using direct charging method. It is clear that the control circuit is helping to increase the over all charge storage by about 10%. The weather conditions on the day when the experiment was carried out are shown on the same figure. Fig. 6 shows the control circuit voltage over the same period. On this figure, one may notice the voltage jumps corresponding to changes in the charging current.

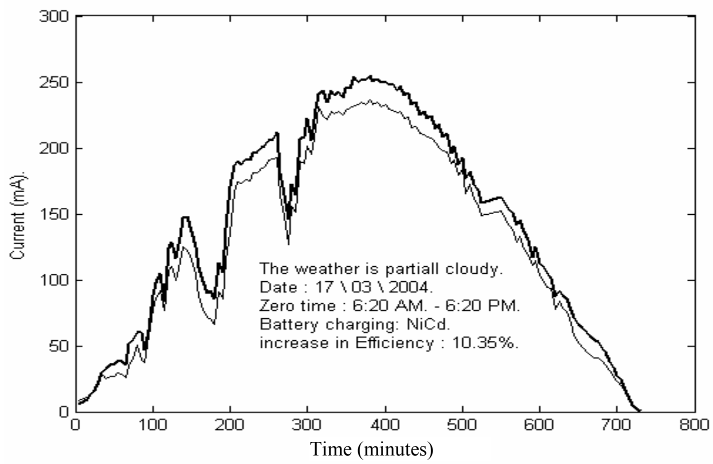

Fig. 5 – Charging current with and with out controller for nickel-cadmium battery.

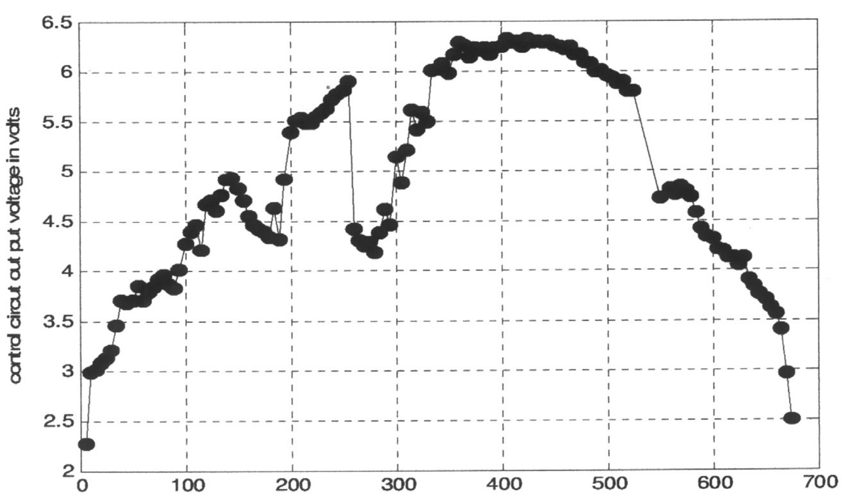

Fig. 6 – Controller voltage during nickel-cadmium battery charging.

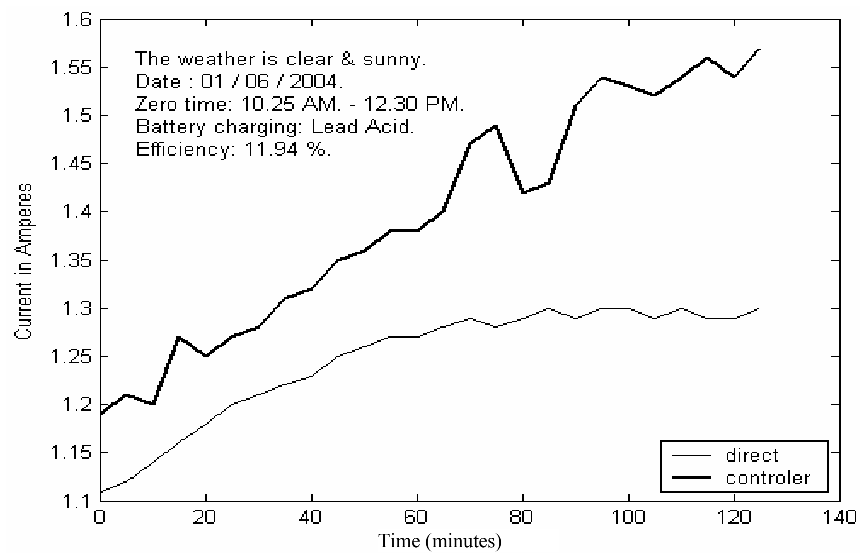

Fig. 7 – Charging current with and with out controller for lead-acid battery.

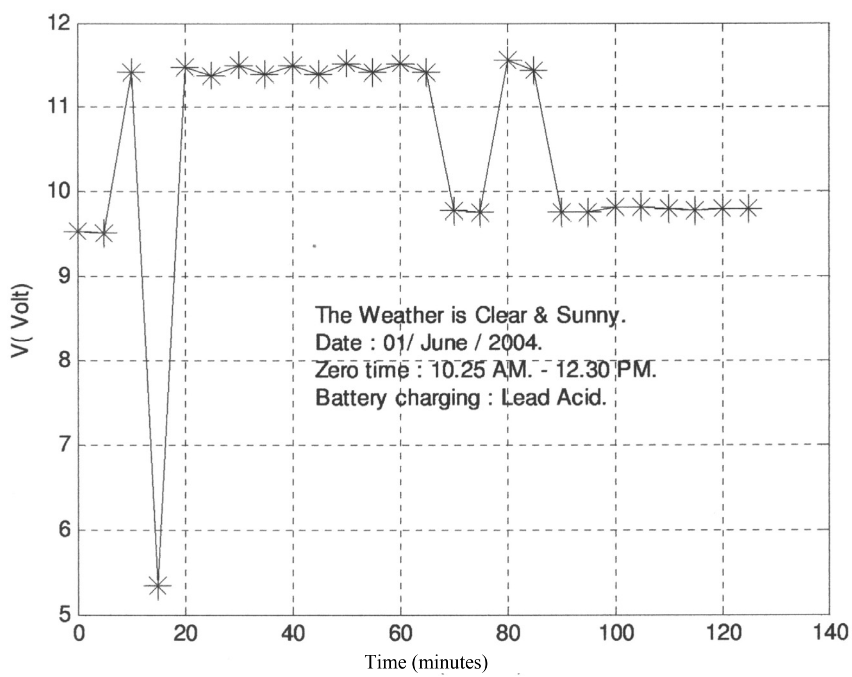

Fig. 8 – Controller voltage during lead-acid battery charging.

Another set of similar experiments on charging the 12V car battery indicate similar behavior. Results for part of the day are shown in Fig. 7. The behavior is almost the same. Here again it is clear that an increase in the charging process efficiency of about 12% has been achieved. Interestingly, the four jumps on the corresponding voltage plot of Fig. 8 are clearly associated with current increases on Fig. 7. It is worth mentioning here that increases in efficiency of about 30% were obtained in some cases. These cases are associated with fully discharged batteries at the start up. However, such cases can not be considered as standard ones.

One argument against this method of controlled charging process is that running such a system over prolonged periods of time will result in uneven charging of individual cells composing the battery. This is true indeed. To overcome this limitation, two more similar circuits were constructed, one for each type of battery. However, these circuits differ from the first two circuits. The difference is that the later circuits are electronic complementary to the original ones. PNP transistors were interchanged for NPN and visa versa. Zener diode directions are also reversed. Thus the two new circuits control the negative current rather than the positive one. The two circuits were made to run on alternative equal periods of time. This process was operated manually for the time being. We are now attempting to try to automate this circuit interchange process. If one succeeds in doing so, the complete control module will comprise the positive charging circuit, the negative charging circuit and the circuit interchange mechanism.

Another important point that must be discussed is the actual energy gain of the circuit. Although the circuit operation is based on the principle of allowing more current to flow as result of fewer battery cells in series with lower impedance, the use of the dual positive and negative currents control discussed above will actually make the energy gain equal to current gain. To elaborate on this point further, let us assume that the circuit was operated for a period of time T controlling the positive current then switched off and replaced by the negative current control circuit for another period T. The total energy stored in the battery will be Q_1V, where Q_1 is the charge and V is the battery terminal voltage. If the battery is to be charged directly for the same period of time $2T$, the energy stored for the whole period of time will be Q_2V. Now assuming we have $(Q_2/Q_1) \approx$ 90%, this will suggest an energy storage improvement by about 10%.

The control circuit power consumption is mainly determined by the resistances of the particular circuit segment that is in the on state. The most important resistance in this respect is the biasing resistance R. The value of this resistance in all segments is 1kΩ. The circuit current will be of the order 6 mA for the nickel-cadmium circuit and 12 mA for the lead acid circuit. These values were actually subtracted from the currents in Figs. 4 and 6.

It must be pointed out at this stage that the circuit operation depends only on the two electromotive forces of the solar panel and the battery. The former is only related to the solar light intensity. The circuit performance would not be thus affected through the use of a maximum power tracking mechanical system. This is true unless there is an over design with a larger number of solar cells forming the solar panel. This can only come at an extra cost. There is no reason also to believe that the circuit can not be scaled up to charge batteries with charge capacities higher than those mentioned above. Such scaling up must involve replacing the power transistors with ones that can tolerate higher currents. Power transistors used in our circuit can pass charging currents of up to five amperes very safely.

CONCUSIONS

An increase of the order of 10% in solar cell battery charging is achieved using a simple easy to build control circuit. This circuit has only cost us about 5$ for discrete components bought from electronic shops in Iraq.

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