Advances in Reliability, Safety and Security, Part 8 – Kołowrocki, Magryta-Mut (eds.)

Advances in Reliability, Safety and Security

ESREL 2024
Monograph Book Series

Strategy of Capital Investment Decision-Making by Integrating Engineering Analysis to Financial Analysis at the Corporate Level for the Electricity Company Sustainability

Dheka Bakti Krisnamurti Winarno, Herry Nugraha

PT PLN (Persero), Jakarta, Indonesia

Abstract

The electricity company is currently having several challenges, one of which is the energy transition to achieve net zero emission in 2060. Therefore, the electricity company must demonstrate the ability to increase profit through the electricity company's financial indicator return on assets (RoA) at least 4%. In the previous research, several methods were developed to solve the problems, namely by optimizing asset interventions. However, these methods cannot be applied in the electricity company because optimization was only performed at the equipment level and/or at the power generation level. This is because assets in the power generation can also generate revenue, which can be one of the considerations in the optimization. Therefore, the electricity company seeks to increase asset productivity by prioritizing asset intervention at the corporate level and using the economic lifetime method. The prioritization is carried out based on key performance indicators (KPIs) of corporate, the power system priority index based on prediction of the power system risk cost, prediction of the highest equivalent annualized profit with combinations of all intervention scenarios (with the intervention scenario being carried out now or postponed in the following years), all compliance criteria (environmental, regulatory, and safety), and prediction of corporate capital cost limit per year.

Keywords: capital investment decision-making, reliability availability maintainability analysis, whole-life cycle cost, economic life, optimization method, prioritization method, power generation, key performance indicator, risk cost

1. Introduction

In an organization (an electricity company), business objectives or visions are contained in the company's long-term plan which is published every 5 (five) years. To achieve the business objectives for the next 5 (five) years, strategic goals and strategic enablers are needed. Strategic enablers consist of 4 (four) enablers, namely organization and people, technology advancement, financial sustainability, and national development. One of the strategic objectives of financial sustainability is to increase company profitability, one of the indicators is return on assets (RoA). The company must be able to prioritize capital costs to increase RoA.

In these conditions, decisions regarding asset management become critical. This means that the electricity company needs to improve its electricity business planning capabilities, improve investment accuracy, and understand how parameters of economic growth relate to electricity demand. Therefore, the electricity company, especially top management, must understand the role of asset management in improving the quality of business decision-making, customer satisfaction, and be able to implement good practices from asset management and asset management systems effectively within the organization. Decision-making is carried out to produce optimal activities, so that organizational objectives are achieved. The decision-making consists of: (a) strategic asset management plans (SAMPs) decision-making, (b) asset management plans decision-making, which consists of capital investment decision-making and operation & maintenance (O&M) decision-making, and (c) implementation of asset decision-making management plans (delivery of plans). In making decisions, asset management plans are divided into 3 (three) levels, namely: (a) individual assets, (b) asset system, and (c) portfolio asset.

In the previous research, optimizing asset intervention at the individual asset level (component / equipment level) were developed by carrying out maintenance strategy (EPRI, 1998), (Sliter and George, E., 2003), (Sabouhi, H. et al., 2016), (Esselman, T. et al., 2012), (EPRI, 2016), (Zarei, S. and Kajuei, P.G., 2017), (Arthur et al., 2018), (Wibawa, A. et al., 2019), operation strategy (Wibawa, A. et al., 2019), (Fu, C.Z. et al., 2015), and fuel strategy (Wibawa, A. et al., 2019). However, these methods cannot be applied in the electricity company because the optimization was only performed at the individual asset level.

Methods were also developed optimizing asset intervention at the asset system level (system / power generation level) by carrying out maintenance strategy (EPRI, 1998), (Sabouhi, H. et al., 2016), (EPRI, 2016), (Zarei, S. and Kajuei, P.G., 2017), (Raghawan, S. and Chowdhury, b., 2012), operation strategy (Fu, C.Z. et al., 2015), (Zhang, C., 2015), (Luo, J. et al., 2016), (Hübela, M., 2017), (Mechleri, E. et al., 2017), dan fuel strategy (Li, M. et al., 2010), (Ploumen, P. et al., 2011), (Stover, B. et al., 2011) (Munir, S. et al., 2011), (Xia, J. et al., 2014), (Xu, C. et al., 2016). However, these methods cannot be applied in the electricity company because the optimization was only performed at the asset system level and did not make revenue as one of the considerations.

In addition, there were also prioritizing asset intervention at the asset portfolio level (structure / corporate level) by carrying out maintenance strategy (EPRI, 1998), (EPRI, 2016), operation strategy (Xu, J. et al., 2017), (Xin, T. et al., 2019). However, these methods cannot be applied in the electricity company because the prioritization did not make revenue as one of the considerations.

Based on the previous research, it was necessary to prioritize asset intervention at the asset portfolio level by making revenue as one of the considerations. The prioritization was carried out based on: (a) key performance indicators (KPIs) of corporate, (b) the system priority index, (c) prediction of the highest equivalent annualized profit with combinations of all intervention scenarios (with the intervention scenario being carried out now or postponed in the following years), (d) all compliance criteria, and (e) prediction of corporate capital cost limit per year. Before prioritizing asset intervention at the asset portfolio level, the asset must be optimized first at the individual asset level and the asset system level respectively. Therefore, only the most optimal asset intervention will be optimized at the portfolio level so that it will increase cost efficiency and asset productivity.

2. Capital Investment Decision-Making at the Individual Asset Level (the Equipment Level)

2.1. Current condition of equipment

This section contains the realizations of technical and financial conditions of equipment which depend on the scope of project, which can be seen in Table 1. For example, if perform a replacement project, then it is only necessary the realizations of technical condition of equipment and power generation and financial condition. The parameters used to inform the technical condition of equipment since the commercial operation date (COD) until now are: (a) failure rate of equipment obtained from enterprise asset management (EAM), (b) failure distribution of equipment, and (c) downtime distribution of equipment. Failure distribution and downtime distribution are calculated by using the reliability software. The parameters will be used to calculate the predictions of technical condition of equipment, which can be seen in section 2.2.

The parameters used to inform the financial condition since construction until now are: (a) capital cost; (b) O&M cost, (c) equivalent annualized capital cost, (d) equivalent annualized O&M cost, and (e) equivalent annualized cost. The equivalent annualized costs are calculated by using Eq. (1). The parameters will be used to create graphs, which can be seen in Figure 1 and 2.

Table 1. Realization and prediction to scope of project.

Scope of Project	Realization and Prediction				
	Equip.	Power Gen.	Power System	Tech. Support	Financ.
Replacement	●	●			●
Uprating	●	●			●
Upgrading	●	●			●
Modernization	●	●			●
Periodic Maintenance		●			●
Relocation		●	●	●	●
Disposal		●	●	●	●

Scope of Project	Realization and Prediction				
	Equip.	Power Gen.	Power System	Tech. Support	Financ.
New Power Gen Construc.			•	•	

•: Must be fulfilled

$$EAC = \frac{NPV}{A_{t,r}} = \frac{NPV}{\left(\frac{1 - \frac{1}{(1+r)^T}}{r}\right)} \quad (1)$$

with:
EAC : Equivalent Annualized Cost (USD/year)
NPV : Net Present Value (USD)
$A_{t,r}$: Annuity factor
r : Discount rate (%)
T : Year

2.2. Operational study

This section contains the predictions of technical condition of equipment until its end of life from: (a) business as usual (BaU), (b) main project, and (c) alternative projects. The parameters used to inform the technical condition are: (a) failure rate of equipment, (b) failure distribution, and (c) downtime distribution. In replacement project, the parameters are obtained from the realization.

2.3. Financial study

This section contains the predictions of the financial condition of equipment until its end of life from: (a) BaU, (b) main project, and (c) alternative projects. The parameters used to inform the financial condition are: (a) capital cost, (b) operation cost calculated by using Eq. (2), (c) maintenance cost calculated by using Eq. (4) and (5), (d) equivalent annualized capital cost, (e) equivalent annualized O&M cost, (f) equivalent annualized disposal cost, (g) equivalent annualized cost.

$$O_t = OC \times MTBF \times (\lambda + n) \times T \quad (2)$$

$$MTBF = \frac{8760 - (\lambda \times MDT)}{\lambda} \quad (3)$$

$$M_r = (\lambda \times M_{CR}) + \left(CR_{RoM} \times (EFDH + FOH)\right) + \left((EFDH + FOH) \times Asset\ Criticality\right) \quad (4)$$

$$M_i = (n \times M_{CS}) + \left(CR_{RoM} \times (EFDH + POH)\right) + \left((EFDH + POH) \times Asset\ Criticality\right) \quad (5)$$

$$Asset\ Criticality = \left(\frac{ENS}{1\ hour} \times (7\% \times BPP_{SYST})\right) + \left(\left(DMN - \frac{ENS}{1\ hour}\right) \times Extra\ Fuel\ Cost\right) \quad (6)$$

$$Extra\ Fuel\ Cost = Marginal\ Cost - BPP_{KIT} \quad (7)$$

with:
O_t : Operation cost (USD)
OC : Operation labour cost (USD/hour)
λ : Failure rate (1/year)
$MTBF$: Mean time between failure (hours)
MDT : Mean downtime (hours)

n	:	Inspection rate (1/year)
M_r	:	Repair cost (USD)
M_i	:	Inspection cost (USD)
M_{CR}	:	Average material cost per failure rate (USD.year)
M_{CS}	:	Average material cost per inspection rate (USD.year)
CR_{RoM}	:	Average service cost per failure rate (USD.year)
$EFDH$	:	Equivalent forced derated hours (hours)
$EPDH$	:	Equivalent planned derated hours (hours)
FOH	:	Forced outage hours (hours)
POH	:	Planned outage hours (hours)
ENS	:	Energy not served (kW)
DMN	:	Net capacity (kW)
BPP_{SYST}	:	Production cost of this power system (USD/kWh)
BPP_{KIT}	:	Production cost of this power generation (USD/kWh)

2.4. Risk study

This section contains the predictions of risk cost of equipment until its end of life from: (a) BaU, (b) main project, and (c) alternative projects. The equipment risk cost is calculated using Eq. (8).

$$Equipment\ Risk\ Cost = (\lambda \times M_{CR}) + \left(CR_{RoM} \times (EFDH + FOH)\right) + \left((EFDH + FOH) \times Asset\ Criticality\right) + \Delta F_t \quad (8)$$

$$\Delta F_t = F_{t.scenario} - F_{t.improvement} \quad (9)$$

2.5. Optimization

This section contains capital investment decision-making at the equipment level based on comparison of scenarios: (a) BaU, (b) main project, and (c) alternative projects. The project optimization method is carried out based on: (a) economic lifetime of equipment (the minimum cost point of the equipment until its end of life), (b) prediction of the lowest equivalent annualized cost of equipment (ISO 55010, 2019), and (c) prediction of the equipment risk cost based on risk appetite statements. The most optimal project will be analyzed at the asset system level. In the case study of equipment replacement, the project optimization can be seen in Table 2 and Figure 1 and 2.

Table 2. Optimization at the equipment level.

Parameter	Prediction		
	BaU	Main Project	Alternative Project
EAC (USD)	28,633.44	25,220.30	26,061.47
Total of Equipment Risk Cost (USD)	177,758.22	158,588,52	165,781.50
	Yes ~~/ No *~~	Yes ~~/ No *~~	Yes ~~/ No *~~
Optimization	~~BaU /~~ Main Project ~~/ Alternative … *~~		

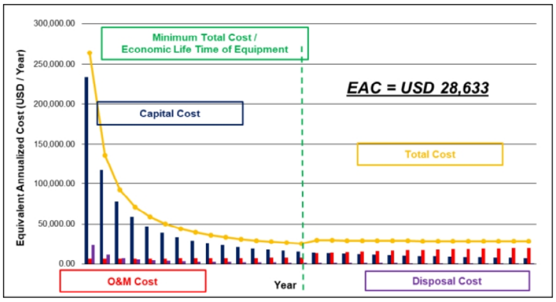

Fig. 1. Equivalent annualized cost (BaU).

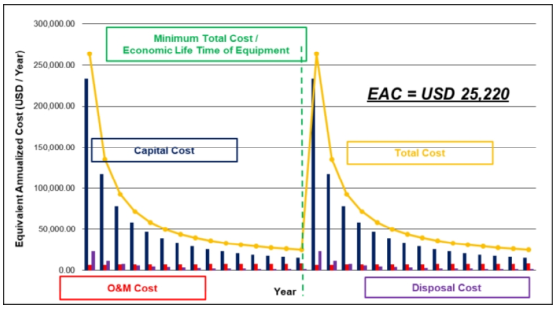

Fig. 2. Equivalent annualized cost (main project).

3. Capital Investment Decision-Making at the Asset System Level (the Power Generation Level)

3.1. Current condition of power generation and power system

This section contains the realizations of technical and financial conditions of power generation and technical of power system and technical supporting which depend on the scope of project, which can be seen in Table 1. The parameters used to inform technical condition of power generation since COD until now are: (a) net plant heat rate (NPHR), (b) NPHR distribution calculated by using the reliability software, (c) failure rate of power generation, (d) EFDH and FOH, (e) equivalent availability factor (EAF), and (f) capacity factor (CF). NPHR, failure rate, EFDH, FOH, EAF, and CF are obtained from performance report.

The parameters used to inform technical condition of power system since the power generation's COD until now are: (a) failure rate of power system, (b) FOH, (c) power flow, (d) short circuit, (e) system stability, (f) power quality, and (g) load (dispatching). Failure rate and FOH are obtained from performance report. Power flow, short circuit, system stability, power quality, and load are calculated by using the power system analysis software.

The parameters used to inform technical condition of technical supporting since the power generation's COD until now are: (a) demand, (b) energy potential, (c) topography, (d) soil investigation, (e) hydrology/hydro-oceaonography, (f) Climatology, and (g) seismography.

The parameters used to inform the financial condition since construction until now are: (a) capital cost; (b) O&M cost, (c) fuel cost, (d) revenue, (e) equivalent annualized capital cost, (f) equivalent annualized O&M cost, (g) equivalent annualized fuel cost, (h) equivalent annualized cost, (i) equivalent annualized revenue calculated by using Eq. (1), and (j) equivalent annualized profit.

3.2. Operational study

This section contains the predictions of technical condition of power generation, power system, and technical supporting until power generation's end of life from: (a) feasibility study (FS), (b) BaU, (c) main project, and (d) alternative projects. The parameters used to inform technical condition of power generation are: (a) NPHR, (b) NPHR distribution, (c) failure rate of power generation, (d) EFDH and FOH, (e) EAF, and (f) CF. In reliability project, NPHR and NPHR distribution are obtained from the realization. Meanwhile in efficiency project, NPHR is calculated by using Eq. (10). EFDH, FOH, and EAF are calculated by using the reliability software.

The parameters used to inform technical condition of power system are: (a) failure rate of power system, (b) FOH, (c) power flow, (d) short circuit, (e) system stability, (f) power quality, and (g) load. Failure rate and FOH are calculated by using the reliability software. Power flow, short circuit, system stability, power quality, and load are calculated by using the power system analysis software.

The parameters used to inform technical condition of technical supporting are: (a) demand, (b) energy potential, (c) topography, (d) soil investigation, (e) hydrology/hydro-oceaonography, (f) climatology, and (g) seismography.

$$NPHR = \frac{Coal\ Flow \times HHV}{GGO - Aux} \tag{10}$$

with:
$NPHR$: Net plant heat rate (kcal/kWh)
HHV : Higher heating value of coal (kcal/kg)
GGO : Gross generator output (kWh)
Aux : Auxiliary power (kWh)

3.3. Financial study

This section contains the predictions of financial condition of power generation until its end of life from: (a) FS, (b) BaU, (c) main project, and (d) alternative projects. The parameters used to inform the financial condition are: (a) capital cost, (b) O&M cost, (c) fuel cost calculated by using Eq. (11) and (12), (d) revenue calculated by using Eq. (13) and (14), (e) equivalent annualized capital cost, (f) equivalent annualized O&M cost, (g) equivalent annualized fuel cost, (h) equivalent annualized disposal cost, (i) equivalent annualized cost, (j) equivalent annualized revenue, and (k) equivalent annualized profit.

$$F_t = \frac{C_f \times NPHR \times (GGO - Aux) \times EAF}{HHV}$$

$$if\ EAF < CF \tag{11}$$

$$F_t = \frac{C_f \times NPHR \times (GGO - Aux) \times CF}{HHV}$$

$$if\ EAF \geq CF \tag{12}$$

$$TR = Electric\ Price \times (GGO - Aux) \times EAF$$

$$if\ EAF < CF \tag{13}$$

$$TR = Electric\ Price \times (GGO - Aux) \times CF$$

$$if\ EAF \geq CF \tag{14}$$

with:
F_t : Fuel cost (USD)
C_f : Coal unit price (USD/kg)
EAF : Equivalent availability factor (%)
CF : Capacity factor (%)
TR : Total revenue (USD)

3.4. Risk study

This section contains the predictions of risk cost of power generation and power system until power generation's end of life from: (a) FS, (b) BaU, (c) main project, and (d) alternative projects. The power generation risk cost is calculated using Eq. (8).

3.5. Optimization

This section contains capital investment decision-making at the power generation level based on comparison of scenarios: (a) FS, (b) BaU, (c) main project, and (d) alternative projects. The project optimization method is carried out based on: (a) economic lifetime of power generation (the maximum profit point of the power generation until its end of life), (b) KPIs of power generation, (c) the equipment priority index based on prediction of the equipment risk cost which can be seen in Table 3, (d) prediction of the highest equivalent annualized profit of power generation, (e) predictions of the power generation risk cost and the power system risk cost based on risk appetite statements, (f) predictions of power flow, short circuit, system stability, power quality, dan load based on grid code, and (g) predictions of energy potential, topography, soil investigation, hydrology/hydro-oceaonography, climatology, and seismography. The most optimal project will be analyzed at the asset portfolio level. In the case study of equipment replacement, the project optimization can be seen in Table 4 and Figure 3 and 4.

Table 3. Equipment priority index (PI) in 2023.

Equipment Names	Year	Risk Cost (USD)
Mill Seal Air Cold Primary Air Duct	2023	2,971.26
Coal Feeder Seal Air Damper	2023	2,841.97
Seal Air Fan Outlet Damper	2023	2,787.55
Mill Seal Air Header	2023	2,670.48
Mill Seal Air Fan Inlet Duct	2023	1,857.49
Mill Seal Air Fan Outlet Duct	2023	1,857.49
Coal Feeder Seal Air Duct	2023	1,857.49

Table 4. Optimization at the power generation level.

Parameter	Prediction		
	BaU	Main Project	Alternative Project
Key Performance Indicator (KPI)			
EFDH + FOH	1,277.31	1,016.83	1,534.56
	Yes ~~/ No *~~	Yes ~~/ No *~~	Yes ~~/ No *~~
EAF	74.46	77.43	82.48
	Yes ~~/ No *~~	Yes ~~/ No *~~	Yes ~~/ No *~~
EA Profit (USD x 1,000)	- 121,923.87	36,587.25	7,870.27
Total Risk Cost of Power Gen. (USD x 10,000)	9,660.15	8,618.39	9,772.96
	Yes ~~/ No *~~	Yes ~~/ No *~~	Yes ~~/ No *~~
Total Risk Cost of Power System (USD)	–	–	–
	–	–	–
Power Flow	–	–	–
Short Circuit	–	–	–
System Stability	–	–	–
Power Quality	–	–	–
Load	–	–	–
Energy Potential	–	–	–
Topography	–	–	–
Soil Investigat.	–	–	–
Hydrology / Hydro-oceaon.	–	–	–
Climatology	–	–	–
Seismography	–	–	–
Optimization	~~BaU /~~ Main Project ~~/ Alternative … *~~		

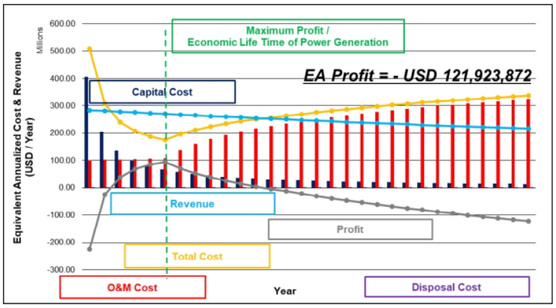

Fig. 3. Equivalent annualized profit (BaU).

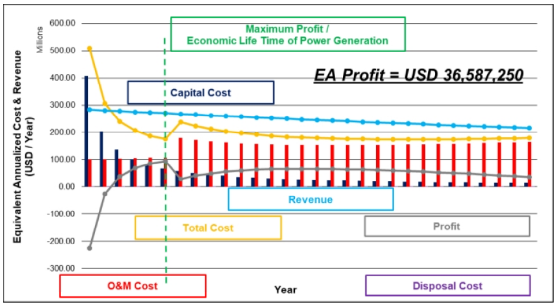

Fig. 4. Equivalent annualized profit (main project).

4. Capital Investment Decision-Making at the Asset Portfolio Level (the Corporate Level)

Capital investment decision-making at the asset portfolio level is the decision-making at the corporate level. The decision-making is carried out based on a comparison of all projects in corporate (not only projects in the power generation). The project prioritization method is carried out based on: (a) KPIs of corporate, (b) the system priority index based on prediction of the system risk cost (structure, system, and component in power system, system is power generation, transformer, etc), (c) prediction of the highest equivalent annualized profit with combinations of all intervention scenarios, (d) all compliance criteria (environmental, regulatory, and safety), and (e) prediction of corporate capital cost limit per year. The project prioritization can be seen in Table 5 and 6.

Table 5. Prioritization at the corporate level.

Parameter	Prediction		
	Project 1	Project 2	Project 3
Equivalent Annualized Profit (EA Profit, USD)			
Postp. = 0	36,587,250.57	36,125,188.95	35,442,342.08
Postp. = 1	34,110,610.75	35,838,051.87	34,858,983.19
Postp. = 2	33,742,917.03	35,128,552.17	34,612,519.75
Environmental			
Postp. = 0	Yes ~~/ No *~~	Yes ~~/ No *~~	Yes ~~/ No *~~
Postp. = 1	Yes ~~/ No *~~	Yes ~~/ No *~~	Yes ~~/ No *~~
Postp. = 2	Yes ~~/ No *~~	Yes ~~/ No *~~	Yes ~~/ No *~~
Regulatory			
Postp. = 0	Yes ~~/ No *~~	Yes ~~/ No *~~	Yes ~~/ No *~~
Postp. = 1	Yes ~~/ No *~~	Yes ~~/ No *~~	Yes ~~/ No *~~
Postp. = 2	Yes ~~/ No *~~	Yes ~~/ No *~~	Yes ~~/ No *~~

Parameter	Prediction		
	Project 1	Project 2	Project 3
Safety			
Postp. = 0	Yes ~~/ No *~~	Yes ~~/ No *~~	Yes ~~/ No *~~
Postp. = 1	Yes ~~/ No *~~	Yes ~~/ No *~~	Yes ~~/ No *~~
Postp. = 2	Yes ~~/ No *~~	Yes ~~/ No *~~	Yes ~~/ No *~~
Prioritization	Combination III Project 2 will be postponed for 1 (one) year (The scenarios combination can be seen in Table 6)		

Table 6. Project scenarios combination.

Project Names	Postp. = 0	Postp. = 1	Postp. = 2
Equivalent Annualized Profit – Combination I			
Project 1 (USD)	36,587,250.57	–	–
Project 2 (USD)	36,125,188.95	–	–
Project 3 (USD)	35,442,342.08	–	–
EA Profit (USD)	108,154,781.60		
KPI	Yes ~~/ No *~~		
Capital Cost Ltd	~~Yes /~~ No *		
Equivalent Annualized Profit – Combination II			
Project 1 (USD)	36,587,250.57	–	–
Project 2 (USD)	36,125,188.95	–	–
Project 3 (USD)	–	34,858,983.19	–
EA Profit (USD)	107,571,422.71		
KPI	Yes ~~/ No *~~		
Capital Cost Ltd	Yes ~~/ No *~~		
Equivalent Annualized Profit – Combination III			
Project 1 (USD)	36,587,250.57	–	–
Project 2 (USD)	–	35,838,051.87	–
Project 3 (USD)	35,442,342.08	–	–
EA Profit (USD)	107,867,644.52		
KPI	Yes ~~/ No *~~		
Capital Cost Ltd	Yes ~~/ No *~~		
Equivalent Annualized Profit – Combination …			

5. Conclusion

In the electricity company, robust capital investment decision-making at the asset portfolio level is very important. Identify and build on the information needed to build a robust plan, including: (a) understand the relationship between stakeholder needs, including capacity and functionality, by using assets to best meet stakeholder needs, (b) understand the cost of assets throughout their life cycle, (c) understand the relationship between maintenance and asset reliability/performance, (d) understand what is required in terms of design and operation of the asset to meet regulatory and other requirements, (e) use the decision-making to determine the type and frequency of maintenance to be performed throughout the asset's life cycle and the performance characteristics that will identify when an asset has reached the end of its economic life.

The main output of this activity is the identification of maintenance strategies for all types of assets. Also included in the scope of this activity group is decision-making on capital investment, which is the basis for identifying the need for developing new assets, the optimal timing for replacement or upgrading of capabilities and providing strong justification for the selected options so that it will increase cost efficiency and asset productivity.

Acknowledgements

This research is supported by PT PLN (Persero) for case study and AMCL as consultant.

References

Electric Power Research Institute (EPRI). 1998. EPRI-106109. Palo Alto. Nuclear Plant Life Cycle Management Implementation Guide.
Sliter, George, E. 2003. Prague. Life Cycle Management in the US Nuclear Power Industry, Transactions of the 17th International Conference on Structural Mechanics in Reactor Technology (SMiRT 17). 1 – 8.
Sabouhi, H., Firuzabad, M.F., Dehghanian, P. 2016. Journal of Power and Energy Systems. Identifying Critical Components of Combined Cycle Power Plants for Implementation of Reliability Centered Maintenance.
Esselman, T., Bruck, P., Menger, C.2012. IAEA. Integrated Life Cycle Management: A Strategy for Plants to Extend Operating Lifetimes Safely with High Operational Reliability. 1 – 8.
Electric Power Research Institute (EPRI). 2016. EPRI-3002008005. Integrated Life Cycle Management.
Zarei, S., Kajuei, P.G. 2017. Indonesian Journal of Electrical Engineering and Computer Science. Evaluation of Various Maintenance Strategies for Reliability Assessment of Thermal Power Plants. 617 – 624.
Arthur, Melani, A.H.A., Murad, C.A., Netto, A.C. 2018. Criticality-Based Maintenance of a Coal-Fired Power Plant, Energy.
Wibawa, A., Ichsani, D., Yuniarto, N. 2019. Journal of Physics: Conference Series, the International Conference on Sciences and Technology Applications. Power Plant Life Cycle Cost Management Framework: A Literature Review.
Fu, C.Z., Anantharaman, R., Jordal, K., Gundersen, T. 2015. Journal of Energy Conversion and Management. Thermal Efficiency of Coal Fired Power Plant: from Theoretical to Practical Assessment. 530 – 544.
Raghawan, S., Chowdhury, B. 2012. Conference: North American Power Symposium (NAPS). Developing Life Cycle Management Plant for Power Plant Components.
Zhang, C. 2015. International Conference on Mechatronics, Materials, Chemistry and Computer Engineering (ICMMCCE). A Software for Optimizing the Thermal Power Plant Operation under Environmental Constraints.
Luo, J., Wu, L., Wan, W. 2016. The 8th International Conference on Applied Energy (ICAE). Optimization of the Exhaust Gas Oxygen Content for Coal Fired Power Plant Boiler.
Hübela, M., Meinked, S., Andrénb, M.T., Wedding, C., Nockea, J., Gierowa, C., Hassela, E., Funkquistc, J. 2017. Applied Energy. Modelling and Simulation of a Coal-Fired Power Plant for Start-Up Optimisation. 319 – 331.
Mechleri, E., Fennell, P.S., Dowell, N.M. 2017. Energy Procedia. Flexible Operation Strategies for Coal and Gas-CCS Power Stations Under the UK and USA Markets. 6543 – 6551.
Li, M., Rao, A.D., Brouwer, J., Samuelsen, G.S. 2010. Journal of Power Sources. Design of Highly Efficient Coal-Based Integrated Gasification Fuel Cell Power Plants. 5707 – 5718.
Ploumen, P., Stienstra, G., Kamphuis, H.. 2011. Energy Procedia. Reduction of CO2 Emissions of Coal Fired Power Plants by Optimizing Steam Water Cycle. 2074 – 2081.
Stover, B., Bergins, C., Klebes, J. 2011. Energy Procedia. Optimized Post Combustion Carbon capturing on Coal Fired Power Plants. 1637 – 1643.
Munir, S., Nimmo, W., Gibbs, B.M. 2011. The Effect of Air Staged, Co-combustion of Pulverized Coal and Biomass Blends on NOx Emissions and Combustion Efficiency.
Xia, J., Chen, G., Tan, P., Zhang, C. 2014. Electrical Power and Energy System. An Online Case-Based Reasoning System for Coal Blends Combustion Optimization of Thermal Power Plant. 299 – 331.
Xu, C., Xu, G., Zhao, S., Dong, W., Zhou, L., Yang, Y. 2016. Journal Energy Conversion and Management. A Theoretical Investigation of Energy Efficiency Improvement by Coal Pre-Drying in Coal Fired Power Plant. 580 – 588.
Xu, J., Gu, Y., Chen, D., Li, Q. 2017. Applied Thermal Engineering. Data Mining Based Plant-Level Load Dispatching Strategy for The Coal-Fired Power Plant Coal-Saving: A Case Study. 553 – 559.
Xin, T., Xu, C., Liu, W., Xu, G., Yang, Y. 2019. Energy Procedia. Thermodynamic Analysis of A Novel Oxy-Combustion Supercritical Carbon Dioxide Power Cycle Integrating Solar-Driven Coal Gasification. 1962 – 1967.
International Organisation for Standardization (ISO) 55010. 2019. Guidance on the Alignment of Financial and Non-Financial Function in Asset Management.