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Control of Solar Powered Cathodic Protection System

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ABSTRACT

Cathodic Protection (CP) is an effective method to reduce the corrosion of metallic structures that submerged in water or buried in soil. In order to reduce the corrosion of any structure, the voltage between the metal to be protected and a reference electrode must be controlled on a preset level called the full protection level. In this paper, a boost converter circuit and L298N integrated circuit were used as a control system to regulate the protection voltage on a preset identified range. The boost converter has been used to raise the supply voltage, while the L298N circuit has been used to regulate the boost converter voltage automatically by adjusting the duty cycle through the Arduino microcontroller.

Before the designing and implementing of the proposed controller, the effect of some different factors should be studied to understand the nature of the system and determine the controller voltage and current ranges. These factors are: The solution temperature, The dissolved oxygen, the anode-cathode distance and the power of hydrogen. The photovoltaic array was employed to impress the electrical current to the system.

السيطرة على منظومة حماية كاثودية تعمل بالطاقة الشمسية

الخلاصة

تعد الحماية الكاثودية من أهم الطرق الفعّالة لتقليل تآكل التراكيب المعدنية المغمورة في الماء، أو المدفونة تحت الأرض؛ إذ يتّم ضبط الفولتيّة بين المعدنِ المراد حمايتُه والقطبِ المرجعيّ على مستوىً مُعدٍّ مسبقاً يُدعى مستوى الحماية الكاملة. ولضبط فولتيّة الحماية على هذا المستوى، تمَّ استعمالُ محوِّلة رافعة والدائرة المتكاملة (L298N) بوصفها منظومة للسيطرة في هذا البحث. لقد استخدمت هذه المحولة الرافعة لرفع فولتية المصدر، بينما تم استخدام الدائرة المتكاملة (L298N) لتنظيم الفولتية الخارجة من المحولة الرافعة أوتوماتيكياً من خلال تعديل عرض النبضة بواسطة المتحكم الدقيق (الأردوينو).

قبل تصميم وتنفيذ منظومة السيطرة هذه، تمّت دراسة عوامل مختلفة لفهم طبيعة منظومة الحماية الكاثودية وتحديد مديات الفولتيّة والتيّار الملائمة لمنظومة السيطرة. العوامل المدروسة هي: درجة حرارة المحلول، وكمية الأوكسجين المذاب، والمسافة بين الأنود والكاثود، وقيمة الأُس الهيدروجيني. كذلك تمَّ استخدام خلايا شمسيّة لتزويد تيّار كهربائي مناسب. بيّن البحث أنّه يجب الحفاظ على فولتيّة الحماية دائماً بين 0.8 و1, لذلك فإنَّ وظيفة منظومة السيطرة هي إرجاع فولتيّة الحماية إلى ذلك المدى المذكور.

الكلمات المفتاحية
محولة رافعة، حماية كاثودية، تآكل، تيّار قسري، طاقة شمسية.

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Introduction

Corrosion is an inherent phenomenon. It is a natural occurrence (follows the natural laws) happens to any metal is not in its natural status. The corrosion process leads to a physical change in the metals surfaces. In addition, a direct current (DC) is generated. Two metals should be existed in the corrosion process. These two metals are called "electrodes". The electrode that releases an electrical energy to the circumference is called an "anode", while the other one that receives the electrical energy is called a "cathode". The flowing process of the electrical current needs a metallic connection between anode and cathode. Anywise, the elements which required for this process of energy exchange construct the corrosion cell which is shown in Fig.1. Unless the metal is existed in a medium that can conduct electrical current, the corrosion process will not be accomplished[1]. Corrosion is a serious problem since ancient times. It is not a modern issue at all. In order to stop the corrosion impact, several methods can be applied. Chemical treatment, electrical current, and coatings can be good examples on these methods[2].

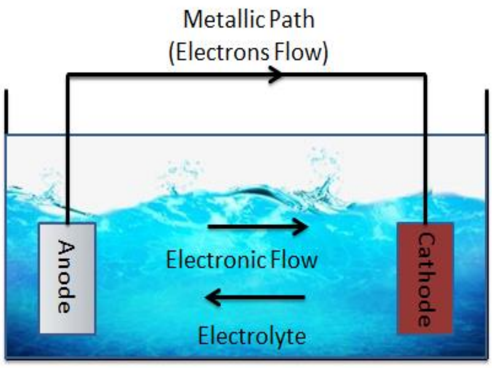

Figure 1. Components of the corrosion cell.

Generally, there is an efficient technique can be considered as the most common method which has been used to eliminate the corrosion. This technique is known as "cathodic Protection (CP)"[3]. It can be applied purely by using an external current source to convert all the anodic areas on the protected structure into cathodic areas to become non-corrosive regions. In order for this current to flow, it is necessary to connect the protected metal to another external metal (anode) [4,5]. However, there are two public strategies for CP: "sacrificial anode cathodic protection (SACP) system" and "impressed current cathodic protection (ICCP) system". CP system with the first approach is named "internal feedback system", whereas with the second approach is named "external feedback system". In the first method, the DC power supply keeps the output voltage and current constant by using an internal stabilization circuit. Moreover, the required protection voltage can be obtained manually or by semi-automatic adjusting only. In the contrary, the protection voltage in the second approach can be monitored automatically and in the real time. However, it is extremely complicated in the actual implementation for long transmission lines when compared with the "internal feedback systems". Furthermore, the "external feedback system" is cheap and economic. At most, the second method has more flexible voltages and currents. In such method, any DC source can be employed to push the cathodic current into the metal surface [6]. The anode should be attached to the positive side of the power supply, while the protected metal should be attached to the negative one[7]. The DC power source can be equipped from a solar power source. Solar or photovoltaic (PV) energy is a quite important renewable energy supply. It is a clean energy, and does not cause any pollutants and gases emissions. The utilization of PV power is increasing significantly in the recent years. As stated by "European Photovoltaic Industry Association (EPIA)", the overall PV power capacity was 177 GW in 2014. Furthermore, 53 million tons of carbon dioxide (CO_2) emissions have been reduced per year[8].

However, This paper gives a brief review about some previous studies and shows the methodology of the proposed system. Also, it introduces the effect of the solution temperature, the dissolved oxygen in the water (D.O), the distance between anode and cathode (D_{ac}), and the power of hydrogen (pH) on the Impressed current. Furthermore, It discusses the design process and the results of practical control circuit. Finally, the conclusion of this work was presented.

Related Works

Many CP systems have been proposed by researchers to solve the problems of corrosion. This section provides a brief review for some of these researches and compares them with the proposed system in this paper.

Akcayol M. A., (2004)[9] regulated the automatic transfer-rectifier output voltage for ICCP system by using a fuzzy logic controller (FLC). This voltage was regulated by PIC16F877 microcontroller. "Trial and Error" manner was applied to develop the rule table and the membership functions of the suggested FLC. The FLC program was developed by "C language" and then conveyed to the microcontroller. Corresponding to the preset required voltage, the control process for the output voltage was executed efficiently, and without any rippling or deviation.

Kharzi S., et. al., (2006)[10] proposed a regulated CP system powered by PV energy. This system was developed to abolish the critical problems that occur with the conventional CP systems. The regulated system supplies the metal to be protected by a constant cathodic protection current (Iprot). In order to carry out this mission, a buck-boost converter should be driven through PIC16F877 microcontroller. The driving signal was extracted by changing the duty cycle from the microcontroller. This change was done through the "pulse width modulation (PWM)" port.

Javadi M., et. al., (2014) [11] presented an intelligent CP system powered by PV energy. This system was proposed for buried pipelines, and comprises a solar cell which act as a power supply. Also, a buck converter was employed in order to minimize the large PV voltage. The output port of this converter must be connected to a buck-boost converter and battery. Lastly, the output of the buck-boost converter should be linked to the CP circuit. A certain function should be formed by the buck converter in order to track the point of maximum power. However, this will improve the system efficiency. As well, this system can be efficiently employed to simulate CP systems. Furthermore, the worst cases in simulation process were taken into account for increasing the system lifetime, and to make the system valid under various circumstances.

Abdul-Sada B. N., et. al., (2016) [3] studied the effect of several variables in saltwater such as conductivity, temperature, and aeration flow rate on the ICCP system. The experimental results showed that the current is raised for increasing any variable. Also, this study included a simulation control of two techniques: "proportional integral derivative (PID)" controller and FLC. Depending on the simulation results, both controllers are capable of controlling the ICCP system.

The comparison between the above controllers and the suggested controller is shown in Table 1:

Table1. Differences between the suggested controller and related controllers.

Researcher	DC Power Supply	Control System
Akcayol M. A.[9]	Conventional	FLC
Kharzi S., et. al.[10]	Solar	Buck-Boost Simulation
Javadi M., et. al.[11]	Solar	Buck-Boost Simulation
Abdul-Sada B. N., et. al.[3]	Conventional	PID and FLC
The proposed System	Solar	Boost and L298N IC

It is important to mention that the solar power supplies are more economical and required less maintenance than the conventional supplies. Also, they have available control systems which are used to reduce the consumption of power. Furthermore, there are some limitations with the use of PID, Fuzzy, buck, and buck-boost in control. These limitations are:

1. PID, fuzzy, and buck converter, require high input voltages in some cases where Iprot is high. For example, the researcher Akcayol M. A. [9] used a supply voltage with 60 V and Abdul_Sada B. N. [3] needs 24 V power supply while in this proposed system the required voltage was only 12 V. So, the solar system that used here does not fit PID, fuzzy, and buck converter controllers.
2. The using of buck-boost converter as an automatic controller is possible, but it requires adapting its design since it has a potentiometer that changes manually. Moreover, All the uses of this control in the related works are simulation methods with no practical application. So, the boost converter and L298N IC can be used as a good practical replacement since they are cheap, available, and easy in implementation and programming.

Methodology

In order to discuss the impact of any parameter on the ICCP system experimentally, it is necessary to install a prototype ICCP system. The proposed system consists of the next parts:

1. Cathode: A carbon steel pipe was used as a cathode. The analysis process of its chemical composition was carried out in "Mechanical Engineering Department, College of Engineering, University of Basrah". The results were as shown in Table 2. This cathode has 35 cm length, 16 cm outside diameter, 14 cm inside diameter and 1 cm thickness.

Table 2. Chemical composition of cathode.

Chemical Element	Rate (%)	Chemical Element	Rate (%)
Carbon	0.16	Molybdenum	0.021
Silicon	0.28	Nickel	0.039
Manganese	1.39	Aluminum	0.025
Phosphorus	0.027	Cobalt	<0.0085

Table 2. Continued.

Chemical Element	Rate (%)	Chemical Element	Rate (%)
Sulfur	0.023	Copper	0.08
Chromium	0.11	Niobium	<0.005
Titanium	0.012	Vanadium	0.0095
Tungsten	<0.04	Lead	<0.010
Tin	0.016	Magnesium	0.036
Arsenic	0.11	Zirconium	0.0042
Boron	0.0047	Iron	97.7

2. Anode: Two aluminum rods were used, each one has a length of 4 cm and a diameter of 3 cm. These rods were placed at the same level with pipe.
3. Reference Electrode: The protection voltage should be measured with respect to a certain reference electrode. The "saturated calomel electrode (SCE)" was utilized here as a reference electrode. The purpose of using this SCE is to measure the voltage between the metal to be protected (cathode) and the electrolyte.
4. Electrical Power Source: A "YA XUN" type DC power supply with model "PS-305D" was used to impress the electrical power for CP system. It should be noted that the DC power supply that used to study the effect of CP factors was a conventional DC supply. The using of this source was to find out the appropriate voltage and current in order to calculate the suitable power for PV array which is employed as a power supply with the suggested control system. As well, the factors changing needs to a voltage source that can be easily changed every few minutes. After that, this supply was replaced by a solar power system to meet the requirements of CP voltage and current from side and the proposed control system from the other side.

All the previous mentioned components should be immersed in a solution. In this experiment, the solution was 125 liter of the reverse osmosis (R.O) water. The analysis results of the used R.O water carried out in "Chemical Engineering Department, College of Engineering, University of Basrah" as shown in Table 3. The R.O water was located at a glass bath of 105 cm length, 43 cm width, and 50 cm height.

Table 3. Chemical Composition of the used water.

Chemical Compound	Rate (ppm)
Sulfur Trioxide	22.154
Total Dissolved Solids	194.22
Bicarbonate and Carbon Trioxide	3.66

Moreover, an additional components were used to accomplish this study. These components are:
1. Electrical heater with temperature degrees from (20 – 80) °C to raise the solution temperature.
2. Two Air pumps were employed to change the D.O ratio of the solution.
3. Digital Temperature Sensor (DS18B20) in order to measure and record the solution temperature.
4. 10.24 Ω resistor as a constant load for constructing a current sensor matching the very small changes in the protection current.

In addition, the anode and the metal to be protected should be in contact in order for CP to be carried out[3]. The electrical connections among anode, cathode, electrode, and DC power supply are shown in Fig. 2:

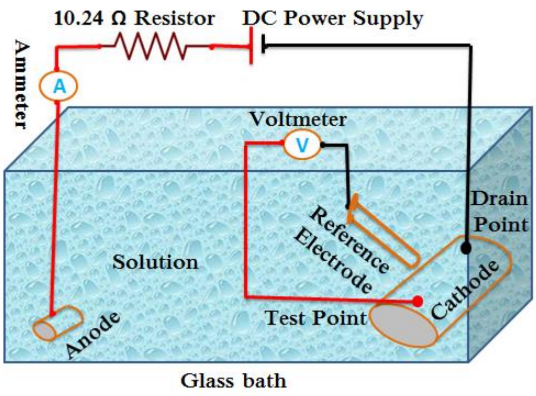

Figure 2. The electrical connections of the impressed current cathodic protection system.

The experimental installation of the ICCP system is shown in Fig. 3:

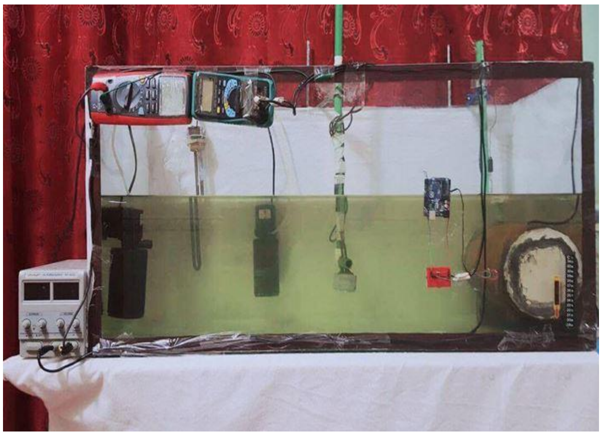

Figure 3. The experimental installation of cathodic protection system.

Factors Affecting Cathodic Protection System

The behavior of CP systems under different factors has already been extensively studied. Many researches has been showed the nature of the relations between such system and multiple factors which have an important impact on corrosion. However, In order to determine the protection voltage and current requirements those needed to design a control system, four factors will be discussed in this section due to their importance impact. These factors are:

1. The Solution Temperature: The temperature of solution was changed in steps from (20 – 40) °C. During this change, the current was observed to be increased due to the increasing of chemical and electrochemical reactions rates, and also the diffusion rate[12]. Figure 4 below shows the effect of solution temperature on the cathodic current.

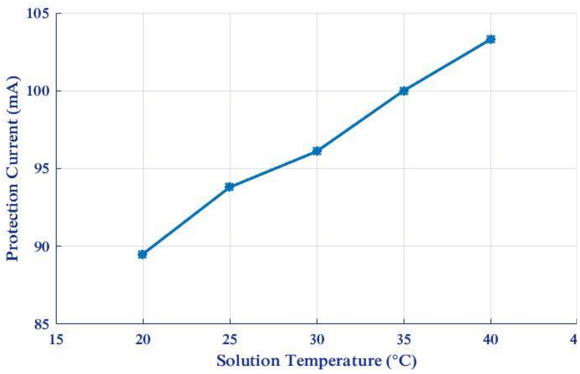

Figure 4. The protection current versus the solution temperature.

2. The Dissolved Oxygen (D.O): In order to discuss the effect of D.O, two air pumping devices were used. Each air pump gives 2.5 mg/l of D.O. The experimental results showed that the impressed current is increased with the increasing of D.O amount. This is due to the reaction between the oxygen and the metal surface with the presence of humidity. This reaction produces the metal oxide, which separates from the original metal. The reaction happens because the oxygen is a strong oxidizing agent. Figure 5 below illustrates the relation between the protection current and D.O amount.

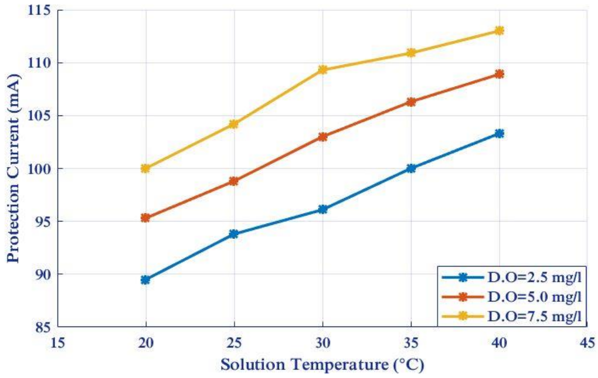

Figure 5. The protection current against the solution temperature at different dissolved oxygen values.

3. The Anode-Cathode Distance (D_{ac}): Three various distances between anode and cathode were taken. These distances were 20 cm, 30 cm, and 40 cm. The practical results illustrated that the increasing in D_{ac} leads to a slight raising in the impressed current. The current was observed to be increased as a result of a decreasing in the solution resistance. Figure 6 below illustrates the relation between the protection current and D_{ac}.

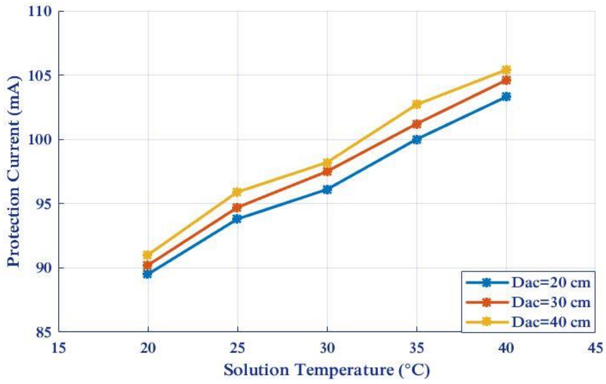

Figure 6. The protection current as a function of the solution temperature at different anode-cathode distances.

4. The Power of Hydrogen (pH): From data measurements, it is obvious that the increasing in the solution pH yields into decreasing in the protection current. The reason belongs to the increasing in hydrogen evolution and oxygen diffusion on the metal surface[13]. Figure 7 shows the decrement in protection current versus pH.

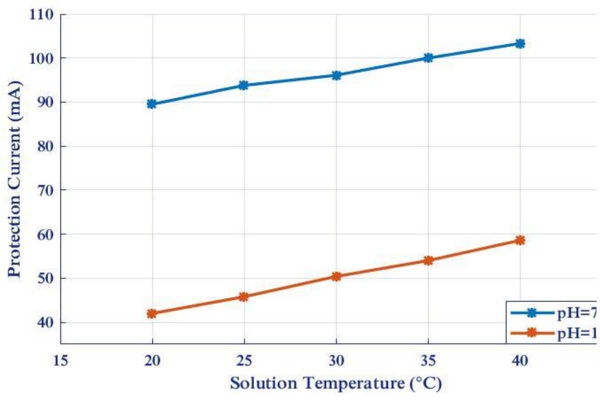

Fig. 7 The protection current as a function of the solution temperature at two different pH values.

Control of Cathodic Protection

For perfect protection, the CP voltage should be adjusted on a suitable value[14]. In order to set this voltage at the full protection level, a suitable control system should be used. The proposed control system and connections among its components is shown in Fig. 8. Also, the practical installation and implementation is illustrated in Fig. 9. However, this controller included two circuits. The first circuit was the boost converter which has been employed to raise the battery output voltage up to 50 V. The second circuit was L298N IC. This IC has been used to regulate the boost converter voltage automatically by adjusting the duty cycle of its PWM through the arduino. The adjustment process of the PWM was achieved by comparing the real voltage that observed between SCE and the test point of the cathode with the level of the full protection voltage. Most of structures that required protection are located at remote and sun exposed areas, where the power stations are not available. So, the PV cells can be used as the best replacement in such regions where the sun is plentiful available. Moreover, it is clean and free emissions energy. However, Each cell has the following features which are depicted in Table 4:

Table 4. Features of solar cells.

Feature	Value
Working Voltage	6 V
Output Power	1 W
Working Current	(0-200) mA
Size	(110*60*2.5) mm

To boost the output voltage, each two solar cells were connected together in series to compose three larger units named modules. The output voltage of each module will become 12 V. Then, these three modules, in turn, were connected in parallel to compose another one larger unit named array. According to this connection, the total voltage equals to 12 V, while the total current is (0-600) mA.

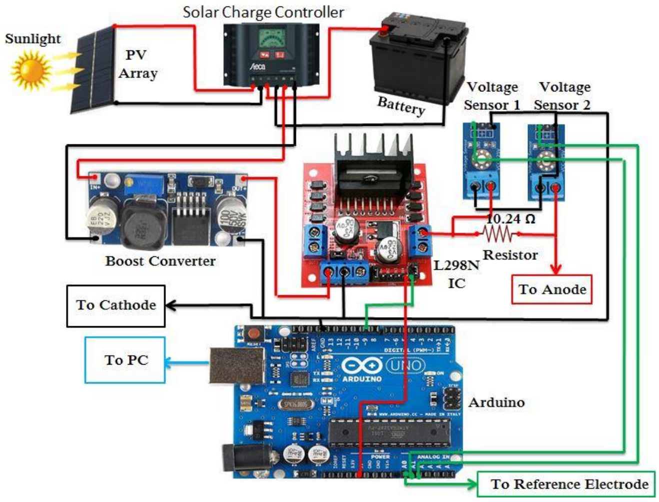

Figure 8. The schematic diagram of the control system.

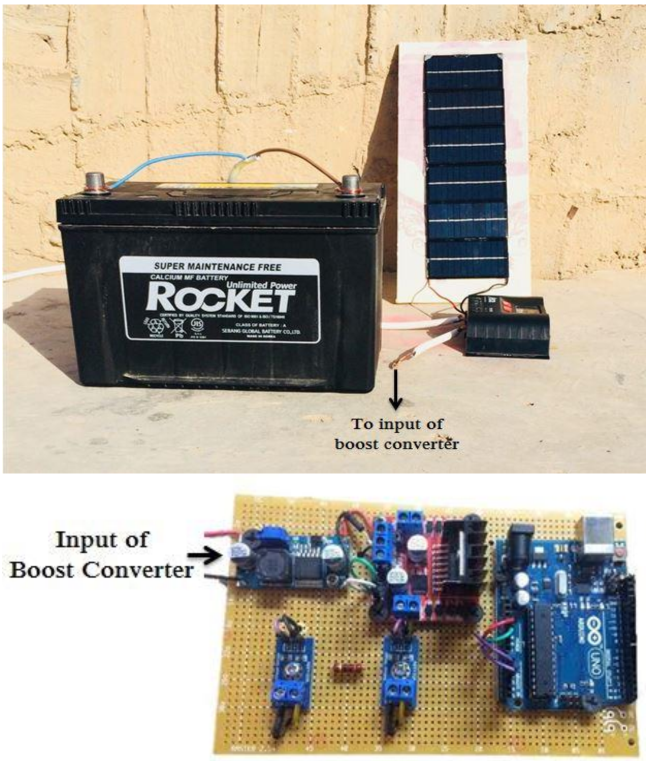

Figure 9. The experimental implementation of the control system.

The proposed control was employed to adjust the protection voltage through changing any of the studied parameters. Figures 10,11,12 and 13 show the experimental results of the protection voltages and currents during the change of solution temperature from (20-30) °C at pH=7 and pH=10 respectively.

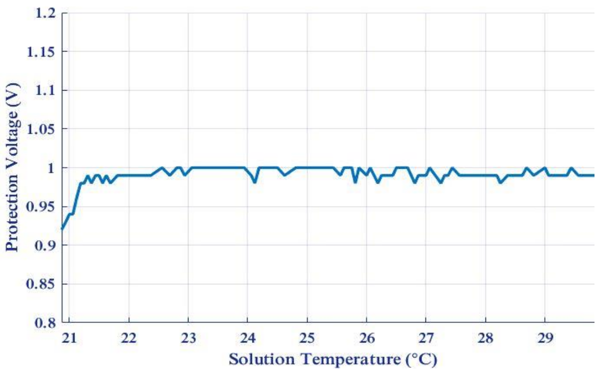

Figure 10. The protection voltage under different solution temperature values at pH=7.

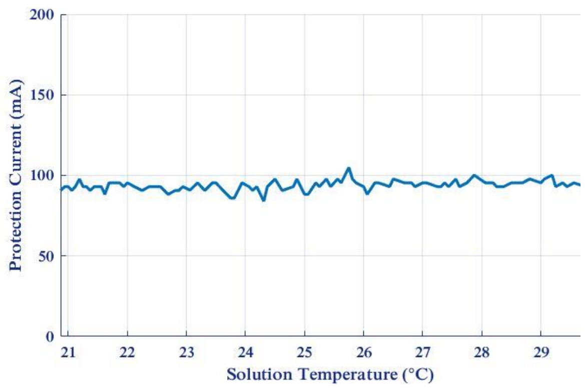

Figure 11. The protection current under different solution temperature values at pH=7.

From the above results, it's obvious that the voltage is stilled in the full protection range during the change of solution temperature from (20-30)°C. This was achieved by changing the output voltage of the L298N IC through adjusting its duty cycle.

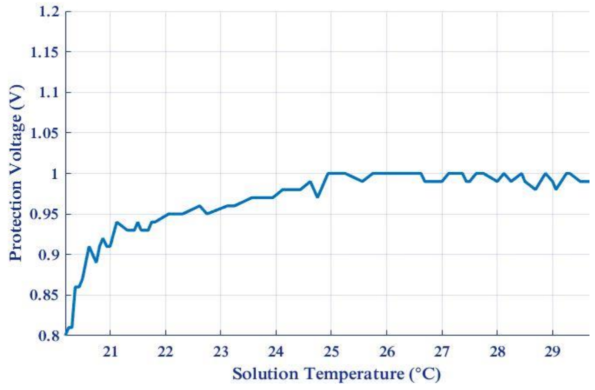

Figure 12. The protection voltage under different solution temperature values at pH=10.

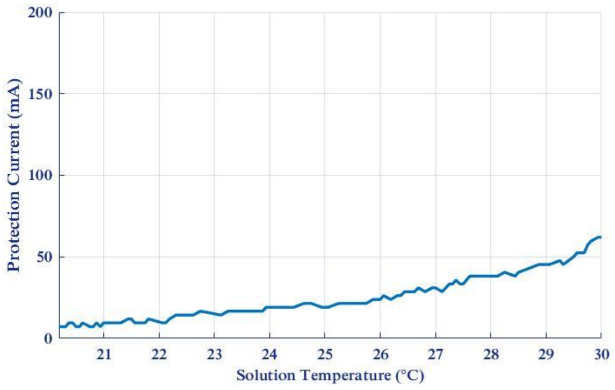

Figure 13. The protection current under different solution temperature values at pH=10.

It is clear that the protection voltage is stable between 0.8 V and 1 V (Full Protection Level). Also, the protection voltage and the impressed current are less than the previous voltage and current. This is due to the increase in the pH from 7 to 10 which mean an increase in hydrogen evolution and oxygen diffusion on the structure to be protected.

Conclusion

This paper included two parts. In the first part, the effect of four serious factors on the ICCP system was discussed. These factors are the solution temperature, D.O ratio, pH value, and D_{ac}. The experimental results showed that the impressed current is increased with the increasing of solution temperature, D.O and D_{ac}. But, it is decreased with the increasing of pH. In the second part, a control system of boost converter and L298N IC was used to regulate the protection voltage through changing any of the studied parameters. The proposed control system was approved its efficiency to control the CP system. It is a good solution, quite easy to use and implement. Furthermore, PV array was used in order to reduce costs related to electrical energy consumption.

As a final result, the overall proposed system has been carried the following tasks:

- Control the PV energy and the battery charge and discharge by using solar charge controller to keep the system effective during night and no sunlight situations.
- Identifying the CP system behavior under almost invariably factors.
- Control the CP system to stopping or, at least, reducing the corrosion processes.

References

1. Paul D., (2016), "DC Stray Current in Rail Transit Systems and Cathodic Protection [History]", IEEE Industry Applications Magazine, vol. 22, issue 1, pp. 8-13.

2. Durham M. O. , and Durham R. A., (2005), "Cathodic Protection, Consequences and Standards from Using CP Systems to Prevent Corrosion", IEEE Industry Applications Magazine, vol. 11, no. 1, pp. 41-47.

3. Abdul-Sada B. N., Ali R. S., and Mohammed Ali Kh. A., (2016), "Identification and Control of Impressed Current Cathodic Protection System", Iraq J. Electrical and Electronic Engineering, vol. 12, issue 1, pp. 214-220.

4. XU L. Y., and Cheng Y. F., (2014), "Experimental and Numerical Studies of Effectiveness of Cathodic Protection at Corrosion Defects on Pipelines", Elsevier Corrosion Science Journal, vol. 78, pp. 162-171.

5. Bahekar P. V., and Gadve S. S., (2017), "Impressed Current Cathodic Protection of Rebar in Concrete Using Carbon FPR Laminate", Elsevier Construction and Building Materials Journal, vol. 156, pp. 242-251.

6. XU L. Y., SU X., and Cheng Y. F., (2013), "Effect of Alternating Current on Cathodic Protection on Pipelines", Elsevier Corrosion Science Journal, vol. 66, pp. 263-268.

7. Mitolo M., and Pettinger A., (2016), "Interactions Between Cathodically Protected Pipelines and Grounding Systems", IEEE Transactions on Industry Applications, vol. 52, issue 5, pp. 3694-3698.

8. Kim J., Kim D., Yoo W., Lee J., kim Y., (2017), "Daily Prediction of Solar Power Generation Based on Weather Forecast Information in Koria", IET Renewable Power Generation, vol. 11, issue 10, pp. 1268-1273.

9. Akcayol M. A., (2004), "Fuzzy Logic Controlled Cathodic Protection Circuit Design", Journal of Science, vol. 17, no. 1, pp. 111-127.

10. Kharzi S., Haddadi M., and Malek A., (2006), "Development of Voltage Regulator for Solar Photovoltaic Cathodic Protection System", Revue des Energies Renewables, vol. 9, no. 4, pp. 259-266.

11. Javadi M., Javidan J., and Salimi M., (2014), "Cathodic Protection of an Underground Pipeline by Photovoltaic Power System Using Intelligent Method", International Journal of Renewable Energy Research, vol. 4, no. 2, pp. 267-274.

12. Schweitzer Ph. A., (2007), "Fundamentals of Metallic Corrosion, Atmospheric and Media Corrosion of Metals", 2nd ed., ISBN 978-0-8493-8243-7.

13. Revie R. W., and Uhlig H. H., (2008), "Corrosion and Corrosion Control, An Introduction to Corrosion Science and Engineering", 4th ed., ISBN 978-0-471-73279-2.

14. Kim I., and Nho E,. (2005), "Module-Type switching Rectifier for Cathodic Protection of Underground and Maritime Metallic Structures", IEEE Transactions on Industrial Electronics, vol. 52, no. 1, pp. 181-189.