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Intelligent Technique to Protect Sensitive Devices from Overvoltage

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Abstract

Objectives: Main objective of the research is to protect multiple ICs on a single PCB board from DC overvoltage through a high-speed MOSFET driver unit. Within 150 μs loads must be isolated from the DC power supply. As DC power becomes again stable the load must be automatically reconnected to the DC power supply. This method should be scalable to AC power supply also. **Methods:** A high-speed PIC 16F877A microcontroller is used whose one machine cycle time is 0.20 μs. The ADC module is operated at its highest speed. Multiple IC loads are connected to the DC power supply through the MOSFET driver circuit. If overvoltage is detected then the load gets isolated from the DC power supply within 131 μs, after becoming DC power supply is stable, the load should be reconnected. PIC 16F877A should provide power on a delay of 10 seconds. **Finding:** Operating the PIC 16F877A microcontroller and the ADC module at the highest speed is the first finding. The second finding is that the total detection, processing, and activation time is 131 μs. The last finding is that connects multiple ICs on a single board series through MOSFET to the DC power supply. PIC microcontroller should provide power on delay. **Novelty:** It is a totally new concept of connecting load to DC power supply through MOSFET driver circuitry. Traditionally it is observed that DC loads are paralleled and connected to the DC power supply and if the DC power supply becomes over then all loads get at the time burned. To overcome this problem we found a technique where all DC loads on a single board must be connected to the DC power supply through high-speed MOSFET driver circuitry so that before burning DC loads MOSFET driver circuitry will isolate these loads from the DC power supply and this is the novelty of our research.

Keywords: Surge Pulse; Overvoltage; High Speed; Series Load; Protection

1 Introduction

D.F. Alfrow & et.al[1] proposed a controlled vacuum discharger-based automatic discharge device technique for protection against switching overvoltage was put forth. The discharge device is made to shunt the inductance of the DC traction network during switching overloads accompanied by a power outage as well as the reactor of the traction substation. They proposed an analog method of isolation that takes time in milliseconds.

Vladan M. Radulovic and et.al[2] worked on one of the most frequent causes of degradation, upset, failure, and/or damage to susceptible equipment in low-voltage (LV) AC power installations is voltage and current surges caused by lightning. Equipment is protected against surges using surge protection systems implemented with surge protective devices (SPDs) installed through LV power installations. Therefore, in order to provide self-protection against overvoltage, their manufacturers typically include built-in varistors inside of the power supply units of devices. Both their protection voltages and their capacity to absorb energy are low for these varistors. A detailed analysis of how built-in varistors with low protection voltages affect surge protection system performance is provided in this article. It operates for AC voltage and is not useful for DC isolation.

Y. Zhang and et. al[3] proposed an article concentrating on the issue that converter stations' relay protection circuits' overly lengthy voltage recovery times during lightning surges. An ultrahigh-voltage (UHV) converter station's relay protection circuit's surge protective device (SPD) is examined. The equivalent circuit model of a series-combined SPD is built based on the behavior of the gas discharge tube (GDT) and metal oxide varistors (MOV) during a 1.2/50 s lightning surge. The work is related to AC supply overvoltage protection.

S. Ravyts and et. al[4] proposed a study that evaluates the effectiveness of fuses as short-circuit protection in low-voltage DC microgrids. Key benefits include its simplicity, low cost, standardization, and low steady-state losses. Fuses may be useful in both DC and AC device protection. But the fuse has also an activation time in milliseconds. Baoze Wei et.al[5] proposed a method of short-circuit protection for a voltage source inverter-based uninterruptible power supply (UPS) system. In order to achieve high reliability of the UPS, short circuit and overvoltage protection schemes are necessary. But it is also restricted to AC supply protection only.

Jordon Shopov and et.al[6] proposed a method in which DC over voltage is detected through semiconductor devices and an LC-based isolating circuit activated. It also operates in milliseconds is the limitation of this method. Teik Hua Kuan and et.al[7] proposed a method where the electro-thermal behavior of varistors is used to get isolation from the surge pulse. Its operation time is in milliseconds also a limitation. Ekuewa and et.al[8] proposed a method for protecting loads from under-voltage and overvoltage by using a PIC microcontroller. However, they have not used the system for the highest efficiency level. Shaunbao niu and et.al[9] proposed the effects of solar plant connection to the grid. While connecting, AC overvoltage pulses are generated, and how to minimize these effects of AC overvoltage. Again these are also related to AC overvoltage protection.

The Datasheet of PIC16F877A shows that ADC's minimum time requirement is of 19.7 μs. Surge pulse width ranges from 2 μs to 50 μs. The fuse activation time duration is 100 milliseconds. MCB requires at least 2.5 milliseconds of time to trip MCB. The excessive voltage across the Zener diode shortens the Zener diode[10] and requires time in milliseconds. If we find the comparative study of all the above research articles all worked mostly on AC protection no one has worked to protect a number of ICs on a single board. By considering all these issues and our product's practical IC burning issue we decided to work on protecting IC on a single PCB board.

There are many ways to avoid overvoltage going across to the load in the traditional method. One of the methods is the fuse-burning method. In this method, we use a fuse of certain dimensions and keep it in series in a given circuit. If the current goes slightly above the rated current or limited current of the fuse, the fuse will burn. But this method is time-consuming before burning the fuse important IC may get burned. Its time tolerance is so high that a surge pulse can easily pass through it. So this method will be beneficial only in certain places like for the motor or where the motor does not burn in a given time so we can call this method 50% to 60% efficient.

Another method is by putting MCB in a series. In this method, the switch breakdown time is near about 2.5 milliseconds. Normally it should be less than 1 millisecond. Another method is putting the Zener diode in parallel but excessive power can also break to Zener diode and this is not too efficient a method. So by considering all these time issues an efficient method must be designed. The only option is we should use a method in which the processing, detecting, and action time will take less than one millisecond, We are suggesting here a method in which the total time is less than 1 millisecond, and all devices on single PCB board will be safe because within 150 μs time, all these devices gets isolated from DC power supply.

There are three important practical rules that must be followed.

1. Control (Driver circuit and loads are connected in series)
2. The detecting, processing, and acting time of the control circuit is less than 1 millisecond, it's in Microseconds
3. By default, the load is in the OFF state

The most important function of the method we are suggesting here is to operate the control (driver) unit in Microseconds. Another important thing is that by default the load is always isolated from the main DC supply. Even after doing this if an extra voltage comes, the control circuit will burn but nothing will happen to the load. Another important property of the control circuit is that it supplies DC supply to the load only if it is in working condition. If the control unit stops working for some reason, the load will not be supplied. That is, if the control unit does not operate due to the overvoltage, the load will not be supplied.

2 Methodology

2.1 System working

While understanding the working of the system there are two things we should keep in mind.

1. Load by default is OFF, no supply is going to it. Therefore, if the line voltage becomes excessive, the first control unit will shut down and automatically isolate the load.
2. Detection, processing, and activation time should be less than 200 Microseconds so the load will be isolated within the overvoltage pulse active.

Initially, the line voltage is fine while understanding the working. The control unit will turn ON. The load will be supplied through the control unit. Everything will continue smoothly. Now suppose an overvoltage is created, the first control unit will burn due to the created overvoltage. It will automatically isolate the load from the line voltage. This process will turn off the MOSFET switch. All this process takes less than 150 Microseconds. At such a high speed, the load line will be isolated from the voltage and will remain safe. In all these processes we have also given direct supply to the control unit, so sometimes if the excess voltage is generated, the control unit will also burn. If we supply the control unit through battery we can say 100% that both the control unit and the load will be very safe.

2.2 System flowchart

Figure 1 shows the flowchart of our proposed system. A single PCB board containing a number of ICs powered up. Initially main microcontroller PIC 16F877A is only powered up and all other loads are in an OFF state. The microcontroller will generate an initial power ON delay of 10 seconds. At this time microcontroller checks whether the supply is stable or not. After 10 seconds time, the microcontroller powers ON all other loads, and in interrupt mode it checks whether the supply is over or not. If the microcontroller detects overvoltage then within 150 microseconds all loads will get isolated from the DC power supply. In this way, the unit works. Figure 2 shows how many times traditional methods isolate the load. Activation time in the fuse method is 100 milliseconds. In the MCB method isolation time is 2.5 milliseconds. In the case of Zener protection, the Zener gets shorted as the extra voltage comes across the Zener. It is also in 10 milliseconds. In the same figure, it is shown that the surge pulse has an average pulse width of 50 Microseconds.

Figure 3 shows the block diagram of the proposed system. The most important part is the control unit, to which the load is connected in series. So if the control unit is not working then there will be a load isolated. The reason behind using the 4 MOSFET driver circuit is that the PIC microcontroller has by default 0-volt logic level on the port pin. Effectively Q2 turns ON giving logic 1 at an intermediate stage so to invert this logic 1 further complementary inverter is used so the final output becomes logic 0, i.e. to achieve by default output of logic 0, 4 MOSFETs are used.

3 Results and Discussion

Figure 4 shows the frequency of the crystal used is 20 MHZ which is the maximum operating frequency of PIC 16F877A microcontroller. Each machine cycle of the PIC microcontroller requires 4T states. So each machine cycle requires 0.20 Microseconds time for execution. As the program executes, the time taken by each step is shown. It takes 131 Microseconds to execute the total program, including detection, processing, and activation. Figure 5 shows the diagram of the proteus simulation. If the incoming voltage is acceptable, the load will turn ON. Here LED is shown as load. Figure 6 shows if the incoming voltage is under limit then after 10 seconds the load is activated. Figure 7 shows if the voltage is excessive then the load will isolate, i.e. the load will shut down. Figure 8 shows the hardware connection of the defined system. When power ON is detected. The load is connected through the MOSFET driver unit. As power ON is detected initially load is isolated for a power ON delay time of 10 seconds. After 10 seconds it starts to check whether the input DC voltage is either over or limited. Figure 9 shows that it has detected overvoltage and the load gets isolated within 131 μs time. Protecting IC on a single PCB board and isolating them

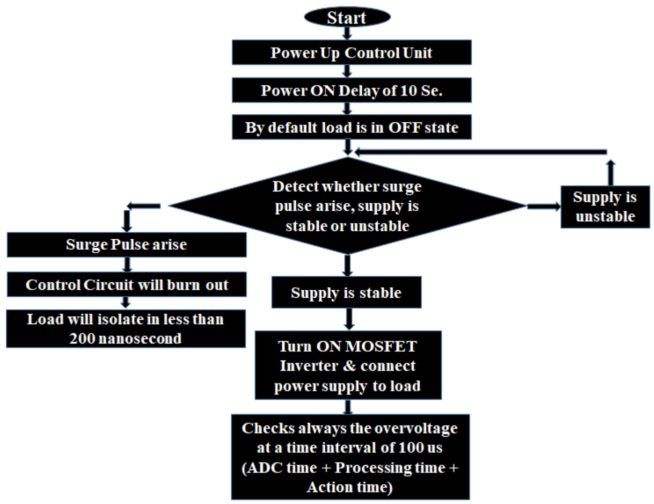

Fig 1. Flowchart of the system

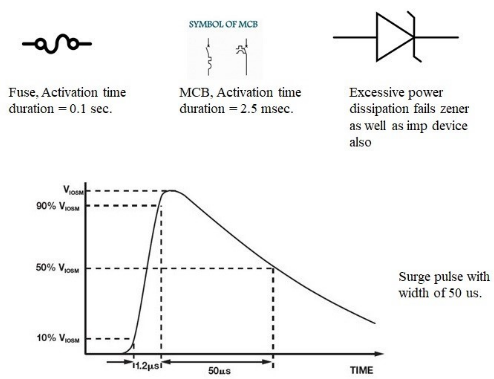

Fig 2. Activation time of traditional methods

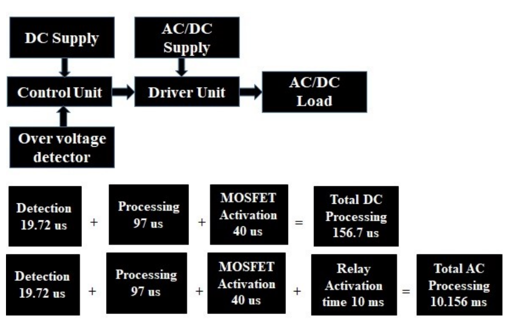

Fig 3. Block diagram of a system

from the DC supply within 150 μs is a novelty in the research. Figure 10 shows the results verification and validation team visit by the Executive Engineer Maharashtra State Electricity Distribution Company Limited (MSEDCL) to experiment set up.

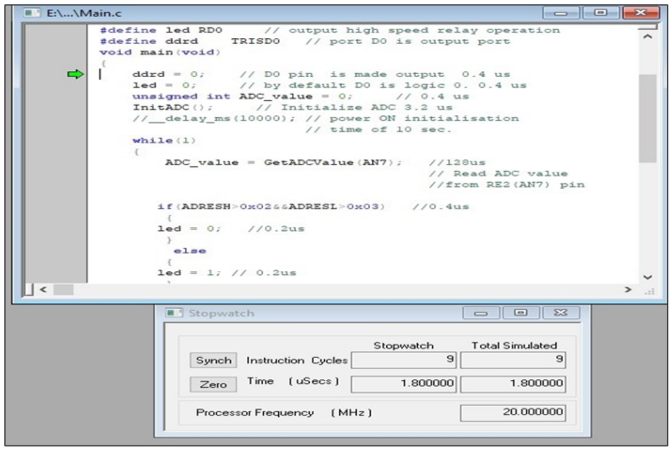

Fig 4. Time required to execute steps

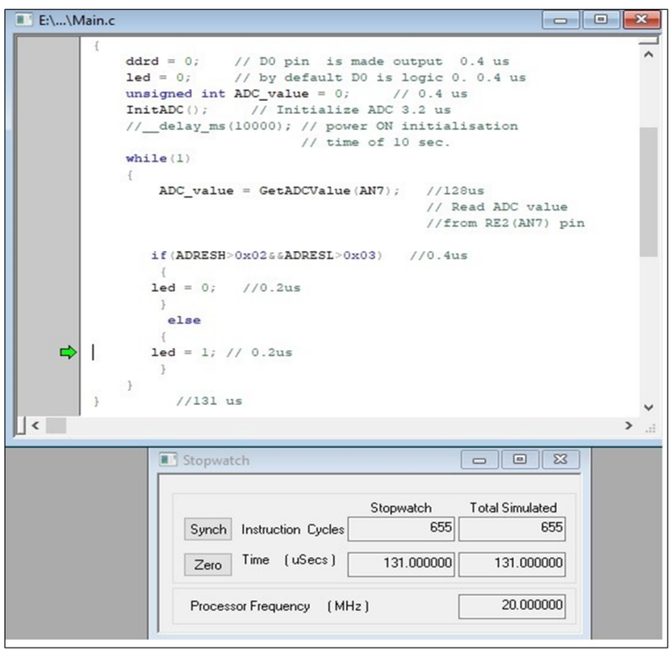

Fig 5. Time required to execute the total program

A commercial device can be prepared and can be made available in the market so that important devices get isolated from the supply. Furthermore, high-speed microcontrollers can be used to reduce processing time. This technique is mostly useful in DC device protection because DC drivers can operate at high speed instead AC device isolation requires some more time. AC devices can be connected through a relay circuit or contactors and these drivers have operating time in milliseconds. In the future, such a special device can be prepared where regular current can be entered. As the current goes away from settled value load can be isolated. Actually, we have a commercial 3-phase motor ON/OFF control unit. In this unit, an SMPS power supply is used. Parallel DC supplies were provided to the microcontroller as well as SIM 800C. As the supply became overvoltage both microcontroller as well as SIM 800C were burning out. Now we have implemented this technology where SIM 800C is supplied through a MOSFET driver circuit. After that implementation, we did have not got SIM 800C burning issue.

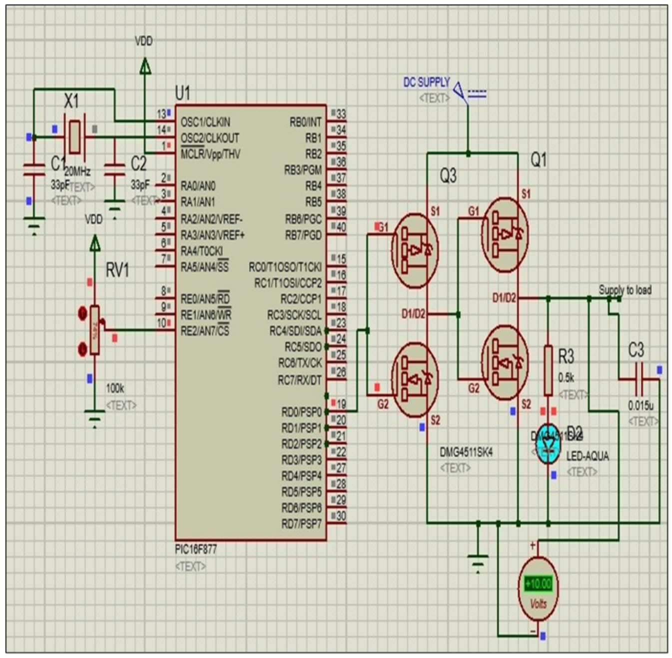

Fig 6. The condition at which the input supply is stable, the load activated

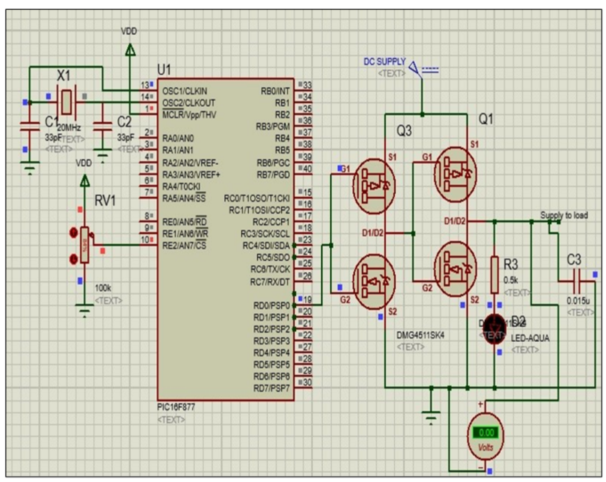

Fig 7. The condition at which the input supply is stable, the load isolated

A major intention behind introducing this technique is to isolate sensitive loads from the power supply as overvoltage is detected. It is widely useful in DC overvoltage protection. Because overvoltage is detected through built-in high-speed ADC (settings are done for maximum speed) which is operated in microseconds. Processing also happens in microseconds and MOSFET device activation also happens in microseconds so the total isolation process operates within 150 microseconds. DC-sensitive devices get isolated and actually practically we have used them in our commercial product. Protection for AC devices becomes slightly difficult because AC contactors operate in milliseconds so it is becoming difficult still further we will work in these sections to enhance the efficiency.

The authors referenced here have mainly worked on protection AC overvoltage protection and they have used the analog method of overvoltage sensing. Their evaluation measures are better for AC protection methods. In comparison to these, we utilized the digital method which has the main advantages of high-speed detection, processing, and activation time duration. From a time perspective, our suggested method is highly beneficial and reliable.

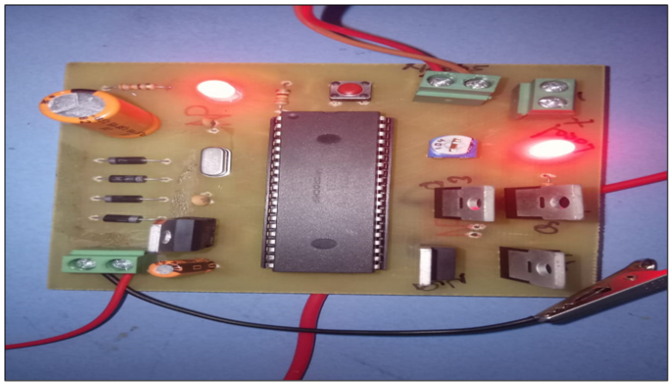

Fig 8. The condition at which the input voltage is under critical limit

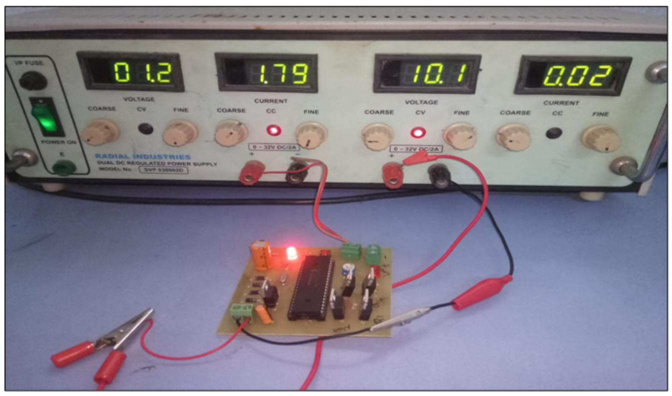

Fig 9. The condition at which the input voltage is over the critical limit and the load is isolated

Fig 10. Research work practical setup containing 1 KVA isolated transformer, 0.5 hp motor, 1.5 KVA VFD drive

4 Conclusion

Protecting a number of devices on a single PCB board from overvoltage is very important. If the line voltage remains of good quality, then nothing has happened to such important items over the years. Saving such multi-component PCB boards from line congestion is the need of the hour. The techniques suggested here prove that if the line voltage is balanced, then only the load is turned ON. It is practically and theoretically proved that DC processing requires near about 156 μs time. Isolating the loads from the DC power supply within μs and reconnecting it as the DC supply becomes normal is the novelty of our research work. This concept must be utilized in a perspective way. It is a need of time. Our suggested method is very reliable, high speed, and buttress quantitatively. At some commercial transformers due to high variations in harmonics, line quality decreases and variations in line voltage may occur. It is recommended that the electricity distribution board should check the total harmonics distortion level. It is also recommended that further, a more high-speed (Nano second) control unit can reduce detection, processing, and isolation time. Effectively it will create a more reliable system. It is also recommended that a common protocol be prepared and all designers should follow this protocol on a single PCB board with multiple numbers of ICs.

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