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PIC MICRO CONTROLLER BASED REMOTE TERMINAL UNIT FOR A SUPERVISORY CATHODIC PROTECTION MONITORING SYSTEM

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ABSTRACT

The design, development and evaluation of a prototype Remote Terminal Unit (RTU) to provide cathodic protection of buried pipe lines are presented. The impressed current cathodic protection (CP) technique is applied in order that the pipe to soil potential is maintained in corrosion free region. The RTU is a closed loop control system designed around a PIC 16F877 micro controller to provide CP to the buried pipe lines. With its on-chip peripheral 10 bit DAQ channels and I/O lines of the micro controller incorporated, the RTU is able to effectively measure the potential of the pipe line and assess the CP status. RTU's serial communication link with a control room monitoring computer paves way to a large supervisory CP monitoring system. The paper deals with the descriptions of the hardware and software package of the RTU with suitable illustrations.

1. INTRODUCTION

Corrosion is an electrochemical phenomenon, whereby a corroding surface consists of anodes and cathodes, with corrosion occurring at the former and protection at the latter. Hence corrosion takes place due to the presence of micro galvanic cells on the same metal surface. In other words, several regions of different electrode potentials on the same metal surface cause corrosion of the metal. Corrosion of metal ceases when the metal is polarized to a potential corresponding to a local cell anode. By application of a suitable voltage, the whole surface is rendered cathodic and hence fully protected [1]. The practice of using cathodic protection (CP), is generally considered to be the most effective and technically appropriate corrosion prevention methodology for buried pipelines [2,3]. CP is an electrochemical process which prevents corrosion or the natural reaction of metals in a particular environment by superimposing an electrochemical cell more powerful than the corrosion cell [4]. The criteria for cathodic protection states that a negative potential swing by 300 mV from the corrosion potential would be sufficient to achieve effective protection of the metal. In order to keep the structure in corrosion free region, attainment of potential of 0.78 V Vs SCE (Saturated calomel electrode) of the steel structure which needs to be protected ensures adequate corrosion protection.

SCADA (Supervisory control and data acquisition) systems which are being installed to protect large buried steel pipe lines or huge off-shore steel platform structures, comprise a network of remote terminal units (RTU) installed to provide CP to various sections of the steel structures [5]. The present work deals with design and development of a similar CP control system which can be employed as an RTU of a SCADA system. The CP technique incorporated is the impressed current technique. The RTU has been designed around a cost effective and versatile micro-controller Microchip PIC (Peripheral Interface controller) IC

16f877. The PIC micro-controller, owing to its Harvard architecture and other advantages such as maintainability, versatility and adaptability has been chosen to be incorporated in the RTU design, which can effectively execute complex control algorithm required to exercise smooth real time control over the CP system. The micro-controller with its on-chip peripherals such as 10 bit DAQ (Data acquisition) channels and digital I/O lines ably provides cathodic protection to the steel structure by means of precision CP potential measurement through its DAQ channels which corresponds to the soil to structure potential with respect to a reference electrode of the CP system. A digital output of the micro-controller drives the high power MOSFET incorporated in the analog interface unit suitably in pulse width modulation mode (PWM) such that the potential of CP system is always maintained in the corrosion free region.

2. HARDWARE

As shown in the schematic block diagram, Fig.1, the hardware package of the RTU includes a PIC micro-controller, an analog interface unit, high power driver, serial communication package that links RTU and the control room PC, a switched mode power supply (SMPS) and the CP system comprising of an anode called Titanium substrate insoluble anode (TSIA) along with reference electrodes and the buried steel structure (cathode). The galvanostatic control unit enables the anode of the CP system to get connected to the positive terminal of SMPS through the high power driver and the steel structure to be protected is connected to the negative terminal of the switched mode power supply through a current sampling resistor, Rx. The reference electrode chosen for the present work is a zinc electrode, its voltage range pertaining to the corrosion immune region lies between –300 mV and –100 mV. If the reference electrode voltage, V_{RE}, is found more negative than –300, then the CP system is said to be in corrosion prone region. Whereas the CP system is said to be in over protected zone when its V_{RE} is found less negative than –100 mV. For convenience of the

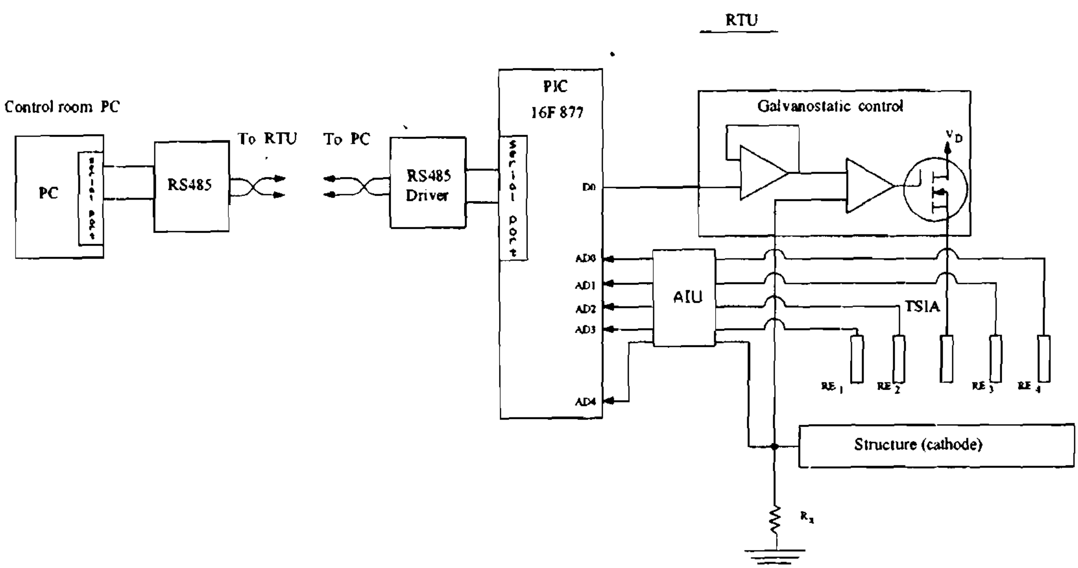

Fig. 1 : Schematic Block diagram of PIC microcontroller based RTU

instrumentation control, the negative zinc electrode potential is converted as positive potential.

In view of its numerous merits such as high operational efficiency, low cost, less weight and compact size, SMPS [6,7] has been chosen as the dc power source for the CP system. The analog interface unit renders signal conditioning to the electrode potentials of four reference electrodes installed at the CP system. Signal conditionings such as buffering, amplification, polarity reversal and filtering of high frequency influences due to surges have been provided to these potential signals in such a manner that the reference electrode potential which represents the CP status of the structure, can be measured effectively with 0.5 mV resolution, by employing the 10 bit DAQ channels of the micro-controller. In order to maintain constant current across the CP system, analog interface unit also incorporates operational amplifier based high power galvanostatic control system which using the micro-controller's on-chip digital output, drives the high power driver, MOSFET IRF540, to impress the current as high as 27 amps in PWM mode, between the TSIA anode and the structure. The high power galvanostat incorporates MOSFET as its power driver for its several advantages [8] such as very fast switching, absence of second breakdown, wide safer operating area, voltage control, negligible drive current and ease of paralleling etc. IC Max 1485, interfaced with the serial ports of both the control room PC and the micro-controller [9,10] is the main component of the RS-485 serial communication package which facilitates interactive communication between the control room computer and the RTU installed at a distance around more than 1 km from the control room. EIA Recommended Standard 485 is designed to provide bi-directional half-duplex multi-point data communications over a single two-wire bus. RS-485 serial communication system has been chosen for its merits such as enhanced communication distance (1.2 Km) , high speed data (as high as 12 Mbps) , very low driver output level (as low as ±1.5 V) and network of 32 drivers and receivers on the serial bus etc..

3. SOFTWARE DESCRIPTION

The software package or the firmware of the RTU is developed using a commercially available C compiler. The firmware comprises of several sub software modules or software driver programs such as DAQ module, CP control module, serial communication module and control room front end virtual instrumentation module. DAQ module supports multi-channel precision reference electrode potential measurement with ±1 mV accuracy. Each of the four on-chip ADC channels interfaced with the analog interface unit, is selected and data acquisition subroutine is executed. After each data acquisition routine, the digital output obtained at the respective ADC channel is converted as the reference electrode potential by means of a real value conversion subroutine incorporated in the software module.

The CP control module employing an output driver program enables a galvanostatic current through an output line, across the CP system in pulse width modulation (PWM) mode. The flow chart of the impressed current cathodic protection (ICCP) control algorithm, as depicted in Fig.2, shows that the galvanostatic pulse current is modulated in direct proportion to the potential of the reference electrode critically chosen to monitor the CP status of the buried steel structure. The off-time of the impressed current has been set as 5 s while the on-time, T_{ON}, is calculated from the difference between the reference electrode voltage V_{RE} and the set potential, V_{SET}, where V_{SET} is set as 200 mV which is the center of the corrosion

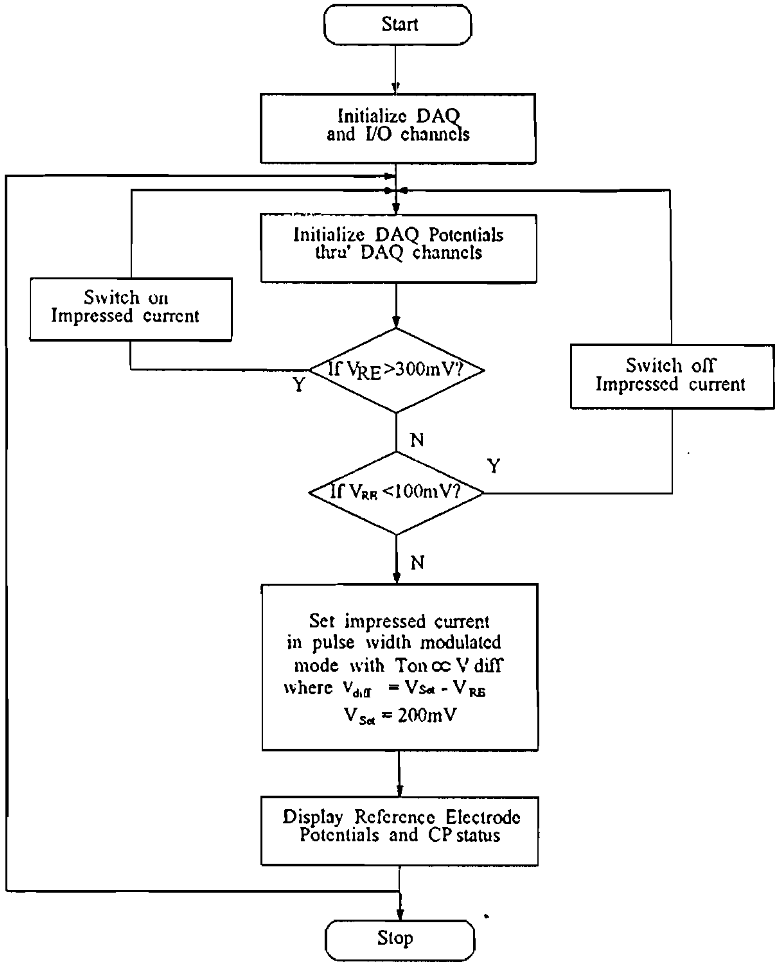

Fig. 2 : Flow chart of ICCP Control Software package of PIC Microcontroller based RTU

immune region. As the reference electrode potential approaches near 300 mV, T_{ON} tends to be 10 s and it tends towards zero when V_{RE} is found nearer 100 mV. At 200 mV, T_{ON} is set as 5 s. The CP current control module ceases to employ PWM mode of impressed current when V_{RE} is found greater than 300 or less than 100 mV. It either switches off the impressed current when it detects overprotected zone or switches on the impressed current continuously when V_{RE} is found in corrosion region. By exercising PWM control only in the corrosion immune region which lies between 300 and 100 mV, the control algorithm enables a very smooth control over the CP system.

The serial communication module provides effective operational link between the RTU and the supervisory control room computer. It enables the supervisory computer to execute on line monitoring and control of the CP parameters such as V_{RE} and the impressed current of the CP system being controlled by the RTU. By employing the interrupt feature of the on-chip serial port's receive line, this module incorporates suitable interrupt service routines (ISR) and treats any instruction received in the form of data from the host computer as an interrupt and executes its relevant ISR and returns to its main functional operation of rendering cathodic protection to the structure which comprises reference electrode potentials measurement and execution of galvanostatically impressed current in PWM mode.

The virtual instrumentation module which is installed at the control room PC has been developed using Microsoft Visual Basic language. The software is developed as modular virtual instruments (V I) that one can easily examine, experiment with, and enhance or integrate into the tests of different groups [11,12]. Virtual instrumentation is the programming technique to use a general purpose computer to mimic real instruments with their dedicated controls and displays. The software package renders versatility to the VI technique. One major development resulting from the ubiquity of the PC is the concept of virtual instrumentation, which offers several benefits to engineers and scientists who require increased productivity, accuracy, and performance. Virtual instruments in the front panel, created by Visual Basic software package, provide online display of V_{RE}, anode voltage (it can be connected to another on-chip ADC channel), the CP current and the CP status depending upon the value of V_{RE} . A window to exhibit an X-Y plot included in the virtual instrumentation package of the supervisory computer facilitates on line data logging and plot of V_{RE} Vs time together with the display of the CP status. The display message such as 'Over protected ' appears when V_{RE} is found to be less than 100 mV and when it exceeds the value of 300 mV, then 'Under protected' appears on the CP status slot. The CP status slot in the front panel virtual instrumentation window shows 'Protected zone ' when V_{RE} lies between 300 and 100 mV . The on line data logging feature of the front end software package of the supervisory PC, supports creation of data file for logging the CP data periodically at an interval of every two hours. In order to monitor entire stretch of the steel structure, all the four reference electrode potentials along with their respective CP status are logged and displayed in the front end virtual instrumentation window.

4. THE CP CONTROL SYSTEM [1,13-16]

For an experimental study, a 20 m long steel pipe line segment with 20 cm diameter, buried in soil was chosen as the structure to be protected. As per the CP design which satisfies the impressed current density requirement of 0.1 mA/m^2 for bare steel structures, location and placement of the anode and the reference electrodes were determined. A few tens of meters away from the structure, the TSIA anode along with four reference electrodes were so suitably installed that the potentials of the reference electrodes which were placed farther from the anode indicate corrosion immune region at the application of 20 V, 2 A dc supply. The RTU was installed near the structure and its communication with the control room PC 100 m away from the RTU, was established through a leased telephone link cable supported by the serial RS-485 drivers installed at the serial ports of the both the PC and the PIC micro-controller of the RTU. In bi-directional, half-duplex mode, at 9600 baud rate, the serial RS-485 communication facilitates effective interactions such as transferring of multi-channel data pertaining to reference electrode potentials and the impressed current value etc., from the RTU to the control room PC and receiving control commands corresponding to the termination or execution of the impressed current either in dc mode or in PWM mode from the control room computer to the RTU. A few weeks after the installation of the RTU, from both the data and the graphical plots obtained at the control room PC, the buried pipe line's CP status has been found shifted from corrosion region to immune (corrosion free) region. The average value of V_{RE} was found to be around 240 mV and the impressed current was seen to be around 1.5 A in PWM mode.

5. CONCLUSIONS

The designed RTU was successfully installed and it is being observed to protect and maintain the buried pipeline in corrosion free region. Remote monitoring and control of CP system together with front end virtual instrumentation window to provide display of V_{RE}, the impressed current of the CP system, logging of CP parameters and graphical plot of CP status of the structure etc., is the unique feature of the SCADA design. Because of its low maintenance and design cost due to improved and versatility of PIC micro-controller, this RTU is also attractive for use in many other industries. With its high power driver of handling CP current as high as 27 amps, the RTU can provide CP to a pipe line as long as 15 times the size of the pipe line employed for this CP experiment. For handling much higher values of CP current i.e., for protecting a pipeline of several hundred metres length, suitable number of modules of high power MOSFET IRF150 (100V,40A) can be employed to combat high CP current requirement. With RS-485 serial communication protocol, 32 RTUs can be networked in the SCADA system with the communication distance around 1.2 km between RTUs and the control room PC. In addition to its primary role of monitoring, reporting and control, the RTU can be programmed to implement complex algorithms to suit numerous applications.

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