PROTECTOR FAULT , BATTERY MONITOR LEVEL +

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Abstract:

Battery level monitor and fault protector is a system designed to be controlled from the panel. In the panel there are many circuits to obtain the level of charging voltage and display. It as indication of appearance. Another circuit is used for shutting down the load when the battery level drops to a specified level that assigned by the user to protect the battery from the damage. The aim of this project is design a completely system, controlled manually or automatically for management of any battery, package as backup supply and to get the following aims;

- **Charging the battery safely without causing over-charging.**
- **Monitoring the percentage level of battery and display it in the device panel.**
- **Shutting down the loads in any selected level to protect the battery upon deep discharging to any fault.**

عرض مستوى شحن البطارية وحمايتها من الاعطال

راشد علي فياض

المستخلص :

رصد مستوى البطارية وحمايتها من الاعطال هو نظام مصمم من خلال لوحة بواسطتها يمكن السيطرة على مستوى شحن البطارية المستخدمة وعلى مستوى العرض للدلالة على كمية الشحن في البطارية . هناك دائرة اخرى لإيقاف الحمل عندما يكون مستوى البطارية ينخفض الى مستوى معين او يعين من قبل المستخدم لحماية البطارية من التلف . والهدف من هذا المشروع هو تصميم نظام كامل التحكم يدويا او تلقائيا عند ادارة أي بطارية وحزمة العرض وللحصول على الاهداف التالية :

- شحن البطارية بأمان دون تسبب الافراط في الشحن.

- مراقبة مستوى البطارية ونسبة العرض في لوحة الجهاز.

- ايقاف تشغيل الاحمال في أي مستوى محدد لحماية البطارية عند التفريغ العميق لأي خطا .

Introduction:

Because of widely uses of rechargeable batteries in many electronic circuits, computers, and communication circuits, so it was found to be interested in studying of charging and discharging these batteries. The operation of the battery level monitor is by determining the absolute voltage dropping for the safety voltage drop range of the battery and comparing this

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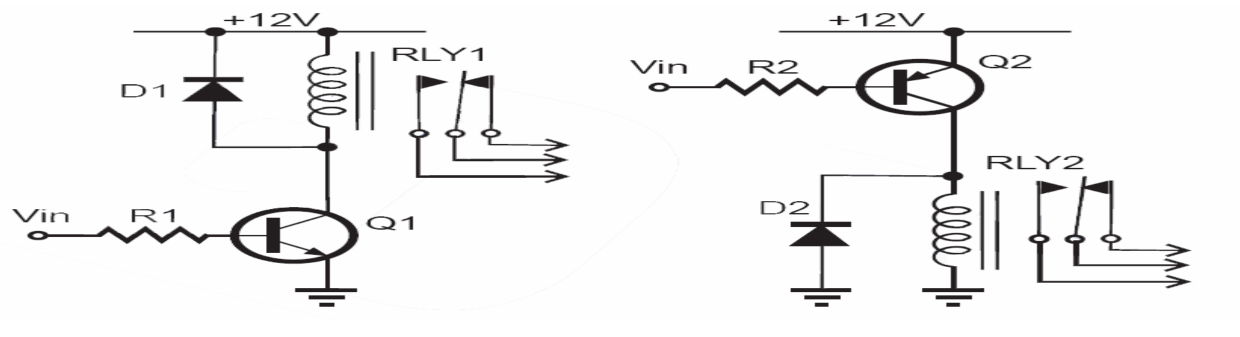
value with reference voltage and divides this comparison into many parts or steps. This process named Level Of Charge (LOC) monitoring. The incensement of these steps leads to more accurate level. The comparing process can be achieve by using operational amplifier as comparator, i.e. (IC.LM741) and this method named; successive approximation .
A battery voltage monitor circuit suitable for inclusion in a protective relay, this circuit helped improving the security and reliability of the relay contact inputs [1] . The two functions of the device, level monitor and fault protection, are designed and integrated with another important power circuits like charger unit and control circuits like overcharge protection circuit in the same device to have a complete device allow any user to work without need of any external charger or control device [2].

2. Theoretical Concepts:

1. Relay Driving:

The relays are components that allow a low-power circuit to switch a relatively high current on and off, or to control signals that must be electrically isolated from the controlling circuit itself. To make a relay operate, we have to pass a suitable pull-in and holding current (DC) through its energizing coil as shown in Fig.(1,a and b). And generally relay coils are designed to operate from a particular supply voltage often 12V or 5V [3]. So the basic idea is to choose a relay with a coil designed to operate from the supply voltage you are using for your control circuit (and with contacts capable of switching the currents you want to control), and then provide a suitable "relay driver" circuit so that your low-power circuitry can control the current through the relay's coil. Typically this will be somewhere between 25mA and 70mA.Often the relay driver can be very simple, using little more than an NPN or PNP transistor to control the coil current to provide enough base current to turn the transistor on and off [3].



(a) (b)

Fig.1 relay driving circuits

As shown in Fig. (1-a) NPN transistor Q1 (say a BC337 or BC338) is being used to control a relay (RLY1) with a 12V coil, operating from a +12V supply. Series base resistor R1 is used to set the base current for Q1, so that the transistor is driven into saturation (fully turned on) when the relay is to be energized. That way, the transistor will have minimal voltage drop, and hence dissipate very little power as well as delivering most of the 12V to the relay coil. How can be worked out the value of R1. It's not hard. Let's say RLY1 needs 50mA of coil current to pull in and hold reliably, and has a resistance of 240W so it draws this current from 12V. Our BC337/338 transistor will need enough base current to make sure it remains saturated at this collector current level. To work this out, we simply make sure that the base current is greater than this collector current divided by the transistor's minimum DC current gain h_{FE}. So as the BC337/338 has a minimum h_{FE} of 100 (at 100mA), we'd need to provide it with at least 50mA/100 = 0.5mA of base current. In practice, you'd give it roughly double this value, say 1mA of base current, just to make sure it does saturate. So if your control signal Vin was switching between 0V and +12V, you'd give R1 a value of say 11kΩ, to provide the 1mA of base current needed to turn on both Q1 and the relay [4].

2. Op-Amp as Comparator

The input stage of an op-amp uses two common emitter configured transistors with a common relatively large negative feedback emitter resistor. The current through this resistor is shared between the transistors in proportion to their input signals. Because the current should be as constant as possible, the resistor is often replaced by a constant current source. Instead of two separate input signals, the input stage can also be driven by a difference signal. The signal from the input stage is strongly amplified (e.g. open loop gain 104) before being fed to the output. Because of the input stage symmetry, common mode input signals (equal voltage on both inputs relative to ground) are not amplified. The operational amplifier is a differential amplifier. Without external components the op-amp functions as a comparator. This is because of the high open loop gain, due to which very small input signal differences are sufficient to drive the output stage into saturation (positive or negative). The maximum output voltage range is determined by the supply voltages, which can be unipolar ($+V_{CC}$ relative to Ground) or bipolar ($+V_{CC}$ and $-V_{CC}$ relative to Ground). A real op-amp has a switching threshold of a few mV, compared with the theoretical value of zero differential input voltage. This value is called the offset voltage [5].

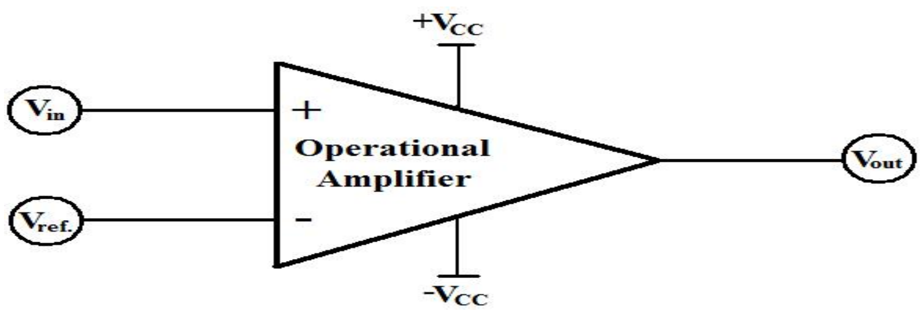


Fig.2 op-am as comparator

Here, in Fig.(2) if we connect ($-V_{CC}$) to the ground, we can apply the following conditions for voltage comparison:

$V_{in} < V_{ref.}$, then: $V_{out} = 0$

$V_{in} > V_{ref}$, then: $V_{out} = +V_{CC}$

3. Voltage and Zener Regulators

The D.C & A.C regulator or converter has been used as in this project. In electronic engineering, a D.C. to D.C. converter is an electronic circuit which converts a source of D.C from one voltage level to another. It is a class of power converter [6]. The uses of D.C. to

D.C. converters are important in portable electronic devices such as cellular phones and laptop_computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different than that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage, and possibly even negative voltage). The zener diode uses a p-n junction in reverse bias to make use of the zener effect, which is a breakdown phenomenon which holds the voltage close to a constant value called the zener voltage. It is useful in zener regulators to provide a more constant voltage, for improvement of regulated power supplies, and for limiter applications with the application of sufficient reverse voltage, a p-n junction will experience a rapid avalanche breakdown and conduct current in the reverse direction. Valence electrons which break free under the influence of the applied electric field can be accelerated enough that they can knock loose other electrons and the subsequent collisions quickly become an avalanche. When this process is taking place, very small changes in voltage can cause very large changes in current as shown in Fig.(3). The breakdown process depends upon the applied electric field, so by changing the thickness of the layer to which the voltage is can be formed which break down at voltages from about 4 applied, zener diodes can be formed which break down at volts to several hundred volts [6].

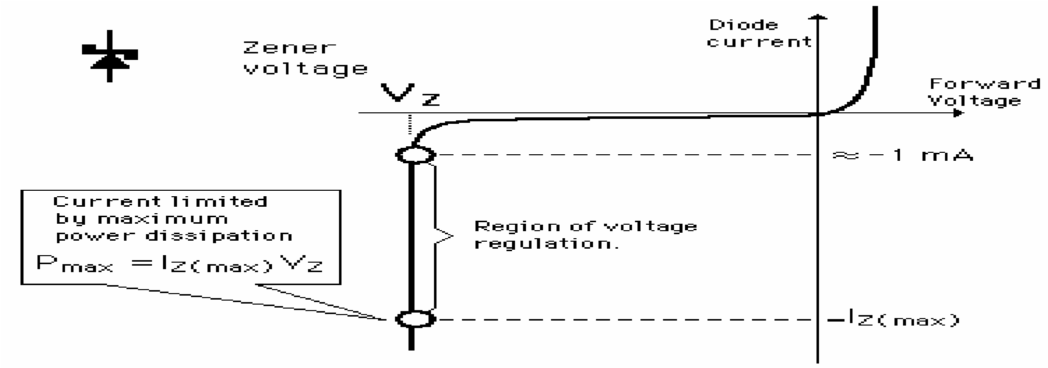


Fig.3 Zener diode characteristics

In Fig.(4) the constant reverse voltage Vz of the zener diode makes it a valuable component for the regulation of the output voltage against both variations in the input voltage from an unregulated power supply or variations in the load resistance. The current through the zener will change to keep the voltage within the limits of the threshold [7].

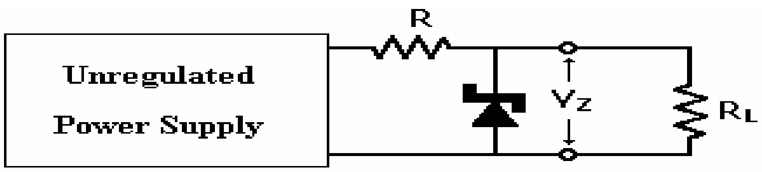


Fig.4 zener diode used as a voltage regulator.

So that, the remainder of the unregulated voltage drops across the resistor (R) ncluding the ripple part. The zener diode holds the voltage constant regardless of the current (within limits). Within the design limits, the load resistor, (R_L) sees a constant voltage, regardless of current [5]. The resistor (R) supplies the zener current I_Z as well as the load current I_{Load} (R_L is the load), (R) can be calculated from the below equation:

$$R = \frac{V_S - V_Z}{I_Z + I_{Load}} \tag{1}$$

Where: V_s is unregulated supply voltage, V_z is zener voltage, I_{Load} is load current, and I_z is current through the zener.

4. Fixed and Adjustable Voltage Regulators

Fixed three-terminal linear regulators (IC voltage regulators) are commonly available to generate fixed voltages of +3V and plus or minus 5 V, 9 V, 12 V, or 15 V when the load is less than about 7 A. Often, the last two digits of the device number are the output voltage; e.g., a 7805 is a +5 V regulator, while a 7915 is a -15 V regulator. The 78xx series ICs can supply up to 1.5 Amperes depending on the model [6].

Any IC voltage regulator can be adjusted to a higher voltage by adding a couple of resistors. As an example, let's consider using the popular 7805 (5 volt) voltage regulator as a 12 volt regulator. In Fig. (5), let's assume 470 **Ω** for R_1 so a constant current of 10.6 mA will be seen between terminals 2 and 3. This constant current plus a regulator standby current of about 2.5mA will flow through R_2 to ground regardless of its value. Because of this constant 13.1 mA, R_2 can now be set to a value which will give us a constant 7 volts across this resistor. A resistor of 533 **Ω** or 510 **Ω** gives us 5 volts across R_1 and 7 volts across R_2, a total regulated value of about 12 volts will appear across terminal 2 and ground. If a variable resistor is used for R_2, then the output voltage can be easily fine tuned to any value greater than 5 volts. The regulator standby current will vary slightly in the 7805 but 2.5mA will yield good results in the calculations. If an exact voltage (within 0.3 volts) is needed then R_2 must be a variable resistor [7].

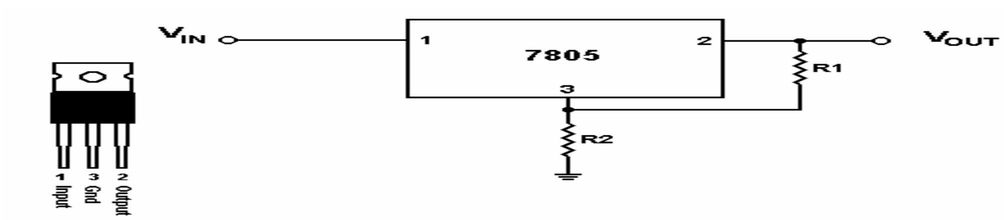


Fig.5 adjustable configuration of (7805) voltage regulator

To make any fixed regulator adjustable, we can use the following formula:

$$V_{out} = V_{fixed} + R_2 \left(\frac{V_{fixed}}{R_1} + I_{Std.by} \right)$$

(2)

Where: V_{out}: Desired output voltage.
V_{fixed}: Fixed voltage of IC regulator (5 volts for 7805).

R_1: Assume any value from about 470 **Ω** to 1K for best results.

I std.by: Standby current of regulator (use 2.5mA for 7805).
R_2: adjustable resistor to get the desired output voltage.

Table.1 the Common Resistor Combinations for the 7805 regulator

V_{out} (Approx.)	R_1 (Ω)	R_2 (Ω)
6 Volts	470	100
8 Volts	470	220
9 Volts	470	330
12 Volts	470	510

As in Table.(1), the famous LM317T adjustable regulator is really nothing more than a fixed regulator with an output voltage of 1.25 volts. Amateurs seldom need voltages below 5 volts so the 7805 regulator is a good choice and it even costs a little bit less than the LM317T [8].

<u>Practical Design concepts:</u>

1.evel of Charge (LOC) Monitoring Unit

The circuit diagram of LOC monitoring unit is shown in Fig. (6) [9] was designed to present simple method for monitoring LOC of the battery with use the obtained level for the second function of the project (Fault Protection Unit) . An approach of "Direct Simultaneous method", was used by dividing the working voltage drop range of the battery into many steps and using LED's to display the available LOC. In this project the working drop voltage range is divided into (10) steps for the battery. This method converts the analogue signal into digital form. So that an op-am (IC-LM741) was used as voltage comparator to build the circuit of the LOC monitoring unit. Since the working drop voltage range of the battery is dividing into (10) steps, (10) comparators with common input voltage and different references were used. To divide the working drop voltage range of the battery into equal steps, equal resistors are using to divide the drop voltage range and the input of each comparator is connected to one resistor.

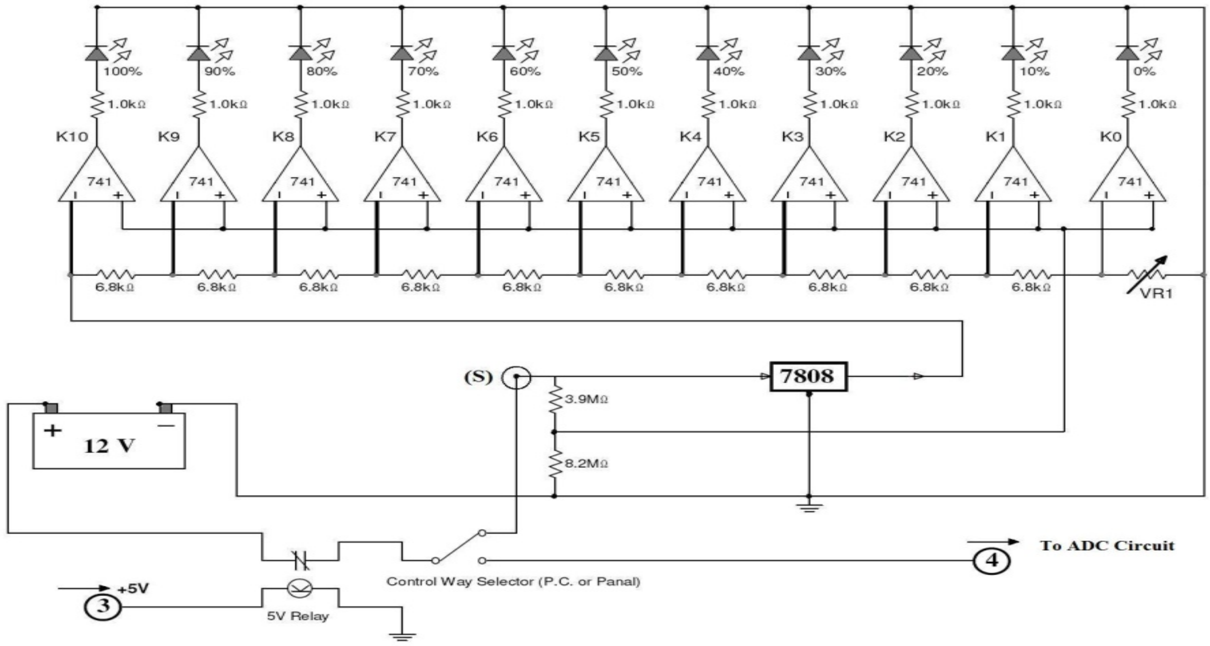


Fig.6 the circuit diagram of LOC monitoring unit

The aim of dividing in form of equal steps is for getting equal steps of level then representing as a percentage value. So as assuming that the working voltage range for the sealed Lead-Acid battery is from (12.2V) to (9.8V), this means that the battery can be worked in safely with this range of voltage. From this range we can easily find the working drop voltage and then dividing it into (10) step as following:

Working drop voltage = $V_{max.} - V_{min.}$ = 12.2V – 9.8V = 2.4 V

This drop voltage will divided into (10) step, so each step equal (0.24V), this means that every (0.24V) increase or decrease in the voltage of the battery will lead to increase or decrease (10%) of its whole LOC. The graph of Fig.(7) explains the limits of the voltage and the corresponding percentage LOC.

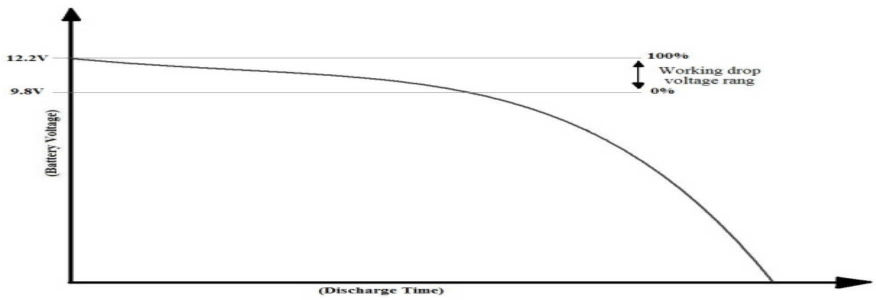


Fig.7 discharge curve of the 12V sealed lead-acid battery

Supplying of LOC Monitoring circuit may be the main problem that faced the operation in designing of this circuit, because no available power supplying when no A.C. source found that power supply has been monitoring. So that the attenuation of the battery voltage to a value could be analyzed even when the battery voltage is dropping to its minimum value.

According to this modification, the common input voltage to all comparators will be attenuated and used fixed voltage regulator for feeding a reference voltage to the comparators through the equal resistors with same attenuation ratio for the common input voltage. Across each comparator output terminal, LED in series with (1kΩ) resistor is connected for indication. This circuit will operate only when no A.C. source available and the battery loaded. It is on-load LOC monitoring circuit. There is an external switch operate by the user to control the way of monitoring, either monitoring by device panel or by P.C. software. For the circuit of Fig. (6), all (IC-LM741) operational amplifiers are supplied directly from the battery voltage through point (S***).*** The components of the LOC monitoring unit circuit are shown in Table (2)

Table.2 circuit components of the LOC monitoring unit

Item	Value	Quantity	Description
Operational amplifier	LM741	11	Voltage comparator.
LED	3V	11	Indicator for LOC.
8V Regulator	LM7808	1	Obtain constant 8 volts.
Switch	Two way	1	To chose the way of control.
Potential resistor	500kΩ , 0.25 Watt	1	Used to adjust the reference voltage.
Resistor (1)	6.8 kΩ , 0.25Watt	10	Used to divide the reference voltage.
Resistor (2)	1K Ω ,0.25 Watt	11	Used in series with the LED's.
Relay (1)	5V , 4A	1	Disconnections the LOC Monitoring function when A.C. is ON.

Table.(3) shows the probability of the LOC at the limited voltage range of (9.8V-12.2V):

Table.3 LED's probability of LOC monitoring

Voltage Range (V)		K0	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10
From	To											
Less than 9.8V		0	0	0	0	0	0	0	0	0	0	0
9.8	10.04	1	0	0	0	0	0	0	0	0	0	0
10.04	10.28	1	1	0	0	0	0	0	0	0	0	0
10.28	10.52	1	1	1	0	0	0	0	0	0	0	0
10.52	10.76	1	1	1	1	0	0	0	0	0	0	0
10.76	11	1	1	1	1	1	0	0	0	0	0	0
11	11.24	1	1	1	1	1	1	0	0	0	0	0
11.24	11.48	1	1	1	1	1	1	1	0	0	0	0
11.48	11.72	1	1	1	1	1	1	1	1	0	0	0
11.72	11.96	1	1	1	1	1	1	1	1	1	0	0
11.96	12.2	1	1	1	1	1	1	1	1	1	1	0
More than 12.2V		1	1	1	1	1	1	1	1	1	1	1

Where: Digit (1) is referred to LED's ON and digit (0) is referred to LED's OFF.

Potential resistor (V_{R1}) adjusts to give the suitable reference voltage by using the voltmeter method. This can be done by replace the rechargeable battery by an external power supply give 12.2V, so we adjust the potential resistor (V_{R1}) to the value make all the LED's become ON.

2.ault Protection Unit

This unit supplementary to that of LOC monitoring unit, it monitor the current level of charge of the battery under load, and turning off the load when the current level of charge drops to the critical value that selected by the user. The disadvantage of this unit is the dependency upon LOC monitoring unit, then the critical values that can be selected by the user are limited according to the number of the LOC monitoring steps. Practically, the circuit connected directly to the outputs of the op-amp's of the LOC monitoring unit circuit, through multi-switches (11 lines – 1 line) as shown in Fig.(8) and the output of the multi-switch connected to the fault protection circuit. Multi-switch is a group of switches, that allow the user to select one line (out of 11 lines) to be operate as the active line, so when user activate one line, this line will be the only line that connected to the output of the multi-switch while the other lines are disconnected. The process of selecting one line from many lines in the multi-switch is mechanical process.

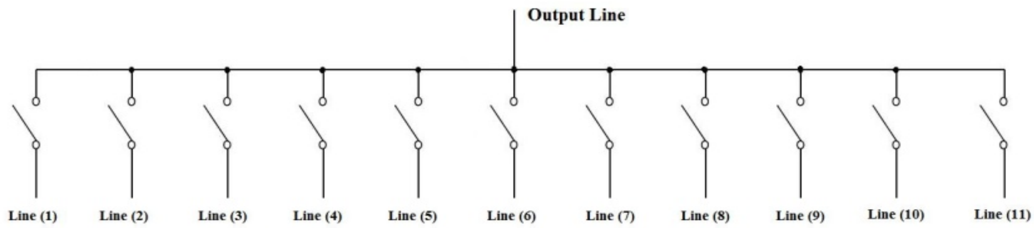


Fig.8 (11 lines – 1 line) multi-switch circuit

The circuit of the fault protection unit contains (reset) button, to restart the circuit when the user changes the selected critical value of LOC, so the button should be pressed every change in the critical value of LOC. Fault protection unit should be operating to turn off the load when the current LOC drops to critical value that selected by user. But when the load turned off, the LOC will be rising immediately according to rising of battery's voltage and the current LOC will rise to value that may be more than the selected critical value then the load will be turn on again and LOC will again drop to the selected critical value and the load will turned off and so on, the same problem will be repeated. Because of this problem and to make fault protection, unit operates only to turn off the load even if the LOC is rising again, we have designed the circuit by using combination of logic gates to get this function. Circuit diagram of fault protection unit is shown in figure (9) below.

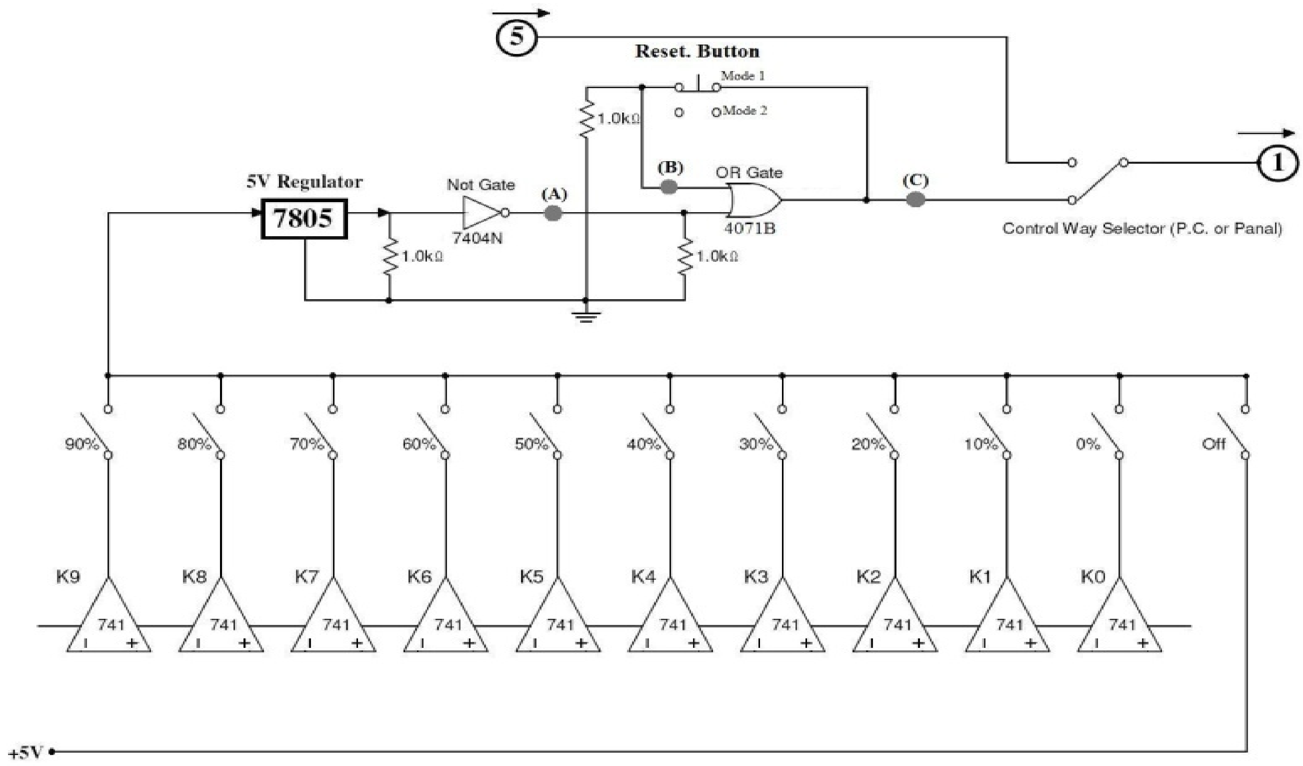


Fig.9 circuit diagram of Fault protection unit

The output line of the multi-switch is connected to fixed regulator voltage (5V) (LM7805) because the output voltage of each op-amp's is equal to its supply voltage when the common input voltage more than its reference voltage, so it reduced to (5V) to satisfy the characteristics of the input voltage for the logic gate IC (SN7404). In other hand, the supply voltage (V_{CC}) of each logic gate IC supplied by using fixed regulator voltage (5V) (LM7805) that is connected to point (S) of LOC monitoring unit circuit.

The operation of the above circuit depends upon the selected switch. For example if ct the switch of 60% is selected, then the load will still operate till the LOC monitoring circuit indicates that there is a less than (60%) of LOC. In this instant, fault protection circuit will operate the relay that controls the supply line of load and so turning off the load. The load will still in turned off even if the LOC returns and rises to value greater than (60%). The operating of the circuit has been explained logically in the following truth table (4).

Table. 4 Truth table of fault protection unit operating

Selected line State	NOT (A)	Button Mode	Feedback (B)	Output (C)	Load State	Notes
1	0	1	0	0	ON	Initial State
1	0	2	0	0	ON	Pressing the button
0	1	1	X	1	OFF	LOC drops to Selected Value
0	1	2	0	1	OFF	Pressing the button
1	0	1	1	1	OFF	LOC rising above the critical value
1	0	2	0	0	ON	LOC rising and pressing the button
1	0	1	0	0	ON	Release the button

Where: A is the output logic of the (NOT) gate and the first input to the (OR) gate ,B is the second input to the (OR) gate . C is the output of the (OR) gate and the relay operating signal , and X is value of don't care (1 or 0) which not affected the result.

The descriptions and values of used components for circuit of Fig.(9) are shown in Table (5).

Table. 5 circuit components of fault protection unit

Item	Value	Quantity	Description
NOT gate	7404N	1	Invert the input signal.
OR gate	4071B	1	---------------
5V Regulator	LM7805	1	Obtain constant 5 volts.
Multi-Switch	(11-1) lines	1	To select the desired critical LOC.
Push-off Button	One line	1	T Reset. the fault protection unit
Resistors	1 kΩ ,0.25Watt	3	Used to set zero volts at input when no voltage applied.

Test and conclusion:

After completing the implementation of the all circuits, as shown in Fig.(10) the device operated and tested under many loads in the college laboratories to determine the reliability of the device as a whole. The conclusion of the test is listed in the following points:

1. Heat problem was produced at charging the rechargeable battery. This heating results from the Power Transistor that used in the charging unit according to the voltage drop in the CE junction (V_{CE}) and the current flowing through collector (I_C). This problem solved by using heat-sink and cooling fan.
2. The mechanism of disconnecting the battery from the charging unit when the battery fully charged is by using magnetic relay is not good reliable for frequently using and continuous oscillation.
3. The obtained device relatively not small, because of using many components that need more supporting components.
4. The accuracy of the LOC obtained by Panel LOC monitoring unit is poor and give only ranges of LOC (e.g. from 70% to 80%).
5. The load current is dependent upon the specification of the electrical components that are used to implement the device circuits.
6. The cost of the device's components is about 60$, all components are available in the local markets.

Fig.10 External view of the device

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