Cost-Effective Micro Programmable Logic Controller for System Automation

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Abstract: The purpose of this study is to check the efficiency of micro programmable logic controller (micro-PLC) for controlling, monitoring and counting purpose of eight different load systems simultaneously. In this project working of different IC's, Keyboard and seven-segment display were used for visual representation of data for the purpose of simplicity and cost effectiveness and also increases productivity. Complete hardware of the system has been designed, tested and made into working condition. The monitor program takes case of all the necessary requirements of the system like, scanning the keyboard, lighting display, listen the written program and its execution. Microcontroller was programmed in C-language and a flash memory of 2-K bytes was used to store controlled program permanently. This micro-PLC was supportable for monitoring and counting industrial processes and can be implemented in multiple domains, largely of small to medium scale manufacturing processes and may be used for home and business automation as well. The efficiency and simplicity of the micro-PLC are strong advantages, easy to code and allowing fast automation on small systems, making the load switching very effective.

Keywords: Micro-PLC, microcontroller, loads, keyboard, automation.

INTRODUCTION

Industrial automation of complex systems (electrical loads) has been very actively studied in the laboratory and by computer simulations. In these days the advancement in industrial automation technology and the needs on efficiency and quality in production processes have resulted in complex and integrated production systems. Micro programmable logic controllers (micro-PLC) have played a dominant role in system design and optimization, and have diverse applications in many process industries (textile, chemical, energy generation, etc.). The existence of micro-PLC is essential for the controlled processes and they introduce new modes and mechanisms of automation processes in industries and home appliance applications. The industrial applications and widespread existence of micro-PLC, combined with a number of their general and standard electronic designed components, make PLC system extraordinary attractive and interesting subject for many researchers. The microelectronic systems combine the physics of semiconductor devices and condensed matters [1-3].

PLCs are the control hubs for a wide variety of automated systems and processes. They contain multiple inputs and outputs that use transistors and other circuitry to simulate switches and relays to control equipments. PLCs are designed for processes and special purposes computers designed for sequence control devices that are developed to replace electromechanical relays [4-6]. We all know that industrial automation is the backbone of a nation for its prosperity since, it reduces the production cost many folds and also increases productivity. For this purpose a wired logic controller (WLC) was introduced for controlling loads and it was the first step in the industrial automation. Later on microcontrollers were introduced which had the advantage of greater flexibility over the WLC. The ATMAL corporation has introduced AT89C2051 microcontroller as member of MCS-51 microcontroller family. AT89C2051 microcontroller is in 20-pin package with 8-bit I/O, 2k-bytes of RAM, serial port, two 16-bit Timer/Counters, 5-Interrupts sources and analog comparator [4, 5, 7]. Eventually, a very sophisticated version of a controller was introduced with a very large I/O handling capability and extreme flexibility called the programmable logic controller, commonly called the PLC. The PLCs were first conceived in 1968 but these introduced in to manufacturing in 1969 and the advent of PLCs begin in 1970 and have become the most favorable choice for all industrial automation choices [4, 5, 8]. Siemens introduced many series of controllers with different capabilities. One of the first series was the SIMATIC-5 Controllers. The PLC available to us is the S5-100U-100. Later on Siemens introduced the SIMATIC-7

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series of controllers and now, we also have the S7-314IFM PLC.

The PLCs are not unfamiliar to the industries of Pakistan. They have been around for quite a long period and are being employed extensively. Even though the demand of this product is considerable here, there has been no effort to develop it indigenously. Since there had been no development in this field in our country and being a requisite of the nation, so as an exercise of logic design, digital electronics, interfacing and software engineering, we undertook this task of making a PLC better than the S5 controllers and comparable to some extent to the S7 controllers. The PLC that we have designed can also be upgraded to support remote data acquisition. For instance, thermal conductivity of complex liquids is an important parameter using in the heat design process [9, 10] which can be controlled through micro-PLC systems [4-8]. Now a day's microcontrollers individually and PLCs collectively are silent working for counting, controlling and monitoring purposes in number of industries [5-7] and in different fields, such as digital calculators, T.V, refrigerators, robots, traffic lights, petrol pumps machines, and other home electric appliances.

The purpose of present study was designing and fabrication of an experimental mico-plc based on AT89C2051 microcontroller for counting and controlling different machines or loads. Parallel interfacing was made between the input port of designed PLC and eight different systems through relays for controlling and counting its parameters, like voltages, currents in terms of counts up and count down. The maximum count through this PLC was up to 1000, which can be reset at any time and data can be saved in its RAM memory. Microcontroller which was the brain of the PLC was worked as an administrator, all major activities was controlled and counted through this microcontroller. Microcontroller sends administrative signals to the output as directed to its incoming parallel port signals and its own programming which was written in C++ language.

This paper is organized as follows: In materials and method section, the design implementation of micro-PLC is described, and this section also describes the software used for controlling applications. Next, the results are presented and discussed with earlier reported experimental results in third section. The work is summarized in last section.

MATERIALS AND METHOD

The micro-PLC based on AT89C2051 microcontroller has been designed, fabricated and tested for different load systems. The basic proposal was to design a micro-PLC to ensure its performance equivalent to dedicated industrial PLC's designed by marketable big companies. The micro-PLC hardware was divided into four major units: power supply unit, input and PLC unit, PLC and display unit and switching unit. The power supply unit consists of two different dc voltage output levels of 5V and 12V. Power supply was designed in a classic way that 5 and 12V regulators were employed to allocate the right voltages to the devices and the capacitors of 1000µF and 100nf were used to cut the appeared spikes. Input and PLC unit consists of parallel port inputs from keypad to microcontroller through 10kΩ pull-up resisters used for signals selecting. Since I/O ports of the microcontroller can be both read and written to (bi-directional), when the key was pressed a low logic goes to microcontroller inputs and the data from the outside world goes to the accumulator of microcontroller for processing. PLC and displaying unit also known as a name processing and displaying unit consists of AT89C2051 microcontroller and seven segment display to show the output data for counting purpose, microcontroller outputs to relays and display *via* serial to parallel shift register and combination of resistors and CE-transistors to control, monitoring and displaying results. With the common anode type seven segments, must connect a current limiting resistor between each light emitting diode (LED) and ground. The size of this resistor determines how much current flow through the LED, and the typical LED current was between 1 to 50mA. Switching modules consists of relays which are activated with the help of dc signals taken from the collectors of CE-transistors connected to microcontroller through serial to parallel shift register to control monitoring systems loads [5-8].

The software of micro-PLC AT89C2051 microcontroller was written in C-51 programming language of MCS-51 microcontroller family [7]. The programming interface accepts either a high-voltage (12V) or a low-voltage, program enable signal. The low voltage-programming mode provides a convenient way to program the AT89C2051 microcontroller than the high-voltage programming mode. This microcontroller was programmed through a hardware programmer makes digital level conversions from serial port levels to levels that microcontroller needs. First, source file DISPLAY.C was converted into object file

DISPLAY.OBJ by cross assembler AVC51. The object file was again converted in to hex file DISPLAY.HEX through linker AVL51. Then software was debugged using simulator AVS51. After debugging DISPLAY.HEX was down loaded into AT89C2051 microcontroller flash memory through programmer (AT89C2051). The assembler and simulator provided by the manufacturer were used to generate a hex and debugged source files. The microcontroller can also be checked in terms of hex file the software of microcomputer based on AT89C2051 microcontroller was written in HEX file. Then software was debugged using simulator AVS51. After debugged the HEX file was down loaded into AT89C2051 microcontroller through programmer [5, 7, 11].

Infect microcontroller works as a brain of the micro-PLC which makes all fetching and execution decisions between input, displaying and switching units. The relays work as an intermediary component between monitoring system loads and PLC [5]. The micro-PLC was centered on AT89C2051 microcontroller provides the standard features. The AT89C2051 microcontroller is an economical and cost effective member of ATMAL's growing family of microcontrollers. The AT89C2051 microcontroller is a low power, high performance CMOS 8-bit microcomputer with 2-k bytes of flash programmable and erasable read only memory (PEROM). It has 20 pins and 15 programmable I/O lines. These pins can be addressed individually or in groups of eight. This microcontroller used in an PLC's for sending and controlling required operations, displaying and interfacing to run decides to ON and OFF. By combining a versatile 8-bit CPU with flash on a monothic chip, the ATMAL, AT89C2051 microcontroller is a powerful microcomputer, which provides a highly flexible and cost effective solution to many embedded control applications [4-8].

RESULTS AND DISCUSSION

In this section, the experimental observations of controlling and monitoring sequence of the micro-PLC with applied external loads through relays were presented. The PLC system was tested by running the eight different electrical loads for the long period of time and in different environments, and the micro-PLC system worked to expectation. Some calibration of the analog to digital conversion (ADC) in the switching module was necessary and this was done using software. Different electrical systems, whether motors or loads voltage and current values can be counted, controlled and monitored with this designed project.

This micro-PLC can command up to 8-relays in addition to display its data on displaying unit (seven segments) in terms of signal count up and down according to application controlled through keypad. The maximum frequency that can be reached on microcontroller's pin is given by the following relation [4, 5]:

$F_{out}= F_{osc}/2= 12/2= 6MHZ$

Where

F_{out} = Pin frequency and

F_{osc} = Timing oscillator frequency

In this work 12MHZ quartz was used, so the pin frequency is 6 MHZ according to above calculated relation. The present calculations (6MHZ) show that there is a maximum value of pin frequency for 12MHZ which is higher than that reported in the previous experimental results by Antonio [4] and Shahzad *et al.* [5], in which the pin frequency with a values of 2.765 MHZ and 5MHZ, respectively. The possible reason for this higher pin frequency is that the frequency of oscillator used in the work of Shahzad *et al.* [5] was lower than and frequency of oscillator used by the Antonio [4] was higher than the presently employed frequency of oscillator. Secondly, the microcontrollers used in both earlier works were 4 ports (40 pins), in contrast, our calculation was used with 2 port (20 pins) microcontroller. This suggests that the previous values have indeed larger statistical errors.

The time taken to execute instruction was: T= 12 x C/ crystal frequency:

T = 12x419/12 = 454.6msec

where C is the total number of machine cycles while crystal frequency is the frequency of the crystal used for microcontroller. Here, total machine cycles were 419 while crystal frequency was 12MHZ. The processing time of the microcontroller for change in input (scan time) was 454.6 msec (milli second), as calculated above, confirming the earlier studies by Shahzad *et al.* [5] and Antonio [4]. The startup time was computed as $t=1/f=1/12x10^6$ Hz= 0.833msec for 12MHz.

In the first mode of this study as controlling and monitoring different systems loads, the efficiency of micro-PLC was studied by different switching systems (ac loads). Eight different signals of sequence are sent

to one of the input port of microcontroller through keyboard, which activates the required destination of systems, confirming earlier results [4, 5]. A command signal was sent from the keypad to the input pins of microcontroller, then to the serial to parallel shift register which activate the transistors that energizes the required relay to monitor system loads and display show which system is on. Eight set of relays control 220Volts of alternating current, each relay operates independently. More than one relays can be turned at the same time i.e. all relays can be turned on simultaneously. Software has been developed in such a way that all systems can be controlled with the single key. If we want to turn on or off required system load, then another key is used for selecting required system load showing on display and a signal is sent to the relay then its associated ac system load is switched on and if signal is sent again to the same relay then its associated ac system load is switched off with the help of key. The relays were used in this work having values of 5Ampere ac, 220 V and 50HZ, therefore, ac load of current less than these mentioned values can be controlled with the help of this PLC [5]. In order to check the performance of this micro-PLC, we have tested the system with eight different motors having less than 5Amperes load. In addition, the performance was also checked by replacing ac relays with dc relays ranging 5Amperes for a long run. During replacing ac relays with dc relays only minor change was done in the switching unit side and rest of the circuit is same. Microcontroller outputs were open-drain and did not support a greater current than 20 mA, and for this reason transistors have been used. The transistors were working in switching mode; the current through the LEDs was limited by resistors.

In the second mode of this project was counting and monitoring the systems. The microcomputer was designed in such a way that there were five keys in the keyboard to increase the number of functions performed by the keys. Software has been developed in such a way that all keys have one function at a time. When micro-PLC was switched on, it displays as 0000, showing the data of internal RAM. In order to check the performance of micro-PLC as a counting mode was studied with different applications, such as petrol pump machine for counting petrol price and quantity by connecting inputs signals at pins 16 and 17 of a microcontroller. Its efficiency was also tested in small scale textile rolling machine for counting cloth in meters by putting counting inputs signals from machines at pins 16 and 17 of microcontroller. Lastly its performance was also tested for electronic balance. It is concluded that the micro-PLC was helpful for counting and monitoring the devices to the working speed by up to 10%**,** same as in earlier results [4, 5]. This technology was safe, reliable and cost effective.

The microcontroller port was programmed and accessed in C-language or in terms of hex file. The keyboard was designed with software so that it was being checked and scanned its incoming inputs every 20msec. If the key was pressed, the data from the outside world would be input to the accumulator register ‘A’ of CPU under the direction of IN instruction of microcontroller in 454.3Msec as calculated above. The data could be stored in the register until the next instruction was fetched and executed. This micro-PLC system for counting and switching was controlled through the keyboard that if one digital key was pressed then its corresponding load was switched ON and the corresponding count data was displayed on seven segments, and if the same digital key was pressed again this load was switched OFF and its corresponding count data was saved until next command executed. Switching load systems were remained turned ON for numbers of hours in order to check its accurate functioning and proper accuracy. This design seeks to highlight a methods and tact to control and count number of other electronic appliances with the help this newly designed micro-PLC.

CONCLUSIONS

Micro-PLC based on AT89C2051 microcontroller was designed to control and monitor for different electrical loads. The brain of micro-PLC was AT89C2051 microcontroller and it was a powerful tool for switching and computing the behavior of load applications (industrial and home appliances) over different electrical parameters with new extended program strength. It was possible to fabricate the micro-PLC without microcontrollers, however, the disadvantage of microcontroller-less micro-PLC is that it is very difficult to trace and remove some faults occur. The presented micro-PLC provides a cost-effective solution in small to medium sized industrial manufacturing and processing plants in addition to all textile industries to count various products in all industrial processes. It can also used to control the home ac load automation like refrigerators, ac units, electric motors, water pumps etc. In industry, this project was used for controlling machines like rotary machines, spinning machines, dying machines,

bleaching and printing machines and boiler etc. Moreover, with the help of this project, a home and an industry can be automated and controlled with this cost-effective micro-PLC. This designed micro-PLC was smaller in size, simple and its programming can be changed without system intervention. The present findings show that the relay of 5 Ampere was used in this micro-PLC system. It remains an interesting subject what other types of relays (e.g. by using 3 phase relays for heavy industry machinery) support PLC and how its strength depends on the controlling range. Finally, it will also be of high interest for future analysis and suggests a need for an experiment or simulation to see how many number relays (16 or 32 relays) effect influence performance of micro-PLC.

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