

# Control System Design to Automate 100KV Impulse Generator

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**Abstract**— This paper is basically the practical study of converting manually operated impulse generator to automatic generator. Ever since 1970 (when the High voltage lab of UET Lahore, Pakistan was constructed) most of the equipment in this lab has been operated manually. In this Lab, we have two impulse generators with capability of 100 and 500 kilo volts which are used for testing purposes. Both of these use the same mechanism for Impulse generation. In this paper a design is proposed to automate the whole working of the Impulse generator (100KV) for which we used Arduino Board which is coded such that the operator has to insert desired impulse voltage through the computer and the rest of the process will be done by the system itself. We used LabView Simulation tool for coding purpose. All coding is in graphical coding environment.

**Index Terms**—Arduino Mega 2560, Capacitor Charging, Capacitor Discharging, Impulse Generator, Impulse Application, Sphere Gap Measurement, Sphere Gap Adjustment, Stepper Motor Control.

## 1 INTRODUCTION

An Impulse generator is an electrical apparatus which produces very short duration high-voltage or high-current surges. Impulse is a signal of very high magnitude and very small duration. This impulse is passed through the transformer for the insulation testing. Impulse voltage generation is a two phase process:

1. Parallel charging of the capacitors
2. Series discharging of these capacitors

A number of capacitors are charged in parallel to a given voltage  $V$  and then connected in series by spark gap switches, ideally producing a voltage of  $V$  multiplied by the number,  $n$ , of capacitors. Due to various practical constraints, the output voltage is somewhat less than  $n \times V$ . Charging and Discharging of Marx Generator is shown in Fig 1.

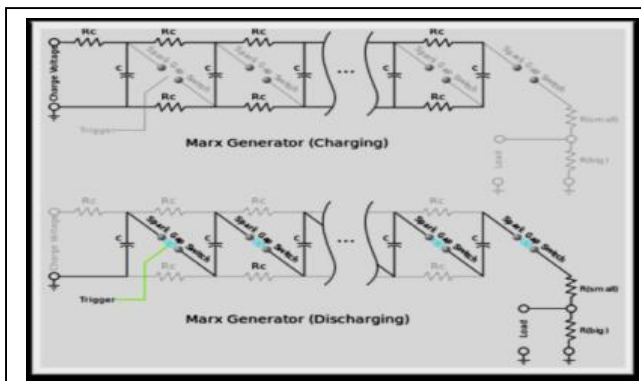


Fig.1 Charging and Discharging of Capacitors

In control systems engineering, a system is actually a group of objects or elements capable of performing individual tasks. They are connected in a specific sequence to perform a specific function. A system is of two types:

1. Open loop system
2. Closed loop system

Both systems have their advantages and disadvantages. Open loop system is simpler, cheaper and can be easily constructed but less accurate, less reliable and can't remove the effects of disturbances. While a closed loop system is more accurate and it can respond to disturbances but more expensive and difficult to construct.

## 2 COMPONENTS OF IMPULSE GENERATOR

### 2.1 Autotransformer

An autotransformer has a single winding with two end terminals, and one or more terminals at intermediate tap points, or a transformer in which the primary and secondary coils have part or all of their turns in common. The primary voltage is applied across two of the terminals and the secondary voltage (taken from two terminals) always has one terminal in common with the primary voltage.

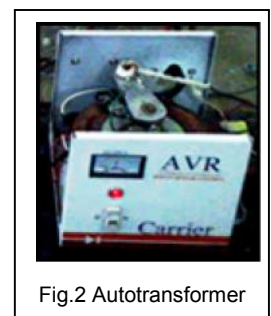


Fig.2 Autotransformer

The primary and secondary circuits therefore have a number of windings turns in common. Since the volts-per-turn is the same in both windings, each develops a voltage in proportion to its number of turns. In an autotransformer, part of the current flows directly from the input to the output and only part is transferred inductively, allowing a smaller, lighter, cheaper core to be used as well as requiring only a single winding. I am using 5KVA variable voltage transformer which takes input 230VAC and

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provides a range of output i.e. 0V-200V depending upon the magnitude required for the impulse.

**2.2 Power Transformer**

A power transformer is a static electrical device that transfers energy by inductive coupling between its winding circuits. A varying current in the primary winding creates a varying magnetic flux in the transformer's core and thus a varying magnetic flux through the secondary winding. This varying magnetic flux induces a varying electromotive force (emf) in the secondary winding. It is a step up (1:500) 10KVA transformer with a primary, secondary and a tertiary winding (for measurement purpose). For example if 35V is applied at its primary winding then 17.5KV will be the voltage at its secondary winding. This way we get a high ac voltage. It should be noted here that the secondary current rating of this transformer is very low.



Fig.3 Power Transformer

**2.3 Selenium Rectifier**

A selenium rectifier is a type of metal rectifier, invented in 1933. They were used to replace vacuum tube rectifiers in power supplies for electronic equipment, and in high current battery charger applications. Vacuum tube rectifiers had efficiencies of only 60% compared to the 85% of selenium rectifiers, partially because vacuum tube rectifiers required heating. Selenium rectifiers have no warm-up time unlike high vacuum rectifiers. Selenium rectifiers were also cheaper and simpler to specify and install than vacuum tubes. However they were later replaced by silicon diodes with high efficiencies (close to 100% at high voltages). Selenium rectifiers had the capability to act as current limiters which can temporarily protect the rectifier during a short circuit and provide stable current. The high voltage produced by the main transformer is converted into DC voltage so that it may be used for the charging of capacitors in the impulse generator connected ahead.

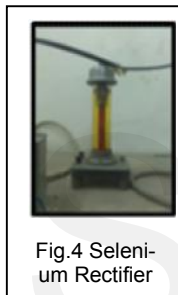


Fig.4 Selenium Rectifier

**2.4 100KV Impulse Generator**

The impulse generator that we have in UET Lahore is a single stage 100KV Impulse generator on which I will be doing my experiment. From now onwards I will implement all my research and modifications on this Impulse generator.



Fig.5 100KV Impulse Generator

**3 PROPOSED MODIFICATIONS**

The main idea of this project is to automate this impulse generator. Following are the steps in sequence:

1. Adjust the sphere gaps between capacitors according to the user input provided through pc.
2. According to impulse level requirement, DC gear motor will set the voltage level by connecting feedback controlled Autotransformer through magnetic contactor.
3. After charging of capacitors, Arduino Board will disconnect the autotransformer by opening magnetic contactor and command it to rotate back to initial position (0 volts) and fire the Trigatron to discharge the capacitors across testing object.
4. Lastly, stepper motor set back the sphere gap to initial position to eliminate the residual charge in capacitors.

As shown in Fig 6:

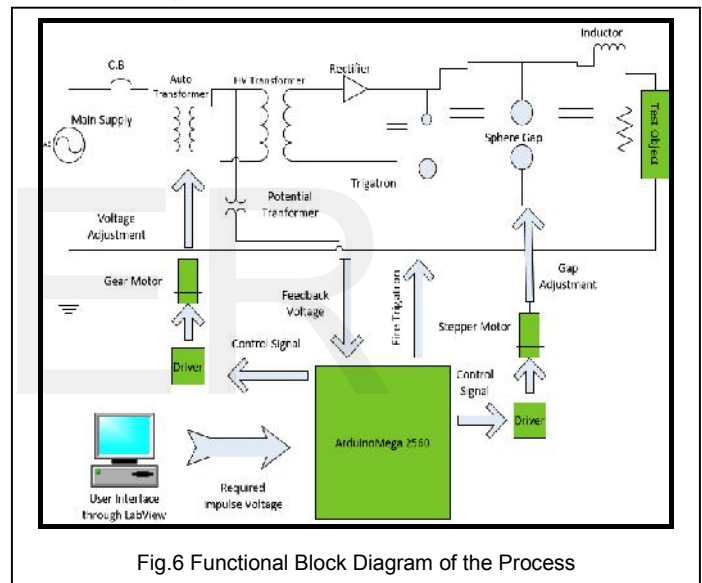


Fig.6 Functional Block Diagram of the Process

**4 ARDUINO MEGA 2560**

In order to understand Arduino one must have a sound knowledge of programmable logics and basic knowledge of the tactics used for such kind of control. Whenever intelligent systems are involved we must clearly know the "Microprocessors" are involved. In the 21<sup>st</sup> century everyone is aware of them as it would not be wrong to say that they are the "Digital Brains" of any system involving them. For example take my Impulse generator, currently everything is being done by specialized personnel with great care especially during charging the capacitors up to a very high voltage. I can teach it to the micro-computers just once and do the same work with great ease in the future.

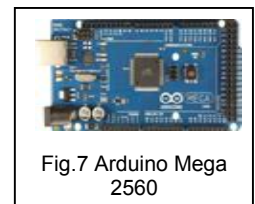


Fig.7 Arduino Mega 2560

### 4.1 Why Arduino Mega Board?

Microprocessor is only the brain and we need some non-intelligent devices which “do as instructed” by the processor. Here is when peripherals come in, so the first option we get to use is a microcontroller which comes with many peripherals e.g. ADC, Serial Communication etc. but still these were not enough for me so I moved onto Arduino board which is a complete package with built in code burning facility.

### 4.2 Overview

The Arduino Mega 2560 is a complete package based on the ATmega2560 controller. Its salient features are as follows:

1. It has 54 digital input/output pins (out of which 15 pins can be used as PWM outputs)
2. 16 pins can be used analog inputs (Integrated ADCs are connected to them)
3. 4 UARTs (Hardware serial communication ports)
4. 16 MHz crystal oscillator
5. Built in USB communication support
6. Power jack for external supply in case if it is a standalone system
7. ICSP header and a reset button
8. Stronger RESET circuit
9. Atmega 16U2

### 4.3 LabView Interface for Arduino

The LabView Interface for Arduino (LIFA) allows users to control sensors and acquire data through Arduino using the graphical programming environment of LabView. LIFA uses open source Arduino firmware to communicate with LabView. LIFA provides a simple yet powerful API for Digital IO, Analog Input, SPI, I2C, PWM and much more. Following are some of the basic features of LIFA.

- Analog Input (Read an individual Analog Input Pin, Read the full Analog Input Port)
- Digital Input and Output Read or write (an individual Digital Pin Read or write the full Digital Port)
- Pulse Width Modulation (Write an individual PWM Pin, Write the entire PWM Port)
- Built In Sensor Support
- Stepper Motors Control (up to 7 stepper motors, fully configurable step and direction control)

## 5 SPHERE GAP ADJUSTMENT

A sphere gap consists of two spherical electrodes separated by a gas-filled insulating interval. Sphere Gaps are used in Impulse Generator to apply the high voltage impulse by connecting the charged capacitors in series. In a single stage Marx Impulse Generator, two capacitors are charged in parallel to a desired voltage value. To retain this charge, a sphere gap is used which acts as a switch. When the breakdown occurs then these parallel capacitors are connected in series which makes the voltage at the output terminals twice of the input charging voltage of the capacitors. It is important to adjust the gap be-

tween the spheres so that when the Trigatron is fired then for sure breakdown of the gap occurs to apply the impulse voltage on the testing equipment connected at the output terminals.

### 5.1 Gap Measurement

The sphere gap mechanism is simple and easy to operate. The breakdown voltage of air is 33kV/cm at standard temperature and pressure conditions (ignoring effect of humidity). I used standard values of distance for different ranges of voltage. TABLE 1 gives the values of distances between spheres for different breakdown voltages.

TABLE 1  
IMPULSE VOLTAGES VS SPHERE GAP REQUIRED

Voltage (KV)	Gap (cm)
5	0.1437
10	0.2874
15	0.4310
20	0.5890
25	0.7603
30	0.9315
35	1.1181
40	1.3150
45	1.5117
50	1.7070

### 5.2 LabView Code for Sphere Gap Measurement

The code segment for sphere gap measurement is shown below in Fig.8:

```

Gap Measurement
v=v/2;
switch v;
case(5)
    gap=0.15+0.;
    vref=0.22;
case(10)
    gap=0.29+0.;
    vref=0.35;
case(15)
    gap=0.43+0.2;
    vref=0.55;
case(20)
    gap=0.59+0.2;
    vref=0.76;
case(25)
    gap=0.76+0.3;
    vref=0.98;
case(30)
    gap=0.93+0.4;
    vref=1.22;
case(35)
    gap=1.12+0.5;
    vref=1.40;
case(40)
    gap=1.32+0.5;
    vref=1.65;
case(45)
    gap=1.51+0.6;
    vref=1.83;
case(50)
    gap=1.71+0.7;
    vref=2.05;
otherwise
    gap=0;
    vref=0;
end
ps=nstp;
nstp=round((1200/11.7)*gap);
stm=nstp ps;
    
```

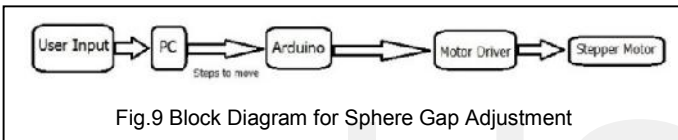
Fig.8 Code Segment for Sphere Gap Measurement

### 5.3 Algorithm for Sphere Gap Adjustment

The Basic algorithm for the adjustment of distance between sphere gaps is as follows:

- User inputs the required impulse voltage into the main computer.
- The main computer sends a signal to Arduino via USB according to the received value of voltage.
- Arduino compares the value of voltage entered with that of distance for the specified range.
- By deciding the distance required between sphere gaps Arduino generates a signal for stepper motor (connected mechanically with the spheres) which performs calculated rotation adjusting the distance to specified value.
- This distance is kept during the whole charging process and after discharging the stepper moves back to initial position joining both the spheres to ground level.

These steps are shown in block diagram below:



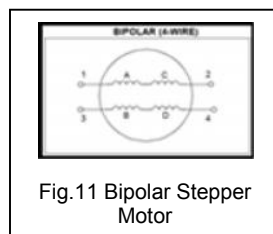
### 5.4 Stepper Motor

A stepper motor, as its name suggests, moves one step at a time, unlike those conventional motors, which spin continuously. Stepping motors fill a unique niche in the motor control world. These motors are commonly used in measurement and control applications. We used stepper motor because we command a stepper motor to move some specific number of steps, it rotates incrementally that many number of steps and stops. Because of this basic nature of a stepper motor, it is widely used in low cost, open loop position control systems. Open loop control means no feedback information about the position is needed. This eliminates the need for expensive sensing and feedback devices, such as optical encoders. Motor position is known simply by keeping track of the number of input step pulses.



It has following advantages:

- Brushless
- Load Independent
- Open Loop Positioning
- Holding Torque
- Excellent response

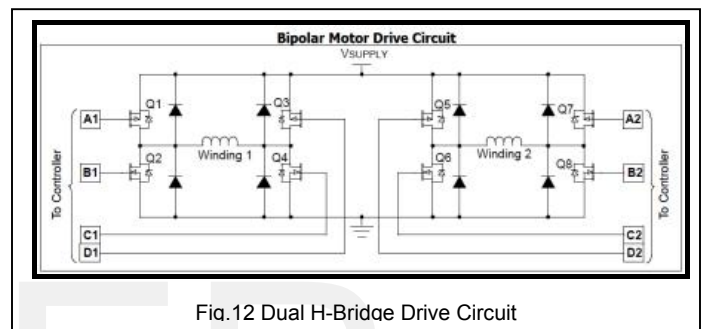


The two common types of stepper motors are the bipolar motor and the unipolar motor. The bipolar and unipolar motors are similar, except that the unipolar has a center tap on each winding. I used a two phase four wire bipolar stepper motor in my project because I needed high torque in adjusting sphere

gap distance. Its schematic diagram is shown in the Fig 11. Unlike unipolar motors, bipolar motors have no center taps. The advantage to not having center taps is that current runs through an entire winding at a time instead of just half of the winding. As a result, bipolar motors produce more torque than unipolar motors of the same size. Bipolar motors have approximately 30% more torque than an equivalent unipolar motor of the same volume.

### 5.5 Drive Circuit

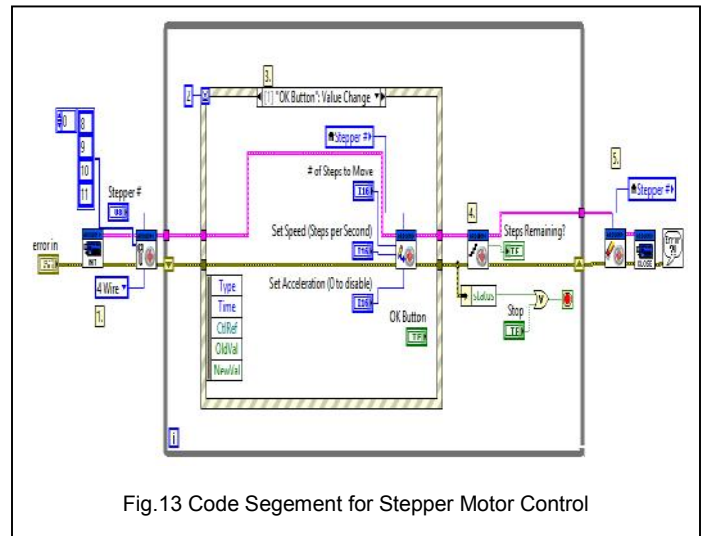
Bipolar stepper motors do not have the center tap. That makes the motor construction easier, but it needs a different type of driver circuit which is called an H-bridge because it resembles a letter 'H'. The current can be reversed through the coil by closing the appropriate switches. A bipolar drive circuit is shown in Fig 12.



After that we need a sequencer to issue proper signals in a required sequence to the H-bridges. Two H-bridges are used to control two windings of the stepper motors as shown in the Fig 12.

### 5.6 LabView Code for Sphere Gap Adjustment

The code segment for Stepper motor control is shown below in Fig.13:



## 6 CHARGING OF IMPULSE GENERATOR

Let's have a look at the details of each and every device involved during this operation.

**6.1 Auto Transformer**

It is the main part of charging phase. An autotransformer is an electrical transformer with only one winding. In an autotransformer portions of the same winding act as both the primary and secondary. The winding has at least three taps where electrical connections are made. An autotransformer can be smaller, lighter and cheaper than a standard dual-winding transformer however the autotransformer does not provide electrical isolation.

In my project I have used an autotransformer of 5 KVA with winding having current rating of 15A.

**6.2 Potential Transformer**

Potential Transformer is used in electrical power system to step down the voltage to a safe value which can be fed to low ratings meters and relays. Commercially available relays and meters used for protection and metering, are designed for low voltage. PT theory is just like theory of general purpose step down transformer. Primary of this transformer is connected across the phases or ground depending upon the requirement. The input voltage is applied across the terminals of primary winding of that transformer, and then proportionate secondary voltage appears across the secondary terminals of the PT. In an ideal PT, when rated burden connected across the secondary the ratio of primary and secondary voltages of transformer is equal to the turn ratio and the two terminal voltages are in precise phase opposite to each other. But in actual transformer there must be an error in the voltage ratio as well as in the phase angle between primary and secondary voltages.

We used 220/9 voltage ratio potential transformer in the feedback loop to get feedback voltage from the autotransformer to accurately adjust the charging voltage.

**6.3 Relay**

A relay is an electrically operated switch. Many relays use an electromagnet to operate a switching mechanism mechanically, but other operating principles are also used. Relays are used where it is necessary to control a circuit by a low-power signal (with complete electrical isolation between control and controlled circuits), or where several circuits must be controlled by one signal. We used two relays in my circuit:

1. For opening the charging circuit when the capacitors are charged to the desired value. It is a 30A 12V dc relay.
2. To fire the Trigratron when required. Its rating is 9A 12V dc.

**6.4 Algorithm for Charging Process**

The Basic algorithm for the charge control unit of IG is described below:

- User inputs the required impulse voltage into the main computer.
- The main computer sends a signal to Arduino via USB according to the input.

- Arduino (after adjusting sphere gap) starts moving the autotransformer in order to increase the voltage on the primary of HV Transformer.
- It continuously takes feedback of the voltage in order to make sure that the capacitors are charged to desired voltage.
- Upon reaching the specified value of voltage, it is cut off from the circuit (after a short delay due to charging time constant) by sending a command signal to 12V dc relay.
- After this process the IG is ready to provide us the desired Impulse when Trigratron is fired.

Its functional block diagram is shown below:

**6.5 LabView Code for Capacitor Charging**

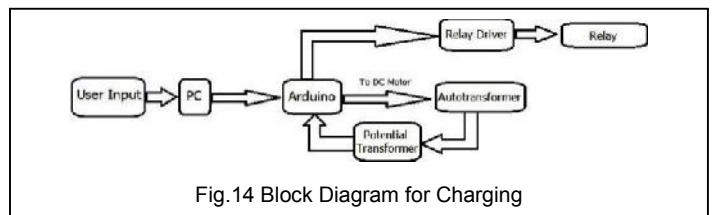


Fig.14 Block Diagram for Charging

The code segment for capacitor charging is shown below in Fig.15:

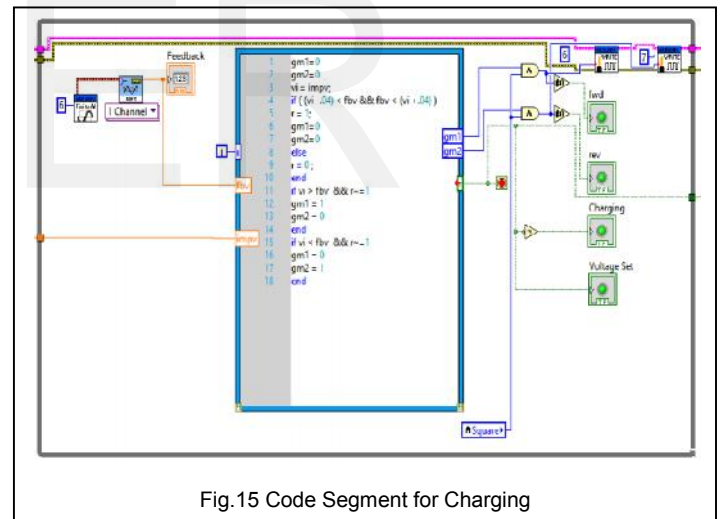


Fig.15 Code Segment for Charging

**7 IMPULSE APPLICATION AND DISCHARGING**

After charging the capacitors and disconnecting the auto transformer from generator, we are ready to apply the impulse on the testing equipment. Impulse is applied by using a Trigratron. When Trigratron is fired, double voltage appears across the sphere gap which causes its breakdown. This breakdown brings the charged capacitor in series and impulse is applied on the equipment.

After application of impulse it is necessary to discharge the capacitor to eliminate the residual charge present in the circuit. For this purpose grounding of the capacitors is required. To achieve this goal, spheres are joined together by using stepper motor already present in the control circuit. After joining them together we have to fire the Trigratron again to ground the capacitors to eliminate the residual charge.

### 7.1 LabView Code for Impulse Application and Discharging

LabView code to apply the impulse and discharge the circuit is shown below in Fig.16:

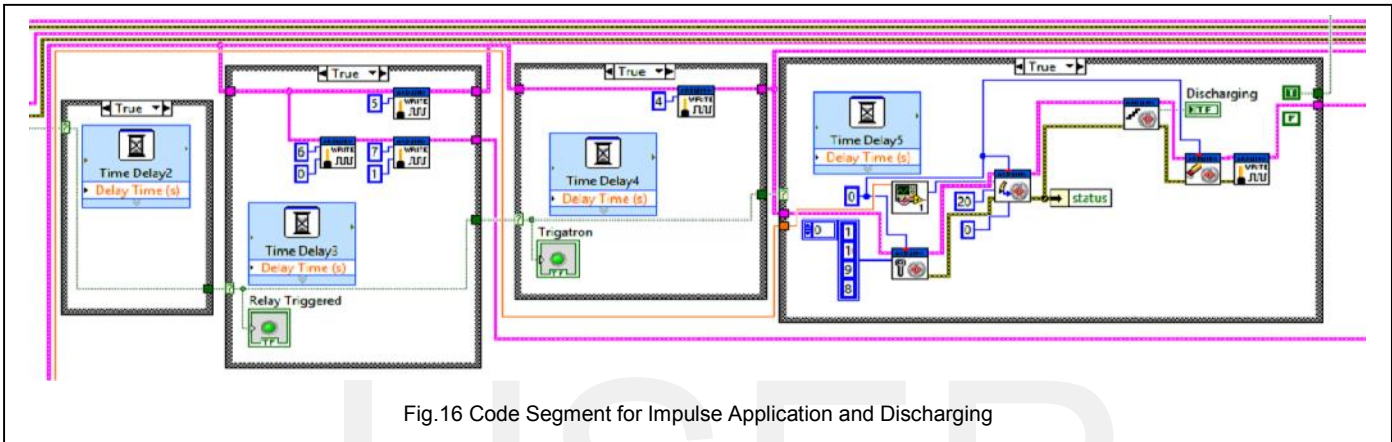


Fig.16 Code Segment for Impulse Application and Discharging

### 8 USER INTERFACE WINDOW

Fig.17 shows the user interface window on Labview software where he can enter the input and observe the whole process completing its stages step by step. Each stage of the process has its corresponding LED on the user interface window to know the current stage of the impulse generator.

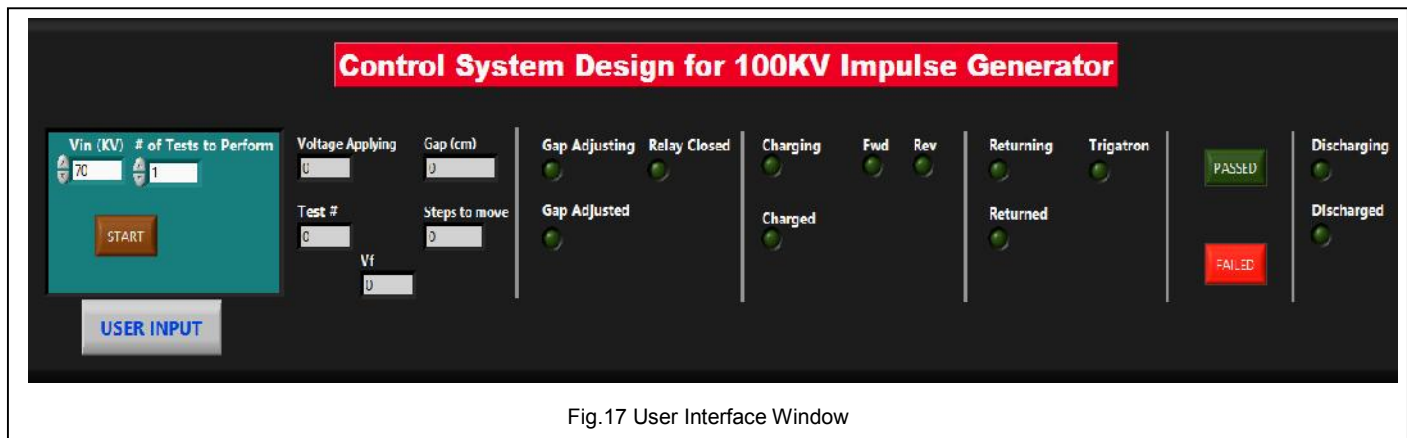


Fig.17 User Interface Window

## 8 CONCLUSIONS

Computerized control systems have significantly improved operations of systems over the last ten years. In the scope of industrialization, automation is a step beyond mechanization. Automation greatly decreases the need for human sensory and mental requirements while increasing load capacity, speed, and repeatability. Now this automated impulse generator has achieved

- Speed
- Repetition
- Efficiency
- Human safety
- Adaptability

The summary of the complete control system is shown below in Fig 18.

In concluding lines we must say that we are really delightful to implement such task for our University's High Voltage lab. It will really help the upcoming sessions in doing their lab tasks and will motivate them to do such projects in near future which are beneficial to them and the University.

## ACKNOWLEDGMENT

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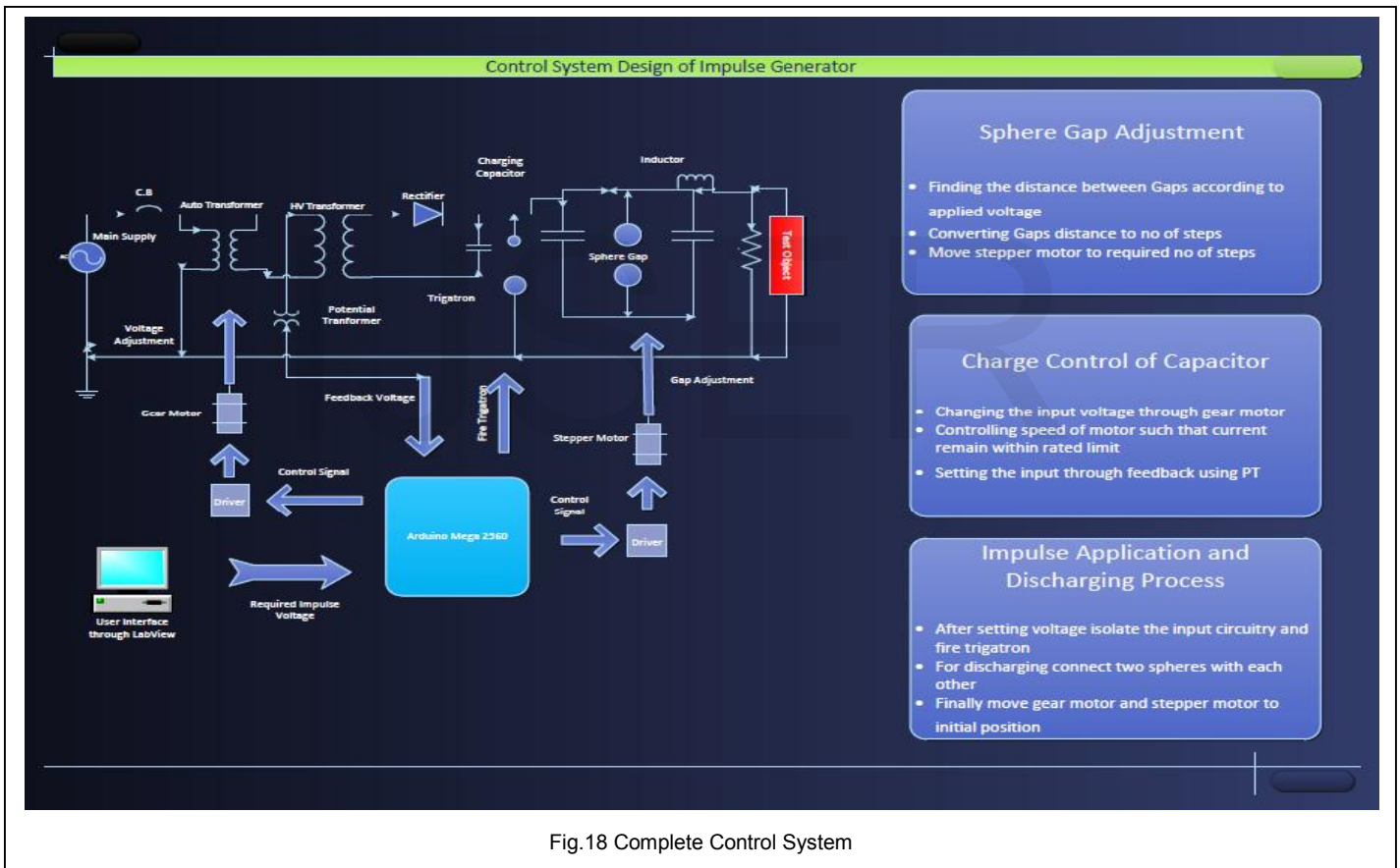


Fig.18 Complete Control System

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