Design & Development of A Microcontroller Based Protection Relay To Protect The System Against Over-Voltage, Under-Voltage, Over-Current Faults

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Abstract: In this paper a laboratory setup has been developed that mainly focuses on the design & development of a microcontroller based digitally controlled system to implement a multi-functional numerical relay for the purpose of single phase online fault detection to protect the electrical equipments against over-voltage, over-current and under-voltage faults. The developed system is highly responsive, highly rugged, configurable, economical and user friendly. The fault parameters/ reference values were made adjustable by the use of dedicated on-board tactile switches. The digital system keeps on comparing the reference values of over/under-voltage and over-current with that of the instantaneous current/voltage values and takes the decision of isolation in real-time by tripping off the relay immediately if any of the reference limits would cross. Hardware prototype with NXP P89V51RD2 as core controller is built to validate the operation.


I. INTRODUCTION

Power systems are built to allow continuous generation, transmission and consumption of energy. The system is capable of sustaining a variety of environmental and operating impacts that resemble normal operating conditions. The abnormal conditions that the system may experience are rare but do happen. They include lightning striking the transmission lines, excessive loading, deterioration or breakdown of the equipment insulation. As a result power systems may experience occasional faults. When a major disturbance occurs, protection and control actions are required to stop the power system degradation, restore the system to a normal state, and minimize the impact of the disturbance [1]. Faults and failures normally occur in power systems and can be severe if not promptly corrected. Protective relays are used to detect any abnormalities in a power system and isolate the faulty part of the system in the shortest time [2]. Protective relay functions as a sensing device, it senses the fault, then determines its location and finally, it sends tripping command to the circuit breaker. The circuit breaker after getting the command from protective relay disconnects the faulted element. From this it can be concluded that protective relay plays a vital role. As a matter of fact clearing the fault fast with the help of fast acting protective relay and associated circuit breaker, the damage to the apparatus is reduced, subsequent hazards like fire, risk to life are reduced by removing the particular faulted section, the continuity of supply is maintained through healthy section, fault arising time is reduced, permanent damage to the system is avoided. All the above objectives can be achieved only if the protective relay is reliable, maintainable and sensitive enough to distinguish between normal and abnormal conditions. The protective relays do not eliminate the possibility of fault occurrence rather their action starts only after the fault has occurred on the system [3]. Numerical Protection Relays (NPRs) are easy to operate, adjust and repair. Over current, Over/Under voltage relays are extensively used in power system protection. Implemented design is basically a System On Microcontroller [4]. Protective relays are designed in order to maintain high degree of service continuity and limit equipment damage in the power systems. The importance of the services that the power systems offer and high amount of investments that represent the facilities and equipments make the normal and constant operation of power systems critical and strategic for every society [5].

II. IMPLEMENTED PROTECTION SYSTEM

The block diagram shown above represents the proposed Digital Protection Relay. It is a device that
is having the ability to control the operation of a circuit breaker by measuring the power system quantities like voltages and currents and processing them through its internal logic. The internal logic allows the relay to initiate a tripping sequence when anomalous conditions arise within the power system [5].

A. Microcontroller
Here in this system the microcontroller’s function is to receive the instantaneous values of the single phase voltage and current through a 10-bit resolution ADC. Then, these samples of the single phase voltage and current will be stored to calculate the RMS values. After that, the RMS values will be compared with the pre-set threshold voltage and current values. If the RMS values exceeds (or falls below in case of under-voltage) the pre-set threshold value, a signal will be sent to trip the relay accordingly [6]. The RMS values are also used in single phase fault analysis to detect the unbalance system and send the tripping signals if so. RMS i.e. Root Mean Square values are the D.C. equivalent of an A.C. value. In other words, if we have two circuits, one D.C. and one A.C., and we want them to use exactly the same amount of power (energy each second) then we would choose the D.C. values of current and voltage to be the same as the RMS values of current and voltage in the A.C. circuit. For a sine wave, the RMS value is approximately 0.707 of its peak value. \( V_{\text{RMS}} = \frac{V_0}{\sqrt{2}} \) and \( I_{\text{RMS}} = \frac{I_0}{\sqrt{2}} \) where \( V_0 \) & \( I_0 \) are the peak values. The Root-Mean-Square is calculated in the way the name suggests; first we square the quantity, then we calculate the mean and finally the square-root of the mean-square, this is how it is done on the microcontroller:

Root-Mean-Square (RMS) Voltage:

```c
for (n=0; n<number_of_samples; n++)
{
    // inst_voltage calculation from raw ADC input goes here.
    squared_voltage = inst_voltage * inst_voltage;
    sum_squared_voltage += squared_voltage;
}
mean_square_voltage = sum_squared_voltage / number_of_samples;
root_mean_square_voltage = sqrt(mean_square_voltage);
```

RMS current calculation is same as the RMS voltage calculation [9]. The microcontroller used here is most commonly used by the students as they are well familiar with this controller’s architecture and operation. It exists in the course curriculum of many universities. The system was built around P89V51RD2 microcontroller for a better understanding of the students. This is an 80C51 microcontroller of NXP make with 64 KB flash and 1024 Bytes of data RAM. It is an 8-bit microcontroller having 5 volt operating voltage from 0 MHz to 40 MHz. It supports both TTL and CMOS compatible logic levels and has three 16-bit timers and 8 interrupt sources. It has SPI and enhanced UART for serial communication. The flash program memory supports both parallel programming and in serial ISP. ISP allows a device to be reprogrammed in the end product under software control. The capability to field/update the application firmware makes a wide range of applications possible [8].

B. Overload & Over current Protection
In actual field the overload means excessive load on the system and over current means some line fault due to insulation failure etc. Over current digital relay is made to operate automatically when the value of current rises above the threshold setting. The overloading of the system has been verified in laboratory by gradually increasing the load with the
help of load bank. Current can be measured by using hall-effect sensors or by installing CTs (Current Transformers) [3]. CTs are indispensable tool to aid in the measurement of AC current. CT is a device that produces a reduced current in its secondary winding accurately proportional to the current flowing in its primary winding. Like a traditional voltage transformer, the ratio of the windings determines the relation between the input and output currents. The secondary (output) current flows into the secondary load, usually called the burden resistor. The primary winding is usually the current conductor passing through an aperture in the CT core. Here a ring type or solid core CT is used. The core is usually annular and tends to be more accurate and compact [10].

![Solid Core Current Transformer](image1)

**Fig. 2. A Solid Core Current Transformer.**

C. Overvoltage & Under voltage Protection

In actual field overvoltage may occur due to poor voltage regulation, by sudden load cut-off, etc. whereas under voltage may arise due to sudden rise in load [2]. Overvoltage and under voltage digital relay is made to operate automatically when the voltage value rises above and below the threshold values set by the user. Both the overvoltage and under voltage conditions has been checked in the laboratory by using an autotransformer. Voltage Transformer or Potential Transformer (PT) with iron-core construction is used here. Since the voltage levels in the power system range well beyond kilovolt values, the transformers are used to bring the voltages down to an acceptable level used by protective relays [7]. A step-down potential-transformer of rating 12-0-12 volts and 500mA at the secondary is used here in the proposed system.

D. Analog to Digital Converter

Analog-to-digital converter (ADC) is a device which can convert analogue voltage to digital numbers so that microcontrollers can handle and process the data. ADCs are the most widely used devices for data acquisition and control. Some microcontrollers have built in ADCs but the 8051 micro controller don't have any built in ADC. So we have to use external ADC for said purpose. There some common and important features about ADCs like resolution of ADC, response time of ADC, mode of work and method of conversion. ADC has n-bit resolution; where n can be 8, 10, 12, 16 or 24 bits. The higher-resolution ADC provides a smaller step size. Step size is the smallest change that can be discerned by an ADC. An ADC has a resolution of 8 bits, the range is divided into $2^8 = 256$ steps (from 0 – 255). But there are 255 quantization levels. Below is table in which Resolution versus Step Size for ADC (if $V_{cc} = 5\text{V}$) is provided [8].

<table>
<thead>
<tr>
<th>n-bit</th>
<th>No. of Steps</th>
<th>Step Size (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>$2^8 = 256$</td>
<td>5/255 = 19.61</td>
</tr>
<tr>
<td>10</td>
<td>$2^{10} = 1024$</td>
<td>5/1023 = 4.89</td>
</tr>
<tr>
<td>12</td>
<td>$2^{12} = 4096$</td>
<td>5/4095 = 1.22</td>
</tr>
<tr>
<td>16</td>
<td>$2^{16} = 65536$</td>
<td>5/65535 = 0.076</td>
</tr>
</tbody>
</table>

Table 1 ADC Resolution vs Step Size

Here in this system a 10-bit ADC of an 8-bit microcontroller ATMEGA8 is interfaced to the main controller via SPI (Serial Peripheral Interface) communication protocol [9].

E. Relay & its Driver Circuit

Relay is an electromagnetic switching device that allows a low-power circuit to switch a relatively high current on and off, or to control the signals that must be electrically isolated from the controlling circuit itself [1]. The 8051 microcontroller can source or sink maximum 20mA current on each of its pins. So, in order to operate the relay through microcontroller there must be a driver in between them like a BJT or ULN2803. The relay driver can be very simple, using an NPN or PNP transistor to control the coil current. All that the low-power circuitry has to do is provide enough base current to turn the transistor on and off. A power diode D1 (1N4001 or similar) is connected across the relay coil, to protect the transistor from damage due to the back-EMF pulse generated in the relay coil’s inductance when Q1 turns off [8].

![Relay Driving Circuit](image2)

**Fig. 3. Relay Driving Circuit**

F. LCD & Keypad Interfacing Circuit

A 16x2 line LCD is interfaced to the microcontroller in 8-bit mode. It can display 16 alphanumeric
characters (each of 5x7 dot) in each of the two lines. It has three control pins, eight data pins, contrast control pin and LCD backlight control pins. The hardware interfacing schematic is shown in figure 2. For driving LCD with the microcontroller, in the firmware, the first step is to initialize the LCD using Command Register and then data to be displayed in the form of ASCII code is given to the LCD by using Data Register [1]. The LCD is used to display the pre-set threshold values and instantaneous values of voltage and current; also it displays the fault due to which relay got tripped/cut. It displays either of the messages for the user like RELAY ON, VH CUT, VL CUT, IH CUT when a fault condition occurs. As discussed earlier, this system is made flexible as the user can set the threshold values for the overvoltage, undervoltage and overcurrent fault conditions by using the user input panel. Here a set of six keys were interfaced to the microcontroller to select the specific mode and increment or decrement its threshold value by using dedicated keys. The keys are basically tactile switches connected to I/O port pins and microcontroller recognizes the key press when a logic low is detected at a particular pin. As these are mechanical switches so when a switch is actuated, the contacts often bounces for some time before settling down to a stable state. It happens when a key is pressed as well as when a key is released. So, to debounce the switch through software a debounce time of 20 milliseconds is generally provided into the logic to ensure a real key press [9]. There are dedicated keys provided on-board to set the threshold limits for High Voltage Cut, Low Voltage Cut, and High Current Cut and also for Increment and Decrement of these values [1].

G. Regulated Power Supply

All the digital circuits require a regulated DC power supply for its operation. A 5V DC regulated power supply is developed for the system as per the circuit given below. A 12-0-12 Volt / 500mA step down transformer is employed to feed a full wave bridge rectifier followed by polarized capacitors for filtering. A DC voltage regulator LM7805 is employed to get a 5 Volt DC output [1].

III. FLOW CHART & ALGORITHM

A 10-bit ADC of ATMega8 is configured with prescaler 128. It is an 8 channel ADC and only two channels are used here to measure instantaneous voltage, current and provide digital values. The voltage and current is measured by ADC back to back on time shared basis [9]. Each time a fresh sample x[n] and previous sample x[n-1] from ADC
are used by this FIR filter equation for dc offset removal i.e. \( y[n] = 0.996*y[n-1] + 0.996*x[n] - 0.996*x[n-1] \) where \( y[n] \) is the fresh output and \( y[n-1] \) is the previous output. The filtered sample is now squared and accumulated in the accumulator. Likewise a number of squared samples get accumulated into the accumulator not exceeding a predefined integer limit. Now all these accumulated values get added and their final sum is saved in the accumulator only. A constant offset, which is added to sampled data sum should not be more than 1/2 LSB*255, typically 80H. Mean is calculated by dividing the total sum of squared samples by the number of samples and finally the program calculates the square root of the mean. Hence RMS value is calculated for both analog voltage and current instantaneously [6]. These RMS values of voltage and current are then compared with the reference threshold values for under-voltage, over-voltage and over-current. This is done in the firmware. If one or more of these threshold limits crossed, then it is detected into the firmware itself and necessary decision will be taken by the microcontroller to command the relay tripping and also display the status onto the LCD screen. The alert will be generated by the buzzer [8].

IV. CONCLUSION

A microcontroller based real time multifunctional digital relay has been implemented for the protection against certain abnormalities in line and is highly reactive and responds in real time. The proposed system is implemented and tested for the desired functionalities. The voltage and current high and low thresholds can be set to define the range of safe operation for the transmission line. The user can rely on this system as it ensures the complete protection of the line against these faults by switching a relay accordingly. All the calculations and decision making is carried out by a high performance eight bit microcontroller. The system was well tested and calibrated to get the optimum results. Through this proposed work we came to know about the utility of current transformer and potential transformer for the switching of a protection relay to protect transmission line against the over-current, over-voltage, under-voltage faults.

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REFERENCES


