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# Dynamic Simulation Model of Electricity Energy Demand and Power Plant Capacity Planning in Madura

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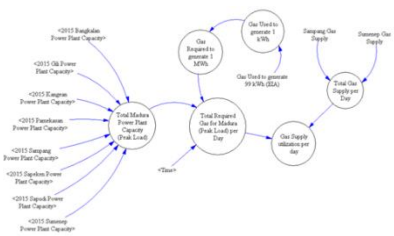
## Graphical abstract




## Abstract

As a country that has many islands, Indonesia faces a challenge of inequality electrification ratio. The big islands with dense population such as Java and Sumatra could build large electricity generation plants and distribute electricity with economies scale. On the other hand, it is not economical to build large power plants on small and isolated islands; because of the investment cost per number of population is still very high. Therefore, a strategy to build an independent power plant in small island such as Madura is still a challenge for the government. In addition, to build a power plant in Madura, requires a comprehensive analysis of electricity energy needs in the future and capacity planning to fulfill the demand. Madura has the potential to develop its own power plant. However, Madura still relies on supplies from the island of Java. Therefore, in this research, we use system dynamics as a framework to develop a simulation model to project the future demand and power plant capacity planning based on consideration that system dynamics can conduct the demand projection and capacity planning as well as developing scenarios to fulfill demand in 25 years.

*Keywords*: System Dynamics, Supply, Demand, Electricity Energy



## 1.0 INTRODUCTION

Madura is one of thousands islands in Indonesia that obtain electricity supply from another island, i.e. Java island. With this condition, the transmission cable must pass through the Madura Strait which has dense ship traffic, therefore, it is vulnerable to damage caused by anchors, as happened in 1999. The transmission cable was snagged by vessel and resulting outages for three months.

The condition of Madura dependence on the electricity supply from the Java-Bali electricity system, led to the idea that Madura can have an independent electrical system. It is reinforced and driven by the demand for electricity in Madura islands, like the island of Gili Raja, that have not been able to obtain electricity [1].

To increase the electrification ratio and in line with technological developments utilization of new renewable energy, it is required for Madura to develop new power plants, based on the needs and potential of the local area, especially small isolated islands in eastern Indonesia. Regarding the power plant generation system, there are several alternative generators that can be developed, those are: Gas Power Plant, Hydroelectric Power Plant with considering the potential and character of the local area.

Therefore, in this paper, we will develop a model that can assist in strategic capacity planning of electricity energy supply to fulfill the demand within the planning horizon. Through the development of the independent power plant, Madura can be self-sufficient in electrical energy supply.

## 2.0 LITERATURE REVIEW

Currently, Madura has 219,439 households. With this amount of households, only about 129,522 households have electricity supply, so that the electrification ratio is about 59.02% [2]. Madura is an area that has the lowest electrification ratio in East Java. This low electrification ratio is the impact of the small number of households in the area, while the distance between areas are far enough. With this condition, the investment for the power plant development become insufficient. In addition, the low electrification ratio in Madura, causing the electrical power available to Suramadu (Surabaya-Madura) bridge is about 100 megawatts, while the projections for future need in electricity supply in 2014 has reached 700 megawatts [3].

### 2.1 Power Plant, Transmission, and Distribution

Power Plant is a place where electricity is first generated. Power plant has turbines as prime mover and a generator that generates electricity. Usually there is also a center of the power plant substation. The main equipment in substations, among others: the transformer, which serves to raise the generator voltage (11.5 kV) to the transmission voltage / high voltage (150kV), safety equipment and regulator. Common types of power plants include hydropower plants, steam power plant, gas power plant, and nuclear power plant).

Transmission system is the electricity distribution process from the power plant to the electric distribution line (substation distribution) so it can be distributed to the consumer. Electric power transmission is the process of transferring electrical energy from generating power plants to the electrical substations. Transmission lines are interconnected with each other, performing transmission networks.

An electric power distribution system is the final stage in the process of delivering the electric power; it carries electricity from the transmission system to individual consumers. With the use of transformers, distribution substations lower the transmission voltage to medium voltage ranging between 2 kV and 35 kV. Primary distribution lines carry this medium voltage power to the distribution transformers. Distribution transformers again lower the voltage to the utilization voltage of household appliances. It consists of several subsystems such as the Distribution Control Center (DCC), the medium voltage channel (which is also commonly called primer voltage distribution) which is the airways or ground wires, medium voltage distribution substation which consists of medium voltage regulator panels and transformer until the low voltage distribution panels (380V, 220V) which generates the working voltage/power line for industry and consumers.

Transmission and distribution lines are required to deliver electricity energy to the customer. Substations are the facilities that provide the interconnection between transmission lines transporting electricity from generation sources (power plant) and reduce high voltage electricity to consumer levels.

### 2.2 Type of Power Plants

Currently, there are many types of resources for the large-scale electric power plants, namely: oil, gas, coal, hydro, nuclear, biomass and geothermal [4]. In power plant development, we should consider about efficient and environmentally friendly technologies. Several types of power plant are as follows:

1. Oil Power Plant
   Oil power plants are also identified with Power diesel. The main advantage the use of oil power plants or diesel is able to operate at all times during the fuel is still available.
2. Gas-Fired Power Plant
   Gas turbines have the higher thermal efficiency compared with similar power plants like coal power plants. The benefit of using a gas power plant is more easily prepared than the steam, so that the power plant could start production quickly, much faster than the plant as well as CO2 emissions are very low.
3. Coal-Fired Plants
   Currently, the coal-fired power plant widely used because of its availability which is pretty much in nature. However, on the other side of the main problems of coal-fired power plants is one of the contributors to the pollution of the largest CO2 gas. It is estimated that coal-gasification will reduce carbon dioxide emissions (CO2) by 35-40%, decrease solid waste by 40-50% and reduce cost savings of 10-20%.
4. Hydroelectric Power Plant
   Indonesia has the potential of hydroelectric power plant amounted to 70,000 megawatts (MW). Generally, the benefit of hydroelectric power plant is in terms of the economy and environment. Economically, hydropower has a relatively low production costs, have a long life, i.e. 50-100 years, can be used as irrigation, or as a reservoir and tourism. In terms of the environment, it reduces carbon emissions.

### 2.3 Capacity Planning in Power Plant Development

The first step of the power plant capacity planning is required to estimate the load of power plant, due to the nature of electricity energy that cannot be stored but directly used up by the consumers [5]. The average load is the amount of load for a certain time. The peak load is a load that occurs at a particular time with the highest load.

### 2.4 System Dynamics

System dynamics was developed in 1950 by Jay W. Forrester in Massachusetts Institute of Technology (MIT). This framework is focused on systems thinking, but takes the additional steps of constructing and testing a simulation model [6].

#### *2.4.1 System Dynamics Characteristics*

System dynamics simulation is performed to learn about the dynamics of the system behavior. The system behaviour may impact the planning solution by using close loop feedback and designing policies to improve the system performance. It treats the interactions among the flows of information, money, orders, materials, personals, and capital equipment in a company, an industry, or a national economy. The main characteristic of this method are the existence of complex system, the change of system behavior, and the existence of the closed loop feedback. System dynamics is a method to analyze and design a policy. It can be used as an approach for modeling and simulation of a complex system.

#### *2.4.2 Steps in Developing System Dynamics*

Several steps are required to develop the system dynamics model [7]: (a) system understanding, (b) model formulation will define the interactions of state variables and parameters [8]; (c) data collection, (d) base model development, (e) validation and verification of the base model, and (f) scenario development. It is important to understand the fundamental concepts to help us in constructing, analyzing and testing the model.

## 3.0 BASE MODEL DEVELOPMENT

The first step to develop a system dynamics model is system understanding. To ensure electricity supply in the future, it is necessary to build a new plant on the Madura Island. In developing the planned capacity, we need to analyze the demand for electricity in the future as well as peak load for each region. Total peak load on Madura Island is approximately 200 MW. After we have a good understanding of the system being modeled, we will develop a causal loop diagram, as the early conceptual framework in developing the model. The causal loop diagram of power plant development can be seen in Figure 1.

According to Figure 1, the causal loop diagram can be grouped into three stages as follows:

1. Requirement Analysis
   In this phase, an analysis of the electrical energy is conducted in the area of Sumenep, Pamekasan, Sampang, Bangkalan, Kangean, Sapudi, Sapeken and Gili.
2. Power System Planning
   In this stage will be calculated how much capacity is needed based on the peak load in each region to meet the electricity needs in the future.
3. Development of Power Generation System
   With the establishment of the power plant, there will be three systems namely electricity generation systems, electric power transmission systems, as well as electric energy distribution system to the consumer.

As a first step to make the strategic plan of the development of power plant capacity, is an analysis of the electricity energy needs based on historical data obtained from State-owned General Electricity Company (PLN=Perusahaan Listrik Negara) in Madura. Simulation result shows that the total requirement per year for Madura between 2000 and 2015 increased by 9% per year as shown in Figure 2. This demand depends on the demand of each region in Madura such as Sumenep, Pamekasan, Sampang, Bangkalan, Kangean, Sapudi, Sapeken, and Gili. In 2000, the total demand was around 2,250 MW. With 9% growth per year, total demand in Madura has reached 8,153 MW in the year 2015.

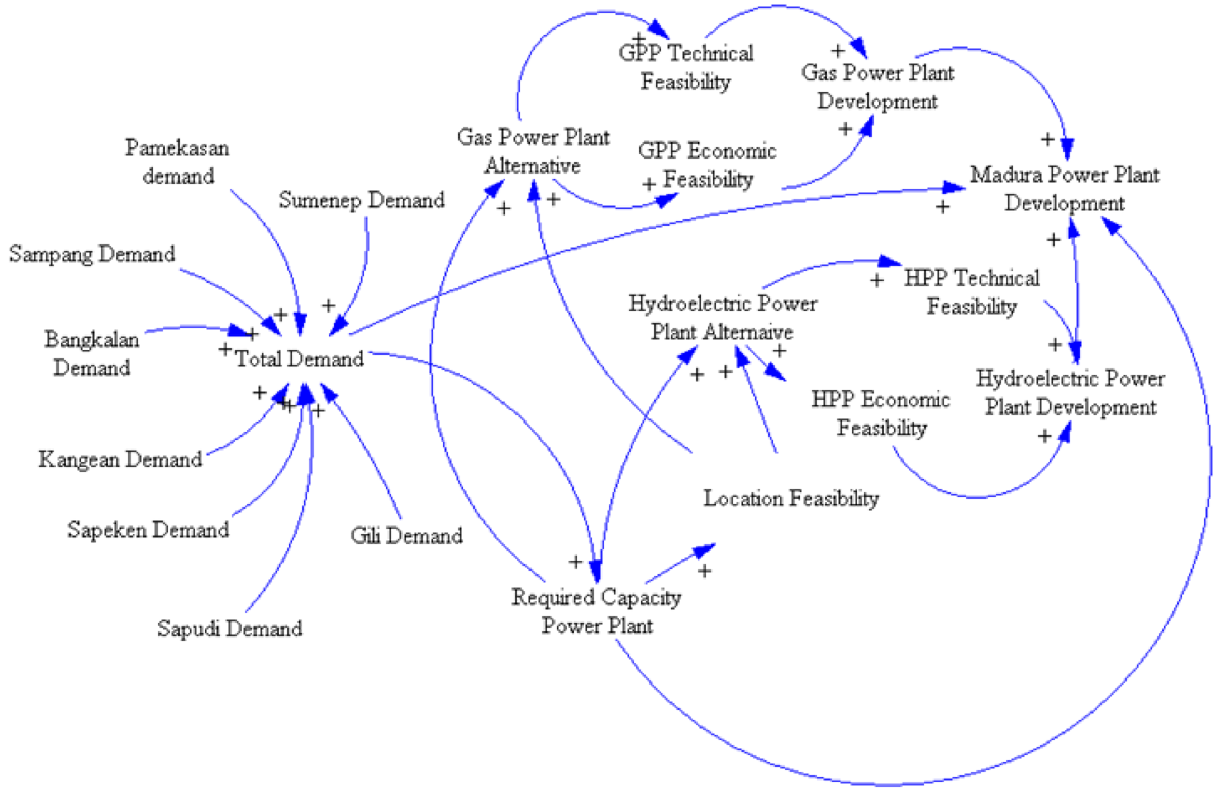



**Figure 1** Causal Loop Diagram of Power Plant Capacity Planning

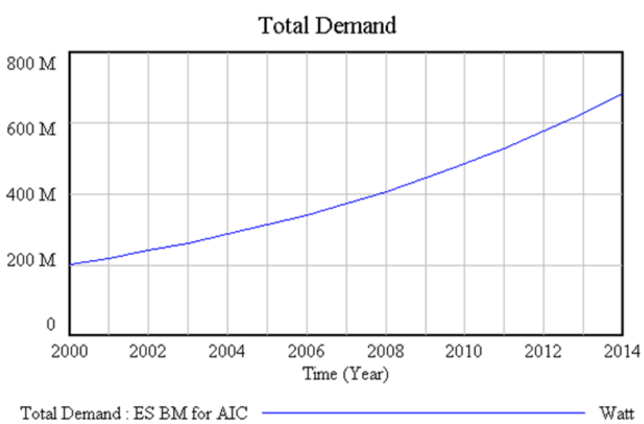



**Figure 2** Power Plant Demand

## 4.0 MODEL VALIDATION

Model validation is required to check the model validity. Modified-behavior prediction can be done if it is possible to find data about the behavior of a modified version of the real system. The model passes this test if it can generate similar modified behavior, when simulated with structural modifications that reflect the structure of the modified real system. Phase-relationship test uses the phase relationships between pairs of variables in the model, obtained as a result of simulations. If certain phase relationships obtained from the model contradict the phase relationships that are observed/expected from the real system, this may indicate a structural flaw in the model. Structure-oriented behavior tests are strong behavior tests that can provide information on potential structural flaws. The main advantage of direct structural tests is that they are much more suitable to formalize and quantify. Direct structure tests, although powerful in concept, have the disadvantage of being too qualitative and informal by their nature. Since structure-oriented behavior tests combined the strength of structural orientation with the advantage of being quantifiable, they seem to be the most promising direction for research on model validation. The two categories of tests discussed above are designed to evaluate the validity of the model structure. Once the model has passed all the structural tests, a modeler can start assessing the behavior pattern tests. In this step we emphasis on pattern prediction accuracy. The best approach in this case is to compare graphical/visual measures of the behavior characteristics [9]. We can compare the means or variations between the simulated model and the historical data that exist in the real system. A model will be valid if the error rate is less than 5% and error variance is less than 30% [9]. Error rate and error variance are defined in Eq. (1) and (2). The base model, once validated, can be reliably used in the scenario development.

$$ErrrorRate = \frac{\left[\bar{S}-\bar{A}\right]}{\bar{A}} \quad (1)$$

$$ErrorVaria\,nce = \frac{\left|Ss-Sa\right|}{Sa} \quad (2)$$

Where:
$\bar{S}$= the average rate of simulation
$\bar{A}$= the average rate of data
Ss= the standard deviation of simulation
Sa= the standard deviation of data

Error rate (E1) and Error variance (E2) of demand can be determined as follows:

$$E1 = \frac{[1{,}191{,}523 - 1{,}165{,}624\,]}{1{,}165{,}624} = 0{,}02$$
$$E2 = \frac{[483{,}891{,}550 - 470{,}761{,}799\,]}{470{,}761{,}799} = 0{,}03$$

## 5.0 SCENARIO DEVELOPMENT

This scenario is developed to check the availability of natural gas supply to fulfill the demand of electricity supply in Madura Island. Currently, Madura has two areas that have abundant gas resources, those are in Sumenep and Sampang District. The Flow Diagram of a gas power plant scenario can be seen in Figure 3.

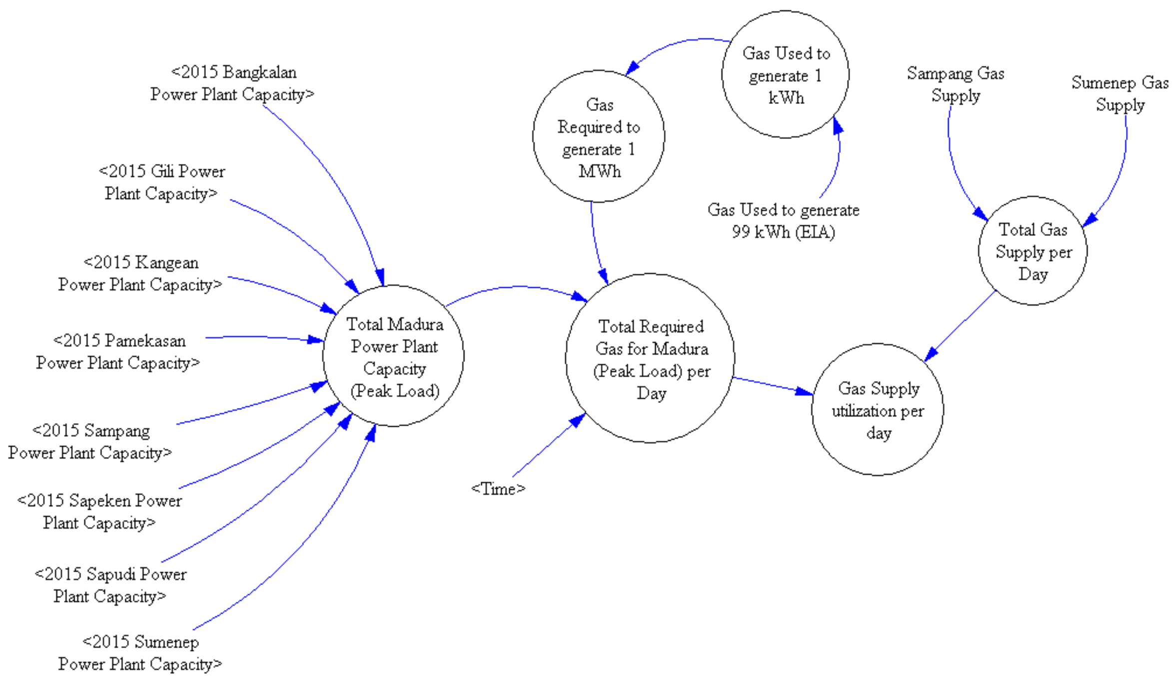



**Figure 3** Gas Power Plant Capacity Planning Scenario

From the simulation result of scenario model, we can obtain the total power plant capacity as shown in Figure 4. Meanwhile the total gas supply and utilization of gas per day can be seen in Figure 5 and Figure 6. From Figure 4, it can be seen that the total generating capacity in Madura is around 234 MW, while the required gas supply per day amounting 2.36 million cubic feet. With this condition the utilization of natural gas per day is equal to 0.013, which means that Madura has good potential for the development of gas power plants, given two gas supplies are plentiful in the area Sumenep and Sampang.

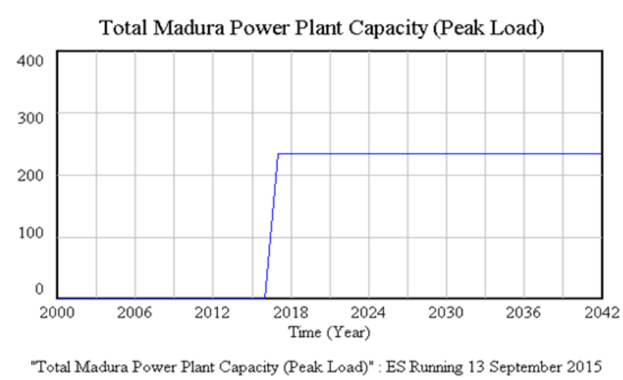



**Figure 4** Madura Power Plant Capacity

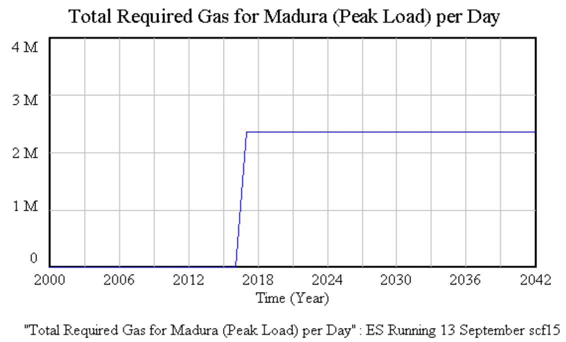



**Figure 5** The required Gas Supply for Electric Power Plant in Madura

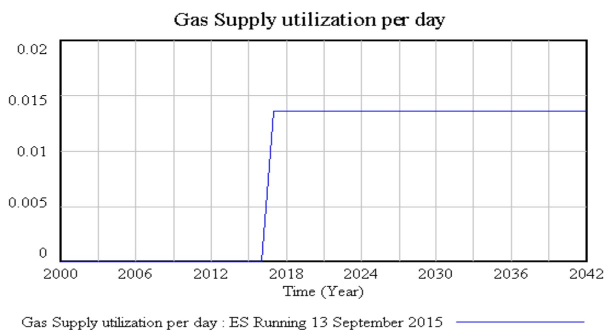



**Figure 6** Gas Utilization per Day for Electric Power Plant in Madura

## 6.0 CONCLUSION

In developing system dynamics model, a comprehensive understanding is required to make the model and scenario become more comprehensive and can address all the problems.

Based on the simulation result of total demand in Madura area, it showed that electricity demand in the year of 2000 was around 2,250 MW. With 9% growth per year, total demand in Madura has reached 8,153 MW in 2015.

Total power plant capacity is the summation of the power plant capacity in each region. Power plant capacity in each region depends on the peak load and load spare which is set of around 20% to cover the demand growth.

We may consider natural gas for the development of power plant in the area of Madura, as this island has abundant gas resources. The required gas supply per day would be around 2.36 million cubic feet to fulfill the demand. Based on this condition, the gas utilization per day would be around 0.013, which means that Madura has a good potential for the development of a gas power plant.

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