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Linear programming for electrical energy generation power plant: An economic optimization approach

*Programación lineal para la central eléctrica de generación de energía:
Un enfoque de optimización económica*

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ABSTRACT

This paper studies how to determine a combined path of an optimum electricity production activity using the Linear Programming method. According to Linear Programming, an optimum generation pattern is influenced by the demand factor, production capacity, raw material stock, operational cost, and efficiency of every unit. With an optimum combination of those aspects, the need for raw materials for each operating unit will be found out; therefore, a continuous and steady supply of raw materials can be maintained, and eventually, an optimum electrical energy-generating process finally results.

Keywords: Electricity production, linear programming, optimum generation, POM software

RESUMEN

Este documento estudia cómo determinar una ruta combinada de una actividad de producción de electricidad óptima utilizando el método de programación lineal. Según la programación lineal, un patrón de generación óptimo está influenciado por el factor de demanda, la capacidad de producción, el stock de materia prima, el costo operativo y la eficiencia de cada unidad. Con una combinación óptima de esos aspectos, se descubrirá la necesidad de materias primas para cada unidad operativa; por lo tanto, se puede mantener un suministro continuo y constante de materias primas, y finalmente resulta un proceso óptimo de generación de energía eléctrica.

Palabras clave: Producción de electricidad, generación óptima, programación lineal, software POM.

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INTRODUCTION

Electricity is a form of energy closely related to the growth of the industry as one important sector influencing a country's economic growth. PT. KDLC is one of several companies in Indonesia dealing with electricity production. An optimum and efficient electrical energy production plays a crucial role to improve company performance to boost the country's economic growth. Therefore, economic optimization can be used to solve problems of allocating limited resources optimally (Donate et al.: 2013, pp. 11-20). Apart from that, human abilities to consider all possibilities to make a decision and action with simple qualitative estimation, generally apply only to simple decisions (Benkachcha: 2015; Ahmad & Ahmad, 2019). Before the best solution to a complex problem - as found in the process of electricity generation - is determined, the first step to be done is to study and understand in detail the interconnection patterns between factors that cause the problem to appear, qualitatively and quantitatively (measurable) (Adhikari & Agrawal: 2013; Akintola et al.: 2011, pp. 467-476). The problem might be worse to see the fact whereas limited resources are used inefficiently (or below capacity). In such a condition, systematic planning models are required to overcome the problems (Bagheri et al.: 2014, pp. 151-157). One of the models that can be used mathematically to solve problems of allocating limited resources optimally is Linear Programming in Operations Research; while for the calculation, POM software is utilized.

METHODS

The problem that will be analyzed in this paper is the problem of electrical energy generation at PT. KDLC. The method used is Linear Programming, considered to be the best method to solve problems that will be analyzed. Hence, variables of problem characteristics of electricity generation need to be identified. Further, based on those variables, a relevant mathematical Linear Programming model is determined.

Variable and parameter of electricity generation

In this part of the paper, the general variable and parameter related to the characteristics of electricity generation at PT. KDLC is identified. The variable and parameter include (Liu et al.: 2014, pp. 327-331):

i_1, i_2, \dots, i_5 represents unit Boiler 1 - 5

j_1, j_2, \dots, j_5 represents unit Turbine 1 - 5

b_1 refers to the cost spent for the use of gas fuel in rupiahs per MMSCFD

b_2 refers to the cost spent on the use of oil fuel in rupiahs per kiloliter

k represents the need of water converted from the demand of X MW of electricity

r_1 refers to the stock capacity of gas fuel

r_2 refers to the stock capacity of oil fuel

r_{12} represents the maximum amount of gas fuel and oil fuel

Z_1 represents the amount of gas fuel usage to convert k water demand to Y a metric ton of steam

Z_2 represents the amount of oil fuel usage to convert k water demand to Y a metric ton of steam

l_1 refers to the amount of water required to produce 3 MW electricity with one MMSCFD gas fuel

l_2 refers to the amount of water required to produce 3 MW electricity with one kiloliter oil fuel

c_{1i} represent the cost spent in rupiahs for the use of the unit i with gas fuel

c_{2i} represent the cost spent in rupiahs for the use of the unit i with oil fuel

Y_{li} refer to the amount of steam per ton produced by a unit i with gas fuel

Y_{2i} refer to the amount of steam per ton produced by a unit i with oil fuel

m_i represents the maximum capacity of steam production in the unit i

n_{1i} is the amount of gas per MMSCFD required for the combustion process in the unit i to produce one metric ton of steam
 n_{2i} is the amount of oil per kiloliter required for the combustion process in the unit i to produce one metric ton of steam
 a_i is the amount of water per MC required to produce one metric ton of steam
 d_{ij} is the cost per rupiah spent to operate unit i to unit j
 X_{ij} refer to the amount of electricity per MW produced from the unit j by using steam from unit i
 Y_{12i} refer to the amount of steam per ton from the sum-up of steam amount resulted from gas and oil fuel combustion process of unit i
 p_j refers to the maximum capacity of electricity production in the unit j
 q_j is the amount of steam per metric ton resulted to produce one MW electricity in unit j

THE SCHEMA OF ELECTRICAL ENERGY GENERATION

Hereunder is the general schema of the electrical energy generation at PT. KDLC:

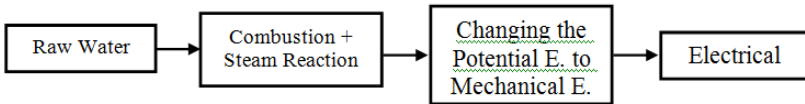


Figure 1. Process of Electrical Energy Generation.

From the above schema, it can be further explained that *demineralized water* put in the *domain water tank* is pumped into the feed water tank. From this tank, the water is pumped with the pressure of 150 bars to the Boiler at the temperature of 145° C. There are combustion and steam reaction in the boiler. The steam produced in the Boiler is further used to change the potential energy into mechanical energy. Thus, it can run the Turbine at the pressure of +0,1 bar producing electrical energy up to 80 MW for every unit. For a clearer picture, it is shown below the production line of electrical energy generation at PT. KDLC with several production steps:

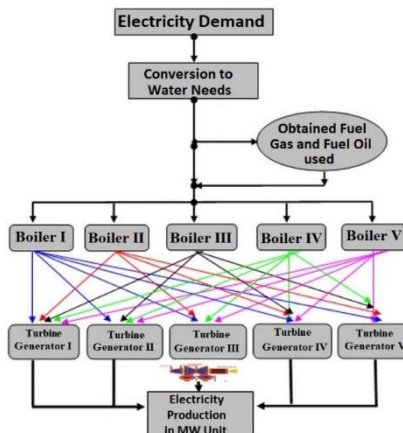


Figure 2. Production Line of Electrical Energy Generation at PT. KDLC.

As can be seen in Figure 2, regards to the production line of electrical energy generation shown above, there are three steps conducted in this research (i) To find out an optimum combination of gas and oil fuel consumption. (ii) To find out a combination of an optimum steam production activity from Boiler using gas and oil fuel and (iii) To find out a combination of an optimum electricity production activity of each turbine.

MATHEMATICAL MODEL

From Figure 2 above, it can be seen that in this electrical energy generation process, there are fourteen interconnected nodes (14 areas). The important aspect of this model is the presentation of a choice whether using a Boiler unit or Turbine Generator in the production activity as it is influenced by the readiness of a unit to operate; while such condition is related to the efficiency (Khashei & Bijari: 2010, pp. 479-489). With the above mentioned three steps that will be conducted, and available variable and parameter, a mathematical model can be derived. The mathematical model that will be applied in this paper is a *Linear Programming* mathematical model (Liu et al.: 2014, pp. 327-331; Efremenko et al.: 2019, pp. 138-147). Factors influencing the problems of electricity generation, in general, are related to the operational cost for the usage of every different unit, maximum operation capacity, raw material and fuel stock, the maximum capacity of steam production of every Boiler, and the maximum electricity produced by the Turbine Generator (Dudek: 2015, pp. 839-846). The generation process is influenced by the efficiency of every unit, as well, by assuming efficiency in the cost. Thus, the higher the efficiency the Boiler and Turbine Generator is, the less the cost to spend; and vice versa. The following is a further explanation of every step mentioned above (Akintola et al.: 2011, pp. 467-476; Husnutdinov et al.: 2019, pp. 41-50). The first step is to find out a combination of gas and oil fuel usage. It will be called Step I. In Step I, the influencing factors, among others, are the cost of gas fuel usage in MMSCFD and oil fuel usage in kiloliter, need of water, stock availability of each fuel, and the maximum capacity of the total amount of the two fuels (Liu et al.: 2014, pp. 327-331). Below is the data table of Step I.

Table 1. Step I Data Table.

Z_1	Z_2	
l_1	l_2	$= k$
1	0	$\leq r_1$
0	1	$\leq r_2$
1	1	$\leq r_{12}$
b_1	b_2	

From Table 1, the following *Linear Programming* model can be formed (Liu et al.: 2014, pp. 327-331):

To minimize: $b_1Z_1 + b_2Z_2$ (1)

Subject to: $l_1Z_1 + l_2Z_2 = k$ (2)

$Z_1 \leq r_1$

$Z_2 \leq r_2$

$Z_1 + Z_2 \leq r_{12}$

$Z_1, Z_2 \geq 0$

The second step is to find out the combination of an optimum steam production activity from the Boiler unit using gas fuel and oil fuel (Khashei & Bijari: 2010, pp. 479-489). This step will be further called Step II. The influencing factors in Step II are: efficiency of every Boiler unit assumed as cost, the requirement of fuel and water that has been pre-identified – for Step II it is changed into stock factor; and maximum steam production capacity of every Boiler unit. A Vector of each factor above with variable and parameter explained previously shall be derived in the following.

There are ten components of cost factor with the following vector:

$$c = (c_{11}, c_{12}, c_{13}, c_{14}, c_{15}, c_{21}, c_{22}, c_{23}, c_{24}, c_{25}) \quad (3)$$

There are ten components for steam production activity of Boiler unit having the following vector (Crone et al.: 2011, pp. 635-660):

$$Y = (Y_{11}, Y_{12}, Y_{13}, Y_{14}, Y_{15}, Y_{21}, Y_{22}, Y_{23}, Y_{24}, Y_{25}) \quad (4)$$

The factor component related to capacity and stock is Z_1, Z_2 the fuel stock, k which is for water stock, while m_1, m_2, m_3, m_4, m_5 are the maximum steam production capacity of each Boiler unit. From the components mentioned above, one vector F is derived:

$$F = (Z_1, Z_2, k, m_1, m_2, m_3, m_4, m_5) \quad (5)$$

Since Step II results in steam per metric ton, a conversion related to the stock of fuel and water is required (Kumar & Jha: 2013, pp. 19-25). Producing one metric ton of steam will require n_{1i} MMSCFD gas fuel with its vector $n_{11}, n_{12}, n_{13}, n_{14}, n_{15}$, or n_{2i} kiloliter oil fuel with its vector $n_{21}, n_{22}, n_{23}, n_{24}, n_{25}$, or a MC water. Below is the data table formed from each above factor:

Table 2. Step II Data Table.

Y ₁₁	Y ₁₂	Y ₁₃	Y ₁₄	Y ₁₅	Y ₂₁	Y ₂₂	Y ₂₃	Y ₂₄	Y ₂₅	
n ₁₁	n ₁₂	n ₁₃	n ₁₄	n ₁₅	0	0	0	0	0	=
0	0	0	0	0	n ₂₁	n ₂₂	n ₂₃	n ₂₄	n ₂₅	=
a	A	a	a	a	a	a	a	a	a	≤ k
1	0	0	0	0	1	0	0	0	0	≤
0	1	0	0	0	0	1	0	0	0	≤
0	0	1	0	0	0	0	1	0	0	≤
0	0	0	1	0	0	0	0	1	0	≤
0	0	0	0	1	0	0	0	0	1	≤
c ₁₁	c ₁₂	c ₁₃	c ₁₄	c ₁₅	c ₂₁	c ₂₂	c ₂₃	c ₂₄	c ₂₅	m ₅

From the data Table, 2 above the following *linear programming* model can be formed (BIRÄU: 2014)

To minimize:

$$(c_{11}Y_{11} + c_{12}Y_{12} + c_{13}Y_{13} + c_{14}Y_{14} + c_{15}Y_{15} + c_{21}Y_{21} + c_{22}Y_{22} + c_{23}Y_{23} + c_{24}Y_{24} + c_{25}Y_{25}) \quad (6)$$

Subject to:

$$\begin{aligned}
 n_{11}Y_{11} + n_{12}Y_{12} + n_{13}Y_{13} + n_{14}Y_{14} + n_{15}Y_{15} &= Z_1 \\
 n_{21}Y_{21} + n_{22}Y_{22} + n_{23}Y_{23} + n_{24}Y_{24} + n_{25}Y_{25} &= Z_2 \\
 aY_{11} + aY_{12} + aY_{13} + aY_{14} + aY_{15} + aY_{21} + aY_{22} + aY_{23} + aY_{24} + aY_{25} &\leq k \\
 Y_{11} + Y_{21} &\leq m_1 \\
 Y_{12} + Y_{22} &\leq m_2 \\
 Y_{13} + Y_{23} &\leq m_3 \\
 Y_{14} + Y_{24} &\leq m_4 \\
 Y_{15} + Y_{25} &\leq m_5
 \end{aligned}$$

$$\begin{aligned} Y_{11}, Y_{12}, Y_{13}, Y_{14}, Y_{15} &\geq 0 \\ Y_{21}, Y_{22}, Y_{23}, Y_{24}, Y_{25} &\geq 0 \end{aligned} \quad (7)$$

The last step of the production line studied in this research is to find out the combination of an optimum electricity production activity of each Turbine. This step is further called Step III. The influencing factors, among others, are: turbine readiness efficiency to operate - assumed as a cost; steam production from Boiler that has been identified from Step II changed into a stock factor in Step III, and maximum electricity production capacity of each turbine unit. The following is the vector formed from each factor mentioned above with variable and parameter explained previously (Akintola et al.: 2011, pp. 467-476).

There are twenty-five efficiency components assumed as the cost with the following vector:

$$d_{ij} = (d_{11}, d_{12}, d_{13}, d_{14}, d_{15}, d_{21}, d_{22}, d_{23}, d_{24}, d_{25}, d_{31}, d_{32}, d_{33}, d_{34}, d_{35}, d_{41}, d_{42}, d_{43}, d_{44}, d_{45}, d_{51}, d_{52}, d_{53}, d_{54}, d_{55}) \quad (8)$$

Factor components related to capacity and stock are: $Y_{121}, Y_{122}, Y_{123}, Y_{124}, Y_{125}$ as steam stock, and p_1, p_2, p_3, p_4, p_5 as the maximum electricity production capacity of each Turbine unit. From capacity and stock factors above, one vector V can be formed:

$$V = (Y_{121}, Y_{122}, Y_{123}, Y_{124}, Y_{125}, p_1, p_2, p_3, p_4, p_5) \quad (9)$$

There are twenty-five components for electricity production activity of each turbine unit having the following vector:

$$X_{ij} = (X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{21}, X_{22}, X_{23}, X_{24}, X_{25}, X_{31}, X_{32}, X_{33}, X_{34}, X_{35}, X_{41}, X_{42}, X_{43}, X_{44}, X_{45}, X_{51}, X_{52}, X_{53}, X_{54}, X_{55}) \quad (10)$$

Since Step II produces electricity in MW, there must be a conversion done related to the stock of steam, in which producing one MW of electricity requires q_j a metric ton of steam with its vector q_1, q_2, q_3, q_4, q_5 . With the variable and parameter defined above, the model for this step can be formed into a data table. From the data Table 2 can further be derived from a *linear programming* model as under (Adhikari & Agrawal: 2013):

$$\begin{aligned} \text{To minimize: } & (d_{11} X_{11} + d_{12} X_{12} + d_{13} X_{13} + d_{14} X_{14} + d_{15} X_{15} + d_{21} X_{21} + d_{22} X_{22} + d_{23} X_{23} + d_{24} X_{24} + \\ & d_{25} X_{25} + d_{31} X_{31} + d_{32} X_{32} + d_{33} X_{33} + d_{34} X_{34} + d_{35} X_{35} + d_{41} X_{41} + d_{42} X_{42} + d_{43} X_{43} + d_{44} X_{44} + \\ & d_{45} X_{45} + d_{51} X_{51} + d_{52} X_{52} + d_{53} X_{53} + d_{54} X_{54} + d_{55} X_{55}) \quad (11) \end{aligned}$$

$$\text{Subject to: } q_1 X_{11} + q_1 X_{12} + q_1 X_{13} + q_1 X_{14} + q_1 X_{15} = Y_{121}$$

$$q_2 X_{21} + q_2 X_{22} + q_2 X_{23} + q_2 X_{24} + q_2 X_{25} = Y_{122}$$

$$q_3 X_{31} + q_3 X_{32} + q_3 X_{33} + q_3 X_{34} + q_3 X_{35} = Y_{123}$$

$$q_4 X_{41} + q_4 X_{42} + q_4 X_{43} + q_4 X_{44} + q_4 X_{45} = Y_{124}$$

$$\begin{aligned}
 q_5 X_{51} + q_5 X_{52} + q_5 X_{53} + q_5 X_{54} + q_5 X_{55} &= Y_{125} \\
 X_{11} + X_{21} + X_{31} + X_{41} + X_{51} &\leq p_1 \\
 X_{12} + X_{22} + X_{32} + X_{42} + X_{52} &\leq p_2 \\
 X_{13} + X_{23} + X_{33} + X_{43} + X_{53} &\leq p_3 \\
 X_{14} + X_{24} + X_{34} + X_{44} + X_{54} &\leq p_4 \\
 X_{15} + X_{25} + X_{35} + X_{45} + X_{55} &\leq p_5 \\
 X_{11}, X_{12}, X_{13}, X_{14}, X_{15} &\geq 0 \\
 X_{21}, X_{22}, X_{23}, X_{24}, X_{25} &\geq 0 \\
 X_{31}, X_{32}, X_{33}, X_{34}, X_{35} &\geq 0 \\
 X_{41}, X_{42}, X_{43}, X_{44}, X_{45} &\geq 0 \\
 X_{51}, X_{52}, X_{53}, X_{54}, X_{55} &\geq 0
 \end{aligned} \tag{12}$$

From the mathematical models of the three steps above, an optimum solution is obtained by first inputting available data according to their variable and parameter (Richard et al.: 2014, pp. 60-64).

RESULTS

Data management

This part of the paper will discuss data management of all the data obtained with the assumption that the data in the following period remains the same (Benkachcha: 2015). However, if there are some changes in the data, they need to be reanalyzed. Based on on-demand data, the total electricity demand was 4,080,000 kWh. Since the model that will be formed needs electricity demand in MW, electricity demand, therefore, needs to be converted into MW first:

$$KW = \frac{KWH}{24} \tag{13}$$

$$MW = \frac{KW}{1000} \tag{14}$$

From equation (3.1) and (3.2) the following is obtained:

$$\begin{aligned}
 \frac{4,080,000 \text{ KWH}}{24} &= 170,000 \text{ KW} \\
 \frac{170,000 \text{ KW}}{1000} &= 170 \text{ MW}
 \end{aligned} \tag{15}$$

Thus, from (3.3) it is found out that electricity demand received by PT. KDLC in MW is 170 MW.

Based on the data of electricity production and raw-water consumption, it is known that the total electricity production of all generators is 170 MW, and the consumption of raw-water is as much as 1,333 MC. Therefore, the conversion to obtain the amount of water required to produce one MW of electricity is:

$$\frac{1,333 \text{ MC}}{170 \text{ MW}} = 7.841 \text{ MC/MW} \tag{16}$$

Equation (3.4) shows it would need as much as 1,332.97 MC of water to produce 170 MW of electricity. It is known that one kiloliter of oil fuel or 1 MMSCFD of gas fuel can produce 3 MW of electricity. Thus, conversion of water use for one kiloliter of oil fuel or 1 MMSCFD of gas fuel can be obtained as under:

$$\frac{\text{Electricity demand}}{3} = \frac{\text{Water need}}{X} \frac{170}{3} = \frac{1,332.97}{X} \quad (17)$$

Hence, it is obtained $X = 23.523$ MC of water/ one unit of fuel measurement

Based on the production capacity data, it is known that the maximum electricity production capacity of all Turbine Generator units is 400 MW. Therefore, the maximum amount of oil fuel and gas fuel is obtained as under:

$$\frac{400\text{MW}}{3} = 133.333$$

For the cost of fuel consumption, it is assumed that the price of oil fuel is IDR 2,600,000.00 per kiloliter. Based on stock data and electricity tariff, the following can be derived:

$$\frac{1,250}{325} = \frac{2,600,000}{Y} \quad (18)$$

It results in $Y = 676,000$. Thus the cost of gas fuel consumption is as much as IDR 676,000.00 per MMSCFD. From the efficiency data of the Boiler unit and Turbine Generator, it is found out that each Boiler unit has different efficiency. Such condition is closely related to the choice of Boiler unit in the production process. The choice is very much influenced by the readiness of a unit to operate. Efficiency is assumed as the operational cost of the unit used to produce one metric ton of steam. The higher the efficiency is, the less the cost to spend; and vice versa. The conversion can be obtained with the following calculation:

$$\text{The cost of using gas fuel /MMSCFD} = \left[\text{IDR } 100,000.00 - \left(\frac{\text{Efficiency}}{100} \right) \times \text{IDR } 100,000.00 \right] \times \frac{100}{91.7} \quad (19)$$

$$\text{The cost of using oil fuel /kiloliter} = \left[\text{IDR } 100,000.00 - \left(\frac{\text{Efficiency}}{100} \right) \times \text{IDR } 100,000.00 \right] \times \frac{100}{92.2} \quad (20)$$

Numeral 100,000.00 above has been chosen with an assumption that if a unit has zero (0) efficiency, the operational cost is IDR 100,000.00. From the equation above, a vector of Boiler unit usage cost with different fuels can be formed as a cost vector in rupiahs as under:

$$C = \left(109051.3, 18538.72, 13086.16, 109051.3, 18538.72, 108459.9, \right. \\ \left. 18438.18, 13015.19, 108459.9, 18438.18 \right) \quad (21)$$

Related to the monthly average steam production data, a conversion can be derived to find out the amount of fuel required for the combustion process to produce one metric ton of steam as the following:

$$\frac{\text{Total steam production}}{\text{Total electricity production}} = \frac{763\text{ton}}{170\text{MW}} = 4.488\text{ton/MW} \quad (22)$$

From equation (3.10) it is obtained that it will require 4.488 metric tons of steam to produce 1 MW of electricity. Since it has been identified that 1 MMSCFD of gas fuel or 1 kiloliter of oil fuel can produce 3 MW of electricity, therefore:

$$\frac{1}{3 \times 4.488} = 0.074 \quad (23)$$

Equation (3.11) above shows that 0.074 of the fuel measurement unit will be required to produce one metric ton of steam. From equation (3.5) and (3.11), the following will determine the conversion to find out the water required to produce one metric ton of steam:

$$23.523 \times 0.074 = 1.740 \text{ MC Water/metric ton steam} \quad (24)$$

Since efficiency data of each Turbine Generator unit available at the efficiency data of Boiler and Turbine unit, the conversion for the operational cost of the unit used to produce one MW of electricity can be made with the following calculation:

$$\text{Cost} = \text{IDR } 1,000,000.00 - \left(\frac{\text{Efficiency}}{100} \times \text{IDR } 1,000,000.00 \right) \quad (25)$$

Numeral 1,000,000 above has been chosen with an assumption that if a Turbine Generator unit has 0 efficiencies, the operational cost is as much as IDR 1,000,000.00. Therefore, from equation (25) the following cost vector can be formed:

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For the cost of fuel consumption, it is assumed that the price of oil fuel is IDR 2,600,000.00 per kiloliter. Based on stock data and electricity tariff, the following can be derived:

$$\frac{1,250}{325} = \frac{2,600,000}{Y} \quad (18)$$

It results in $Y = 676,000$. Thus the cost of gas fuel consumption is as much as IDR 676,000.00 per MMSCFD. From the efficiency data of the Boiler unit and Turbine Generator, it is found out that each Boiler unit has different efficiency. Such condition is closely related to the choice of Boiler unit in the production process. The choice is very much influenced by the readiness of a unit to operate. Efficiency is assumed as the operational cost of the unit used to produce one metric ton of steam. The higher the efficiency is, the less the cost to spend; and vice versa. The conversion can be obtained with the following calculation:

$$\text{The cost of using gas fuel /MMSCFD} = \left[\text{IDR } 100,000.00 - \left(\frac{\text{Efficiency}}{100} \right) \times \text{IDR } 100,000.00 \right] \times \frac{100}{91.7} \quad (19)$$

$$\text{The cost of using oil fuel /kiloliter} = \left[\text{IDR } 100,000.00 - \left(\frac{\text{Efficiency}}{100} \right) \times \text{IDR } 100,000.00 \right] \times \frac{100}{92.2} \quad (20)$$

Numeral 100,000.00 above has been chosen with an assumption that if a unit has zero (0) efficiency, the operational cost is IDR 100,000.00. From the equation above, a vector of Boiler unit usage cost with different fuels can be formed as a cost vector in rupiahs as under:

$$C = \left(109051.3, 18538.72, 13086.16, 109051.3, 18538.72, 108459.9, \right. \\ \left. 18438.18, 13015.19, 108459.9, 18438.18 \right) \quad (21)$$

Related to the monthly average steam production data, a conversion can be derived to find out the amount of fuel required for the combustion process to produce one metric ton of steam as the following:

$$\frac{\text{Total steam production}}{\text{Total electricity production}} = \frac{763\text{ton}}{170\text{MW}} = 4.488\text{ton/MW} \quad (22)$$

From equation (3.10) it is obtained that it will require 4.488 metric tons of steam to produce 1 MW of electricity. Since it has been identified that 1 MMSCFD of gas fuel or 1 kiloliter of oil fuel can produce 3 MW of electricity, therefore:

$$\frac{1}{3 \times 4.488} = 0.074 \quad (23)$$

Equation (3.11) above shows that 0.074 of the fuel measurement unit will be required to produce one metric ton of steam. From equation (3.5) and (3.11), the following will determine the conversion to find out the water required to produce one metric ton of steam:

$$23.523 \times 0.074 = 1.740 \text{ MC Water/metric ton steam} \quad (24)$$

Since efficiency data of each Turbine Generator unit available at the efficiency data of Boiler and Turbine unit, the conversion for the operational cost of the unit used to produce one MW of electricity can be made with the following calculation:

$$\text{Cost} = \text{IDR } 1,000,000.00 - \left(\frac{\text{Efficiency}}{100} \times \text{IDR } 1,000,000.00 \right) \quad (25)$$

Numeral 1,000,000 above has been chosen with an assumption that if a Turbine Generator unit has 0 efficiencies, the operational cost is as much as IDR 1,000,000.00. Therefore, from equation (25) the following cost vector can be formed:

$$d_{ij} = \begin{pmatrix} 1000000,750000,750000,710000,1000000,1000000,750000,750000, \\ 710000,1000000,1000000,750000,750000,710000,1000000,1000000, \\ 750000,750000,710000,1000000,1000000,750000,750000,710000, \\ 1000000 \end{pmatrix} \quad (26)$$

Data analysis

As explained previously, within the production line to generate electrical energy, this research has made three steps of the process for an easier solution. The results of the three steps carried out are: As the need of raw-water is known as much as 1,332.97 MC converted from demand as much as 170 MW, therefore, the first step is to find out an optimum combination of gas and oil fuel usage. The following will explain the *Linear Programming* model for Step I whereas the data are taken from equation (13) until (18):

$$\begin{aligned} \text{To minimize:} & \quad 676000Z_1 + 2600000Z_2 & (27) \\ \text{Subject to:} & \quad 23.523Z_1 + 23.523Z_2 = 1332.97 \\ & \quad Z_1 \leq 132.083 \\ & \quad Z_2 \leq 1,25 \\ & \quad Z_1 + Z_2 \leq 133.333 \\ & \quad Z_1, Z_2 \geq 0 & (28) \end{aligned}$$

An optimum solution is obtained by inputting the mathematical model of equation (3.15) and limit function (3.16) above into the *linear programming software module* POM. From such data management it can be explained that the optimum combination of fuel consumption suggested by POM is 56,667 MMSCFD for gas fuel and 0 kiloliters for oil fuel; meanwhile, the total cost for fuel consumption is assume did 38,306,660.00. The result of Step I will be used in Step II that is to find out the combination of optimum steam production activity from the Boiler unit using gas fuel and oil fuel. The following explains the *Linear Programming* model for Step II whereas the data are taken from equation (3.7) until (3.13):

$$\text{To minimize:} \left(\begin{aligned} & 109051.3Y_{11} + 18538.72Y_{12} + 13086.16Y_{13} + 109051.3Y_{14} + \\ & +18538.72Y_{15} + 108459.9Y_{21} + 18438.18Y_{22} + 13015.19Y_{23} + \\ & +108459.9Y_{24} + 18438.18Y_{25} \end{aligned} \right) \quad (29)$$

By inputting the mathematical model of equation (28) and limit function (29) above into *linear programming software* module POM, an optimum solution results as shown in Table 3. This table indicates that the combination of an optimum steam production activity in a metric ton of each Boiler unit by using gas and oil fuel suggested by POM is as under:

Table 3. Steam Production of Each Boiler Unit.

Description	Steam Production of Each Boiler Unit in Metric Ton				
	I.	II.	III.	IV.	V.
Operation usind gas fuel	0	350	350	0	65.77
Operation usind oil fuel	0	0	0	0	0
Total production	0	350	350	0	65.77
Cost Assumption	IDR 12,288,000.00				

As can be seen in Table 3 the total productions are 350, 350 and 65.77 ton for steps II, III and V respectively. Also, the cost assumption is 12,288,000 IDR.

Step III of this model is to find out the combination of optimum electricity production activity of each Turbine Generator, using the raw-steam resulted from the combustion in the Boiler unit at Step II. The following explains the Linear Programming model for Step III in which the cost data come from equation (26):

$$\text{To minimize} = \left(\begin{array}{l} 1000000X_{11} + 750000X_{12} + 750000X_{13} + 710000X_{14} + \\ +1000000X_{15} + 1000000X_{21} + 750000X_{22} + 750000X_{23} + \\ +710000X_{24} + 1000000X_{25} + 1000000X_{31} + 750000X_{32} + \\ +750000X_{33} + 710000X_{34} + 1000000X_{35} + 1000000X_{41} + \\ +750000X_{42} + 750000X_{43} + 710000X_{44} + 1000000X_{45} + \\ +1000000X_{51} + 750000X_{52} + 750000X_{53} + 710000X_{54} + \\ +1000000X_{55} \end{array} \right) \quad (30)$$

$$\begin{aligned} \text{Subject to: } & 4.488X_{11} + 4.488X_{12} + 4.488X_{13} + 4.488X_{14} + 4.488X_{15} = 0 \\ & 4.488X_{21} + 4.488X_{22} + 4.488X_{23} + 4.488X_{24} + 4.488X_{25} = 350 \\ & 4.488X_{31} + 4.488X_{32} + 4.488X_{33} + 4.488X_{34} + 4.488X_{35} = 350 \\ & 4.488X_{41} + 4.488X_{42} + 4.488X_{43} + 4.488X_{44} + 4.488X_{45} = 0 \\ & 4.488X_{51} + 4.488X_{52} + 4.488X_{53} + 4.488X_{54} + 4.488X_{55} = 65.77 \end{aligned}$$

$$\begin{aligned} X_{11} + X_{21} + X_{31} + X_{41} + X_{51} & \leq 80 \\ X_{12} + X_{22} + X_{32} + X_{42} + X_{52} & \leq 80 \\ X_{13} + X_{23} + X_{33} + X_{43} + X_{53} & \leq 80 \\ X_{14} + X_{24} + X_{34} + X_{44} + X_{54} & \leq 80 \\ X_{15} + X_{25} + X_{35} + X_{45} + X_{55} & \leq 80 \\ X_{11}, X_{12}, X_{13}, X_{14}, X_{15} & \geq 0 \\ X_{21}, X_{22}, X_{23}, X_{24}, X_{25} & \geq 0 \\ X_{31}, X_{32}, X_{33}, X_{34}, X_{35} & \geq 0 \\ X_{41}, X_{42}, X_{43}, X_{44}, X_{45} & \geq 0 \\ X_{51}, X_{52}, X_{53}, X_{54}, X_{55} & \geq 0 \end{aligned} \quad (31)$$

An optimum solution to Step III is obtained by inputting the mathematical model of equation (30) and limit function (3.20) above into *linear programming software* module POM. Based on POM, the combination of an optimum electricity production activity in MW of each Turbine Generator can be seen in Table 4 below:

Table 4. Electricity Production of Turbine Unit from Steam Produced by Each Boiler Unit.

Turbine Unit Boiler Unit	I.	II.	III.	IV.	V.
I.	0	0	0	0	0
II.	0	2.014	10.626	65.345	0
III.	0	77.986	0	0	0
IV.	0	0	0	0	0
V.	0	0	0	14.655	0
Total Electricity Production	0	80	10.626	80	0
Cost Assumption	IDR 124,769,600.00				

As can be seen in Table 4 the total Electricity productions are 80, 10.626 and 80 for steps II, III and IV respectively. Also, the cost assumption is 124,769,600 IDR.

From the data above, it can be determined that the need for raw material for each operating unit is, among others, as under:

1) Water and fuel need for each Boiler unit can be calculated using the following equation :

2)

$$\text{Water need} = \text{Steam Production} \times 1.74 \tag{32}$$

$$\text{Fuel need} = \text{Steam Production} \times 0.074 \tag{33}$$

Numeral 1.74 and 0.074 above result from the conversion of equation (23) and (24).

3) The need of steam for each Turbine Generator unit can be determined using the following equation:

$$\text{Steam need} = \text{Electricity production} \times 4.488 \tag{34}$$

Numeral 4.488 above is obtained from the conversion of equation (22).

From equation (33) until (34), it can be identified that the need for raw material for each unit can be seen in the following table:

Table 5. The Need for Raw Material for Each Boiler Unit.

Boiler Unit	The Need for Raw Material			
	Raw Water W/Gas Fuel	Raw Water W/Oil Fuel	Gas Fuel	Oil Fuel
I.	-	-	-	-
II.	609 MC	-	25.9 MMSCFD	-
III.	609 MC	-	25.9 MMSCFD	-
IV.	-	-	-	-
V.	114.44 MC	-	4.867 MMSCFD	-

As it can be seen in Table 5 the needs for raw water are 609, 609 and 114.44 MC for boiler unit II, III and V respectively. Also, needs for gas fuel are 25.9, 25.9 and 4.867 MMSCFD for boiler units II, III, and V respectively. The following schema (Figure 3) provides a better picture of an optimum generation path based on POM and the above data:

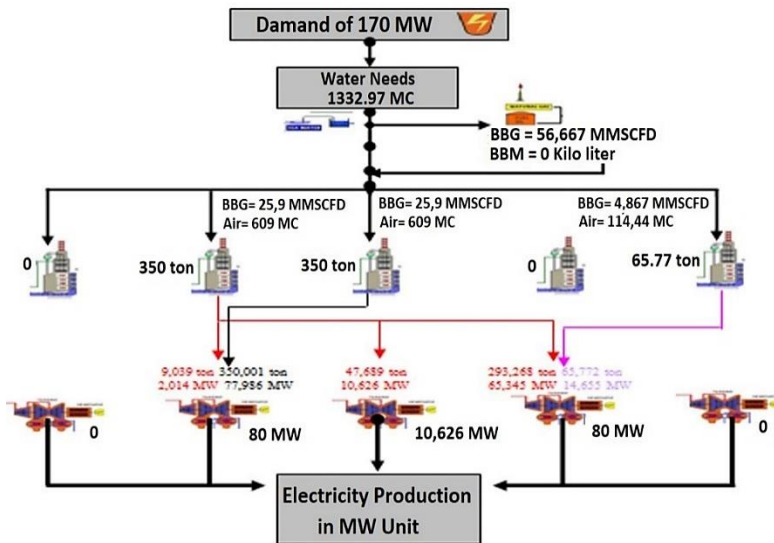


Figure 3. Electrical Energy Generation Optimum Path at PT. KDCL in a Linear Programming Model.

DISCUSSION

The data analyzed in this research were monthly average data, collected from PT. KDLC. Those included data of electricity demand, maximum operation capacity, raw material, and fuel stock, the maximum steam production capacity of each Boiler, the maximum capacity of the electricity produced by Turbine Generator, the mechanism of electrical energy generation done by PT. KDLC, as well as efficiency in every Boiler unit and Turbine Generator, assumed as cost.

This paper has applied a Linear Programming Model for the economic optimization of electrical energy generation at PT. KDLC. The discussion is closely related to the choice of Boiler unit operated in a production process that is influenced by the unit ready to operate. Efficiency is assumed as unit usage operational cost to produce one metric ton of steam

CONCLUSION

There are twenty-five efficiency components considered as cost factors. Based on cost factors, the combination of an optimum electricity production activity of each Turbine Generator, with Raw Steam, is further found out. According to data management using POM, the combination of an optimum electricity production activity in MW of each Turbine Generator can be seen in Table 4. Further, from the analysis, it is recognized that factors influencing the generation process at PT. KDLC is, among others: the demand factor, production capacity, the stock of raw water and fuel, operational cost, and efficiency of every unit. Based on the final result of this generation model, the need for raw material for each operating unit can be determined to maintain the supply of raw material and eventually to obtain an optimum electrical energy generation.

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