Rust Prevention in Structural Establishments using Cathodic Protection Technique Driven by an MPPT based Solar Charge Controller

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Abstract- This paper is aimed at the implementation of a novel technique to prevent the formation of rust in structural establishments. The existing metallic structures usually exceed their original design lifetime and hence require a potent protection mechanism for a rust-free life extension. The Impressed Current design of Cathodic Protection coupled with simple design features, installation procedures and cost effectiveness presents an ideal technological solution to the prevalent issue of rusting and subsequent degradation of structural establishments. This method makes use of the abundantly available Solar Energy for battery charging, which provides the required impressed current for cathodic protection. In this method, Maximum Power Point Tracking based digital charge controller is employed to ensure maximum charging efficiency and economic feasibility. The charging module is operated in buck configuration to maximize the rate of charging. This enhanced design of Impressed Current Cathodic Protection ensures precise, standard industrial levels of protective current in metallic structures used in infrastructure and commercial buildings. This process provides sufficient protection to metallic structures by ensuring efficient transfer of electrical current through the structure's concrete sections. A suitable anodic material is cast onto the top surface of the concrete slab present above the steel frame structure. The experimental results indicate the effectiveness of the proposed design in terms of ease of design, economic considerations and superiority over existing models. The proposed model exhibits extreme potential to inhibit rust formation which can be adopted for various industrial applications.

Keywords-Impressed Current Cathodic Protection Technique, Solar Maximum Power Point Tracking, Rusting**.**

I. Introduction

Rusting is an electrochemical process which is characterized by the exchange of electrons. It can also be defined as the slow process of deterioration of materials due to their reaction with the environment. Various environmental factors contribute to the process of rusting. Iron oxidizes naturally into various forms of Iron Oxides which are less stable than the original form of steel/iron. Both moisture and air are required for the corrosion of metals to occur. The common methodologies employed to prevent rusting include the usage of anodic and cathodic inhibitors, application of barrier coatings and sacrificial anodic method. However, it has been proven to a great extent in various research studies that the most efficient of these methods is the process of Impressed Current Cathodic Protection. Engineering knowledge is incomplete without an understanding of rusting, its adverse effects and thereby devising a solution to overcome this undesirable phenomenon. A technique to minimize the ill effects of rusting is Impressed Current Cathodic Protection, employed when the system to be protected is subjected to an aggressive environment to a great extent to which cathodic protection is technically feasible and suitable.

This technique involves impressing current over the cathode which is the structure to be protected, by providing a stream of electrons over the metallic surface [1]. This process is clearly more preferred than the sacrificial anodic method. The voltage differences between the anode and the cathode are limited in the sacrificial anode systems to approximately one volt or less, depending upon the anode material and the particular type of environment. Impressed current systems can make use of larger values of voltage differences. The larger voltages available with the impressed currents allow remote anode locations, thereby producing much more efficient and uniform current distribution patterns along the protected cathode. These larger voltages achieved are useful in low conductivity environments such as freshwater and concrete [4]. Solar Energy is used to drive the process of Impressed Current Cathodic Protection, thereby ensuring a reliable source of power supply. The process of solar charging is enhanced by utilizing a Digital Maximum Power Point Tracking based solar charge controller. In this proposed model of rust prevention using Impressed Current Cathodic Protection, an Arduino Duemilanove with ATmega 328 based solar charge controller is designed to provide the desired value of current to be impressed over the structure to be protected. In this era of energy and power crisis, it is imperative to utilize renewable energy sources like solar energy to overcome various technological challenges. In particular, this model exhibits immense potential to help mitigate corrosion in various metallic structures to a large extent.

II. Fundamentals of Rusting

A potential difference usually exists between two dissimilar metals when subjected to a corrosive or conductive environment. When metals are electrically connected or are in direct contact with each other, a corrosion cell is formed and a certain value of potential difference produces an electron flow between them. A corrosion cell is comprised of the following components:

Anode: The anode is usually represented as the negative terminal of the corrosion cell. In Impressed Current Cathodic Protection technique, the positive terminal of the battery is connected to the anode portion of the cell. The required number of anodes are installed and interconnected by means of a feeder wire. Graphite has been employed as the anode in this proposed model. Graphite happens to be a good conductor of electricity and it enhances low current density current discharge. It also further offers low resistance to the electrolyte, due its high ratio value of surface area to the weight. The consumption rate of graphite is 0.25 Kg/A/Year which makes it a favorable and an economical choice for the system, among the various anode materials available.

Cathode: The Cathode is represented as the positive terminal of the corrosion cell formed. In Impressed Current Cathodic Protection technique, the negative terminal of the battery used is connected to the cathode. The areas of the metallic structure targeted for protection constitute the cathode portion. The wire connections given to the metal provide a return path to the power supply unit, as the negative part of the circuit.

Electrolyte: The electrolyte is the electrically conductive portion of the cell that enables the flow of electrons and must be present for rusting to occur. The protective current intended for rust prevention is passed through the stonework or masonry with the help of a mortar or concrete connection with the steel frame. It is observed that freshwater sources have a great tendency to contribute to the process of rusting of metallic structures.

Table I: Current density and consumption rates of various anodic materials

S. No.	Material	Typical Anode Current Density (A/m^2)	Consumption Rate per A year
1	Si-Cr Cast Iron	5-10	0.1-0.5 kg
2	Platinum on Substrate	540-1080	0.006 g
3	Platinum Clad or Wire	1080-5400	0.02g
4	Graphite	10.8-40	0.225-0.45 kg
5	Scrap Steel	5-15	9 kg
6	Aluminium	0.6-2.5	3.4 kg

III. Impressed Current Cathodic Protection

Impressed Current Cathodic Protection technique is employed primarily in many of the structural establishments where the electrolyte resistivity is high and it is comparatively more economically feasible than ordinary sacrificial anodic protection systems. Impressed Current Cathodic Protection (ICCP) systems use an anode which is connected to a DC power source. Anodes for ICCP systems are tubular and solid rod shapes or continuous ribbons of various specialized materials. This technique on the principle that rusting is an electrochemical reaction in which iron or steel acts as a cathode while graphite acts as the anode. At the cathode corrosion occurs as iron gives up electrons and forms soluble iron ions. At the anode the electrons released by the corrosion process combine with water and oxygen to form hydroxide ions. In this system the metal to be protected is made to act as the cathode, which is unaffected by the corrosive reaction, preventing further rusting [2]. When employed to protect structural iron and steel, this is achieved by means of passing a defined industry standard small value of electric current through the structural material. This ensures a constant stream of electrons to satisfy the cathodic reaction and thereby helps to inhibit the rusting process.

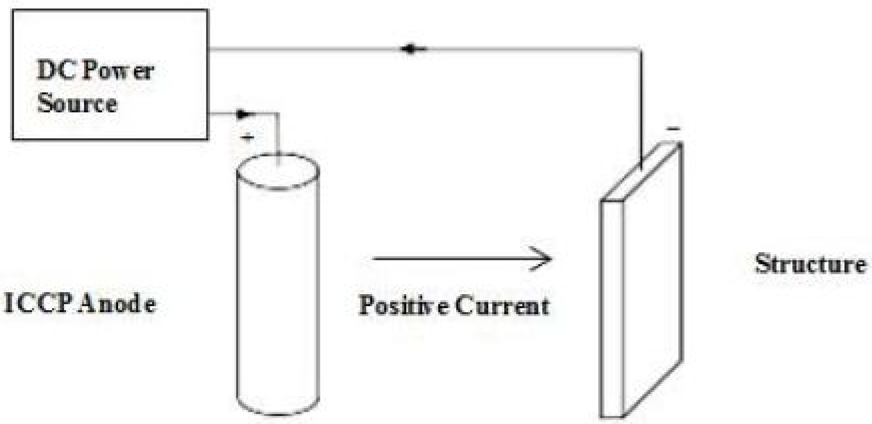

Figure 1. Impressed Current Cathodic System for Structural Establishments.

The primary advantage of Impressed Current Cathodic Protection in the protection of embedded metalwork in structures is that it provides protection from rusting without changing the immediate physical environment. It provides the electrochemical conditions to control the rusting process. The implication of this process is that there is no need to gain full access to the structure by means of removing the surrounding material and that it can remain largely intact [5]. Impressed Current Cathodic Protection has a clear advantage over other methods of corrosion prevention. It makes it possible to adjust the value of current and voltage, with an ability to provide an unlimited required current output. This technique can be adopted over a wide range of resistive environments and works extremely well on large structures which are typically employed in most of the petrochemical industrial sectors and other crucial commercial establishments [3].

IV. MPPT solar Charging System

The Maximum Power Point Tracking based solar charging unit is designed to ensure maximum efficiency in the charging rate of the battery along with minimal energy loss in the system [8]. The battery is utilized to provide the requisite industry standard value of impressed current over the cathode to drive the process of Impressed Current Cathodic Protection. The system involves dynamic measurement of voltage and current values of the Solar Panel and the DC Battery at all times. The voltage of the solar panel is sensed using a voltage divider while the current value is determined by an ACS712 Hall Effect Sensing Module. The voltage value of the battery is also measured using a voltage divider. The measured values are processed by the

Arduino Microcontroller to determine the charging state of the system and to set the corresponding rate of charging of the battery. The electrical parameters of the solar panel are passed on as inputs to the Microcontroller whereas the battery voltage value is sent to the Microcontroller as a feedback. The main functionality of the Microcontroller is to provide pulse width modulation (PWM) control. It also controls the conversion ratio of the microcontroller based on the values of the input electrical parameters. The DC-DC converter which is used in buck configuration converts the higher voltage and lower current of the solar panel input into lower voltage and higher current for battery charging [9]. At every stage, the Microcontroller computes Maximum Power Point by using an iterative algorithm. Also, the various charging states are set based on the comparative analysis of the input electrical parameters.

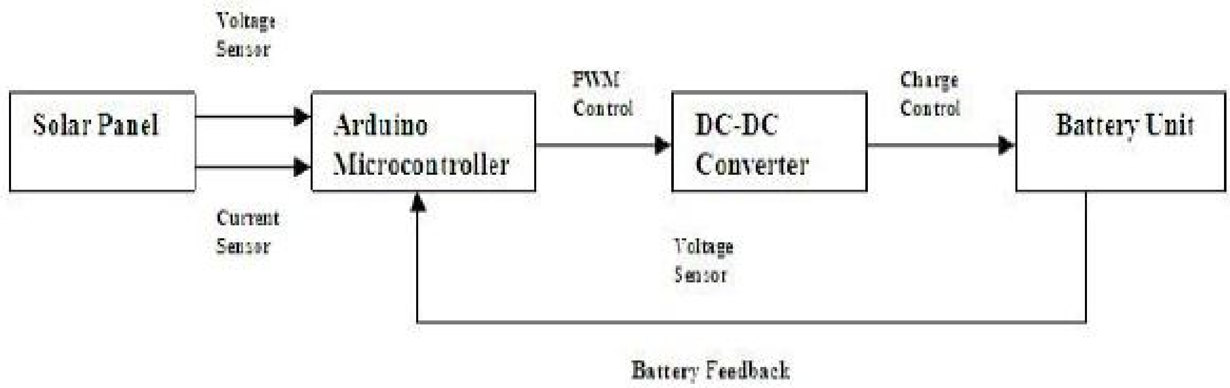

Figure 2. Block Diagram of MPPT Solar Charging Setup.

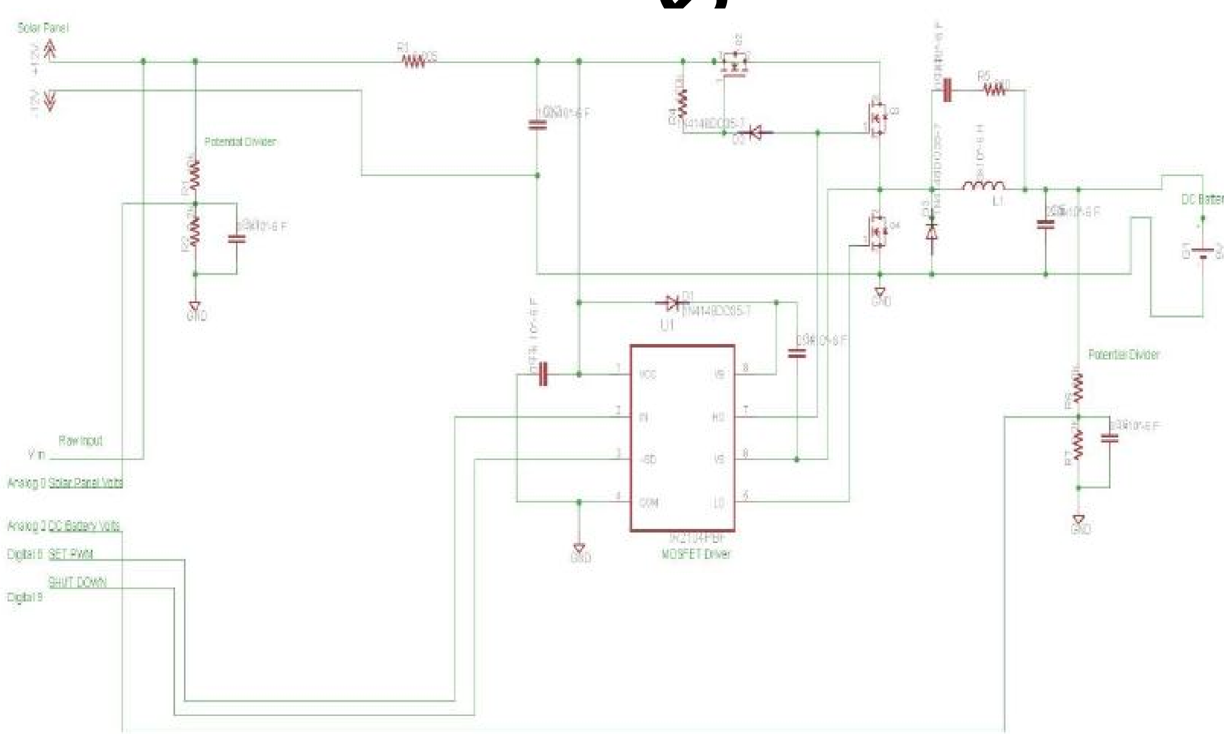

Figure 3. MPPT Based Solar Digital Charge Controller Schematic Using Eagle V 6.6

The microcontroller also sets the pulse width modulation duty cycle on the MOSFET driver IR2104 integrated circuit, which is used to switch the MOSFETs. The pulse width modulation is maximum or

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hundred percent when maximum power is to be achieved. In all other cases, it is suitably set to a lesser value. The charging circuit is basically a buck converter controlled by the Arduino microcontroller [7]. The microcontroller determines the voltage of the solar panel where the peak or maximum power is produced and controls the buck converter to match the solar panel voltage to the battery voltage. This solar charging module is primarily designed to vastly improve the charging efficiency of the Solar Charging process. It proves to be a better alternative to the commercially available, high cost maximum power point tracking solar charge controllers. Additionally, in this solar charge controller, the electrical parameters are monitored dynamically and displayed in the output screen to establish a monitoring mechanism. The monitoring system provides details pertaining to: charge state (on, off, bulk, float), pulse width modulation, duty cycle, voltage and current values of the solar panel and voltage value of the DC battery. The microcontroller determines the voltage of solar panels at which the maximum power is produced and controls the buck converter to match the solar panel voltage to the battery voltage [10]. The solar panel input voltage is connected to the VIN input of the microcontroller and the solar panel ground input is connected to the ground of the microcontroller. The solar input current is read using a hall-effect current sensor module. This project utilizes the ACS712 hall-effect based linear current sensor. This is a three pin module with pins: Vcc, Gnd and Output. The sensor module is powered up by connecting the Vcc pin to 5 volts pin provided in the microcontroller. The ground is connected to the common ground of the entire circuit. The output pin is connected to one of the analog pins of the microcontroller which is used to read the current value. The positive ends of the solar panel and the battery are connected across the current sensor module for determining the current value. The solar panel input voltage is divided down by two known standard resistors and sent to the analog 0 input pin of the Arduino microcontroller.

Figure 4. Experimental setup of the MPPT Solar Digital Charging Module.

Q1 is the blocking MOSFET that prevents reverse flow of the battery power into the solar panel. This can be achieved by using a diode. However, MOSFETs are preferred as they tend to have lower power dissipation. The intrinsic MOSFET diode doesn't conduct since Q1 is turned around. Q1 turns on when Q2 is on from voltage through diode D2. The resistor connected across this MOSFET drains the voltage off the gate of Q1 so it turns off when Q2 turns off. Q2 is the main switching MOSFET for the DC-DC converter operated in buck configuration and Q3 is the synchronous switching MOSFET. The MOSFETs are driven by an IR2104 MOSFET driver. The IR2104 takes the pulse width modulation signal from the processor digital input pin 9 on pin 2 and uses it to drive the switching MOSFETs. The IR2104 also has the shutdown functionality. This is done by controlling the signal from the processor digital pin 9 on pin 3. The program always keeps track of the pulse width modulation duty cycle and never allows maximum or hundred percent [6]. It caps the pulse width modulation duty cycle at almost maximum to keep the charge pump working. D1 is the diode that starts conducting current before Q3 turns on. It makes the buck converter more efficient. L1 is the main inductor that smoothens the switching current and along with C3 it also smoothens the output voltage.

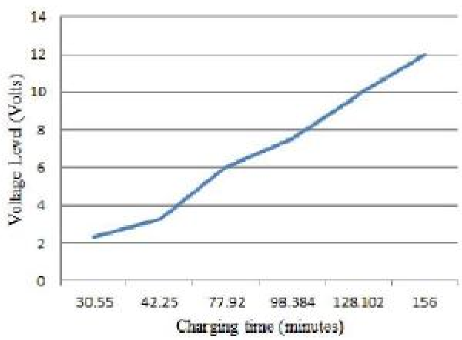

Figure 5. Charging time required to attain different voltage levels, using the proposed solar charge controller module.

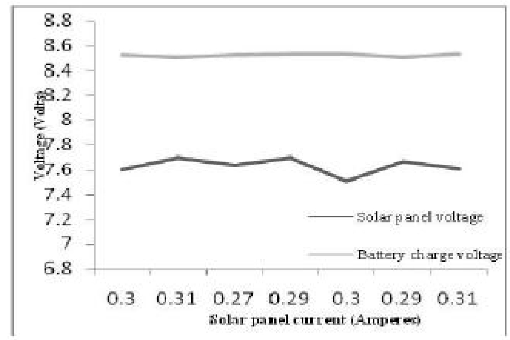

Figure 6. Solar Charge controller Characterisitcs in float charging state.

V. Calculations

A crucial consideration for the design calculations in the implementation of Impressed Current Cathodic Systems on existing metallic structures is the industry standard value of current density. A metallic structure requires an industrial standard current density value of 0.2 milli ampere per square metre to be impressed on its surface.

The calculations are computed by suitably considering the coating efficiency of the metallic structure used in this particular model. The coating efficiency is approximated to eighty percent.

Impressed Current Computation Parameters:

Current Density of Metallic Structure in freshwater [J_s] = 10mA/m^2

Radius of Metallic Structure = 2 cm.

Length of Metallic Structure = 16 cm.

Surface Area of the metallic structure = 0.02009 m^2

Actual Impressed Current Computation:

Current I_s = ($s*J_s*[1-CE]$) (1)

CE [Coating Efficiency] = 80 %

Current I_s = ($0.02009*10*10^{-3}[1-0.8]$)

= 0.1608 mA

Actual Current Value = Current I_s + 40% Spare Current (2)

= 0.22 mA

VI. Experimental Results

The Digital MPPT Solar Charge Controller efficiently processes the information obtained from the electrical devices: solar panel, current sensor and dc battery instantaneously. This information is used to compute the iterative maximum power point algorithm to perform efficient battery charging. The use of this system ensures minimum energy loss as well as maximum utility of the solar panel. This method also provides solar panel protection by making sure that power doesn't flow in the reverse direction from the dc battery towards the solar panel.

Figure 7 (a) Final state of metallic structure with proposed ICCP system.

Figure 7(b) Final State of metallic structure with no protection.

The exhaustive experimental analysis was performed on two sample rusted metallic structures, to exhibit the conformity of the model for real time applications. Impressed Current Cathodic Protection was applied to the one of the metallic structures whereas the other was left isolated, without being subjected to any kind of protection. The experimental setup was left undisturbed for a period of more than two weeks and then the results were observed. The metallic structure subjected to Impressed Current Cathodic Protection portrayed not even marginal corrosion signs whereas the isolated structure developed corrosion in the same duration.

Figure 8. Contrasting final states of the two metallic structures.

VII. Conclusion

This enhanced design of Impressed Current Cathodic Protection for rust prevention in structural establishments provides cost-saving in excess of fifty percent in comparison with traditional approaches like protective coating and replacement of corroded material. The power supply to this system for providing subsequent low value of impressed current is enhanced by the usage of the digital MPPT based solar charge controller. The efficiency of the solar charging process is improved by using the charge controller in buck configuration. Additionally, it also provides sufficient protection against backflow of power from the battery to the solar panel. This model adheres to the industry standard value of impressed current required for protection of metallic structures. This model also proves to be a beneficial method for rust prevention in terms of system operating parameters and economic feasibility. Thus the overall investment in a long term rust mitigation system is brought down and it serves to be an ideal strategy for protecting metallic structures.

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