Control of Impressed Current Cathodic Protection Systems

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About the Authors

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Introduction

Metal structures are susceptible to oxidation due to interaction with their surrounding environment. If left unaddressed, metal deterioration due to oxidation can ultimately lead to structural failure. The typical first line of defense against oxidation is shielding exposed metallic surfaces with a protective coating such as paint. However, microscopic flaws in the external coating or the eventual effects of weathering can still lead to structure compromise.

Additional protection against oxidation is provided by cathodic protection systems. These utilize electro-chemistry to counter-act the oxidation process. Cathodic protection systems may utilize sacrificial anodes made from materials with high electron mobility (such as zinc), but these systems, while they may be effective at protecting the structure, require ongoing maintenance that can be expensive and impractical.

Utilizing an independent source of electrical power to impress a current between the structure and its surrounding medium, Impressed Current Cathodic Protection (or "ICCP") systems offer effective long term protection, with much reduced maintenance. While ICCP systems have been in use for more than 75 years, control of these systems has not kept pace with technologies made available in other electronic systems.

This paper examines the control needs of ICCP systems and outlines a series of products that provide optimized control and reduced ongoing maintenance requirements.

Cathodic Protection Theory

Oxidation is a process whereby a metallic surface interacts with its surrounding media by exchanging electrons. The media surrounding a structure can act as an electrolyte, forming an electrical circuit with the structure whereby electrons are passed between the two. Figure 1 presents the equivalent electrical schematic diagram. If not protected, an electrical potential can be detected between the structure and the surrounding media. Typically, this is measured via a volt meter connected between the structure and a Copper/Copper Sulfate ($Cu:CuSO_4$) measurement electrode. As shown in Figure 1, a potential of -0.5 to -0.8V would be the typical value observed for a steel structure.

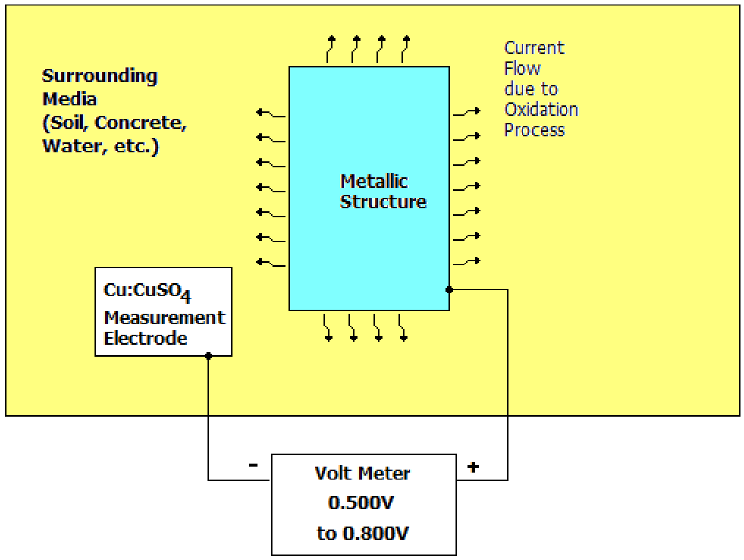

Figure 1 – Oxidation Process

Electrons will flow from the surrounding media into the structure, which shows a more positive potential. Corrosion occurs at the point where positive current leaves the metal surface.

Cathodic protection is a method used to prevent oxidation and corrosion on structures by providing a DC current that subdues the electro-chemical response which occurs during oxidation. Installing sacrificial anodes which exhibit a lower electrochemical potential in the vicinity of the structure is one method for achieving cathodic protection. However, the difference in potential between the sacrificial anode and structure will be modest (typically less than a volt) and this may not be adequate to overcome the electrical resistance of the surrounding media to the point where adequate protection is realized. In addition, sacrificial anodes will degrade over time and require periodic replacement, which is often either impractical or very expensive.

With Impressed Current Cathodic Protection, an external power source is used to force a current between the structure and surrounding media that is opposite to the current that results from the oxidation process. Once applied, ICCP current polarizes the surface of the structure such that the measured voltage reverses polarity, indicating a current flow from the ICCP anode toward the structure.

Care must be taken while implementing ICCP systems that they do not over-protect the structure, as excessive ICCP current can result in structure deterioration due to Hydrogen embrittlement.

Traditional ICCP System Control

Typical ICCP systems utilize a step down transformer / rectifier to generate a DC voltage that is applied between the structure and its surrounding media, as shown in Figures 2 and 3.

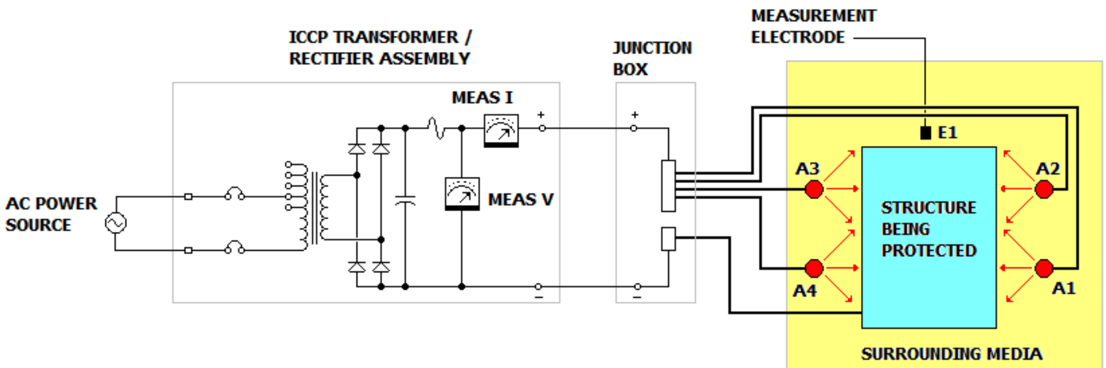

Figure 2 – Typical ICCP System

The positive output voltage terminal of the ICCP Transformer/Rectifier is connected to a series of current emitting anodes (labeled A1 through A4) that are embedded in the media surrounding the structure being protected. The rectifier's negative voltage terminal is connected to the structure being protected.

Figure 3 – Typical ICCP Rectifier

The effective protection range of ICCP current can be determined via a number of methods, but a method that is oftentimes employed measures the voltage between the structure being protected and the surrounding media via a series of measurement electrodes (usually referred to as reference electrodes) strategically placed around the structure.

Measurements are made with the ICCP rectifier operating and non-operating. Measurements made while the rectifier is operating will be effected by any IR drops that result from protection current passing through the surrounding media. For this reason, ICCP system checks oftentimes require an interruption of ICCP current and a measurement of voltage between the reference electrode and protected structure

Rectifier output voltage is manually adjusted via a series of taps on the primary winding to the point where the current being produced produces measurements within the desired effective protection range.

The resulting current is dependent on a number of factors, including input voltage and the resistivity of the media surrounding the structure. Swells or dips on the incoming power line, or media resistivity changes caused by moisture or other conditions, can lead to current variations that result in either under or over-protection of the structure. For this reason, systems typically require a significant amount of periodic manual monitoring and readjustment to assure adequate protection is being applied.

Improved ICCP Control Methods

Constant Current Control

The most basic improvement for ICCP system control is to provide a power converter that automatically regulates its output current in response to input voltage variations, or anode-to-structure impedance variations. Figure 4 provides a block diagram of such a system.

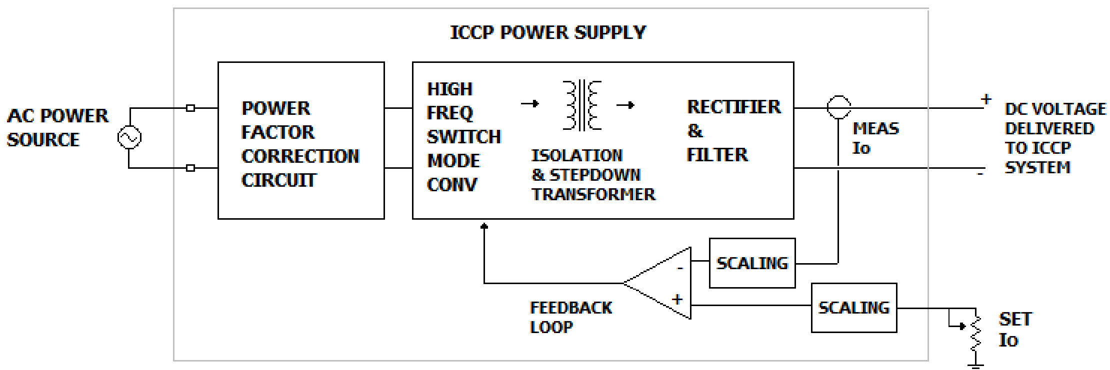

Figure 4 – Constant Current ICCP Power Supply Block Diagram

As depicted in Figure 4, the ICCP power supply is a high frequency switch mode (HFSM) design that presents a modulated, high frequency (typically 100-kHz or more) AC voltage to an isolation and step down transformer. This voltage is then passed through a rectification circuit and low pass filter so that low voltage DC is presented to the output.

Most modern HFSM designs also feature an additional converter at the AC input that forces input current to have low harmonics and input power factor to be very near to unity. Note that conventional ICCP rectifiers, as depicted in Figure 2, do not have this feature and their input power factor (and input harmonic content) suffers, to the point where for larger structures, utility power usage can be significantly higher than what is actually required to support ICCP. Some regions in the world place limitations on power factor and harmonics that a conventional ICCP rectifier cannot meet.

Control of the power supply's output current is achieved by monitoring output current and comparing it to a reference that is user adjustable. These then form a difference signal that is applied to the power converter's feedback control loop so as to maintain output current at a constant value over a wide range of output load resistance (and corresponding load voltage).

The range of voltage that output current can be regulated over is generally called the voltage compliance range. This is chosen so that proper current can be supplied over the expected range of DC resistance between the structure being protected and the surrounding current emitting anodes.

Systems employing this type of control will be safeguarded against current variations due to input voltage variations or surrounding media conditions.

Monitored Voltage Control

In situations where the current required to protect the structure is anticipated to change based on climatic or surrounding media changes, such as that found in a marine vessel, a system that monitors the potential between the structure and surrounding media, and continually adjusts current until this potential is within a desired range, is often employed. Figure 5 presents a simplified block diagram of such a system.

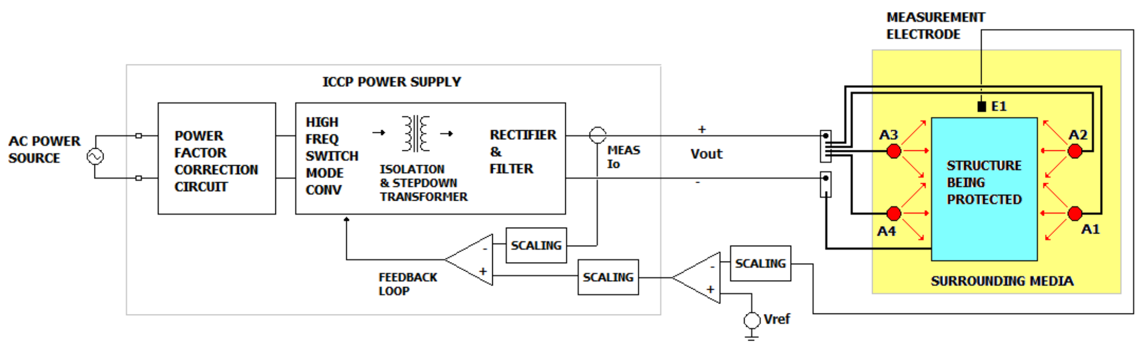

Figure 5 – Monitored Voltage Control

In Figure 5, the voltage potential between the structure and surrounding media is monitored via electrode E1. This signal is appropriately scaled and applied to circuit that forces the power supply's output current to be at a level which maintains the voltage between the structure and media within a predetermined band. As surrounding media conditions change, power supply output voltage will automatically adjust to maintain a current that produces the desired voltage between the structure and media.

ICCP System Monitoring

Normal monitoring of ICCP system performance includes input power status, output power status (voltage and delivered current), temperature monitoring, system fault status, and cathodic process monitoring.

Cathodic process monitoring usually revolves around checking the voltage potential between the structure being protected and the surrounding media. This can accomplished with the protection system active and the protection system turned off, or by monitoring the voltage between the structure and surrounding media as a function of time and/or applied current. Collected values are compared with predetermined limits to verify protection is effective.

In order to automate these measurements, the ICCP system must feature an on board data acquisition system that provides adequate precision, accuracy and data storage capability. Effective means of transmitting collected information to an external system monitor is also required.

Figure 6 illustrates the concepts of precision and accuracy.

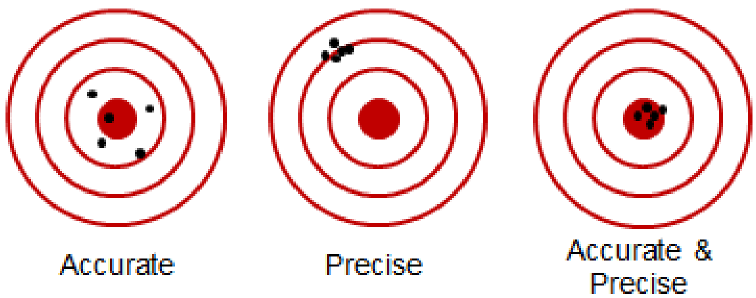

Figure 6 – Illustration of Accuracy and Precision Concepts

In an ICCP system, voltage to be monitored will typically be on the order of hundreds of millivolts while current can be as high as hundreds of amperes. Any onboard data acquisition system must be capable of accurate and precise measurements in these ranges. Care must be taken in that ICCP systems may be implemented in electrically noisy environments where extraneous signals can interfere with accurate measurements.

Certain ICCP test routines require monitoring of ICCP potential over time periods on the order of minutes during the application or right after the removal of ICCP current. Other ICCP test routines, such as verifying the system is operating in the Tafel Segment of the E-Log_I Curve, may require up to 1000 individual current measurements. An on-board data acquisition system should provide adequate data storage to facilitate these types of tests.

TDI Product Offerings

TDI Power is providing a number of ICCP system rectifiers to satisfy system needs from low to high power, along with built in ICCP system control ranging from simple to complex.

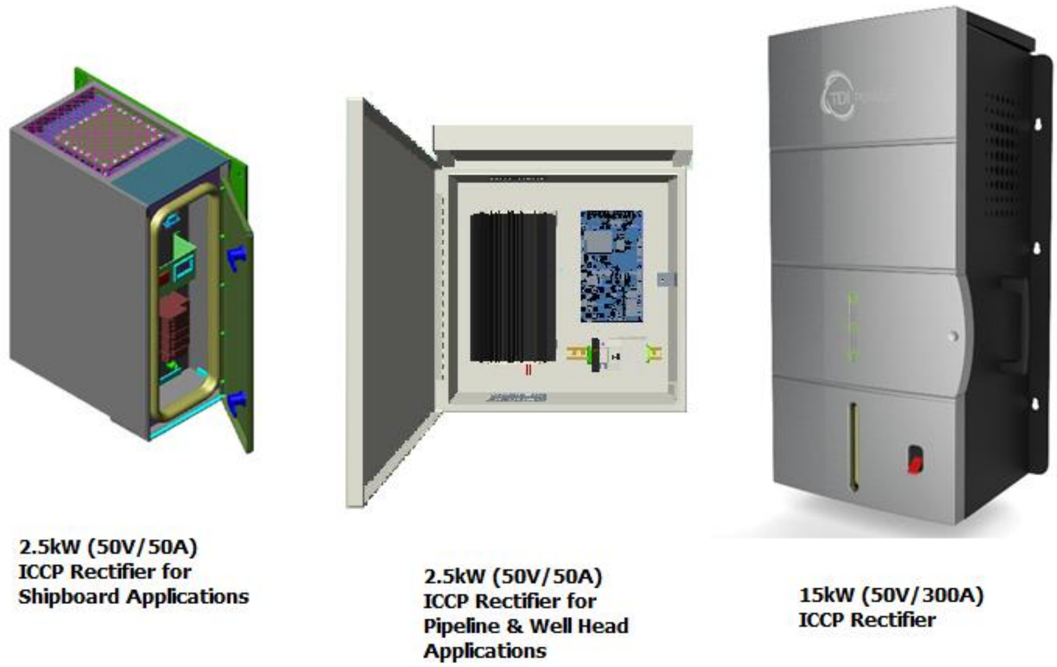

Figure 7 - TDI Power ICCP Rectifier Product Offerings

Figure 8 presents the typical block diagram for TDI's ICCP rectifiers.

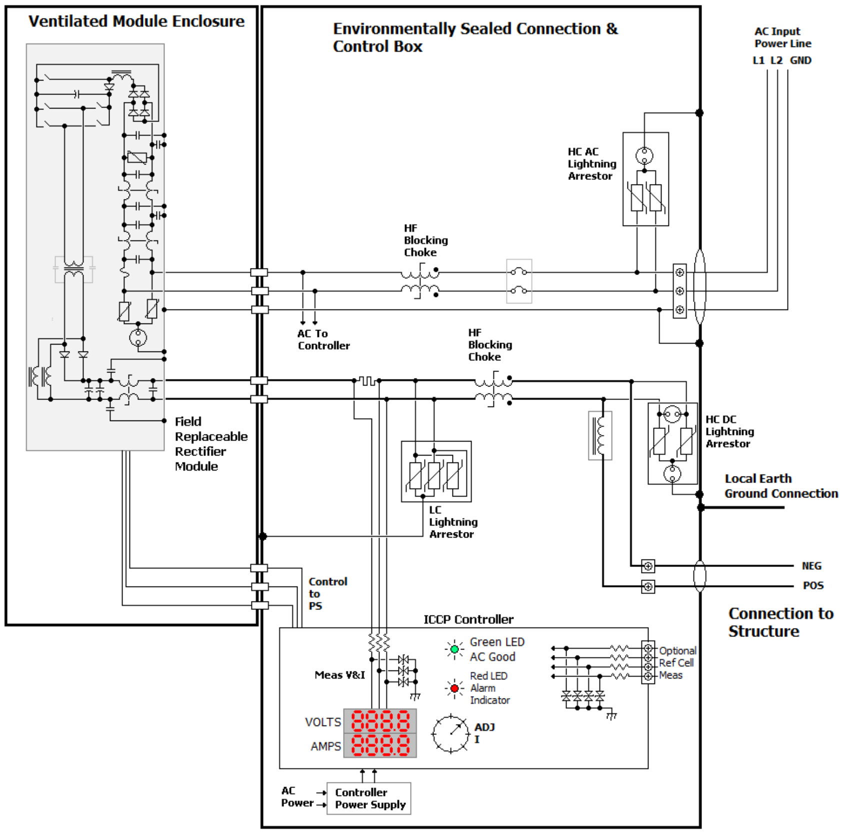

Figure 8 – ICCP Rectifier Block Diagram

Alongside an environmentally sealed power converter and extensive lightning and surge protection, these systems feature an onboard controller assembly that can be configured for either simple manual control (Simple ICCP Controller), or more complex automated control (Advanced ICCP Controller).

With the Simple ICCP Controller, a lockable, rotary potentiometer to set system output current is provided. System output current and voltage are provided via digital meters on the controller assembly. Once the desired output current is reached, the rotary control can be locked and the system will maintain the current set point. The manual control mode controller also provides LED indicators for input power good, and indicators for input and output surge protector status. System operation can be interrupted via an onboard circuit breaker for the AC input.

The Advanced ICCP Controller provides the features of the Simple Controller, along with provisions to:

a. Interface via USB to a local computer to enable local system monitoring and control.

b. Interface via Ethernet for remote system monitoring and control.

c. Remote setting of current in constant current mode.

d. Operate the system in voltage regulation mode where up to four remote sensing electrodes are monitored for ICCP voltage measurements. These readings are averaged together to achieve a composite ICCP voltage that is actively regulated to be within a user settable band.

e. Provide the ability to remotely enable or disable the ICCP rectifier to allow for various ICCP system measurements.

f. Provide an onboard data processor with data storage so that up to 1000 data points (time stamp, system output voltage, system output current and monitored remote measurement electrode data) can be recorded and stored. The processor is user programmable regarding time step and rectifier output conditions.

g. Provides extensive alarms, including measurement electrode reading out of range, rectifier failure, surge protector tripped, AC power line status, and system operating temperature.

Conclusion

Opportunities for ICCP system optimization are provided with implementation of modern power conversion and control technology. Leveraging lessons learned from other heavy duty industrial applications, these technologies promise both improved reliability along with reduced costs. Critical structure integrity can be more precisely controlled while operational data collection is automated for easy access and review.