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Design Anaysis of Defibrillator and Implementing Wireless Charging System

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***Abstract*—This work is aimed to evaluate the design of the defibrillator and to determine the difficulties to incorporate a wireless charging system in external defibrillator. Defibrillators are the life saving equipment used for a patient having sudden cardiac arrest. The main component in a defibrillator is the high voltage capacitor which should get charged quickly. In a classical monophasic defibrillator, energy range is of 150 to 400Joules and in biphasic defibrillator 150 to 360Joules energy is produced for time duration of 8 to 10msec. Such a huge energy in a small period of time will produce a high output voltage in the range of 200 to 1000V. In case of internal defibrillator, the energy up to 40J is released to the cardiac muscles directly. The capacitor of an external defibrillator should be charged fully in order to discharge required energy to the patient's heart and the charging time should be small enough to provide maximum of three consecutive shocks in failure of first and second attempt. Nowadays, the wireless charging system is most common in every area, but not much among medical devices. In case of external defibrillator, when designing a wireless charging system, the device size will get reduced into the size of defibrillator paddle. In this work, when designed an external defibrillator for discharging 150J in duration of 10msec, the capacitance value obtained is 0.03F and the discharge voltage of 866V. There is no such capacitor with this much voltage rating of smaller size is available today. So it is designed to implement wireless charging in a defibrillator and developed such a circuit model in printed circuit board (PCB) at the end. The output energy produced by the prototype of wireless charging defibrillator is 45J.**

***Index Terms*—Arrhythmia, biphasic and monophasic defibrillator, implantable defibrillator, wireless charging system**

I. INTRODUCTION

A sudden cardiac arrest is known to be the cause for death of one quarter of entire human population. The most effective therapy to overcome sudden cardiac arrest occurred due to ventricular fibrillation is electrical defibrillation. If the defibrillation energy is delivered properly, the chance of survival rate is more than 75% [1]. The initial external defibrillators worked using alternating current from a 1000 and greater voltages were passed through the paddle electrodes to the heart. Since it was AC defibrillation, chance of getting burns is high. Later it was found, the direct current defibrillation with energy of 100 – 200J is effective and safe [2]. The biphasic defibrillators were introduced first in the implantable cardioverter defibrillator, and then implemented in the external defibrillator instead of monophasic. Biphasic external defibrillators when compared to monophasic defibrillator capable to defibrillate the heart at much lesserenergy. When studied, the difference between biphasic and monophasic waveform in mechanically ventilated pigs, biphasic waveform defibrillation had shown very less impairment in ECG and arterial pressure [3].

In this work, it is tried to design and develop wireless charging defibrillator in order to make the device more user friendly. If this is made wireless, the entire size of the device will get reduced in to normal defibrillator paddle size. There are lot of difficulties and limitations to develop such an external defibrillator since, the unavailability of capacitors with the designed ratings. It is widely used in medical implantable devices but not much in external devices [4].

A. Arrhythmia

Arrhythmic or irregular beating of heart is known to be arrhythmia [6]. This can be due to coronary artery disease, electrolyte imbalance in blood, injury from a heart attack or can occur even in normal hearts. The arrhythmia developed from ventricular myocardium is called ventricular arrhythmia. This kind of arrhythmia is the main reason for death due to sudden cardiac arrest. Ventricular arrhythmia is classified into ventricular fibrillation, ventricular flutter, ventricular tachycardia, ventricular bradycardia and ventricular flutter [7]. Among this, ventricular tachycardia which is the rapid rate from ventricles is most serious one [8].

B. Defibrillator

Defibrillator is lifesaving electrical equipment for treating patients suffering with most threatening arrhythmia called ventricular fibrillation. The synchronized electrical impulses are emitted from the heart by the help of its natural pacemaker. In arrhythmia condition, the natural pacemaker fails to work on its normal rhythm and here the defibrillator comes to play [9]. Defibrillators are of two type; External cardioverter defibrillator and implantable cardioverter defibrillator. Usually the energy produced by external defibrillator ranges from 100–400J and an implantable defibrillator applies a shock ranging from 15-50J.

The main components in a defibrillator circuit include a power source, a high voltage capacitor, variable transformer, rectifier and an inductor [10].

C. AC and DC defibrillator

The first defibrillator introduced was an AC defibrillator, which uses alternating current to produce shock for defibrillation. It uses 2000-3000V and 25-30A AC for defibrillation which requires powerful huge generator or transformer in hands [11]. DC defibrillators are not only effective but also have very less complications. The DC units are providing counter shock by storing an energy level of 100-200J in a capacitor by charging nearly up to 1000V [2]. Alternate current defibrillator with a modulated AC shock can act like a DC biphasic defibrillator [12].

D. Monophasic Waveform Defibrillator

In past, external defibrillators are designed to produce monophasic exponential waveforms. The energy produced by these kind of defibrillators ranges from 200-360J for efficient defibrillation [13]. The current will move in one direction only, from one electrode pad through heart to other pad and reaches the defibrillator again. Monophasic defibrillators contain a large component, which is an inductor having a large coil of wire in the circuit. Inductor is used to slow the current which will reduce the peak of the current and also make it spread over a long period of time. This is considered as better for some clinical reasons. For a successful defibrillation, it needs specified energy delivered not a particular amount of current. This is the reason for placing an inductor in the circuit, to slow the discharge rate and limit the current, thus decreasing the chance of myocardium burns.

Monophasic exponential waveforms are usually truncated for many reasons. After the discharge, the tail of the waveform will reach the lower current region in the graph. This smaller current tail is dangerous, which can cause the heart to fibrillate again. To remove this small current, the waveform is truncated.

E. Biphasic Waveform Defibrillator

Biphasic waveforms are the most common type used in both internal and external defibrillators now. The current flow is in two directions between the paddles. Biphasic defibrillators start by sending current from one paddle, through the heart in the forward direction. In the reverse direction, the current will flow from second paddle to the other paddle through heart and then back to the defibrillator. The defibrillation by using this can be achieved at a much lower energy compared to monophasic and the current producing successful defibrillation can be reduced. The switching of forward and reverse current, switching interval and truncation are controlled by using H Bridge switch circuit. The four switches are controlled by microprocessor which is programmed for timing these events [14].

In the waveform it shows like the reverse current gradually decreases and eventually reaches zero. But it should not occur in the real life so that, the switches are manipulated such a way that, reverse current cannot ends in its natural way. This is done by truncating the tail of the waveform. The defibrillation current should be large enough for effective defibrillation since, the small current can cause fibrillation in the heart again. The small current at tail end of reverse current has a potential to fibrillate the heart. In order to avoid this situation, defibrillator should cut off the dangerous tail end of the biphasic waveform. This is called truncation. For this, along with reverse current switches, switch 1 of the forward current also put “on”. This will suddenly create a short circuit forcing the current to return back to the capacitor without passing through the heart. This is called Biphasic Truncated exponential Waveform.

These types of defibrillators are able to defibrillate the heart using much lesser energy compared to monophasic defibrillators. An energy of 150-200J is enough to defibrillate the patient, where a monophasic defibrillator may use much higher energy [15]. So biphasic waveform based defibrillators can reduce the chance of myocardial damage when compared to monophasic [1].

TABLE I
Comparison of Defibrillators Existing based on the successful Defibrillation Energy.

SL NO	Defibrillator Type	Defibrillation energy level
1	MONOPHASIC WAVEFORM DEFIBRILLATOR	200-360J
2	BIPHASIC WAVEFORM DEFIBRILLATOR	120-200J
3	RECTILINEAR BIPHASIC WAVEFORM DEFIBRILLATOR	150-200J

F. Average and Peak Current

When the role of current is considered in defibrillation, it is important to analyses both peak current and average current. The peak current has not that much role in a successful defibrillation; rather it will give a high chance of getting myocardium injuries. Average current is responsible for successful defibrillation. It has an advantage of being more efficient to provide effective counter shock when different monophasic waveforms and duration are compared. This was the reason to use low tilt biphasic truncated exponential waveform to reduce peak current at the same time increasing average current. So in biphasic defibrillator, much lower current is needed to terminate fibrillation successfully at the same time device size can be reduced [5].

G. Defibrillation Energy and Chemical composition

Defibrillation energy has some effects on the chemical composition in the heart. The concentration of Creatine kinase (CK), CK-MB and their ratio is very important for defibrillation success. They provided a shock energy varying from 50J to 360J. Increased current during defibrillation will also results in release of chemical CK-MB into the blood resulting into adverse effects. Current has to be maintained in safe level during defibrillation for preventing increment in the CK-MB concentration not more than 6 percentage of its total amount [16]

H. Defibrillation and Time of shock

Apart from providing defibrillation shock at right time, proper pulse energy and waveform plays a crucial role in defibrillation success. Duration of the pulse energy is also a factor affecting the successful defibrillation.. It is not possible to increase the time duration for achieving the energy requirements since, prolonged shock duration can decrease the average current and also the main reason is the energy released should fall in the heartbeat rather than in refractory period of heart muscles. So the energy accuracy of the defibrillators has to be improved [17].

I. Prototype design for Wireless Charging Defibrillator

The wireless charging system is designed for transmitting 12V from transmitter to the receiver coil. The input power supply to the transmitter is given from the AC supply and step down into 12V. Bridge rectifiers and capacitive filters are used to rectify and filter the input voltage at the transmission level. Also a small capacitive filter is included in the circuit for removing noises or to absorb unwanted peaks. The coil of 1mm thickness is used for winding transmitter and receiver and the number of turns is almost same at both ends. A voltage regulator is also there at the receiver end which is the connected to the arduino and the battery. The arduino board is used for controlling the relay operations and to display the input power. The defibrillator circuit is controlled by the relay. The shock is delivered through a pair of ECG probe.

II. METHODOLOGY

The first part of the work is to analysis the design and study the changes occurred in the defibrillator design through the years and are trying to integrate defibrillation and wireless charging technologies together to make the device which is highly useful to the medical industry. In a condition of arrhythmia, defibrillators are the device comes in to picture. It will provide a shock to an irregular beating heart, which will depolarize a critical mass of cardiac muscle, eliminates the arrhythmia and helps to regain its normal sinus rhythm [5]. In the case of patients suffering from frequent arrhythmia, it is advised to implant a defibrillator in the patient’s body. So that, it will automatically detect the irregularity and it will provide a shock directly into the heart. The main issue facing with an implantable defibrillator is battery replacement. If it can be charged wirelessly, it is able to reduce the risk of battery replacement surgery.

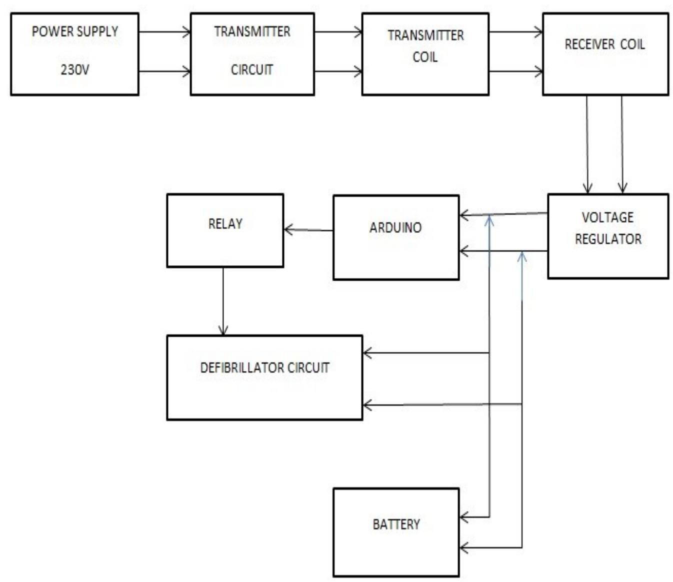

Fig. 1. BLOCK DIAGRAM OF THE PROTOTYPE OF DEFIBRILLATOR

In this work, it is designing a wireless charging system for normal defibrillator model which can produce output energy of 45Joules. A 12V is transferred from transmitter to the receiver in order to charge the battery. A relay is used to control the charging and discharging of the defibrillator. The relay operation is controlled using an arduino board in the circuit.

The transmitter and receiver coils are designed such a way that, both the circuit having almost equal number of turns. It is done in order to transfer the same charge from the transmitter side to the receiver side. The transmitter circuit is provided with a step down transformer and a bridge rectifier. LM7812 voltage regulator immediately after the rectifier will regulate the voltage in a value of 12V at the transmitter side. The receiver side is also providing with a bridge rectifier, capacitor filters and voltage regulator. The defibrillator charging and discharging is controlled using a relay which is connected with an arduino board. Instead of defibrillator paddle, used a simple ECG probe to deliver the shock.

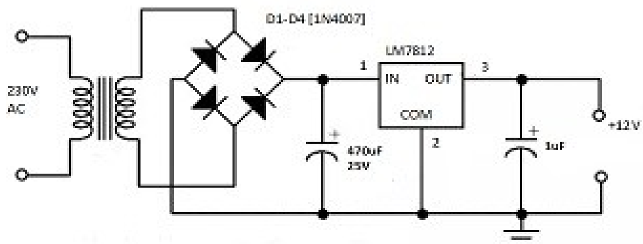

Fig. 2. TRANSMITTER CIRCUIT FOR WIRELESS CHARGING

III. RESULTS AND DISCUSSION

By analyzing the basic working principles and parameters deciding the performance of defibrillators, it is concluded that many factors together compliment for a successful defibrillation. The device should also be able to operate simple and safe from a user point of view. Defibrillator can be designed for both AC and DC power supply. There are monophasic and biphasic defibrillators which can produce energy for counter shock at different current peaks. Using biphasic waveforms will reduce the defibrillation threshold (DFT) that makes the reduction in the energy levels associated and cause very less myocardial injury [1]. For a safe and successful defibrillation, DC defibrillators are better. AC voltage defibrillators can induce atrial as well as ventricular fibrillation in a defibrillated heart [18]. Some other works which can be taken in to the account for improving the wireless charging defibrillator design are introducing single stage converter at receiver side and usage of ultracapacitor. In order to keep lesser number of components and reduce the losses, a single stage boost rectifier can be introduced at the receiver side instead of the two stage power conditioning. This is made possible by using the bidirectional conduction property of MOSFETs [19].Ultracapacitors are small capacitors with high charge density and wide range of temperature adaptability [20]. Usage of ultracapacitor will help to reduce the size of the device.

In the designed wireless charging defibrillator model and input of 12V is transferred from the transmitter to the receiver. A battery of 6V capacity is charged using the wireless charging system. The input of 6V from the battery is given to the defibrillator circuit by the help of relay operation. Inside the defibrillator circuit, the voltage is stepped up to 32V to charge the capacitor. The output energy obtained at the time of discharging to the paddles is 45J. Fig 3 is the prototype build for the wireless charging defibrillator with output energy of 45J. Wireless charging defibrillator will make the device more users friendly and portable.

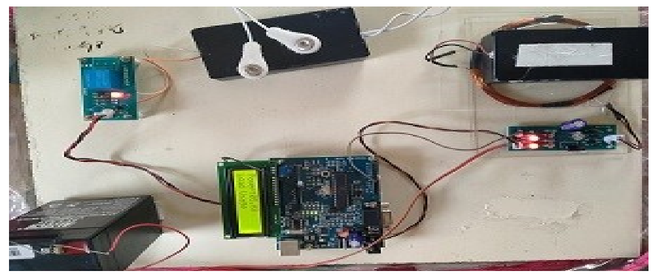

Fig. 3. PROTOTYPE OF WIRELESS CHARGING DEFIBRILLATOR

IV. CONCLUSION

From the design evaluation of the defibrillator, it is understood that biphasic waveform DC defibrillators are more common today and the performance is much better compared to monophasic waveform defibrillator. Biphasic defibrillator can defibrillate the heart at much lesser energy when compared to monophasic defibrillator.

Wireless charging system is not much common in the medical field. When using implantable cardioverter defibrillator patients are supposed to undergo surgery in order to change battery after some years of implantation. So if wireless charging is incorporated in the implantable cardioverter defibrillator, it can be avoided. Also the wireless charging will make external defibrillator user friendly. Building a prototype of a defibrillator with lesser the size and cost of the original defibrillator is not possible until a small sized capacitor with a capacitance ranging from 0.03 – 0.05F with a voltage rating of minimum 800V is available.

In future, if wireless charging system is incorporated in an external defibrillator the device will be more users friendly. The size of the entire device can be reduced into two paddle size which makes the device portable. More researches has to be done in the field of capacitors to design a capacitor with lesser size and larger value of capacitance.

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