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Design and implementation of a novel dust collector controller for powder production industry

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Abstract

Industries those work with powder either in production or processing always left a portion of industrial dust in the air. By releasing this air directly in the surrounding environment of the industry pollution occurs. Therefore air filtration system is mandatory in these industries and usually bag filter dust collector controller is used. To control and maintain the proper functionality of the bag filtration system PLC based control system or a modular control board is used. In this paper, a novel dust collector controller is designed which can be installed by any user without having any programming knowledge. The main control keys of the control board are the pulse duration and pulse interval which drive the solenoid valves to release air pressure on the filter bags sequentially. Pulse duration can be controlled in the range of 0.01-0.9 seconds and pulse interval can be varied in the range of 1-99 seconds to control 10 rows of pulse jet simultaneously connected with the solenoid valve. The Number of rows can be adjusted and expanded if required. Moreover, noiseless switching provides silent operational functionalities and switching durability as well as the addition of surge controller ensures a complete protection from any sudden high electrical surge. The finally developed prototype was tested in different industries and provides maximum operational efficiency, which can effectively control online bag filter dust collector to separate micro dust particles from the polluted air.

Keywords: Dust Collector; Air Pollution; Pulse-jet; Baghouse; Industrial Controller; Powder Production Industries

1. Introduction

Different types of powder processing industries such as cement, coal, steel, electricity, flour, feed industries and building industries produce an uncountable amount of dust [1]. The emitted dust particles are not only harmful for the industry workers but also for others in the society and the atmosphere. The control of emitted dust particles is being more significant [2,3]. Authors have shown that, construction industries are the major sources of dust pollution and construction practitioners may face long-time illness or premature death [4,5]. The worldwide Environment policies are being improved and becoming stricter for industries. Industries use dust collector to separate dust particles from air or gas. A numerous types of dust collector are available such as electric dust collector, cyclone type, wet dust collector, bag filter, and so on [6]. Among the various types of dust collector bag filter dust collector is more popular and widely used for being cost effective and high efficiency [7]. Already a lot of works has been done for improving the filtration procedure of bag type dust collector. Researchers have studied cleaning mode influence on pressure drop under varying particle size on the filter. The study on Clean-on-Demand (C-D) mode vs. Clean-on-Time (C-T) mode was carried and concludes that the C-D mode is better than C-T mode for fine and medium particulate matters, while C-T and C-D mode shows equal performance for large particulate matters filtration [8]. A sawdust dust removal system was proposed in which PLC control technique is used to design the system [9]. Similarly, a novel colliding pulse jet for dust collection system was designed and later the performance was evaluated mathematically. Authors have studied pulse-jet performance, air consumption and nozzle outlet pressure in top-jet, bottom-jet and colliding cleaning mode. They

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have also studied the influence of trigger time [10]. Authors in [11] have studied the stability of pulse-jet regenerated bag filter operation. They have also studied the effect of upper and lower pressure drop effects on stable and unstable operation. Authors have proposed a modular control board that is capable to operate in both AC and DC current and can be configured or programmed through PC [12].

No other studies have been found on programming technique or User Interface (UI) programming of the bag filter controller. That makes the installation easier for any user by spending a couple of minutes. At present these bag filter dust collector controllers are operated through PLC devices which require a PLC programmer to program and reinstallation of the controller in the industry site. In developing or under developed countries, it takes a few or a couple of days to manage a PLC programmer in case of damage or malfunction. This leads to a sudden downtime in production as the filtration system becomes shutoff. Electrical surges one of the major issue which may damage the controller is a prior concern in designing the industrial controller [13]. By addressing these limitations, we have proposed a novel dust collector controller prototype, that is capable to program and install by anyone without having PLC programming knowledge, so that the minimization of installation time can be obtained in case of any device malfunction or damage. In addition to achieve this goal, the prototype should be developed to integrate with the existing bag filtration system running in the industries and capable of running effectively in both Alternating Current (AC) and Direct Current (DC). Finally, the device was designed to be durable in switching operation and protective from any electrical surge that may damage or cause any malfunction in the processing section of the controller.

2. Existing Baghouse Configuration

Baghouse is the chamber in which a lot of bags are organized in matrix form. The bags are organized in rows and columns. The baghouse are placed vertically to use the gravitational force leading to collect dust particles presented in the air. The entire bag house is divided into two successive chambers or spaces. Dust containing air is inserted into the lower chamber of the baghouse through an inlet and clean air is passed through the outlet from the upper chamber. Here, air can be passed from the lower space to upper space only through the filter bags. A bag cage is inserted into each filter bag to ensure proper alignment of bag cartridge during operation. As the dust containing air is passed through the filter bag, the tiny holes of the bag filter become filled with dust particles. An air reserve tank or concealed chamber with pressure indicator is attached or connected through pipe with the baghouse. Air contains humidity and to be removed through filtration process before being used it in pulse jet [14]. Air is compressed under pressure in the chamber before being released through pulse releasing nozzle.

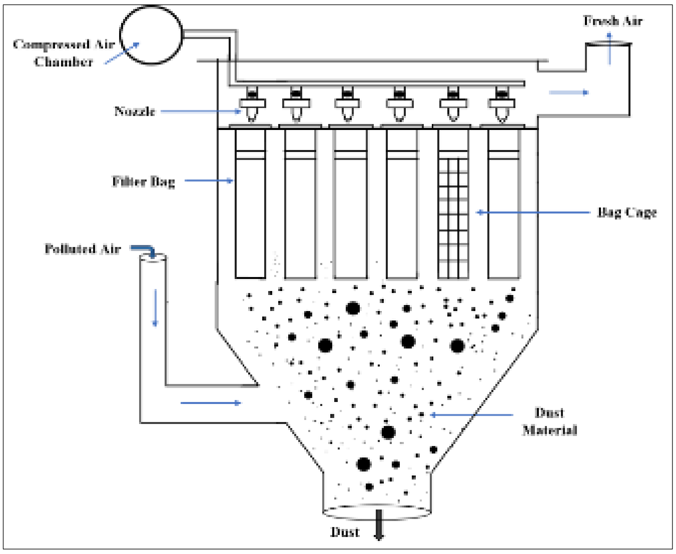

Figure 1 Baghouse configuration of dust collector.

Each row or column of filter bags is controlled through a solenoid valve. Generally 7 to 16 such rows are very common in the existing industries. The number of rows indicates the number of solenoid valves to be controlled. These bag filter dust collectors can be controlled in either online and offline mode of operation and the operational procedure is different in online and offline mode. In online mode, the pulse-jet cleaning with the fan still running and airflow unstopped while in offline mode the pulse-jet cleaning with the fan and airflow is stopped [15]. So the programming of the controller should be different. As, the controller is developed to be operational in online mode, each solenoid valve of the dust collector is energized for a particular time while suction fan is running. Typically each valve is energized for ms (milliseconds) which is termed as pulse width/ duration and the time required to energize the next solenoid valve is termed as pulse interval time typically in sec (seconds). The entire baghouse configuration can be realized from Figure 1.

3. Proposed Controller System Architecture

Figure 2 illustrates the block diagram of the controller system architecture. At first AC power is given to the AC to DC power conversion circuit through current and voltage protection unit. In this section, current is limited by fuse and high voltage spike or surge is protected. In the next stage, pure 5 volt DC is produced to provide supply in the control section. The next stage is control section. This section includes a manual input switch which set the saved program to run in either programming mode or in run mode. In programming mode, the push button input section is used to adjust the pulse width and pulse interval. The program is saved in the microcontroller processing unit. Two 7 segment displays are used to show the pulse width, interval and valve number. The upper display shows the pulse width and interval time sequentially in programming mode and in the run mode it displays the countdown of the interval time. The lower 7 segments only display the valve number. The solenoid valves are controlled through Solid State Relay (SSR) control unit. The entire controller system is divided in 4 sub-sections. The main function of first section is to convert the AC to DC and provide required protection in industrial operation. This section can be omitted by applying required DC voltage to the control section. Following section performs processing and control mechanism and it is operated by using interfacing through microcontroller. The third section performs actuation to control the solenoid valves which directly performs the cleaning process. The last section is also SSR control module. The only difference is that it has the capability to control 6-solenoid valves whereas the previous could control 10-solenoid valves.

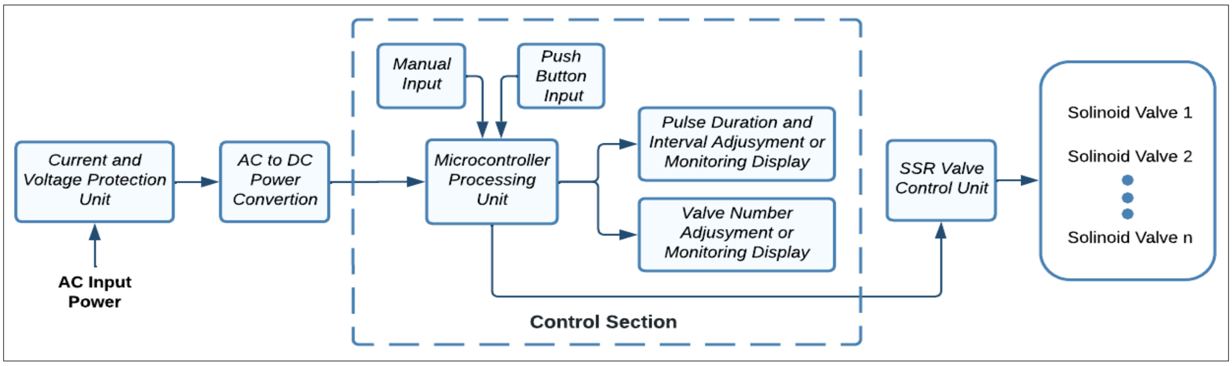

Figure 2 Block diagram of the controller system architecture.

3.1. AC to DC Conversion Section

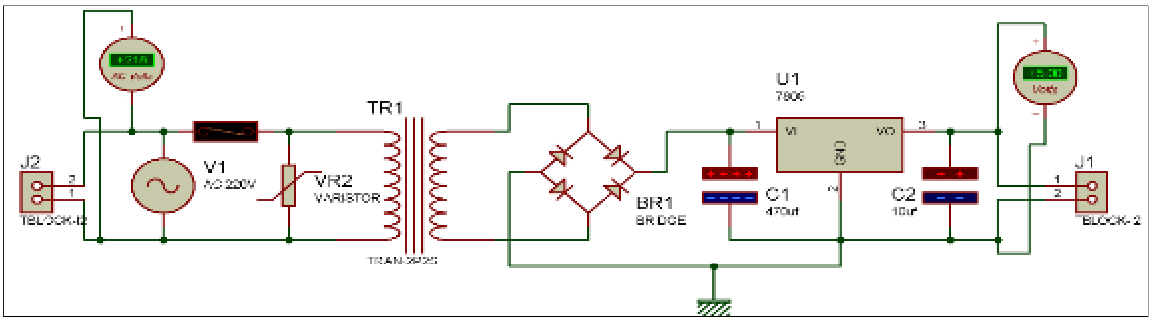

Figure 3 Simulation circuitry of AC to DC conversion unit.

This section provides necessary power supply for control section, switching circuit and cascade unit. The conversion of 220 volt AC to 5 volt DC is the main responsibility of this section. The corresponding simulation circuitry is shown in the Figure 3. At first, AC current is passed through a fuse, which provides high current protection functionality. Later, a surge protector is used in parallel with the AC. The details of the surge protector can be found in the book [16]. Now, the high voltage AC is converted to low voltage AC through step-down transformer. Then the reduced AC voltage is applied to a full wave bridge rectifier. The rectifier produces a pulsating DC voltage, which is applied to the 7805 linear voltage regulator IC through a capacitor. The use of capacitor makes the DC voltage linear. Finally 5 volt linear DC voltage is obtained at the output of the 7805 IC.

3.2. Control Section

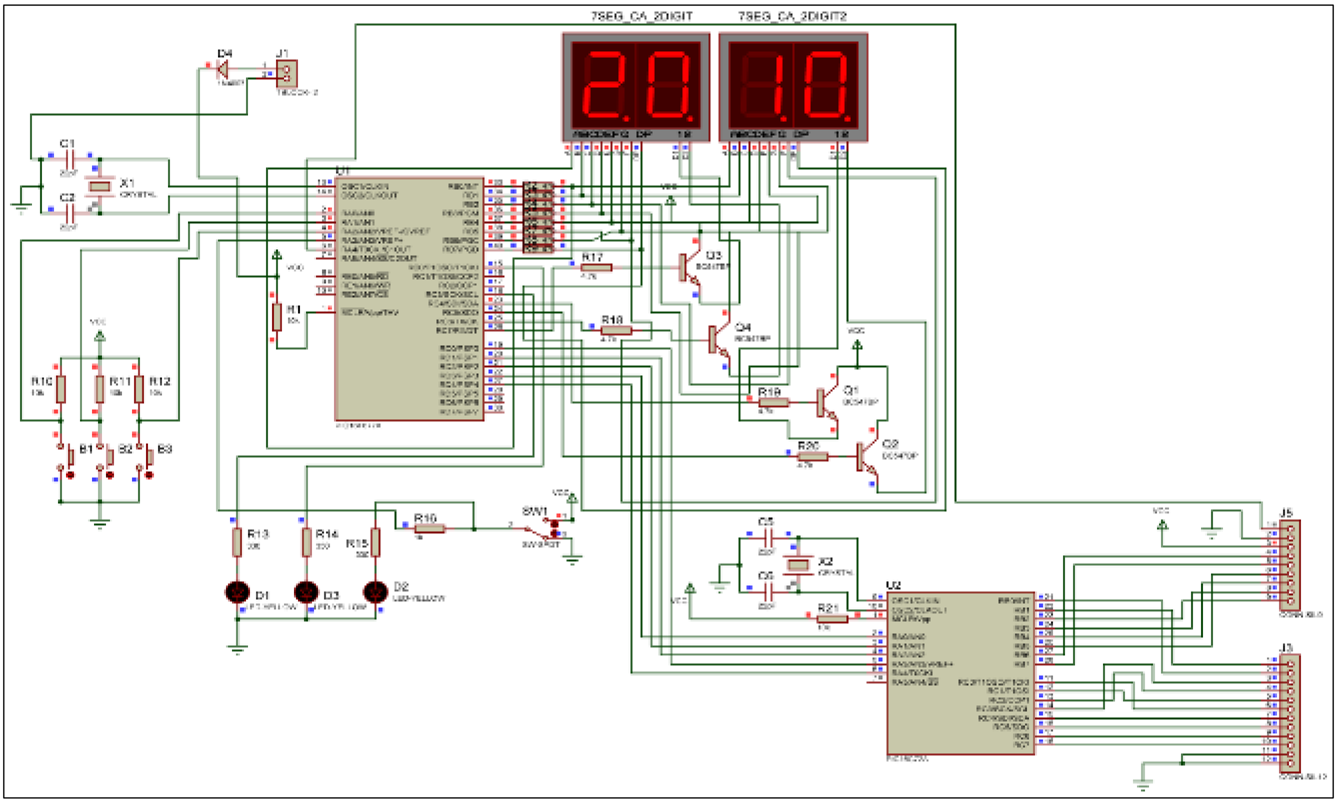

Figure 4 Simulation circuit diagram for processing and control unit.

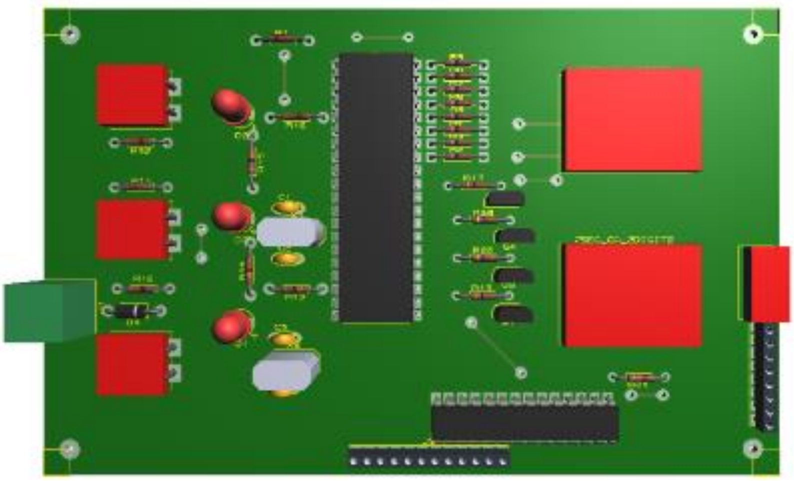

Figure 5 Virtual PCB arrangement of Control Section.

The circuit diagram and PCB visualization of the controller can be seen from Figure 4 and Figure 5 respectively. PIC16F877A microcontroller is used as the core processing unit, which is programmed using mikroc programming language. The external clock pulse for the microcontroller is set at 8 MHz and supplied through a crystal oscillator indicated by X1. The simulation is performed using Proteus ISIS Professional software. Here, switch SW1 is used for mode changing of the programming. If the connected pin voltage of the microcontroller is kept low the entire system will work in run mode, otherwise the circuit will work in programming mode. We have used two seven segment multiplexed displays for displaying the valve control parameters. Each digit display is shown alternatively for 10ms duration. As a result, two digits visualization can be obtained from the display. The uses of 7 segment displays ensure proper calibration of parameters in high precision rather than the use of a potentiometer. In the proposed system, the parameters pulse interval and pulse duration always remain constant and it maintains an infinite loop for n number of channels. The left three push buttons indicating B1, B2 and B3 are used for parameter adjustment. LEDs D1, D3 and D2 indicate the parameters which are being adjusted at that time. We have also used another microcontroller PIC16C72A for controlling the next actuation section and cascade unit. J3 is used for 10-channel SSR circuit module and J5 is used for 6-channel cascade unit.

3.3. Switching Circuit and Cascade Unit

The switching circuit includes an arrangement of SSRs (Solid State Relay). This section includes 10 SSRs in a parallel arrangement and can be controlled through a PIC16C72A/ PIC16F72 microcontroller. Here, PIC16C72A works as a decoder circuit. Required switching time for each cycle is:

$$\psi = n \times \sum_{i=1}^{n} (\tau + \delta) ----(i)$$

Where, ψ and n indicates switching time for each cycle and number of rows or solenoid valves respectively. τ refers to the pulse duration or pulse width, δ stands for pulse interval and $i = 1,2,3 \dots n$. The main switching element is BTA12 Triac. As the Triac operates with the AC current, the control circuit having microcontroller is separated through MOC3021, which is Triac driven zero-crossing optocoupler. MOC3021 has a light and a light sensing device with no internal connection. They are connected optically i.e. switching is done through optics [17]. Through this way, logic level voltage can control the high voltage AC current required to operate solenoid valve in the industries (Figure 6, 7).

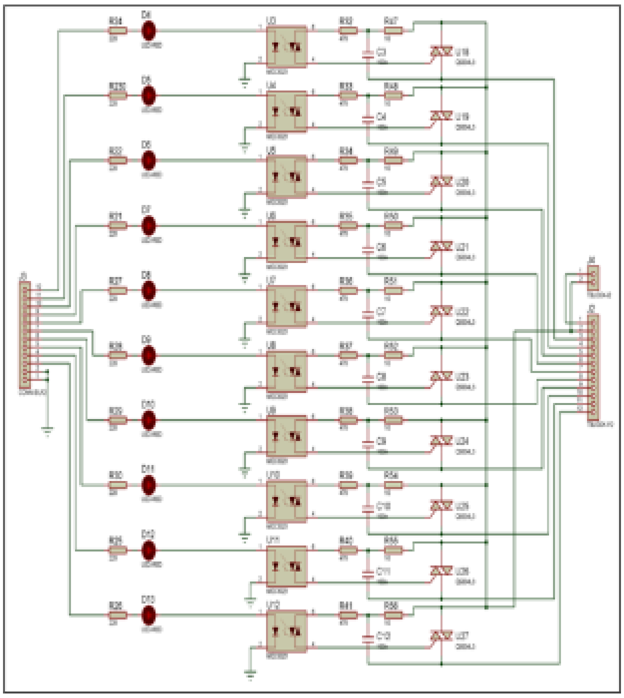

Figure 6 Circuit diagram of the switching circuit

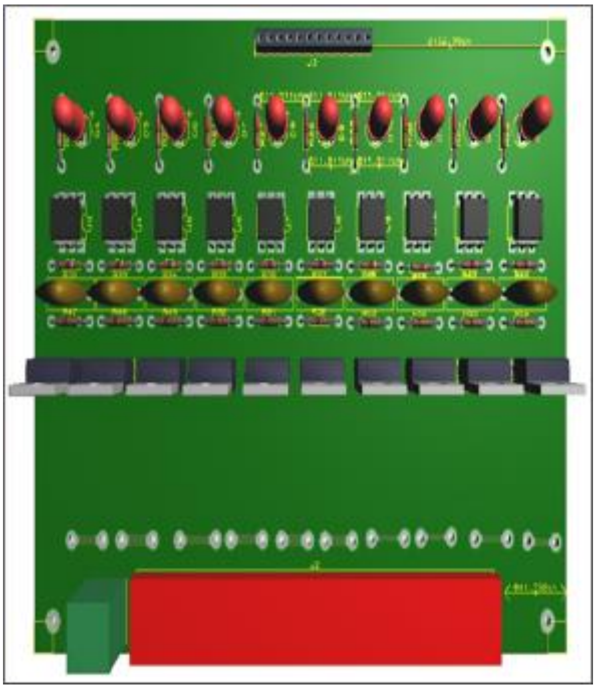

Figure 7 Virtual PCB arrangement of Switching Circuit

The Cascade unit is as same as the switching circuit shown in Figure 8. Except that it contains six SSRs that can be connected in a cascade fashion to the main controller unit. This section can be connected through a DB9 Female and Male connector. If the demand of controlling solenoid valve exceeds more than 10 then this unit can be connected.

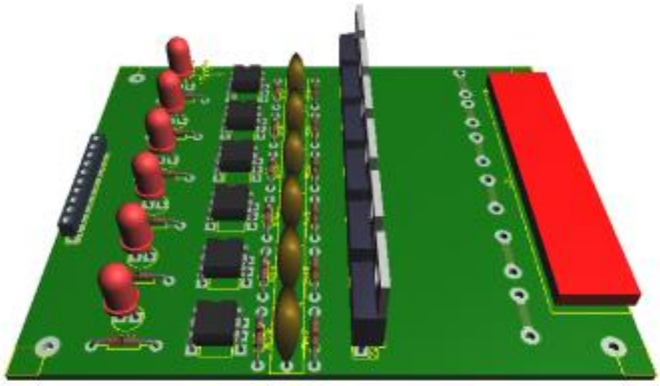

Figure 8 Virtual PCB arrangement of Cascade Unit.

3.4. Operational Flow Diagram

Operational flow diagram can be understood by the flow chart given in Figure 9. This section performs the main programming functionality through User Interface (UI). The internal programming is done in such a way so that the parametric adjustment do not require PLC coding leading to reduce the industrial downtime in case of any malfunction or damage. To adjust the parameter user needs to follow the flow diagram. At first the system is given necessary power which may be AC or DC. After that, controller operational mode is selected, which can be operated in either programming mode or run mode. In programming mode, the pulse width, pulse interval and channel number can be selected, adjusted and saved in Electrically Erasable Programmable Read Only Memory (EEPROM) sequentially by using three buttons. The switching from one parameter to another is performed by holding button B3 shown in Figure 4. After setting all the parameters user needs to operate the program in run mode. In run mode, the saved parameters of the EEPROM are read and according to the program specific SSR is triggered sequentially to activate the specific valve.

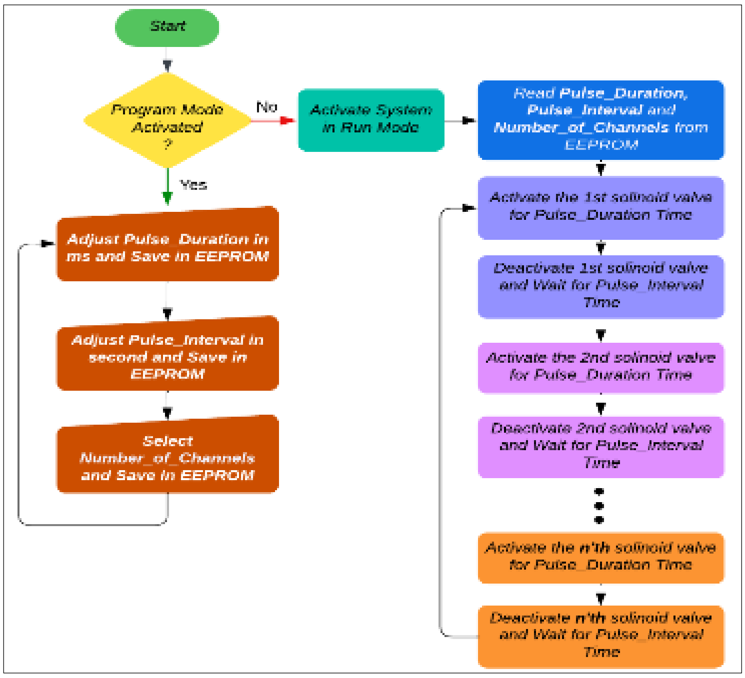

Figure 9 Operational Flow Diagram of the controller.

4. Result and Discussion

The simulated controller circuit has been assembled and the hardware setup of the controller can be visualized from the Figure 10.

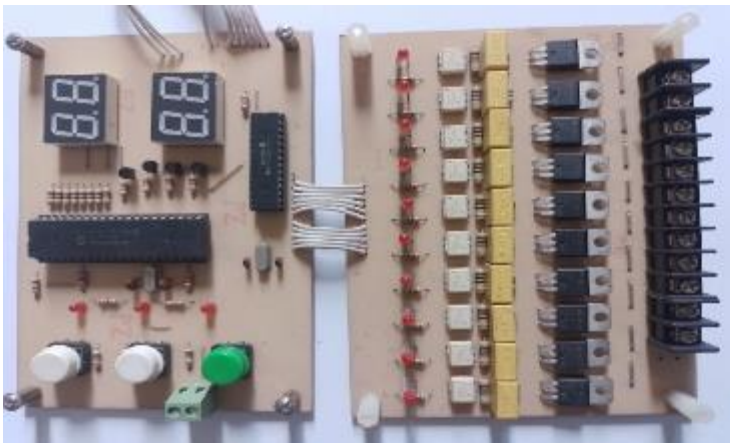

Figure 10 Hardware setup of the controller circuitry.

The above circuitry has been installed in three different powder producing industries and the operational time in each day has been observed and recorded in hours for 30 days. The recorded data are represented in the table-1. After organizing the table data in ascending or descending order their median values can be calculated as:

$$Median, \vartheta = \begin{cases} X\left[\frac{i+1}{2}\right], & if\ i\ is\ odd \\ \frac{X\left[\frac{i}{2}\right] + X\left[\frac{i}{2}+1\right]}{2}, & if\ i\ is\ even \end{cases} ----(ii)$$

By using the above equation, we get

$$\vartheta_1 = \frac{X_1[15] + X_1[16]}{2} = 20\ hr ----(iii)$$

$$\vartheta_2 = \frac{X_2[15] + X_2[16]}{2} = 19\ hr ----(iv)$$

$$\vartheta_3 = \frac{X_3[15] + X_3[16]}{2} = 16\ hr ----(v)$$

Where,

X_1 represents sorted data for plant-1 and ϑ_1 represents corresponding median operational time.

X_2 represents sorted data for plant-2 and ϑ_2 represents corresponding median operational time.

X_3 represents sorted data for plant-3 and ϑ_3 represents corresponding median operational time.

Table 1 Data table for operational time observation

Plant No.	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**	**Day 8**	**Day 9**	**Day 10**	**Day 11**	**Day 12**	**Day 13**	**Day 14**	**Day 15**
Plant-1	20	21	19	21	20	22	8	22	21	23	23	21	21	6	22
Plant-2	19	18	20	21	19	19	17	18	19	6	17	19	20	21	20
Plant-3	17	18	17	16	16	17	16	15	14	6	15	18	17	18	18
Plant No.	**Day 16**	**Day 17**	**Day 18**	**Day 19**	**Day 20**	**Day 21**	**Day 22**	**Day 23**	**Day 24**	**Day 25**	**Day 26**	**Day 27**	**Day 28**	**Day 29**	**Day 30**
Plant-1	19	18	21	22	22	8	21	18	19	20	20	19	7	20	18
Plant-2	18	20	20	20	0	20	21	19	22	19	20	20	18	19	6
Plant-3	17	16	17	18	6	18	15	16	14	12	14	18	15	17	6

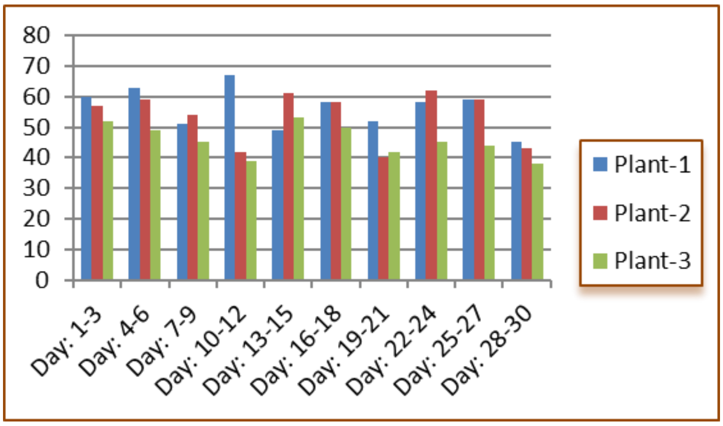

Figure 11 Bar Diagram representation of operational time for 30 days observation.

Later, we have plotted the summation of three day's operational time, which represents a single bar in the bar diagram shown in Figure 11. Three colors are used to differentiate three different plants represented as plant-1 (Blue bar), plant-2 (Red bar) and plant-3 (Green bar). Due to load shedding, factory operational issues and requirement of production capacity each bar represents a different time interval. The bar apexes for each industry form wave shape. The miniature bar indicates factory maintenance time after certain time duration. We have also calculated the median values to find out the central tendency of operational time. The values represent a good operational time for each day of the controller in the industrial test. The test also proves that no further manual action is required for the controller at power reset.

5. Conclusion

In this paper a novel dust collector controller has been proposed, which solves the programming time delay problem of PLC devices through expert. Such existing controllers require PLC programming knowledge to setup the controller in case of any malfunction or damage, they may not have any display for precision tuning or doesn't have proper safety circuitry. To address these drawbacks we designed a UI based novel bag filter dust collector controller, which solves all the above mentioned problems. It can be programmed almost instantly in a high precision, without having PLC programming knowledge. This becomes possible due to the efficient interfacing of microcontroller. In addition, the switching for each valve is done through triac instead of typical relays. This provides noiseless switching capability and switching durability for long term. The controller can be installed in any existing bag filtration system without any modification in the mechanical setup which provides the best integrity with the existing system running in today's industries. The device can be powered through AC or DC power and can handle the AC solenoid valves for ms duration. The industrial test shows that the controller can handle 16 to 20 hours operation easily in the industries and no manual restart or setup is required in case of power reset.

Compliance with ethical standards

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Disclosure of conflict of interest

All authors declare that they have no conflicts of interest.

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