Design of SCADA for Protection System of Uncoiled DC Motor’s Temperature using PLC ABB AC 800PEC Based on Wonderware Intouch

J T Putra, A Diantoro, U Yusmaniar Oktiawati, A Surriani, A B Pradana, L Subekti
Department of Electrical and Informatics Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia
E-mail: jimmytriputra@ugm.ac.id

Abstract. Continuous Tandem Cold Mill (CTCM) operates many types of DC motor for various processes. The continuity of the DC motor is very important to ensure the automation process are working perfectly and safe. One of the abnormal condition when operating DC motor is overheating at Field winding and Field bearing. Therefore, this research is needed to avoid further damage in the DC motor by designing and implementing protection system of temperature based on PLC (Programmable Logic Controller) ABB AC 800PEC and PT100 sensor. SCADA (Supervisory Control and Data Acquisition) system was implemented so the operator can supervise the motors. When temperature is increasing and higher than the allowed maximum temperature, the system should generate Fast Stop signal to stop every process that have been running at entry section CTCM. The protection system was implemented successfully and generated Fast Stop signal when the Field winding temperature was higher than 100-degree Celsius or when the Field bearing temperature was higher than 75-degree Celsius.

1. Introduction
PT. Krakatau Steel is the largest integrated steel producer in Indonesia and produces various steel product. As a state-controlled company engaged in steel making and rolling mill industry, PT. Krakatau Steel has 7 production facilities, and one of them called CRM (Cold Rolling Mill) that produces cold rolled coil.

CTCM (Continuous Tandem Cold Mill) is one of seven production lines in CRM plant which reduce the thickness of strip. The entire process in CTCM are consist of many mechanical equipment driven by DC motor such as uncoiled motor, tension reel, bridle and main drives. This research focused on uncoiled DC motor. DC motor has several heating issues when it is operated. Increasing temperature of DC motor reduces its lifespan, insulation life, physical damage and eventually causes motor failure. Therefore, it is important to develop temperature monitoring and protection system for DC motor as a preventive action to maintain the continuity of production line and minimize the risk.

The temperature of uncoiled DC motor obtained by RTD (Resistance Temperature Detectors) sensor placed in bearing and inductor. When temperature is increasing and higher than the allowed maximum temperature, it can generate Fast Stop signal to stop every process that have been running at
entry section CTCM. Fast Stop Signal will be forwarded to DC Drive ABB DCS 800 through AA11 controller module.

The type of RTD used in this research is PT100, this sensor has a high accuracy and linearity. This sensor has been tested to protect temperature of induction motor. The system was built without SCADA and used 2 wire PT100 and shows that PT100 has linear characteristic towards temperature changes and has a high sensitivity [18]. Other research about temperature monitoring also performed by Ponjavi [21]. Meanwhile, previous research to monitor temperature also used PT100 [22].

SCADA is an industrial control system that help operator and engineer to monitoring and control the plant [15, 20, 23,24]. SCADA is implemented as protection system of temperature controlled with PLC ABB AC 800PEC. PLC is control module consist of Central Processing Unit (CPU), I/O module and Programming Device. PLC has become industrial standard for control system because of its reliability [13]. PLC could be used to monitor and control line as reported by Kaur and Bansal [23]. HMI is designed with integrated development environment called Wonderware Intouch and data acquisition system is developed with IbaFop4 module.

In the previous research, PLC ABB AC800 PEC was used to test the performance of ABB OPC server compared to other communication protocol [17]. According to that research, the time required to transmit data through OPC is not more than 45ms with 30% CPU load. In the other hand, the controller of ABB x800 system have 25 µS cycle time that is fast enough to handle complex automation process [1]. It is obviously clear that this protection system needs faster controller to make sure Fast Stop signal is generated as immediate as possible. This research used newest controller from ABB programmed by Function Block Diagram that is easier to maintain than any other PLC programming language such as Ladder and Structured Text [6].

Controller module AC 800PEC is also can be programmed by MATLAB as mentioned in previous research [16]. This system consists of an I/O module and single Field Communication Interface (FCI) to simulate PLC with soft controller.

Wonderware Intouch has commonly used by engineer in industrial field such as packaging automation system [19]. In this case Wonderware Intouch is used to develop HMI for DC motor temperature system. Wonderware Intouch has better graphic library compared to other SCADA software such as Citect SCADA and WinCC [19]. This advantages make Wonderware Intouch become a standard SCADA software for industrial purposes [19].

The design of protection system on DC Motor based SCADA has been carried out on the research. In addition, HMI based in Wonderware Intouch and ABB OPC was also made to facilitate the operator in monitoring the temperature that occurs in DC Motor. Analysis of the resistance characteristics on the 3 wire PT100 sensor to temperature changes is also described.

2. Methodology
The whole SCADA system has been designed using PLC ABB AC800 PEC as a controller and I/O module as a Remote Terminal Unit (RTU). Temperature data is obtained from PT100 sensor, a RTD sensor that commonly become industrial standard for measuring temperature. Analogue value from PT100 will be converted to digital using internal ADC in Analogue Input Module 830. Digital signal from AI830 will be transmitted to Controller through Profibus. In the controller data will be processed due to program logic which has been made using Function Block Diagram. HMI in this case is necessary to display value of temperature in real time and control several configuration regarding temperature protection system. IbaDAQ is a data acquisition module, it can be used to saved temperature data with high sampling rate, stored in hard drive and make it accessible for assessment purpose or checking if there is a problem in the future. Function block of the system shown in Figure 1.
PT100 sensor refers to Wheatstone bridge connected to RTD, from equation (1) shows that wire A, B and C need to be the same length to make Wheatstone bridge balanced.

\[
\frac{R_1}{R_2} = \frac{R_A + R_{RTD}}{R_B + R_C}
\]  

(1)

When each branches have the same potential difference, the output will be zero and ADC convert it to digital value equal to 0°C.

\[ R = 0.385T + 100 \]  

(2)
where R is the resistance of PT100, T is temperature measured by PT100 and 100 is a constant that actually represent the resistance when Wheatstone bridge is in balance condition. On the other word, when temperature is 0°C then the R as output of Wheatstone bridge is equal to 100 Ω.

Meanwhile, the power dissipated in the sensor causes its temperature to rise above its ambient temperature by equation (3).

\[
\Delta T = (I^2R_{RTD})\theta
\]

Where \(\Delta T\) = the change in temperature due to internal power dissipation; \(I\) = excitation current; \(R_{RTD}\) = the value of the RTD in ohms; and \(\theta\) = the self-heating effect in °C/mW.

3. Design of PLC

ABB AC 800PEC is a PLC controller module from ABB designed to handle complex automation process. It has dual core CPU, 1 GB SDDR3 RAM and communication port. This PLC is modular which has been separated into piece of modules depend on the functionality [4]. This module can be added or reduced as needed, so this make AC 800x system has high flexibility to make automation system run efficiently.

This system consists of three controller module, CI854 as a Master FCI (Field Communication Interface), CI801 as a Slave FCI, AI830 as an Analogue Input Module designed to read RTD sensors and TU 810 (Termination Unit) as a connector [6]. AI830 is placed in cabinet RA05, CI801 can handle up to 12 I/O device [7]. Data transmitted from I/O module to communication interface CI801 through module bus [3]. CI801 is connected with other slave FCI 801 through PROFIBUS cable in series [5]. The last FCI will be connected to Master FCI CI854 through FROFIBUS cable in series and connected to other CI854 as well. The last CI854 will be connected to controller module through CEXBUS cable to process the data from sensor. Data will be calculated and the result will be transmitted from AA15 to AA12 and AA12 to AA11 through fibre optic cable. The system architecture shown in Figure 3.

![Figure 3. PLC ABB AC 800x system architecture](image)
4. Design of PLC Programme
PLC Program is developed using FBD (function block diagram) of integrated development system provided by ABB called Compact Control Builder. Program in Compact Control Builder separated in control module that will be connected to task-time [2]. This system consists of four main program as following details.

4.1. Main Program
The main purpose of this program is to determine motor status by checking the temperature sensor measurement. Fault signal can be classified into four different conditions, each condition generate depend on minimum bearing and inductor temperature. Bearing temperature alarm will be generated if bearing temperature is higher than 60°C. Bearing temperature trip will be generated if bearing temperature is higher than 75°C. Inductor temperature alarm will be generated if field winding temperature is higher than 90°C. Inductor temperature alarm will be generated if field winding temperature is higher than 100°C. Flowchart of main program can be seen on Figure 4.

4.2. Selector Program
Selector program is made to implement force I/O when sensor gained false sensing that might be different with actual temperature. False sensing occurred when PT100 cannot measure temperature of DC motor accurately. This condition implies that fast stop entry executed for wrong reason. Forcing the I/O is necessary to avoid this condition by passing the measurement signal through selector program.

4.3. HMI Program
Data measurement from PT100 sensor will be transmitted to HMI server using OPC. One of the common problem in industrial field is the diversity of communication protocol developed by the manufacturer. This protocol is used to communicate as read or write from PLC to computer or
otherwise [12]. Diversity of protocol communication causes decrease capability some of PLC with the system. Therefore, a universal protocol called OPC (Ole for Process Control) have been made to accommodate all of PLC, make it able to communicate between PLC to PLC or PLC to computer despite there are from different manufacturer [8]. OPC was developed by a foundation and distributed as a open source project [9]. OPC is also implement COM and DCOM technology which allows transfer data between computer to computer using TCP/IP architecture [11].

4.4. Data Acquisition Program
Data acquisition is a part of SCADA that have been playing important role to make system can be monitored and integrated efficiently. Data measurement from PT100 sensor will be transmitted to Iba Data Acquisition server using FPGA library included in Compact Control Builder. Data type AA15ComIbaReal is declared on FPGA library to receive real value of temperature signal and transmit them to the server. This data obtained simultaneously and can be monitored in real time.

4.5. Data Transfer Program
Fast stop signal generated from main program in AA15 controller module need to be transmitted to AA11. AA11 controller module is designed to handle every mechanical and electrical equipment for all automation sequence in entry section. Uncoiled DC motor is located in entry section, therefore fast stop signal will be executed in AA11 controller module, but unfortunately there is no direct fibre optic communication module from AA15 to AA11 and that why it must be transmitted to AA12 first.

Data transfer from one controller to another controller require two function block called BctoDint and DintToBc. BcToDint placed in transmitted controller that will convert binary coded data to double integer and same process will be implemented in receiver controller. DintToBc will convert double integer data to binary coded, thus the data will be returned to the original bit.

5. Design of HMI
Human Machine Interface (HMI) is used to monitor control process of the plant and warning system for operator when fault occurred eventually. HMI layout and program has been created with Wonderware InTouch. Designing the HMI is conducted with several steps, started with identifying process, listing parameter tag name, determining the logic flowchart and designing the layout.

This system is consisting of three window application, there are main window showed text based temperature data, main window 1 showed real time trend based temperature data and setting windows showed slider to set minimum temperature fault. The layout can be seen respectively on Figure 5.
6. PT100 Sensor
The are eight sensor placed in bearing and inductor of uncoiled DC motor. Uncoiled DC motor is mechanical equipment to hold coil and maintain the strip tension between uncoiled DC motor and bridle. Uncoiled DC motor consist of 2 DC motor called MC1 (Motor Control1) and MC2 (Motor Control2). The sensor placed in the following order that can be seen on Table 1.

| Name   | Sensor Placement |
|--------|------------------|
| Sensor 1 | MC1 Bearing 1    |
| Sensor 2 | MC1 Bearing 2    |
| Sensor 3 | MC1 Inductor 1   |
| Sensor 4 | MC1 Inductor 2   |
| Sensor 5 | MC2 Bearing 1    |
| Sensor 6 | MC2 Bearing 2    |
| Sensor 7 | MC2 Inductor 1   |
| Sensor 8 | MC2 Inductor 2   |

Table 1. PT100 Sensor Placement
The important thing that need to be considered during commissioning is the length of extension cable. It must have the same length for each cable because RTD sensor implement Wheatstone bridge to compensate resistance from extension cable [14].

7. System Testing
System testing is conducted to ensure the entire system is successfully implemented without problem and run perfectly and safe. The testing process divided into 4 sections.

7.1. Testing PLC Program
PLC program has been tested with ABB soft controller which is made for simulation purposes only. Input A1830 is given with different value for each condition such as Bearing Temperature Alarm, Bearing Temperature Trip, Inductor Temperature Alarm and Inductor Temperature Trip. The result of this experiment showed on Table 2.

| Sensor          | Input A1830 | Temp Limit (Alarm/Fast Stop) | Output PLC |
|-----------------|-------------|-----------------------------|------------|
| MC1 Bearing 1   | 61          | 60/75                       | Alarm      |
| MC1 Bearing 2   | 62          |                             | Alarm      |
| MC1 Inductor 1  | 92          | 90/100                      | Alarm      |
| MC1 Inductor 2  | 94          |                             | Alarm      |
| MC2 Bearing 1   | 61          | 60/75                       | Alarm      |
| MC2 Bearing 2   | 63          |                             | Alarm      |
| MC2 Inductor 1  | 94          | 90/100                      | Alarm      |
| MC2 Inductor 2  | 95          |                             | Alarm      |
| MC1 Bearing 1   | 76          | 60/75                       | Fast Stop  |
| MC1 Bearing 2   | 79          |                             | Fast Stop  |
| MC1 Inductor 1  | 101         | 90/100                      | Fast Stop  |
| MC1 Inductor 2  | 105         |                             | Fast Stop  |
| MC2 Bearing 1   | 78          | 60/75                       | Fast Stop  |
| MC2 Bearing 2   | 77          |                             | Fast Stop  |
| MC2 Inductor 1  | 102         | 90/100                      | Fast Stop  |
| MC2 Inductor 2  | 110         |                             | Fast Stop  |
| MC1 Bearing 1   | 34          | 60/75                       | Normal     |
| MC1 Bearing 2   | 33          |                             | Normal     |
| MC1 Inductor 1  | 37          | 90/100                      | Normal     |
| MC1 Inductor 2  | 36          |                             | Normal     |
| MC2 Bearing 1   | 35          | 60/75                       | Normal     |
| MC2 Bearing 2   | 38          |                             | Normal     |
| MC2 Inductor 1  | 34          | 90/100                      | Normal     |
| MC2 Inductor 2  | 32          |                             | Normal     |

The response of Function Block Diagram for Bearing Temperature Alarm and the whole testing experiment can be seen in Table 3.

| Condition      | Alarm | Trip  | Normal |
|----------------|-------|-------|--------|
| Bearing Alarm  | true  | false | false  |
| Bearing Trip   | true  | true  | false  |
| Inductor Alarm | true  | false | false  |
| Inductor Trip  | true  | true  | false  |
7.2. Testing HMI Application

Testing HMI application conducted with three different condition, there are when normal condition, when signal temperature alarm is set to be true, when signal temperature trip is set to be true, when input signal AI830 forcing with HMI and when minimum temperature changed from setting window. The result of this experiment can be seen respectively on Figure 6.

![Figure 6](image1)

(a) HMI normal condition

![Figure 6](image2)

(b) HMI temperature alarm

![Figure 6](image3)

(c) HMI temperature trip

Figure 6. Result window

Force mode is implemented to bypass the input signal received in AI830 with standard value for this case, it set by 30°C. Thus when false sensing occurred or PT100 itself has been broken, it might be decrease the ability of measuring physical value accurately and then fast stop will be executed for wrong condition. Production line need to be operate immediately as quick as possible after stop and false sensing has been confirmed, therefore forcing the I/O through HMI is necessary. To ensure that the system is working properly Bearing1 MC1 set to 95.6 Inductor2 MC1 set to 93.5 and Inductor 2 set 95.1, it will generate both fault signal. Force button is pressed and the result can be seen on Figure 7.
The last one is testing window setting. Operator have ability to change the minimum temperature for bearing nor inductor. For this case bearing alarm decreases by 40°C and inductor alarm decreases by 40°C as well. Based on Figure 8, it can be seen that the HMI show alarm for MC 1 Main Pole 1 and MC2 Bearing 2 even though the temperature is normal.

7.3. Data Acquisition Testing

Data Acquisition is one of the most important part in SCADA system. Data acquisition help engineer to analyse anomaly and data that have been measured by sensor. Data is gained from data acquisition module called IbaFob41, this module runs 24 hours a day and gather data from sensor continuously. Every 15 minutes, all data will be stored in hard drive and can be accessed for assessment purposes. However, during data acquisition process, engineer has ability to monitor the sensor real-time. The graph can be seen on Figure 9 for MC1 and Figure 10 for MC2.
7.4. PT100 Sensor Testing

PT100 sensors that have been installed on uncoiled DC motor need to be tested to make sure the sensors are working properly. Extreme Industrial Environment condition need to take into account during commissioning. So, if extension cable of the sensor interferes with any other signal, it would be decreases the sensor accuracy. The testing conducted by checking the resistant value over the terminal AI830 and compared with calculation result.

This equation is used for calculate $R_{\text{meas}}$ shows in Table 4. From Table 4, it can be confirmed that commissioning PT100 is successfully installed due to small error below 5% obtained from this experiment.

| Sensor          | Temp (°C) | $R_{\text{meas}}$ (Ω) | $R_{\text{calc}}$ (Ω) | Error (%) |
|-----------------|-----------|------------------------|------------------------|-----------|
| MC1Bearing1     | 38.6      | 115.8                  | 114.86                 | 0.81      |
| MC1Bearing2     | 31.5      | 114.5                  | 112.13                 | 2.07      |
| MC1Inductor1    | 41.7      | 121.3                  | 116.05                 | 4.32      |
| MC1Inductor2    | 42.1      | 120.6                  | 116.21                 | 3.64      |
| MC2Bearing1     | 31.3      | 114.5                  | 112.05                 | 2.14      |
| MC2Bearing2     | 40.1      | 118.4                  | 115.44                 | 2.50      |
| MC2Inductor1    | 39.6      | 119.6                  | 115.25                 | 3.64      |
| MC2Inductor2    | 38.9      | 117.3                  | 114.98                 | 1.98      |

The error of sensor measurement in Table IV can be occurred in several reasons. There are the wires are not equal in length, wire have resistance and if one of the wires is unequal to the other will implies to unbalanced Wheatstone bridge that have been explained by equation (1) in previous section and self-heating of the sensor. Therefore, PT100 with three wires should have the same length in single wire, if one of them have different length this will increase measurement error.

AI830 have 10mA excitation current to the PT100 sensor and based on the equation (3), an PT100 with $\theta = 0.05$°C/mW, and a resistance value of 100 Ω at 0°C using a 10 mA excitation current will have a drift error of 0.5°C. To reduce error caused by self heating, it can be done by reducing the excitation current for example by 100 µA that will be effectively lower this error by 10000. However, the sensor output will be reduced by 100. The PT100 with $\alpha = 0.385$ Ω/°C will have 100mV of output scale and if the excitation current reduced to 100 µA will have 1 mV of output scale. This will become
problem because we know that industrial environment has a lot of interference signal and any other noise. So choosing an ADC with 10mA excitation current will be fine as long as the temperature error not exceed by 5%.

Table IV showed difference of inductor and bearing temperature. This is normal because the heat that arises in the winding is a square function of the current, therefore a slight increase of armature current will result a large increase of heat. Uncoiled DC motor have 50 A of current when its operated in nominal speed. Therefore, each of DC motor must be equipped with ventilation system. Ventilation system consist of an induction motor placed on the top side of DC motor. Without ventilation system, the temperature may arise above 90 °C. On the other hand, bearing of DC motor has a collier consist of grease lubricated in the bearing that will prevents the harsh metal-to-metal contact between the rotating element and races that reduces friction and thus improves performance and reduces temperature as well. That’s why the temperature in bearing relatively lower than inductor temperature.

8. Conclusion
The design of SCADA based temperature protection system for uncoiled DC motor was successfully implemented due to several testing and experiment. Fast Stop Entry will be executed when bearing temperature increase and higher than 75°C or when inductor temperature higher than 100°C, Alarm will occur when bearing temperature increase and higher than 60°C or when inductor temperature higher than 90°C. HMI and data acquisition as part of SCADA has successfully implemented due to several test and experiment that showed data acquisition to HMI and IbaPDA running properly. PT100 sensor is used for measuring temperature of uncoiled DC motor has a good accuracy and the data indicate that error measurement below 5%.

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