SIMPLIFIED BIOMEDICAL SYSTEM FOR ARTIFICIAL DEFIBRILLATION

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ABSTRACT

Sudden deaths due to various forms of heart failures are very common at present, especially in Sri Lanka. Whatever the causes and types of ailments are, the final stage known as fibrillation causes the patient to die within minutes. Fibrillation is the complete disorder of the heart beat pattern as shown in the Electro-cardiogram (ECG). In order to overcome this condition, it is attempted to give a strong electrical pulse to the heart of the patient, this is done by the use of an equipment called the defibrillator. It is seen that only a few hospitals are equipped with this instrument in Sri Lanka, mainly due to its high cost.

This paper presents a design of low cost defibrillator, which will work on a new concept with advanced features and hardware system satisfying the safety standards found in commercial equipment.

INTRODUCTION

The human heart (Fig.1) is an extraordinary pump that works almost automatically based on mechanical, electrical, chemical and biological principles, in order to maintain blood circulation to keep the being alive. Heart muscles expand and contract to receive blood from the body and from the lungs, and to send blood to the body and to the lungs. These actions are caused by movement of positive Na, K, Ca ions and negative Cl ions into and out of muscle tissues. These ionic movements when tapped using electrodes kept on the body surface give rise to the ECG waves [1].

The heart pumps blood at an average rate of 70 times per minute for a normal person giving a regular ECG pattern. Variations in this pattern give various heart or cardiac disorders, the most fatal of which is fibrillation. Features of fibrillation will be outlined below.

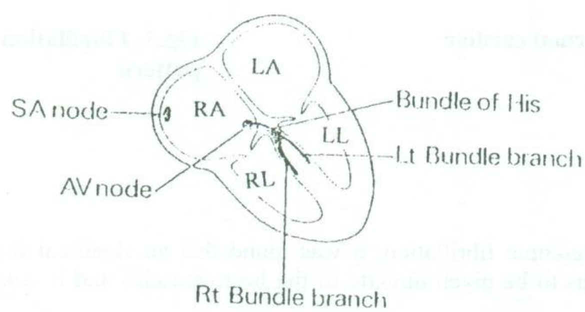

Fig.1: Human heart

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Fibrillation

In order for the heart to function in the normal cardiac rhythm, it should get the stimulating electrical pulses from the autonomous muscle tissue called 'sinoatrial' or SA node (Fig.1). But when electrical pulses coming from the SA node are either slow or fast, and the cardiac rate then becomes either low or high, this type of abnormality is known as fibrillation. A prolonged P-Q interval (Fig.2) would indicate that the pace maker signal (electrical pulses coming from the SA node) is having trouble reaching the lower chambers or the ventricular area and several categories of fibrillation types can be identified.

Ventricular fibrillation is a non-synchronized and rapid ventricular contraction. Its rate is up to 500 per minute. Here the ventricles are not contracting, instead, they are quivering. Cardiac output (blood flow) drops almost to zero. This condition is fatal unless it is terminated within minutes.

A similar condition caused by defective nerve impulses or irritable muscle tissue is known as Atrial flutter. Its rate will range from 200 – 400 per minute. An occasional pulse may pass through the AV node to cause a ventricular contraction. Thus the ventricular rate may approach normal. [1]

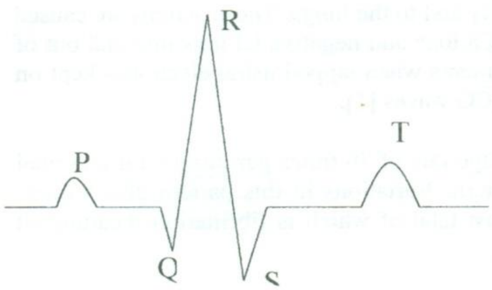

Fig.2: Normal cardiac rhythm

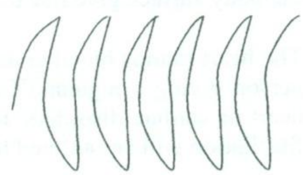

Fig.3: Fibrillation wave pattern

In order to overcome fibrillation, it was found that an electrical impulse of high energy has to be given directly to the heart muscles and it is known as defibrillation.

Defibrillation

In a case of fibrillation, due to non-unified ventricular action, there is an immediate loss of cardiac output and a drastic reduction in blood pressure. The result of this is a rapid deterioration of life functions due to tissue hypoxia, acidosis, and a build up of metabolic waste products in the cells of the body. If the condition is not reversed quickly, the person will die. Diagnosis of ventricular fibrillation is made on the basis of the absence of an arterial pulse and replacement of the R and T waves of the ECG (Fig.2) by a random rapidly fluctuating waveform called a fibrillation wave (Fig.3).

Ventricular fibrillation generally will not spontaneously revert back to a normal cardiac rhythm. The most effective way to achieve ventricular defibrillation known at this time is to deliver a pulse of electric current through the heart. This has the effect of depolarizing a critical mass of cells that have re-polarized and prolongs the refractory period of those already in a depolarized state.

A piece of equipment known as 'Defibrillator' is used to deliver a defibrillate shock and a brief description of the main categories available in the market are out lined below.

Defibrillator Equipment

These are categorized mainly on the source of energy and hence the shape of the pulse, and four types can be identified [2],

<u>AC Defibrillator</u>

One of the earliest forms of electrical defibrillator was the ac defibrillator, which applies several cycles of alternating current to the heart from the power line through a step up transformer [2]. This type is not used today due to adverse effects on the heart.

<u>DC (Capacitive Discharge) Defibrillator</u>

This type of defibrillator uses a DC source and a high voltage capacitor as the energy storing device. See Fig.4 For the shape of the defibrillation pulse used.

<u>Delay Line (Damped Sinusoidal) Defibrillator</u>

By application of inductors to the above mentioned type, the output signal is modified to have a more rectangular pulse shape and equipment available in Sri Lanka is mostly of this type.

Square Wave Defibrillator

It uses capacitors as the energy storing devices and specially arranged silicon controlled rectifiers (SCR) to control the delivery of energy to the subject. These are the most advanced, most modern type available in the world. But due to its high price, not even a single unit is available in government hospitals in Sri Lanka.

Although there are many features available in these equipment, there are various drawbacks even in the most modern defibrillator and some of them are given below:

Drawbacks

After market and hospital surveys conducted in last year, drawbacks of the existing types available in the local market and hospitals were gathered.

Not a single defibrillator is manufactured in Sri Lanka and all the available equipment are branded products of other countries. There is an authorized agent / reseller for a particular brand and they are responsible for the selling and after sales services such as maintenance and repair works. The Defibrillator is an expensive device, which usually sells at around a cost of Rs. 600,000/=. In addition to this, higher charges are levied for the maintenance/repair work after the lapse of warranty period.

In these existing types of defibrillators, a short duration – usually around 3 to 4 milliseconds – (Fig.4), high amplitude – usually around 5000 volts for 360 Joules – single electric shock is used. This amount of voltage may cause adverse effects on patients and is definitely lethal to the operator, if accidentally subjected to it. The duration of the pulse is beyond the control of the operator. If a consecutive second pulse is required, operator has to charge the equipment once again wasting valuable time.

In the most modern square wave defibrillator available commercially (although not available in government hospitals in Sri Lanka), thyristors are used to control the energy [2]. Hence it is difficult to control the circuit once triggered and it is also possible to show that the shape of the pulse is not true trapezoidal or square as mentioned. (It is said that a square wave defibrillating wave pattern will be very effective on defibrillating a fibrillated heart [2]).

Associated with high voltages and currents, defibrillators can be considered as life savers. They can be killing machines when operated inappropriately or in accidental situations such as paddle short-circuiting, touching the patient while operating the equipment etc.

[redacted]

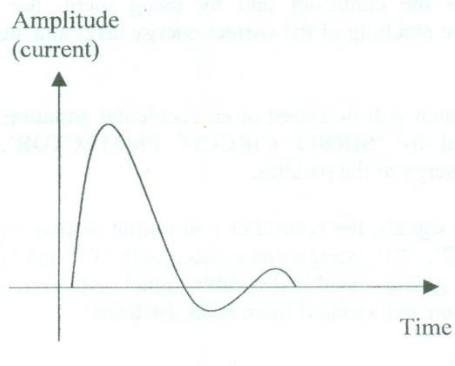

Fig.4: Pulse delivered by DC defibrillators

In the proposed system, most of the above drawbacks are overcome and features of the new equipment are presented in the next section.

NEW DEFIBRILLATOR

This new defibrillator is based on the concept 'Water Tank Theory' where the energy is not drained instantly and instead delivers desired amounts in steps as required. In order to perform this action, Power MOS-FET drivers are used as switching elements and a microcontroller is responsible for the correct functioning of the entire equipment.

Circuit Implementation

Figure 5 depicts the block diagram of the new microcontroller based defibrillator and the operation of it is as follows.

Microcontroller

In the system, the microcontroller is used to control the inputs and outputs, for obtaining accurate timing, for carrying out calculations, for indications and for easy programming etc.

During the operation, the microcontroller is fed with the information of switch positions for 'ENERGY', durations of 'T1', 'T2', 'T3' and it fetches the actual numerical values from the stored memory for calculations and indications.

Manually controlled 'CHARGE' and 'DEFIB' switches will give the correct instances of time to charge the capacitors and to deliver the pulses.

While charging is in progress, the voltage comparator circuit feeds the 'HIGH' and 'LOW' signals to the controller and by using them, the controller automatically detects the reaching of the correct energy level and stops further charging or draining.

"ERROR IN' signal which will be raised at an accidental situation of paddle short circuit, generated by 'SHORT CIRCUIT PROTECTOR', prevents delivering of charged energy to the paddles.

In addition to the input signals, the controller will output display signals such as durations of 'T1', 'T2', 'T3', energies associated with 'T1' and 'T2'. It will also guide the operator giving visual and audible signals when the equipment is 'READY' for operation and a tone if there is an 'ERROR'.

High Voltage Generator

This unit generates the high voltage required by using a step-up tapped transformer.

Energy Storage Device

Capacitors are used as the energy storing device since they are compact in size, can be arranged in arrays for high voltage and capacity values etc.

Voltage Comparator

The required voltage value, especially when changing the energy selector once charged, and giving indication (high, low or correct voltage) is obtained by a voltage comparator.

Short Circuit Protector

This unit checks whether the paddles are accidentally short-circuited and prevents supplying stored energy into the paddles. In such a situation, the operator is warned by short duration tone pulses.

Drain Circuit

Unused energy is drained after a pre-determined period (approximately 1 min.), and it also drains when adjusting a high-energy value to a low energy value.

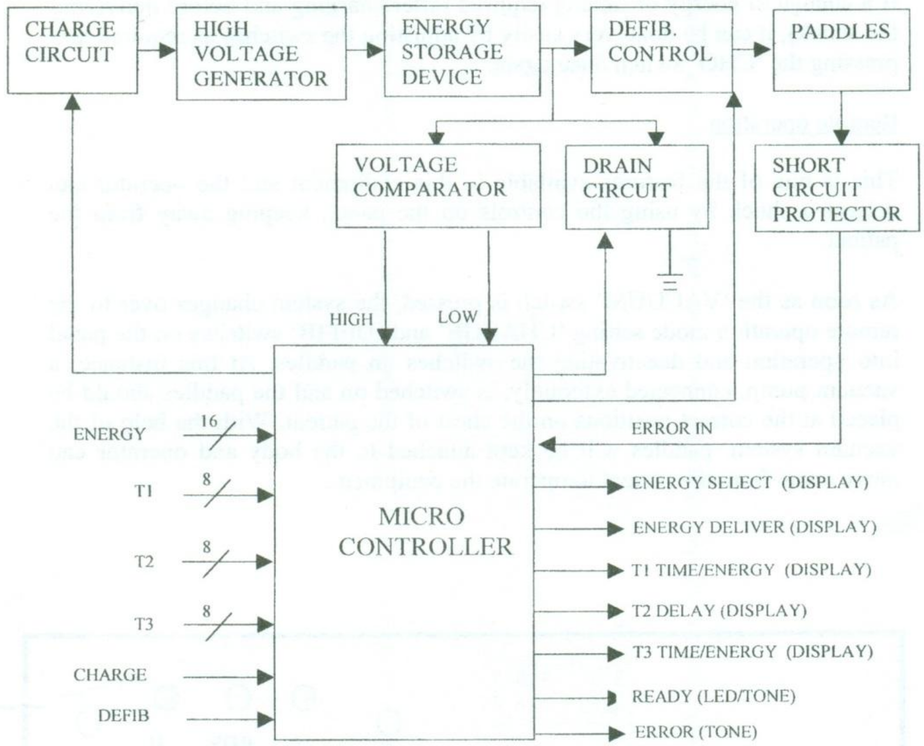

Fig.5: Basic building blocks of the new Defibrillator

The front panel layout of the new defibrillator is given in Fig. 6 and its operation is described below.

Operation

When operating this equipment, it is necessary to select the desired energy first by using 'ENERGY SELECT' rotary switch, then selecting duration of the first pulse T1, delay for the second pulse T2 and duration of the second pulse T3 if required. After that, it is necessary to activate the charging by depressing the switch 'CHARGE' either on the paddle ('STERNUM') or on the panel in case of remote operation. At this instance, the selected energy and associated time settings will be displayed on the panel and one can direct one's attention towards the maximum energy available for a particular 'ENERGY SELECT' position and the portion of it which will be delivered by the pulse/s on 'ENERGY DELIVER', in addition to the durations of the pulse/s. These will be accompanied with an audible tone to signal to the operator that the equipment is ready to deliver Defibrillation Pulse/s. Either by activating the two switches on the paddles or the switch ('DEFIB') on the panel, the charged energy can be delivered to a patient.

If a change of energy or time is required (after charging and before delivering the shock), it can be done very easily by adjusting the switches as required and pressing the 'CHG' switch once again.

Remote operation

This is one of the features available in this equipment and the operator can deliver a shock by using the controls on the panel, keeping away from the patient.

As soon as the 'VACUUM' switch is pressed, the system changes over to the remote operation mode setting 'CHARGE' and 'DEFIB' switches on the panel into operation and deactivating the switches on paddles. At this instance, a vacuum pump, connected externally, is switched on and the paddles should be placed at the correct positions on the chest of the patient. With the help of the vacuum system, paddles will be kept attached to the body and operator can move away from the patient to operate the equipment.

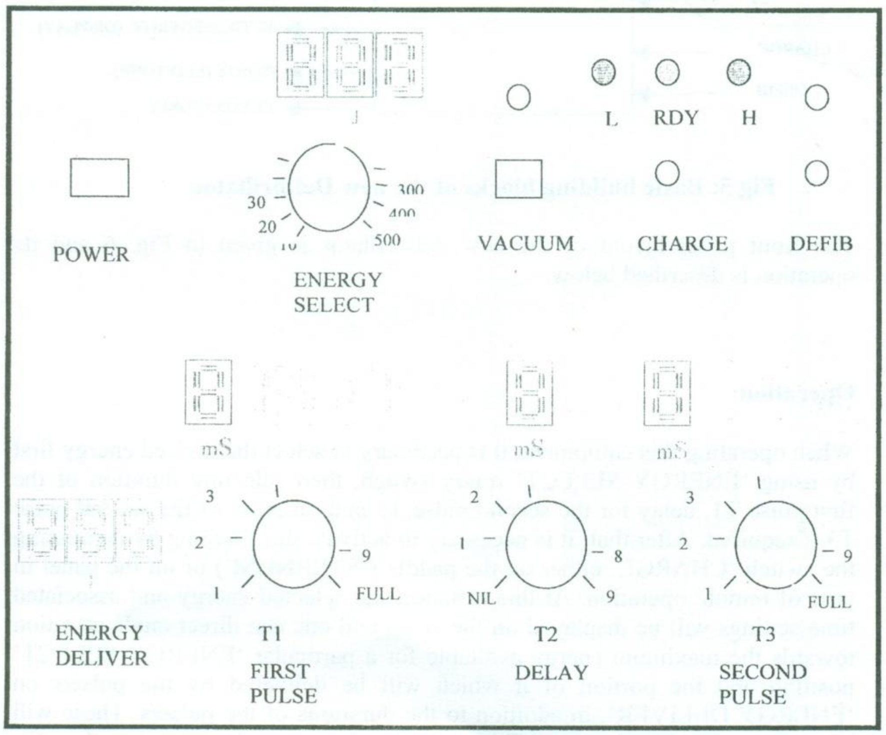

Fig.6: Front panel layout

Features of the New Defibrillator

In this equipment, it was sought to overcome drawbacks of the existing types and also to provide some advanced features.

Low cost freely available components, which can be bought from the local market, were used throughout. A capacitor bank is used as the energy-storing device since high voltage and high capacity values are capable of being achieved with small capacitors arranged in an array so that capacitors are connected in series for higher voltage values and in parallel for higher capacitive values.

There are facilities to deliver single electric shock (defibrillation pulse) or continuous 2 shocks with a delay in between if required (Fig.7). Further, it is capable of adjustable pulse durations of 1st & 2nd electric shocks, delay between them, and possible application of long duration pulses (compared to the existing defibrillator pulse of duration 3 to 4 milliseconds).

The above mentioned pulses are very close to square wave pattern, and hence less energy (less peak voltage) will be required to get the desired action. A high 1st pulse for overriding the body resistance with a continuous low 2nd pulse to defibrillate the heart muscles will be very effective for reducing the risk and damage that may occur from the application of high voltage to the heart.

Since the energy storing capacitors are not fully discharged instantly and the unused energy is conserved for a short period of time, less time is required to charge the unit for another set of pulses if required. This in tern gives less charging time with high-energy efficiency.

Short circuit sensitive paddles prevent accidental defibrillation when applying electrolytic gel to the paddles and other accidental short circuit situations and warn the operator by delivering a continuous tone.

Remote operation (if necessary) will mean less risk for the operator as well as greater ease in the operation of the equipment.

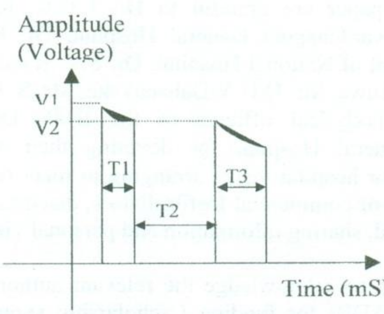

Fig.7: Pulse/s delivered by new Defibrillator

DRAWBACKS AND IMPROVEMENTS

While designing and constructing this equipment, the main objective was to produce a low cost Defibrillator and there are certain associated drawbacks, some of which are outlined below.

When treating certain cardiac disorders like Atrial Defibrillation, a synchronized ECG system is required to observe the cardiac pattern; in order to use this equipment for such a situation, it is necessary to couple an existing ECG machine or arrange a suitable method to observe the cardiac patterns.

Whether the 'CHARGE' button is pressed or not, the high voltage generator circuit is in operation at all times, consuming electrical energy; hence further improvement on conservation of energy will be useful.

Cardiac disorders can occur at any time and anywhere; hence a battery backup to work when the line power is not available will be essential.

Arrangements to adjust the pressure of the vacuum system according to various body shapes to hold the paddles firmly to the body will be an added advantage.

CONCLUSION

The design of a Defibrillator to deliver a square wave pulse was presented. The system was designed with features such as ability to deliver high voltage short duration second pulse to override the body resistance with consecutive low voltage, long duration pulse to defibrillate the heart muscles; this will reduce the risk and damage arising from high voltage application to the heart.

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