Implementing Risk-Based Maintenance Strategies for Distributed Control System as Power Plant Asset Management

D T Yulianto1*, R M Isman1, S N Ihsan1 and H G Susanto1

1Pembangkitan Jawa Bali UP Muara Tawar, PLTGU Muara Tawar 1 street, West Java, Indonesia
Corresponding email: *danantriyulianto@ptpjbl.com

Abstract. The electricity generated from the power plant is subject to several requirements for active power, voltage, and frequency according to the grid system, so the machine must be controlled to achieve requirement by a power plant control system knows as Distributed Control System (DCS). DCS system in block 1 Muara Tawar power plant using Procontrol P-13 for gas turbine and Procontrol P-14 to control steam turbine. These systems had operated since 1997 and had been nearly operating for 23 years until now, and several failures tend to increase from time to time. The failures of the DCS and the lack of control cards will result in the loss of production. DCS system assets must handle properly to maintain the overall reliability of the power plant system. A method and strategy to maintain DCS must be carried out and ensure reliability and risk always under controlled conditions. Implementing Risk-based maintenance by carrying out quantitative calculations through the reliability approach and the level of the consequence of failure to calculate equipment risk is one of the methods of the DCS system. The result of Risk-based maintenance method show the highest risk on risk map of the DCS system was in cubicle 14CBA02, 14CBA03 with a high-risk level and gas turbine and HRSG cubicle in medium-high level. The interval preventive maintenance time calculated by reliability within a year showed that cubicles 14CBA02 and 14CBA03 suggested to be maintenance every 29 days to reduce possibilities to failure.

1. Introduction
PT. Pembangkitan Jawa Bali is a subsidiary of PT PLN which has the main business in electricity generation and one of its power plants is PT PJB UP Muara Tawar. Muara Tawar power plant generates power by operating gas turbines and steam turbines engine with a total capacity of 2,062 MW with total assets around 11,858 equipment. The electricity generated from the power plant must adequate the demand for active power, voltage, and frequency related to Java-Bali’s grid requirements, to control it a control needed to regulate the process from the beginning of the process to the last to produce electrical energy. The control system used is known as the DCS (Distributed Control System). In general, the DCS architecture of the Muara Tawar Block 1 plant is as shown in Figure 1 [1]. DCS system architecture shows that the components and equipment are related in a network topology with their respective functions. The DCS component, especially the card controller, is the most important part to plays a role in regulating and controlling the process. DCS system in block 1 of Muara Tawar with the type of Procontrol P13 in Gas Turbine and Procontrol P14 in Steam Turbine manufactured by
ABB control system. This Procontrol DCS system has installed since 1997 and operates for is 23 years until now. These old systems have a strong probability to have failures and affect to the main power plant system as a limited spare part and partly damaged give influenced on DCS reliability. Failure of the system card and DCS results in loss of the production process so that it will operationally result in losses.

![Figure 1. Distributed Control System Architecture](image)

Figure 1. Distributed Control System Architecture

![Figure 2. Failure on Procontrol DCS system](image)

Figure 2. Failure on Procontrol DCS system

The number of DCS failures both cards control and monitoring system (human-machine interface) based on record during 2016 to mid-2020 shows the Procontrol DCS system contribute failures and result in operations and production decreasing. Based on data released by ABB as DCS Procontrol P13 and P14 manufacturers in 2015, shows that the card control and the whole system are in the classic, limited, and absolute phases. The classic phase to absolute has a span of 10 years. This situation
brought a major issue on the availability of spare cards, especially how to keep and maintain the
dependability of the overall DCS system.

**Table 1. P13 Control Card Assessment**

| Functional Area | Component Name | Component Description | Number | LC2014 | LC2015 |
|-----------------|----------------|-----------------------|--------|--------|--------|
| Decontic        | XT376A-E       | Buffer output module (x10) | 1      | C      | C      |
| Power Supply    | XT377E         | Supervisory module for positive voltages | 1      | C      | C      |
| Power Supply    | XT32B          | Power supply distribution module for positive voltage | 1      | L      | L      |
| Control         | 70PR05B-ED     | Programmable processor | 2      | C      | C      |
| Communication   | 70BK03B-ES     | Bus coupler local bus/serial | 1      | C      | C      |
| Communication   | 70BK03C-ES     | Bus coupler local bus/serial | 1      | C      | L      |
| Communication   | 70BK06A-E      | Bus coupler local bus/serial (Modbus RTU) | 2      | C      | C      |
| Communication   | 70BV05A-ES     | Bus traffic director | 21     | C      | C      |
| I/O             | 70EA02A-ES     | Input module for 2-wire transducer 4...20mA (x4) | 5      | C      | C      |
| I/O             | 70EB01B-E      | Output module for binary signals (x16) | 8      | C      | C      |
| I/O             | 70EB02C-E      | Input module for contact signal (x16) | 8      | C      | C      |
| I/O             | 70AA01A-E      | output module for voltage signal (x4) | 1      | C      | C      |
| I/O             | 70AA02B-E      | Output module for current signals (x4) | 4      | C      | C      |
| I/O             | 70IE05A-E      | Input module for rotational speed | 3      | C      | C      |
| Termination     | 70BT01C        | Bus isolating amplifier | 1      | C      | C      |
| Termination     | 70BA01C        | Bus end module | 1      | C      | C      |
| Decontic        | DT370A         | AND-gate module (x8) | 3      | C      | C      |
| Decontic        | DD370A         | Diode module (x21) | 3      | C      | C      |
| Decontic        | LT370C         | Buffer module (x10) | 3      | C      | C      |
| Decontic        | UT386B         | Monitoring module for eddy current probe | 3      | C      | C      |

According to card assessment data in Table 1 showed the GT11 CRC20 cubicle, majority of cards are in the classic and limited phases. This happened in all GT blocks 1-2 and ST 14 that used P13 and P14 Procontrol system. DCS card failures data according to the type of card control can be shown in figure 3 the pareto diagram according to failure of each type of card. Maintenance of DCS systems is an asset management challenge, especially on how control card management takes part in the situation where the availability of spare cards is starting to be limited and it will greatly affect the operation, production and at the same time the safety factor of the plant. A maintenance pattern is needed to accommodate and maintain the reliability of the DCS system. The ability to maximize the capabilities and reliability of DCS is an important asset to improve the power plant performance and profitability.
This research seeks to formulate a method of maintenance based on DCS’s Risk-based Maintenance and is expected to answer some maintenance problems in the DCS system then classify the possible causes of the failure of the DCS system. This research also shows how much the consequences arising from interference are, how likely the occurrence of the interference is, how big is the risk of DCS failure and how to plan a DCS system maintenance strategy.

2. Method

Distributed Control System (DCS) is a control system that is often used in manufacturing systems, processes, or other systems where the controller is not centralized in a particular location but is distributed in several locations into sub-systems that are controlled by one or several controllers. This subsystem is connected to a communication network and monitored in a system interface. The main DCS system generally includes controllers that are distributed at subunits, input-output cards, communication systems, supervisory stations in the form of HMI and engineering stations. The DCS system in Muara Tawar Block 1 PLTGU uses ABB products namely PROCONTROL-P and consists of several island processing stations or sub units in cubicles that control gas turbines with Egaterol DCS system and for steam turbine used turbotrol and turbomat’s DCS system. Each station is connected by a redundant remote bus for signal communication and data synchronizing as shown on figure 4.
The DCS system is divided into subunits which are divided into several areas by addressing cards based on cubicle numbers. Ecatrol hardware control systems with various control cards will regulate and control the process both in gas turbines and steam turbines with various types of control. DCS system in Ecatrol has several functions known as closed-loop control, open-loop control, a protection system that processes in the processor card named 70PR05 card in P13 or 83SR04 card ecatrol P14 system. Every function of each type of control separated as shown on figure 5.
Egatrol's DCS system is distributed to several interrelated components in an interconnected network system. Each equipment and control card has their respective roles and functions to work together and control the desired process system. Risk-Based Maintenance is a quantitative method that integrates reliability as statistical method and the risk management to achieve an optimal maintenance strategy and schedule. Risk-based maintenance methodology provides a tool for maintenance planning and decision-making to reduce the probability of failure of equipment and the consequences of failure[10]. This maintenance method aims to reduce the risk caused by failures that occur in operating facilities. The quantitative value of risk is the basis for prioritizing maintenance and inspection activities [3]. The Risk-Based Maintenance methodology provides a means for maintenance planning and decision making to reduce the possibility of equipment failure and the consequences of failure and minimize the total cost of maintenance costs.

**Figure 5.** Control Function on DCS [1]
Figure 6. Risk Base Maintenance Methodology[4]

The steps in the Risk Based Maintenance methodology divided into three main parts:

- Determination of risk which consists of identification and estimation of the risk with various methods including reliability analysis.
- Risk evaluation which consists of avoidance and acceptance of the risk of an equipment.
- Maintenance planning by considering risk and reliability factors.

The development of RBM research is carried out in the manufacturing world, especially those related to machinery, piping and heavy industry. There has been an increased focus on risk-based maintenance optimization in the offshore industry prompted by the recent functional regulations on risk[5]. Some research conduct to risk-based maintenance proposed an expert system for the establishment of Risk-Based Inspection (RBI) programs for oil and gas pipelines [6]. The research about risk-based maintenance also taking part on oil transfer technology with risk and condition based maintenance (RCBM) task optimization technology. Utilizing the internet of things (IOT), real-time database, signal-processing, Gray Neural Network, probability statistical analysis and service oriented architecture (SOA) technology [7]. The research on DCS maintenance using risk-based maintenance method never been done since DCS system has special purpose with sophisticated technology.

The research variables in this study is aimed to show the variation of the research object in terms of maintenance of DCS system that will affect or have a risk to the power plant performance. The concept definition and operational definition can be described as shown in Table 2.
Table 2. Research Variables

| Variable       | Indicator                                                                 |
|----------------|---------------------------------------------------------------------------|
| DCS System     | a. Cubicle Location                                                       |
|                | b. Type of Card or monitoring system.                                     |
| DCS Failures   | a. Failure report (Work Order)                                             |
|                | b. Critical control card according to cubicle location.                    |
|                | c. Number of failure within duration time (MTTF).                          |
| DCS Risk       | a. System performance lost                                                 |
|                | b. Financial lost                                                          |
|                | c. Human health loss                                                       |
|                | d. Ecological loss                                                         |
|                | e. Acceptance criteria                                                     |
| Maintenance    | a. Maintenance strategy                                                    |
|                | b. Maintenance interval                                                    |

Data analysis is carried out following the steps in the preparation of equipment maintenance strategies on figure 6, related to the DCS in its cubicle system that uses Risk based maintenance. The following steps are:

- Classification of DCS generating systems based on cubicle according to pareto chart that reflected number of failure.
- Determine the scenario of failure by analyzing the possible causes of disruption of the DCS system.
- Determine the evaluation of consequences in a semi-qualitative way by determining the risk criteria for ranking loss of performance of units, financial, ecological and health and safety so that the total consequences resulting from a system failure. The four factors are then combined to produce a total assessment of the consequences of equipment failure on the system and formulated with [4]:

\[
\text{Consequence} = [0.25A^2 + 0.25B^2 + 0.25C^2 + 0.25D^2]^{0.5}
\] (1)

- Conduct probabilistic analysis with precise distribution in accordance with the characteristics of the failure interval data so that the reliability value can be found as a basis for calculating the failure probability of DCS system. The reliability value can be calculated using the equation:

\[
R(t) = 1 - F(t) = \int_0^\infty f(t)dt
\] (2)

The failure rate distribution that used in this research are:

a. Normal distribution
   Normal distribution or commonly called a gaussian distribution is often used to describe data distribution. The reliability value of the normal distribution can be written as in the equation:

\[
R(t) = 1 - \frac{1}{\sigma \sqrt{2\pi}} \exp \left[ -\frac{1}{2} \left( \frac{t - \mu}{\sigma} \right)^2 \right]
\] (3)

b. Lognormal Distribution
   Reliability values for the lognormal distribution are shown in the equation:

\[
R(t) = 1 - \frac{1}{\sigma \sqrt{2\pi}} \exp \left[ -\frac{1}{2} \left( \ln t - \frac{\mu}{\sigma} \right)^2 \right]
\] (4)

c. Weibull Distribution
   Reliability values for the weibull distribution are shown in the equation:
\[ R(t) = \exp \left\{ -\left( \frac{t - \gamma}{\eta} \right)^\beta \right\} \]  \hspace{1cm} (5)

d. Exponential Distribution

Reliability values for the exponential distribution are shown in the equation:

\[ R(t) = 1 - \lambda e^{-\lambda(t - \gamma)} \]  \hspace{1cm} (6)

- Risk assessment by combining the consequences of risk and analyzing the probability of failure that produce an acceptable or rejected value. At this stage a matrix of risk is drawn to describe the position of DCS system risk.

- Based on the risk level and duration of operation of the DCS system, the most appropriate type of maintenance interval can be determined to ensure the reliability of DCS system. Evaluation of maintenance by making comparison the maintenance process before risk-based maintenance carried out and after this method implemented. The reference of reliability value must not be less than 80% or 0.80 [8]. The results of the comparison then plotted into a graph to find out the relationship between DCS reliability values and operational time.

3. Results and Discussion

There are several cubicles at PLTGU Muara Tawar Block 1 that handles the DCS system, which are for gas turbine 1.1, gas turbine 1.2, gas turbine 1.3 balance of plant (common unit), water steam cycle, and steam turbine. In each function details described on the Table 3.
Table 3. Function for each cubicle PLTGU Muara Tawar Block 1

| No | Unit     | Cubicle Name | Function               |
|----|----------|--------------|------------------------|
| 1  | Gas      | 11CRC10      | Open Loop, Protection  |
| 2  | Gas      | 11CRC20      | Closed Loop, Protection|
| 3  | Gas      | 11CRC30      | Open Loop, Protection  |
| 4  | Gas      | 12CRC10      | Open Loop, Protection  |
| 5  | Gas      | 12CRC20      | Closed Loop, Protection|
| 6  | Gas      | 12CRC30      | Open Loop, Protection  |
| 7  | Gas      | 13CRC10      | Open Loop, Protection  |
| 8  | Gas      | 13CRC20      | Closed Loop, Protection|
| 9  | HRSG 1.1 | 11CBA11      | Control HRSG           |
| 10 | HRSG 1.2 | 12CBA11      | Control HRSG           |
| 11 | HRSG 1.3 | 13CBA11      | Control HRSG           |
| 12 | WSC      | 90CBA02      | Control Water Steam    |
| 13 | BOP      | 90CBA03      | Control BOP            |
| 14 | ST 1.4   | 14CBA01      | Protection Steam Turbine|
| 15 | ST 1.4   | 14CBA02      | Control Steam Turbine  |
| 16 | ST 1.4   | 14CBA03      | Control Steam Turbine  |

The failure of DCS system will give troubles for equipment operation and function of the plant[9]. Malfunction in the DCS sub-unit will affect the overall system performance so that the reliability of DCS must be well maintained at each cubicle. The failure scheme of plant caused by DCS system illustrated on figure 8.
Determination of the DCS system criticality rate is based on a failure record in each cubicle, so it can be used to map how reliable the system is. The time period used for data on the number of DCS failure for risk-based maintenance analysis is from 2007 to early 2020. The biggest score of number of DCS failure occur in GT 11 CRC 30 cubicle that handles the open loop control and protection, also in 12CBA11 cubicle that handles HRSG 12 operation. The DCS system criticality rate data will be determined the probability of failure within a certain period of time as quantitative assessment based on failure reports.

The calculation result of risk consequences and likelihood risk analysis of DCS failure then used for estimate the failure risk potential on each unit. The likelihood risk calculation for unit failure in each cubicle within a certain period of time described on figure 10 and 11. Figure 10 describe reliability and failure rate for card DCS on 14CBA02’s cubicle with normal distribution based on failure time that happened within 3 years. It showed that failure will tend to increase during operation time and last than a year it must be maintenance to avoid some failure that might happen. Figure 11
showed the Weibull 2 distribution from the failure records and had relatively less failure at beginning of operation. The distribution show failure rate slightly increasing after 300 hours of operation.

![Figure 10. Reliability and Failure Rate of DCS 14CBA02](image)

![Figure 11. Reliability and Failure Rate of DCS 14CBA02](image)

Acceptable risk criteria are determined and used to decide whether the estimated risk of each system failure in a cubicle is acceptable or not [10]. DCS system failures that result in unacceptable risks are used to determine maintenance policies for the system and the DCS card components involved. The estimation values of each cubicle according to probability to failure within a year and number of consequences describes on Table 4.

| Unit    | Cubicle Address | Probability of Failure within 1 year | Consequence | Risk | Risk Index |
|---------|----------------|-------------------------------------|-------------|------|------------|
| HRSG12  | 12CBA11        | 1                                   | 2.12        | 2.12 | Medium     |
| ST14    | 14CBA02        | 1                                   | 2.87        | 2.87 | High       |
| ST14    | 14CBA03        | 1                                   | 2.87        | 2.87 | High       |
| GT11    | 11CRC30        | 1                                   | 2.48        | 2.48 | Medium High|
| GT12    | 12CRC30        | 1                                   | 2.48        | 2.48 | Medium High|

The risk mapping of DCS system based on each cubicle in Muara Tawar Block 1 power plant from likelihood risk identification and consequences based on the failure report then visualized in a risk matrix (figure 12) as part of DCS system risk mitigation process in case to failure prevention that have uncontrollable impact. The DCS system that classified as high risk are 14CBA02 and 14CBA03, which are the system handle the control of steam turbine system. Meanwhile, the medium risk were 11CRC30, 12CRC30 cubicle that handles the control of gas turbine and 12CBA11 cubicle handles control of HRSG 12. Risk control is carried out by making recommendations for maintenance and modification based on the level of risk and the likelihood of damage to the DCS system in a cubicle.
Maintenance planning is based on the level of risk and the time interval for DCS system failure so that the most appropriate type and maintenance intervals can be seen and the DCS can be maintained. Based on the calculation of the decline in reliability values obtained maintenance time intervals that have been recapitulated in Table 5.

**Table 5. Critical Equipment Maintenance Intervals**

| Unit   | Cubicle Address | Maintenance Interval (hrs) | Preventive Maintenance Interval (days) |
|--------|-----------------|---------------------------|----------------------------------------|
| HRSG12 | 12CBA11         | 900                       | 38                                     |
| ST14   | 14CBA02         | 700                       | 29                                     |
| ST14   | 14CBA03         | 698                       | 29                                     |
| GT11   | 11CRC30         | 623                       | 26                                     |
| GT12   | 12CRC30         | 1004                      | 42                                     |

Determination of the maintenance interval of the DCS system on the cubicle with a critical level is crucial if it were done in a period based on the failure rate from time to time. Spare part readiness can help maintain DCS assets as an important part of a power plant.

**4. Conclusion**

The level of DCS system risk which is included in the high category and is a major concern is in cubicle 14CBA02 and 14CBA03 with risk values reaching 2.87 while DCS systems with medium-high category are DCS in cubicles 11CRC30, 12CRC30 and 12CBA11. Maintenance planning with the implementation of preventive maintenance intervals on the DCS system on cubicles 14CBA02 and 14CBA03 carried out in vulnerable around 29 days. Periodic maintenance can be done by maintaining the condition of the room to keep it in accordance with the standards and ensuring that indicators are always monitored to show the performance of the DCS system. The risk mapping and maintenance schedule will help the maintenance to prevent the loss production from DCS failure. Further research can be directed to take into account the value of the reliability of DCS electronically equipment, especially card components to get a more accurate component age and reliability approach.

**Figure 12. Risk Matrix on DCS Cubicles**

*CONSEQUENCE
PROBABILITY 1 2 3 4 5
0
0.25
0.5
0.75
1
12CBA11
14CBA02
11CRC30
12CRC30
0.5
Acknowledgement
We thank our colleagues from PT. Pembangkitan Jawa Bali who provided insight and expertise that greatly assisted the research.

References
[1] Alstom 2011 Gas Turbine Automation Egatrol Control System Course 80501 & 80510 Alstom Switzerland Ltd
[2] Krishnasamy, L., Khan, F., & Haddara, M. 2005 Development of a risk-based maintenance (RBM) strategy for a power-generating plant (Journal of Loss Prevention in the process industries) 18(2) p 69-81
[3] Khan, F. I., & Haddara, M. M 2007 Risk-based Inspection and Maintenance (RBIM): Multi-attribute Decision-making with Aggregative Risk Analysis (Process Safety and Environmental Protection), 82(6) p 398-411
[4] Khan, F. 2003 Risk-based maintenance (RBM): a quantitative approach for maintenance/inspection scheduling and planning (Journal of Loss Prevention in The Process Industries) p 865
[5] Sarkar, A., & Behera, D. K. 2012 Development of risk based maintenance strategy for gas turbine power system International Journal of Advanced Research in Engineering and Applied Sciences, 1(2) p 20-38
[6] Wang, Q., & Gao, J. 2012 Research and application of risk and condition based maintenance task optimization technology in an oil transfer station (Journal of Loss Prevention in the Process Industries) 25(6) p 1018-1027
[7] Singh, M., & Markeset, T. 2009 A methodology for risk-based inspection planning of oil and gas pipes based on fuzzy logic framework (Engineering Failure Analysis) 16(7) p2098-2113
[8] Yulianto, D.T. 2017 Pengembangan Risk Based Maintenance Sebagai Dasar Penentuan Prioritas Pemeliharaan Peralatan di PT Pembangkitan Jawa Bali UP Muara Tawar (Jurnal MM Universitas Mercu Buana)
[9] Min, M. G., Lee, J. K., Lee, K. H., Lee, D., & Lim, H. T. 2017 Verification of failover effects from distributed control system communication networks in digitalized nuclear power plants (Nuclear Engineering and Technology) 49(5) p989-995
[10] Arunraj, N. S., & Maiti, J. 2007 Risk-based maintenance—Techniques and applications (Journal of hazardous materials) 142(3) p 653-661