Diagnosing Causes of Coal Power Plant Energy Losses Using Bayesian Belief Network

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Abstract

Power system consists of some power plants with variant types. Each power system has typical problem, but usually the main problem is inability power plant to perform as it is desired. Thus the power system could not serve the peak load reliably. There is a gap between installed capacity (design capacity) and real capacity called hidden capacity. The hidden capacity which operating in period hours called energy losses. This study would diagnose the root cause of energy losses using Bayesian Belief Network (BBN). Software Genie 2.0 is used to solve this problem. Based on data from power system planning dispatcher division, the most contribution energy losses came from coal fire power plant. The root cause of energy losses would be found quantitatively by considering its probability. This study also gives a quantitative prediction result that would be achieved and benefit that would be obtained when some scenarios were executed.

Keywords (12 font)
hidden capacity; energy losses; coal fire power plant; bayesian belief network;

1. Introduction

The main problem that usually happen in an asset is a gap between initial capability with desired performance. Initial capability is "what asset can do" while desired performance is "what users want to do". This gap generally called as "margin for deterioration". That case also occur in a power plant. Its performance would deteriorate when power plant get older. The extreme case also can happen when power plant deteriorate in the beginning of operation, it is called by "infant mortality". Equivalent Availability Factor (EAF) and Equivalent Force Outage Rate (EFOR) are parameters that indicate performance of power plant.

$$EAF = \frac{AH-(EFDH+EMDH+EPDH+ESEDH)}{PH}\ x\ 100\% \quad (1)$$

$$EFOR = \frac{FOH + EFDH}{FOH + SH + Syncr\ Hrs + EFDHRS}\ x\ 100\% \quad (2)$$

AH	:Available Hours
EFDH	:Equivalent Force Derating Hours
EMDH	:Equivalent Maintenance Derating Hours
EPDH	:Equivalent Planned Derating Hours

ESEDH	:Equivalent Seasonal Derated Hours
PH	:Period Hours
FOH	:Force Outage Hours
SH	:Service Hours
SynchrHrs	:Synchronous Hours
EFDHRS	:Equivalent Force Derating Hours during Reserve Shutdown

Due to EAF more representative to explain the operational condition of the power plant (energy production), thus it parameter would be used in this study.

Based on data from power system planning dispatcher, the worse EAF in the system is a coal fire power plant with EAF 26.66 %. This power plant has 660 MW installed capacity with targeted energy production in 2012 was 2171 GWh (equivalent to +3289 availability hours). By assumed that period hours in a year is 8760 hours, then the real power plant availability in 2012 is only + 2335 hours. In other word, in 2012 the power plant had + 954 hours loss of opportunity to product. This period is equivalent to + 630 GWh energy losses. Then this study would focus on this coal fired power plant.

First step to solve the problem is breaking down the causes of energy losses until found the root cause. Every single problem in power plant that causes outage or derating must be reported to dispatcher. The report consists of some information i.e : Status of the problem (Force Derating, Force Outage, Planned Derating or Planned Outage etc), the amount of derating or outage (MW), time to start failure, time to finish failure, duration of the failure, energy losses as a consequence of failure and cause code of problem.

2. Methodology

Generally the methodology consists of five steps;

1. Root cause analysis
2. Optimization and simulation
3. Sensitivity analysis
4. Scenario analysis
5. Benefit cost analysis

2.1 Root Cause Analysis

The first step in this study is identification the causes of energy losses. The goal of this identification is find the root cause of energy losses. Then root cause analysis consists of two steps;

1. Identification the causes of energy losses. This step would be done based on data cause code of problem.
2. Check the interrelatedness or correlation between some factors that cause energy losses. This correlation is important to construct a Bayesian Network model.

2.2 Optimization And Simulation

The next step is optimization and simulation by developing Bayesian Belief Network (BBN) model. Bayesian network would give generally illustration about some factors that cause energy losses. This step also determining the probability every causes. After develop the model, then validation process is needed to confirm that model has represented the system well. Software Genie 2.0 will be used to solve the simulation.

2.3 Sensitivity Analysis

Then sensitivity analysis is conducted to find the root cause of energy losses. Sensitivity analysis is used to know which equipment that has the most significance contribution to energy losses.

Scenario Analysis

There are 2 scenarios that would be achieved in this study;

1. EAF is equal to North American Electric Reliability Corporation (NERC) standard. Based on NERC standard 2007 – 2011, the average of EAF in class of coal fire power plant with capacity 660 MW is 81,93%.
2. EAF is equal to maximum EAF that could be achieved in the system; 97%.

2.4 Benefit Cost Analysis

Benefit Cost Analysis (BCA) means a systematic process to compare between benefit that could be achieved and cost as consequence that arise from an activity, decision or policy. By finding the root cause of energy losses in coal power plant, the operator could make improvement about equipment which has more failure probability. In case failure probability get decrease, the availability of the power plant would be increase, consequently the revenue would be increase and the usage of oil power plant-expensive energy- in the system is not needed anymore.

$$\text{Benefit} = S - COS \tag{3}$$

Where simulation is obtained by following formula:

$$S = ((OE\text{-}\Delta EL) X ACOE) + (CE + \Delta EL) X ACC + TSA \tag{4}$$

And COS is obtained by following formula:

$$COS = (OE \ X \ ACOE) + (OE \ X \ ACC) + TSA \tag{5}$$

With:

S	: Simulation (USD)
COS	: Cost of Sales (USD)
OE	: Oil Power Plant Energy (kWh)
ΔEL	: Gap Energy Losses existing with scenario (kWh)
ACOE	: Average Cost of Oil Energy (USD/kWh)
CE	: Coal Power Plant Energy (kWh)
ACC	: Average Cost of Coal Energy (USD/kWh)
TSA	: Transfer Sales Agreement (USD)

While cost arises from implementation of mitigation. By finding the root cause of energy losses, the operator could arrange some improvements to mitigate the problem. These improvements certainly need a cost as consequence. Because of sufficiency of data, so the cost factor in this study is neglected. This methodology can be seen in figure 1 as follow:

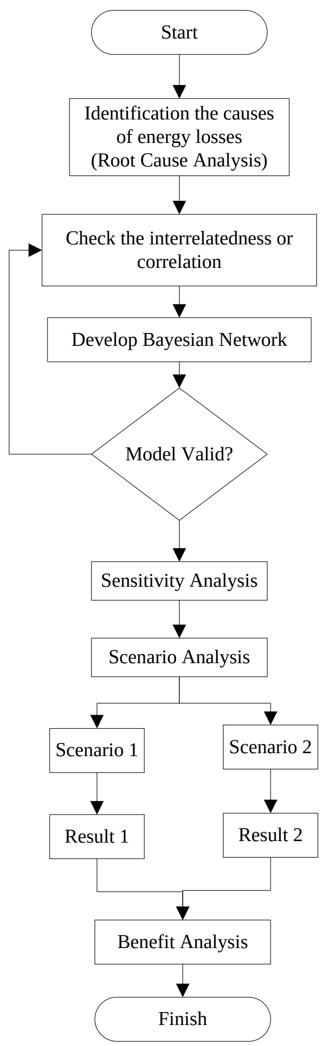


Figure 1. Flowchart of Methodology

3. Result and Analysis

3.1 Develop Models

Before developing the models, we should arrange the structure of the model first. The structure of the model is called by Bayesian Belief Network (BBN). The main data takes from cause code of the coal fire power plant. For example, to predict the probability of energy losses, there are some equipment (variables) that influence directly e.g : boiler, balance of plant, external, steam turbine, generator and pollution control equipment. These variables are antecedent variables from the code. And every single antecedent has descendent variable as a root of a cause code. For example we have Root Cause Code (RCC) 01AA0080. The two first numbers are antecedent variable, number 01 is for boiler area, while AA0080 refers to stacker / reclaimer equipment as a root variable.

The probability of failure or outage in a single equipment (root variables/descendent variable) that causes energy losses is obtained by following formula:

$$P(f_{\text{equipment}}) = \frac{Equipment\ energy\ losses}{annually\ energy\ targeted} \quad (4)$$

For example, the power plant annually energy targeted in 2012 is 2,170,739 MWh. While energy losses for variable stacker / reclaimer in 2012 is 24828.25 MWh. Then the probability of failure or outage for variable stacker / reclaimer in 2012 is:

$$P(f_{\text{stacker/reclaimers}}) = \frac{24828.25}{2170739} = 0.0114 = 1.14\% \quad (5)$$

This probability represents the level of unability of equipment (stacker/reclaimers) to support the power plant in achieving the target.

After the probability of equipment (root variable/ descendent variable) is determined, then the probability of antecedent like boiler area, balance of plant area, steam turbine area, generator area etc is obtained deterministically, which is by assume when one of the root variable/ descendent variable failed, then the descendent variable also failed. Finally, the probability of energy losses is obtained by following formula:

$$P(f_{\text{energy losses}}) = \frac{Frequency\ of\ antecedent\ variable}{Total\ event} \quad (6)$$

The structure of the model then is developed and completed by Genie 2.0. The complete database of the model can be seen in the table 1 as follows:

Table 1. Database of The Model

RCC	Equipment	Failure Probability (%)	Energy Losses (MWh)
01AA0030	Coal conveyors and feeders	0,59	12757,5
01AA0080	Stackers/reclaimers	1,14	24828,25
01BA0250	Pulverizer feeders	1,40	41982,25
01BA0260	Primary air fan	11,54	344971,1
01BA0262	Primary air fan lube oil system	0,33	9798,75
01BA0265	Primary air heater	13,05	283361,3
01BA0330	Pulverizer coal leak (pulverizers only)	0,03	1035,5
01D0800	Drums and drum internals (single drum)	0,25	5494
01F1060	First reheater	32,32	701678,6
01IA1421	Secondary air fans/blowers	1,08	32174,75
03B3211	Circulating water pump motors	9,47	283086,2
03E3412	Feedwater pump drive - steam turbine	6,44	139757,8
03E3413	Feedwater pump coupling and drive shaft	0,57	16985
03H3620	Main transformer	18,72	406433
03H3621	Unit auxiliaries transformer	2,04	60977,25
03H3661	4000-7000-volt circuit breakers	3,90	116460,5
05C4610	Hydrogen cooling systempiping and valves	0,42	12556,25
01AA0030	Coal conveyors and feeders	0,59	12757,5

Based on database above then model could be developed using Software Genie 2.0. The result of all equipment failure probabilities can be seen in figure 2 as follow:

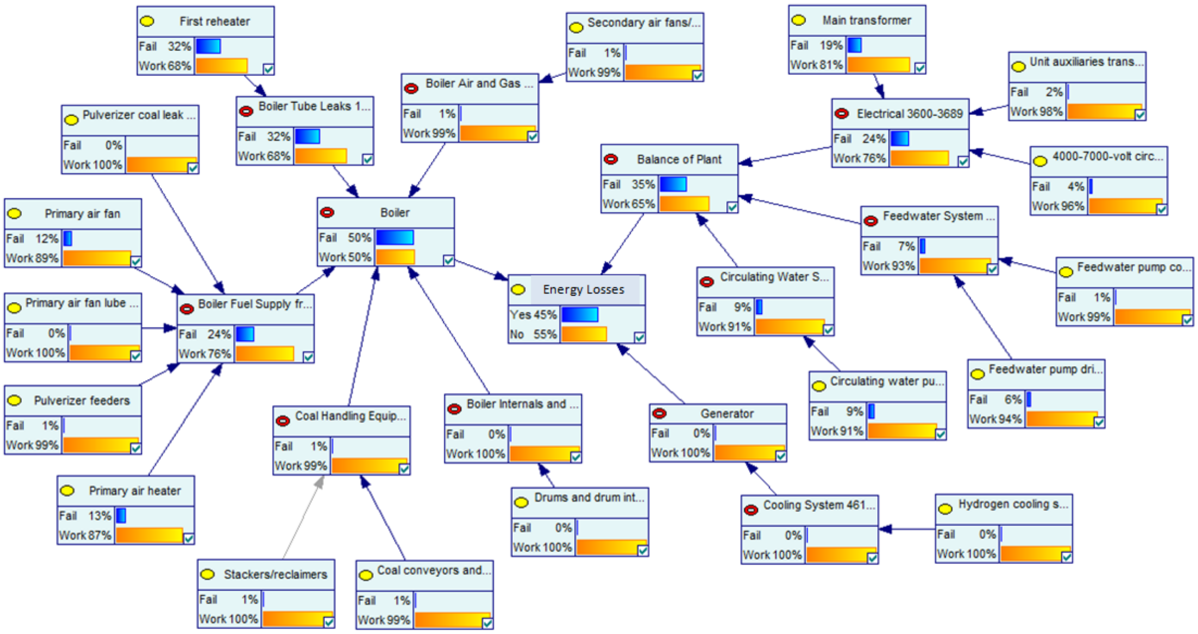
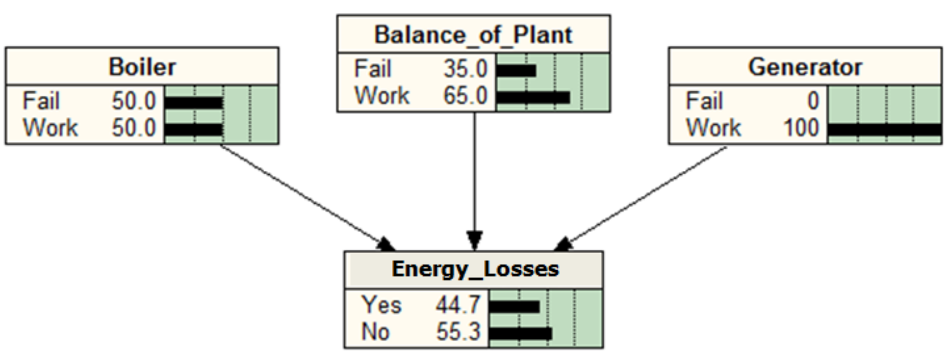


Figure 2. Bayesian Belief Network Model (Bar Chart)

From the figure above could be seen that energy losses probability in power plant is 45%. The next step to validate the model is by comparing model with actual energy losses. From the actual data, it is found that energy losses is 49,85% from the total energy targeted. Thus the validity of the model is about 90%. The validity of model depend on the number of interrelated variable and sufficiency of data.

3.2 Sensitivity Analysis

As discussed before, sensitivity analysis is used to know which equipment that has the most significance contribution to energy losses. Software Netica is used to solve this analysis. The result of sensitivity analysis using software Netica could be seen in following figure:



Node	Mutual Info

Energy_Losses	0.99187
Boiler	0.40562
Balance -of_Plant	0.05558
Generator	0.00000

Figure 3. Sensitivity Analysis

Figure above shows that boiler is the most significance cause of energy losses due to have the highest value of mutual info. Based on database, the variable which the most sensitive in boiler area is first re heater. When asset operator could decrease the failure probability of first re heater then the energy losses would be less

3.3 Scenarios For Optimization

In order to complete the scenarios, only equipment(s) which has sensitive cause that would be improved, while the other equipment(s) that has no sensitive cause is assumed have the same performance with the existing condition. Using software Genie 2.0, the Bayesian Belief Network model could be solved like following table:

Table 2. Optimization Power Plant Based on 2 Scenarios

Equipment	**EAF 26.66%**		**NERC 81.93%**		**EAF 97%**	
	CP1)	**EL2)**	**S13)**	**EL**	**S24)**	**EL**
Primary air fan lube oil system	0.3	9798.8	0.15	4483.3	0.12	3586.6
Primary air heater	13.0	283361.3	6.60	143268.8	5.11	110925
First reheater	32.3	701678.6	16.4	356001.2	12.6	273079
Circulating water pump motors	9.4	283086.2	6.60	197262.9	6.13	183215
Feedwater pump drive - steam turbine	6.4	139757.8	4.70	102024.7	4.36	94644.2

1) CP = Current Failure Probability (%)
2) EL = Energy Losses (MWh)
3) Failure Probability in Scenario 1 (%)
4) Failure Probability in Scenario 2 (%)

3.4 Benefit Analysis

Benefit analysis is conducted based on previous 2 scenarios above. The column of simulation, production cost and benefit is obtained by formula (1), (2) and (3). Assume rate 1USD = 13,000 IDR, Thus the result of the benefit could be seen in the following table:

Table 3. Benefit Analysis Based on 2 Scenarios

Scenario	**ΔEnergy Losses (kWh)**	**Simulation (Million USD)**	**Cost of Sales (Million USD)**	**Benefit (Million USD)**
NERC 81,93%	719.342.067	5189	5309	120
EAF 97%	882.330.622	5162	5309	147

The table 3 above concludes that potential benefit which can be earned in scenario 1 is 120 Million USD and 147 Million USD for scenario 2.

4. Conclusion

In this paper, the process for diagnose the main cause of energy losses using the method of Bayesian Belief Network is presented, the method of developing Bayesian Belief Network is proposed and software Genie 2.0 could perform faster to solve the problem. The result indicates that this method is feasible and valid for diagnosing energy losses in coal fired power plant.

The shortcoming of this study is the data sufficiency. There is sufficient data in descendent variable level, but there is a lack of data in ascendant level. Thus the calculation of ascendant probability deterministically would less the validity of result. However in this specific case, the number of ascendant variable is less, so the validity is relatively high.

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Biography

Muhamad Iqbal Felani was born on April 16th,1986 in Temanggung, Central Java, Indonesia. He received his B.Eng degree in Mechanical Engineering from University of Gadjah Mada, Yogyakarta in 2008. He also received M.Eng degree in Electrical Engineering from Institute of Technology Bandung, Bandung in 2011. Now he is as researcher in Research Institute of PLN Indonesia. He conduct the research in reliability, risk management and optimization.

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