A New Design for a Microcontroller Based AC Voltage Relay

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Abstract

This paper presents a new design for a dedicated function microcontroller based AC voltage relay. The designated controller is a Texas MSP430f148, 16 bit RISC architecture microcontroller (μc). The general hardware architecture and software are briefly explained. The relay is capable of detecting and issuing tripping signal to breaker for both over and under voltage faults. Tripping timing for both are user settable from 0.5 sec to 20 sec. after a fault inception, the relay is able to issue trip signal to corresponding breaker with in the settable time with an error of ±15ms. Proposed relay offers very desirable features of speed, flexibility and economy. The most attractive feature of the relay is its LCD display which displays the all three phase voltage, frequency and the faults. The relay can be used either for single phase or for three phase which is a user selectable quantity. A dropout of approximately 2sec is also given.

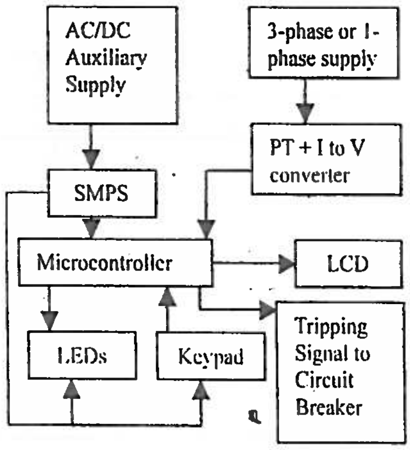
Key Words: Power System Protection, Microcontroller, Voltage Relay

1. Introduction

Digital relays for protecting power systems and industrial plants have been a major problem and ongoing research and development field. Many approaches were introduced and a variety of promising results were demonstrated. Some of the prototypes have been installed and tested in actual power systems the complexity of hardware and software algorithms are of most concern.

Basically, a good relay scheme has to have many good features. These features must include high through-put controller, accuracy, modularity and economy. The technically justifiable systems must almost always lack cost rationalization. The microcontroller based digital relays introduced in the paper technically capable for being implemented for more complicated algorithms. The system represented here has Dedicated function microcontroller architecture. The controller employed is an ultra low power, 16-bit RISC μC, the Texas MSP430 family. It consumes less than 400 μA in active mode operating at 1 MHz in a typical 3-V system and can wake up from a <2μA standby mode to fully synchronized operation in less than 6μs. The MSP430 family has an abundant mix of peripherals and memory sizes enabling true system-on-a-chip designs. MSP430f148 has 48kb +256b Flash, 2kb Ram. The peripherals include a 12-bit A/D, slope A/D, multiple timers (some with capture/compare registers and PWM output capability), on-chip clock generation, H/W multiplier, USART(s), Watchdog Timer, GPIO, and others[13]. Potential application of this relay includes industrial as well as commercial equipments protection. It can be used for the protection of refrigerator systems, motor protection, and generator protection. Relay has been calibrated with the ISA T1000 RELAY TEST KIT.

The basic block diagram for the relay is given as under:



Application:

The voltage supervision relay protects electrical power generators, consumers & operating components against over & under voltages.

Among other applications relay can be used

- For detection of over & under voltages in power generating plants & energy generating systems.
- To protect generator against critical over voltages in case of defective voltage regulators.
- As under voltage protection for motors.

Features &Characteristics:

- Microprocessor technology & watchdog timer.
- Digital filtering of the measured values.
- Voltage supervision with under/over voltage detection.
- Completely independent time setting for voltage supervision.
- Display of all measuring values & setting parameters for normal operation via an alphanumeric LCD, Keypad & LEDs.

1. Hardware Structure of The Relay

The hardware structure is divided into three main parts:

a) SMPS plus the D.C. relay
b) The analog input.
c) Microcontroller.
d) LCD.

2.1 SMPS

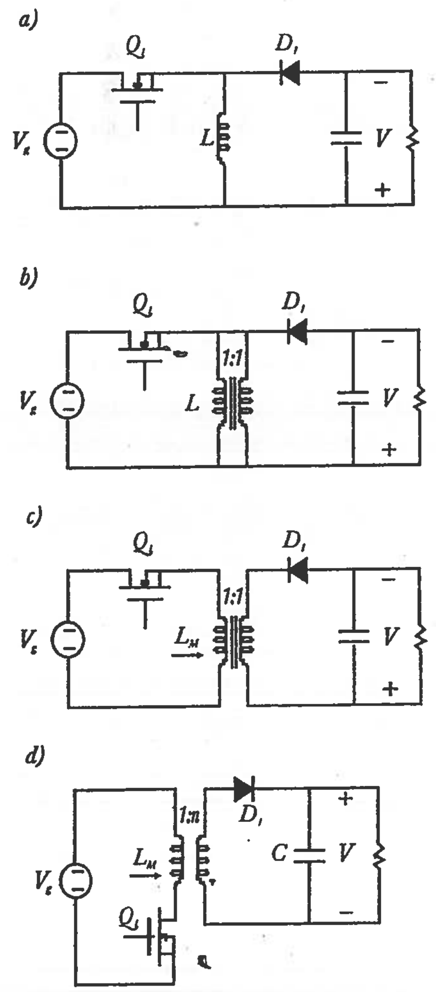
Regulated dc power supplies are needed for most analog and digital electronic systems. Most power supplies are designed to meet some or all of the following requirements:

- Regulated output
- Isolation
- Multiple outputs

In switching power supplies, the transformation of dc voltage from one level to another is accomplished by using dc-to-dc converter circuits (or those derived from them). These circuits' employee solid-state devices (transistors, MOSFETs, etc.), which operate as a switch: either completely off or completely on. Since the power devices are not required to operate in their active region, this mode of operation results in lower power dissipation.

The one most popular converter used in these types of relays is Flyback Converter[1,2,3,4,5]. The flyback converter is based on the buck-boost converter. Its derivation is illustrated in Fig. 1. This figure depicts the basic buck-boost converter, with the switch realized using a MOSFET and diode. In Fig. 1 (b), the inductor winding is constructed using two wires, with a 1: 1 turn's ratio. The basic function of the inductor is unchanged, and the parallel windings are equivalent to a single winding constructed of larger wire. In Fig. l(c), the connections between the two windings are broken. One winding is used while the transistor Q_1 conducts, while the other winding is used when diode D_1 conducts. The total current in the two windings is unchanged from the circuit of Fig. 1 (b). However, the current is now distributed between the windings differently. The magnetic fields inside the inductor in both cases are identical. Although the two-winding magnetic device is represented using the same symbol as the transformer, a more descriptive name is "two winding inductor". This device is sometimes also called a "flyback transformer". Unlike the ideal transformer, current does not flow simultaneously in both windings of the flyback transformer. Figure l(d) illustrates the usual configuration of the flyback converter. The MOSFET source is connected to the primary-side ground, simplifying the gate drive circuit. The transformer polarity marks are reversed, to obtain a positive output voltage. A 1:n turns ratio is introduced; this allows better converter optimization.

It has the advantage *of* very low parts count. Multiple outputs can be obtained using a minimum number *of* parts: each additional output requires only an additional winding, diode, and capacitor. The peak MOSFET voltage is equal to the dc input voltage *Vg* plus the reflected load voltage *V/n*;–in practice, additional voltage is observed due to ringing associated with the transformer leakage inductance. A snubber circuit may be required to clamp the magnitude *of* this ringing voltage to a safe level that is within the peak voltage rating *of* the MOSFET.



Fig(1) (a) buck-boost converter, (b) inductor *L* is wound with two parallel wires, (c) inductor windings are isolated, leading to the flyback converter, (d) with a 1:*n* turns ratio and positive output.

Relay Interface

The data acquisition & supervisory control system has one output relay. The function of this relay is to generate a tripping signal when ever there is a fault.A relay is an electromagnetic device which can often be activated relatively with little energy, causing a movable ferromagnetic armature to open or close pair of electrical contact points located in another control circuit or in a main circuit handling large amounts of energy. Relays are found in many applications in all fields of engineering, especially in situations where control of a process or machine is involved. Relay consists of an exciting coil placed on a fixed ferromagnetic core equipped with a movable element called the relay armature. Fig 2 shows the basic composition of the relay.

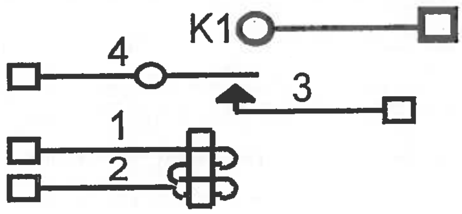
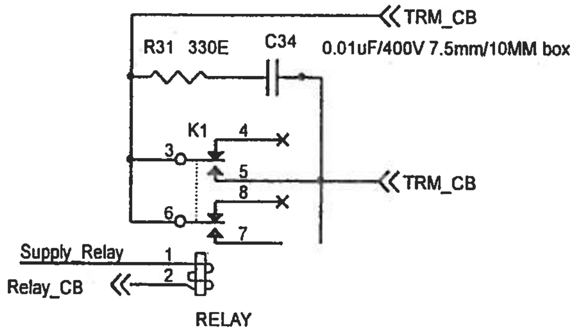


Fig 2

The relay is energized from a constant voltage source through an adjustable resistor R. I am using single pole 5 volt relay having Coil resistance of 280 ohm and current rating of 1A. We can't drive the relay directly from the port pin of the microcontroller because of the limitation of microcontroller port for the current sinking and souring limits. So I am using transistor as a switch to energize the relay as shown in the figure 3

1. Output relay



Relay is protected with an RC snubber circuit. In the mounting of the relays two sort of provisions are left.

2.2 Analog Inputs

Given relay is an AC voltage relay so the analog inputs must be the three phase voltages which μC will calculate and compare with the reference voltage and issues the tripping signal.

Analog circuit consists of three P.T.s (potential transformer) with 1:1 turn's ratio. Output of these PTs is not directly given to the ADC of controller but through an op-amp IC (LMV324). Actually these are special type of transformer which transforms input voltage to current through LMV324. This IC does two jobs, firstly it shifts the input signal by a dc offset of 1.25volts then it converts the voltage signal to current signal which is then given to the ADC.

Eight different analog signals can be fed to the ADC, which calculates the no. of samples for the given signal by the formula:

$$N_{ADC} = 4095 \times \frac{V_{in} - V_{R-}}{V_{R+} - V_{R-}}$$

VR+ and VR are two programmable/selectable voltage levels to define the upper and lower limits of the conversion range.

2.3 Microcontroller

Since I have already discussed the controller briefly, so I will not be explaining it again. For further information on this controller family refer [13].

2.4 LCD

The Oriole's Display Module (ODM) is a dot matrix liquid crystal display that displays alphanumeric, Kana(Japanese) characters and symbols. The built-in controller & driver LSIs provide convenient connectivity between a dot matrix LCD and most 4 or 8 bit microprocessors or microcontrollers. All the functions required for a dot matrix liquid crystal display drive are internally provided. Internal refresh is provided by the ODM. The CMOs technology makes the device ideal for Applications in hand held, portable and the other battery powered instruments with low power consumption.

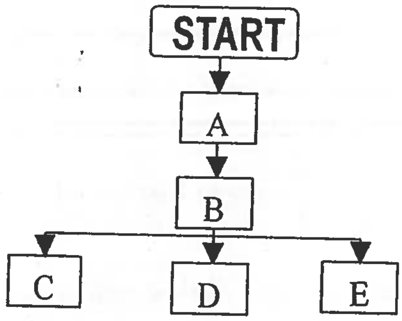
Features

- Easy interface with a 4-bit or 8-bit MPU.
- Built-in Dot Matrix LCD Controller with font 5×7 or 5×10 dots.
- Display Data RAM for 80 characters (80×8 bits).
- Character generator ROM, which provides 160 characters with font 5×7 dots and 32 characters with font 5×10 dots.
- Both display data and character generator RAMs can be read from the MPU.
- Internal automatic reset circuit at power ON.
- Built-in Oscillator circuit. (No external clock required) Wide range of instruction functions: Clear Display, Cursor Home, Display ON/OFF, Cursor ON/OFF, Cursor Shift, Display Shift.

3. Software Structure

The software for the given relay has been written in 'C' language [7,8,9,10,11,12]. This section tells the microcontroller what to do and when to do. So software is the most important part of the relay and the accuracy and speed of relay depends on how perfect is your program. It can be divided into following parts:

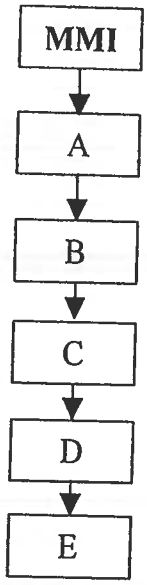
- MMI (man machine interface)
- Measurement
- Control



A: Initialize all ports, clocks, timers, ADC, LED, LCD, keypad and watchdog timer.
B: Rest part of the software is divided in to the following three main parts.
C: MMI (Man Machine Interface)
D: Measurement
E: Control

3.1 MMI

The MMI section performs the following tasks: keypad scanning, LCD display, voltage and frequency of input supply and display the type of fault. This part of the program allows the user to interact with the relay. It includes the display of voltages, blinking of LEDs, editing and saving of different quantities, etc. all through keypad.



MMI: man machine interface via LCD, Keypad and LED

A: This part of the software continuously scans for keypad action by the user and displays the values of voltages, frequency, fault type and no. of phase selected.
B: If any key is pressed then the action is taken according to it i.e. either cursor will move up or down or the screen will change.
C: If user choose the edit/view parameter screen he/she can edit the different values with the help of increment or decrement keys.

D: After changing the value of any parameter and if user wants to save the given value, relay will ask for the password, and after entering the correct password only the given value will be saved.

E: After entering the correct password, only then the value of the given parameter will be saved in the program memory.

3.2 Measurement

This part of software is responsible for healthy operation of the relay. If the measured value of voltage is not correct then false tripping will occur and the very first objective of relay will not be achieved. So measurement must be accurate and as fast as possible.

Voltage Measurement

The Fig 4 shows the circuit implementation of AC voltage measurement. The incoming voltage is applied to Potential transformer (1:1) with two resistance of 200K ohm in series with the primary coil of the transformer, and same current appears at the secondary side of the transformer. A rail to rail OPAMP LMV324 [8] at the secondary coil of transformer, in the I to V configuration gives the equivalent voltage at the output with in the range of 0V to +2.5V.

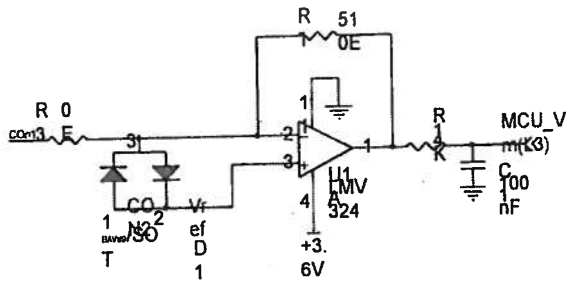
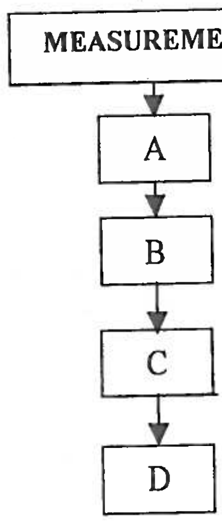


Fig 4.

The ADC in the microcontroller is unipolar so to get accurate values for the negative cycles of AC voltage, a reference shifting circuit is applied to shift the level by 1.25V, which will be deducted or compensated in terms of software programming of the microcontroller on getting its sample from ADC 2.5V reference is converted into 1.25V reference needed for to avoid the direct loading on voltage reference; otherwise any fluctuation in this reference will destroy the linearity of the ADC and voltage measurement technique.

Frequency Measurement

For the measurement of Frequency of the incoming signal, there is no requirement of any extra hardware as RMS voltage measurement itself gives this value only by some calculations in software program. Whenever the sample value changes from positive to negative value, it means there is a Zero Cross Over and by calculating this Zero Cross over we can easily calculate the Frequency of incoming signal. Number of Zero Cross Over in 1sec gives the frequency of the incoming signal. Therefore, software routine of the microcontroller program counts the no of zero crossovers within 1sec and gives the frequency for the mains and similarly for generator.



Measurement: This section of the software as name suggests it measure the values of voltages and frequency.

A: Analog signals (voltage signal) are given to the ADC of the controller, which is working in capture and compare mode and capture the samples at a rate of 40 samples per cycles.

B: According to hardware the formula, by which ADC measures the value is modified as:

$$S = 4095 \times \frac{510 \times Ic}{2.5}$$

Where Ic = secondary current of PT

2.5 is the maximum peak to peak current, which can be fed to the controller.

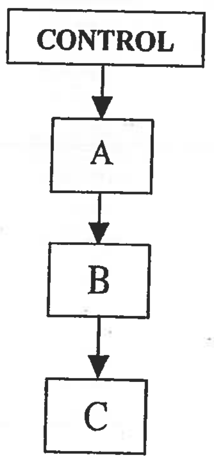
510 is the value of resistance connected on the secondary side of PT.

C: These value of samples (40) are then squared in the hardware multiplier, and rms value of the voltage is calculated which get displayed on the LCD.

D: Frequency of the signal is measured through the capture mode of the ADC. It calculates after how much time the logic value changes from 0 to 1.

3.3 Control

The control section logically compares the measured values of voltages with the voltage ranges set by the user and according to that; it issues the tripping signal after the set time for over or under voltage is elapsed.



CONTROL is a very important part of the relay, which governs the tripping of relay. This part of software will work only if Unit is enabled.

A: Measured value of voltages will then being compared continuously for under and over voltage limit with the reference voltage set by the user.

B: If measured value of voltage of any line/phase is out of range, timer starts and LED starts blinking until timer overflows and relay issues the tripping signal and displays the type of fault on LCD.

C: As soon as all line/phase voltages come back to the normal range relay reconnects the system but with a hysteresis of 2sec. Relay will reconnects the system iff all line/phase voltages are in normal range.

Software Flowchart

On system startup or power on, first the microcontroller, timers, LCD and ADC conversions are initialized. Then it will reset the relays and status of LEDs. After this microcontroller will come into MMI section, under which it will scan the keypad and check if any key is pressed. If user has pressed any key and if the pressed key is editing key, microcontroller will change and display various editable parameters on LCD. Before coming out from this loop it will also ask for the saving of changes made, if any, in its ROM.

In case there is no key press and ADC conversion is over, then microcontroller displays the voltage of supply on LCD. With this, it will also simultaneously calculate the frequency by calculating the no of zero crossovers with in one second. It will also display the fault if any. There are three voltage measurement sections and, so total three channels are multiplexed which give their results in one conversion cycle of ADC (35μsec).

After this microcontroller will check these measured parameters for their under and over voltage ranges. If they are with in the defined range, then microcontroller will only update the LCD display. However, if any parameter is out of range, microcontroller will change relay tatus along with fault LED indication. Similarly this endless flow will continue from MMI to measurement and then to control section.

Conclusion

Microcontrollers have become powerful tool for embedded system applications.

These small programmable chips serve for dedicated functionality. In this era of System-On-Chip, no doubt microcontrollers are economical and best solution, when a dedicated flawless protection system has to be setup. Utilizing microcontroller high speed, accuracy and reliability is the key feature of this implemented work. It is anticipated that the insight gained from research, principles developed and practical aspects of this project work will give a new direction to protection system for power system. This work focuses, at a high level, on requirements of efficient cum economic Data Acquisition. This work would also be able to remove the errors and delays caused by human being.

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