Natural Gas Network Design using Superstructure Method in East Java Indonesia

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Abstract. East Java is one of the provinces in Indonesia which has total natural gas reserves of 4.66 trillion standard cubic feet (TSCF) spread across several locations. Natural gas in this province is used by a variety of consumers, such as petrochemical industries, power plants, industrial fuel, transportation and household needs. However, there are obstacles in the utilization of natural gas due to differences in operating time and differences capacity between suppliers and consumers. Therefore, to optimize the utilization of natural gas in East Java, a natural gas network design is required which is considering the operating time and the capacity of suppliers (source point) and consumers (sinks point). In this study, a natural gas network design of East Java area was developed by modelling superstructure methods which consider the operating time and capacity. The superstructure natural gas network model developed in this study was optimized using GAMS software. From 5 source points and 6 sink points, an optimum natural gas network design has been obtained with a total gas distribution of 4,832.8 billion standard cubic feet (BSCF) in a period of 30 years. Due to mismatch of operating time, it is also known that the amount of excess gas supply from this area (export gas) is 1,364.1 BSCF and the demand for gas supply from other areas (import gas) is 1,105.7 BSCF. With this superstructure method, it is possible to know the optimum network configuration and the natural gas balance in an area which has different operating time, flowrate and capacity between sources and sinks.

1. Introduction
Indonesia has large natural gas reserve of 135.55 trillion standard cubic feet (TSCF) which are spread over several regions. Especially in East Java region, it has natural gas reserve of 4.66 TSCF and predicted still be available for the next 30 years [1]. The large availability of natural gas in this region is spread over several locations with different capacities, flow rates and time operations. Natural gas in this province is used by a variety of consumers, such as petrochemical industries, power plants, industrial fuel, transportation and household needs [1]. However, there are obstacles in the utilization of natural gas due to differences in operating time and differences capacity between suppliers and consumers. Therefore, to optimize the utilization of natural gas in East Java, a natural gas network design is required which is considering the operating time and the capacity of gas suppliers (source point) and consumers (sinks point).

Several studies are discussing about the natural gas network design and optimization. Anugraha et al (2020) [2] were developed a systematical method to design a natural gas network system in a single region using pinch analysis and introduced the heuristics of natural gas pairing between source and sink streams in a grid diagram based on the cascade natural gas calculation. Su et al (2019) [3] were developed
a multi-objective optimization methods for natural gas pipeline networks by considering trade-off reliability and power demand in the systems to obtain the minimum gas supply shortage risk and minimum power demand. Mikolajková et al (2017) [4] were developed a pipeline network design for gas distribution which considering different supply of gas, such as external gas networks, injected biogas, or gasified liquefied natural gas (LNG) at terminals. Sidarto et al (2017) [5] were developed an approach to determine the natural gas pressure distribution in natural gas pipeline networks system using Broyden method. Ríos-Mercado et al (2015) [6] reported a review in optimization of natural gas transportation systems which focused on specific categories such as short-term basis storage, gas quality satisfaction and compressor station modelling. Rodriguez et al. (2014) [7] were used an sequential quadratic programming (SQP) algorithm to obtain optimum natural gas networks with minimum fuel gas consumption of the compressors. However, as far as authors know, there are no research in open literature discussing about the natural gas network design using superstructure method which considering different capacity, flowrate and time operation between gas suppliers and consumers.

Therefore, in this study, natural gas network design of East Java area was developed by modelling superstructure methods [8] which consider the suitable operating time and capacity. The developed superstructure model was optimized by GAMS software to obtain maximum natural gas transferred from source points to sink point with suitable operating time, flowrate and capacity.

2. Research Methodology

2.1. Supply and Demand Data

The supply and demand data for this study were obtained from the annual report on national gas balance issued by Energy & Mineral Resources Ministry of Republic Indonesia, as shown in Table 1 and Table 2. The supply and demand data listed in Table 1 and 2 were the simplified data from the annual report on national gas balance in East Java region by consideration of the nearest location.

| Code | Source Place | Start Time (year) | Duration (year) | End Time (year) | Natural Gas Production Rate (BSCF/year) | Natural Gas Capacity (BSCF) |
|------|--------------|-------------------|----------------|----------------|----------------------------------------|---------------------------|
| SRM1 | Madura Field 1 | 2                 | 16             | 18             | 142.4                                  | 2278.4                    |
| SRM2 | Madura Field 2 | 5                 | 18             | 23             | 87.6                                   | 1576.8                    |
| SRG1 | Gresik Field  | 3                 | 13             | 16             | 34.7                                   | 451.1                     |
| SRB1 | Bojonegoro Field | 6             | 23             | 29             | 56.6                                   | 1301.8                    |
| SRL1 | Lengo Field   | 7                 | 23             | 30             | 25.6                                   | 588.8                     |
|      | **Total Source** |                 |                |                | **6196.9**                             |                           |

BSCF = billion standard cubic feet

| Code | Sink Place         | Start Time (year) | Duration (year) | End Time (year) | Natural Gas Consumption Rate (BSCF/year) | Consumed Natural Gas (BSCF) |
|------|--------------------|-------------------|----------------|----------------|------------------------------------------|----------------------------|
| SKP1 | PT. Petrokimia      | 2                 | 28             | 30             | 54.8                                     | 1534.4                    |
| SKG1 | Gas Power Plants    | 3                 | 22             | 25             | 113.2                                    | 2490.4                    |
| SKE1 | PT. Pertamina Tuban | 10                | 20             | 30             | 45.6                                     | 912.0                     |
| SKI1 | Industrial Complex  | 4                 | 16             | 20             | 54.8                                     | 876.8                     |
| SKR1 | Domestic Gas        | 8                 | 22             | 30             | 0.7                                      | 15.4                      |
| SKT1 | Transportation Gas  | 5                 | 15             | 20             | 7.3                                      | 109.5                     |
|      | **Total Sink**      |                   |                |                | **5938.5**                               |                           |

BSCF = billion standard cubic feet
The “start time” column in Table 1 and 2 means the year from the supply points to start delivering the natural gas and the year from demand points to start receiving the transferred natural gas, respectively. The “end time” column in Table 1 and 2 shows the year when the supply points no longer produce the natural gas and the year when demand points had run out of the gas contracts, respectively.

2.2. Modelling and Optimization
The natural gas network modelling was approached using superstructure pairing concept which shown in Figure 1. Figure 1 shows the possible scenario of the natural gas network of the supply and demand data from Table 1&2 which can be obtained by superstructure pairing network.

![Figure 1](image)

**Figure 1** The possible scenario of the natural gas network by superstructure pairing network.

Each source points were connected to all sinks points and created multiple possible connections which is equal to the number of source points times the number of sink points. The start time and end time of each connection were determined by choosing the larger start time between paired source and sink point and choosing the smaller end time between paired source and sink point, respectively. For each connection, from a source point \( i \) to a sink point \( j \), delivers a certain flowrate of natural gas transported \( x_{i,j} \) in BSCF/year. Reminder, the value of flowrate of natural gas transported \( x_{i,j} \) must be less than the annual flowrate of source point and sink point.

From this possible scenario of superstructure modelling, linear programming (LP) formulation can be obtained [9] and also the constrains (explained in subsection 2.3). The LP mathematic model was optimized using GAMS software [10] to obtain the maximum total natural gas transferred from source to sink. Then, the optimum transfer flowrate and configuration was drawn in a grid diagram to visualize the natural gas network and to calculate the alternative supply and excess supply. All steps of the modelling and optimization procedures were described in a flowchart as shown in Figure 2.
2.3. Parameters and Equations

As described in previous sub-section, the objective function \( z \) in this study is maximizing total natural gas transferred from source to sink which described in following equation:

\[
z = \text{NG transferred} = \sum_{i=1}^{5} \sum_{j=1}^{6} t_{i,j} \cdot x_{i,j}
\]  

(1)

where,  
\( \text{numbering of source points (1 – 5)} \)  
\( \text{numbering of sink points (1 – 6)} \)  
\( t_{i,j} \) = duration transfer of natural gas connection from source \((i)\) to sink \((j)\) in years  
\( x_{i,j} \) = flowrate transfer of natural gas connection from source \((i)\) to sink \((j)\) in BSCF/years.

The value of flowrate natural gas transported \( x_{i,j} \) cannot be negative value and must be less than the annual flowrate of source \( (S_i) \) and sink \( (D_j) \) point. This statement could be defined as the constraints which described in Equation 2 – 4:

- for each source point,
  \[
  \sum_{j=1}^{6} x_{i,j} \leq S_i
  \]

(2)

- for each sink point,
  \[
  \sum_{i=1}^{5} x_{i,j} \leq D_j
  \]

(3)

- for all connections,
  \[
  X_{i,j} \geq 0
  \]

(4)
where, \( S_i \) = the maximum annual flowrate of source point \((i)\)
\( D_j \) = the maximum annual flowrate of sink point \((j)\)

This means that all transferred gas to all sink points from source point \((i)\) could not be higher than the maximum annual flowrate of source point \(S_i\) and all received gas from all source points to sink point \((j)\) could not be higher than the maximum annual flowrate of sink point \(D_j\).

After optimizing the value of the flowrate transfer of natural gas connection \((x_{i,j})\), the amount of excess supply and excess demand of the system could be obtained with following equation:

excess supply \((ES)\):
\[
ES = \sum_{i=1}^{5} S_i (t_{end,i} - t_{start,i}) - \text{NG transferred} \tag{5}
\]

excess demand \((ED)\):
\[
ED = \sum_{j=1}^{6} D_j (t_{end,j} - t_{start,j}) - \text{NG transferred} \tag{6}
\]

where, \( t_{start,i} \) = start time of source point \((i)\)
\( t_{end,i} \) = end time of source point \((i)\)
\( t_{start,j} \) = start time of sink point \((j)\)
\( t_{end,j} \) = end time of sink point \((j)\)

3. Results and Discussion

3.1. Optimization Result

In this study, the flowrate natural gas transported \((x_{i,j})\) for each connection between source point \((i)\) to sink point \((j)\) were optimized using GAMS Software. Table 3 shows the optimized value of the flowrate natural gas transported \((x_{i,j})\) for each connection.

Table 3. The optimized value of the flowrate natural gas transported \((x_{i,j})\) for each connection between source point \((i)\) to sink point \((j)\) in BSCF/year.

| \(X_{i,j}\) value | SKP1 | SKG1 | SKE1 | SKI1 | SKR1 | SKT1 | \(\sum_{i=1}^{5} x_{i,j}\) |
|------------------|------|------|------|------|------|------|-----------------|
| SRM1 \(S_1 = 142.4\) | 18.9 | 25.6 | –    | 54.8 | –    | 7.3  | 106.6           |
| SRM2 \(S_2 = 87.6\)   | –    | 87.6 | –    | –    | –    | –    | 87.6            |
| SRG1 \(S_3 = 34.7\)   | –    | –    | –    | –    | –    | –    | 0               |
| SRB1 \(S_4 = 56.6\)   | 11   | –    | 45.6 | –    | –    | –    | 56.6            |
| SRL1 \(S_5 = 25.6\)   | 24.9 | –    | –    | –    | 0.7  | –    | 25.6            |
| \(\sum_{i=1}^{5} x_{i,j}\) | 54.8 | 113.2| 45.6 | 54.8 | 0.7  | 7.3  |                 |
\[x_{ij} = \text{flowrate transfer of natural gas connection from source (i) to sink (j) in BSCF/years.}\]
\[S_i = \text{the maximum annual flowrate of source point (i) in BSCF/years.}\]
\[D_j = \text{the maximum annual flowrate of sink point (j) in BSCF/years.}\]

As shown in Table 3, the total flowrate natural gas transported from a source point to all sink points is less than the annual flowrate of the source point \((S_i)\). And also, the total flowrate natural gas transported to a sink point from all source points is less than the annual flowrate of the sink point \((D_j)\). There are no negative value of the flowrate natural gas transported \((x_{ij})\). Therefore, by this optimum pairing configuration, the maximum total natural gas transferred from sources to sinks is 4832.8 BSCF.

3.2. Grid Diagram of Optimized Natural Gas Network

The optimum pairing configuration can be drawn in a grid diagram to visualize the natural gas network and to calculate the alternative supply and excess supply. Figure 3 shows the grid diagram of the optimized natural gas network by superstructure method.

Figure 3. The grid diagram of the optimized natural gas network by superstructure method in East Java Region.

As shown in Figure 3, all pairing between source and sink point were connected in suitable time, no time is overturned or delayed. From the grid diagram, the excess supply and excess demand were obtained with value of 1364.1 BSCF and 1105.7 BSCF, respectively. The excess supply means the amount of natural gas that must be exported from this region to other regions, meanwhile the excess demand means the amount of natural gas that must be imported from other regions to this region. Therefore, from the grid diagram, it is known that how much natural gas can be utilized directly domestically and the amount of gas that must be exported and imported in a certain region. With this superstructure method, it is possible to know the optimum configuration and the natural gas balance in an area which has different operating time, flowrate and capacity between sources and sinks.

4. Conclusion

In this study, natural gas network design of East Java area was developed by modelling superstructure methods which consider the suitable operating time, flowrate and capacity. The developed superstructure model was optimized by GAMS software to obtain maximum natural gas transferred from source points to sink point with suitable operating time, flowrate and capacity. The maximum total
natural gas transferred from sources to sinks is 4832.8 BSCF. The excess supply and excess demand were obtained with value of 1364.1 BSCF and 1105.7 BSCF, respectively. With this superstructure method, it is possible to know the optimum network configuration and the natural gas balance in an area which has different operating time, flowrate and capacity between sources and sinks.

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