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Dynamic Simulation Model to Reduce Electricity Distribution Losses in Medium and Low Voltage Networks

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ABSTRACT

The reliability of electricity distribution systems plays an important role to guarantee the sustainability of electrical power supply to consumer. The main reason why we should sustain the electrical power supply is to reduce "blackout". This blackout will result a domino effect to work or other related matters. It is therefore in this research, we developed a System Dynamics simulation model to simulate the behavior of electricity distribution network. This research provides insights to National State Electricity Company in achieving interoperability of electrical distribution network. We developed a set of model which has the ability to detect electricity distribution losses based on existing condition and several scenarios to reduce technical losses in medium and low voltage networks.

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1. INTRODUCTION

Today, the reliability of electricity distribution systems plays an important role to guarantee the sustainability of electrical power supply to consumer. The main reason why we should sustain the electrical power supply is to reduce "blackout". Blackout may cause some disadvantages such as declining of small industries competitiveness since they are unable to produce in economical scale, declining of information transfer rate since the communication network is cut off, increasing risk of damage to information technology devices which are the backbone of business transaction, and increasing service time because of unavailability of information technology devices. All these incidents will eventually result in declining of business competitiveness value.

In this research, we utilized electricity distribution systems in Pamekasan District as a study case. Pamekasan is a district on the island of Madura, East Java, Indonesia. It consists of 13 districts, which are subdivided over 178 villages and 11 urban villages. Currently, electricity demand in Madura Island is supplied from Java, Madura and Bali interconnection through undersea connection. This network is connected from Gresik Power Plant through Kamal Substation (as main station relay) and then distributed to the whole area of Madura. In general, the distribution systems used by State Electrical Company is a centralized electric system. With this centralized system, it brings several negative impacts on the electricity distribution in Indonesia such as a lot of area that are hard to reach by electrical network because of geological factor, the loss of electrical power, instability of electrical voltage, and power outage.

System dynamics (SD) model is used to model the electricity distribution systems based on consideration that system dynamics is a powerful (simple ideas can be combined into complex systems models), useful (it makes the integration of modeling and experimenting a simple matter), and natural (the simple ideas behind SD models correspond to a basic form of human thought) framework to learn the system behavior [3]. It provides a flexibility framework in developing several scenarios to reduce technical (TL).

Electricity distribution losses defined as the difference between the electricity that goes into the distribution network and that leaves it towards the customer site [4]. Ideally, electricity distribution losses should be around 3 to 6% [1]. It is not greater than 10% in developed countries. Electricity distribution losses are caused by the physical properties of the components of power system, such the internal electrical resistance, transmission lines, power transformers, measurement system, and so on [2]. Fig. 1 represents the electrical power distribution system. As we can see from Fig. 1, electricity losses may occur in whole distribution parts, starting from middle voltage networks to home connection.

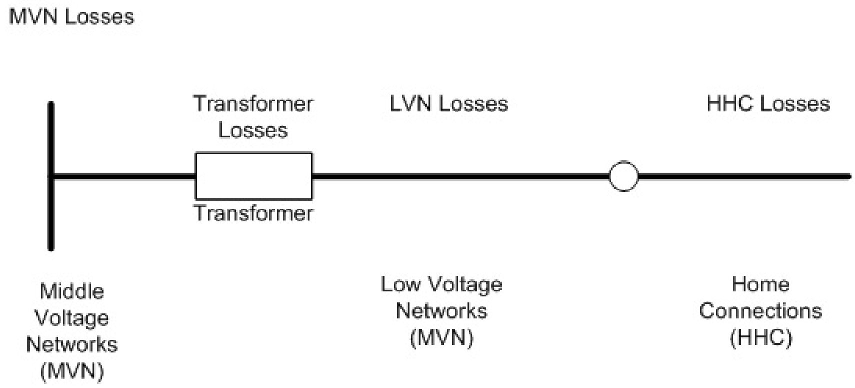

Figure 1. Electrical Power Distribution System

These losses can be classified into technical loses and non-technical losses. Technical losses are resulting in: losses in drivers, corona effect, iron of the transformers, eddy currents, connectors, and ohmic losses [5]. In this research we focus on technical losses in Medium Voltage Networks (MVN) and Low Voltage Networks (LVN) for the case study.

Technical losses reduction can be done through changing several devices in transmission and distribution system or periodic maintenance. Meanwhile, to reduce illegal usage, some steps need to be taken such as accelerating privatization policy, developing regional price policy, increasing people's awareness about economic and social dimension of illegal usage, and pushing people to use other source of energy [6]. Distribution losses can be reduced by choosing the right transformer and feeder, distribution network reconfiguration, and placing shunt capacitor in the right place [7]. Each network service unit need to be improved either internal or external. Several factors can affect the performance of electricity distribution system such as providing knowledge about the electricity distribution and socializing company's program about energy saving to the local community periodically to reduce operational cost and increase company income [8].

2. RESEARCH METHOD

The reliability of a distribution system is greatly influenced by electrical network infrastructure, so that the electrical energy distribution to consumer can run smoothly with a standard quality. In electrical energy distribution, losses may occur in the station of power generation, transmission line, and distribution process. However, the biggest losses percentage occurs in distribution process caused by network configuration, such as increasing length of network and overload [9].

To demonstrate the electricity distribution system more comprehensively, a causal loop diagram which explains the relationships among elements of the distribution system is presented in Fig. 2. As we can see from Fig. 2, losses in MVN are caused by current, length of MVN, MVN resistance, correction factor, l equivalent, and loss factor. In Low Voltage Networks (LVN), Losses are caused by feeder's current, length of LVN, l equivalent, correction factor, loss factor, and LVN resistance. Furthermore, this causal loop diagram (CLD) will be used as a foundation in developing system dynamics model, by converting the CLD into stock and flow diagram (SFD). Stock and Flow diagram enables us to visualize the model variable into stock or level variable (accumulation), rate, and auxiliary (to formulate complex equations that can be an input to rate or the auxiliary itself). We separate the model into Medium Voltage Networks (MVN) sub-model and Low Voltage Networks (LVN), sub-model. This MVN and LVN losses could be reduced by increasing cross sectional area in MVN and power factor (Cos Q) improvement.

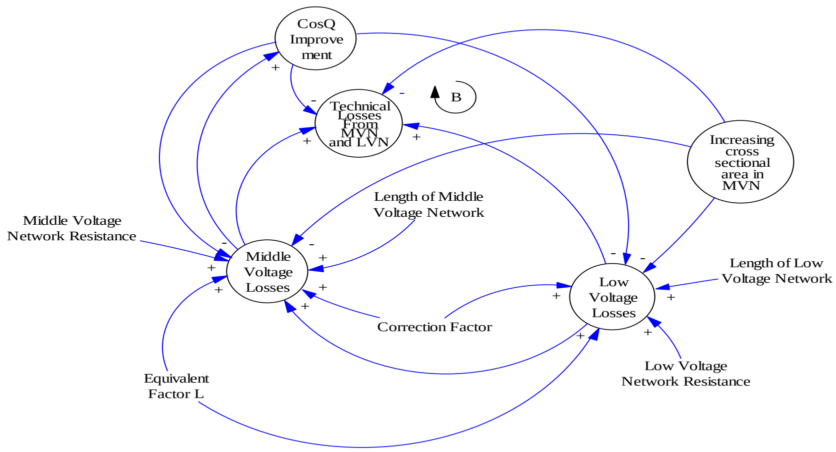

Figure 2. Causal Loop Diagram of MVN and LVN Losses

3. RESULTS AND ANALYSIS

3.1. Medium Voltage Networks Sub-model

Medium Voltage Networks (MVN) is a part of the distribution network, usually around 1 – 60 KV depends on the network operator. A radial network structure is more common in MVN rather than a meshed structure such as depicted in Fig. 3. Based on this structure, we assumed MVN as one main feeder where the node is a distribution transformer placed in the main feeder which has the same the Load Density Factor (LDF) for the whole feeders. According to Rudi Mulyadi [11], MVN losses are caused by current, length of MVN, MVN resistance, correction factor (a factor that occur because of unbalanced load, resistance factor, and temperature) that ranging between 0.69 and 1.87, loss factor, L equivalent, and ignition timing (1 month = 730 hours). All these relationships are shown in Eqs. (1) - (2).

$$\text{MVN resistance} = \frac{\text{Output Voltage}^2}{\text{Total Feeder's Power}} \quad \text{Eq. (1)}$$

$$\text{MVN Losses} = 3 \times \text{feeder's current}^2 \times (\text{Length of MVN} \times \text{MVN Resistance} \times L_{equivalent} \times \text{LLF} \times t) \times \frac{\text{Correction\_F}}{1000} \quad \text{Eq. (2)}$$

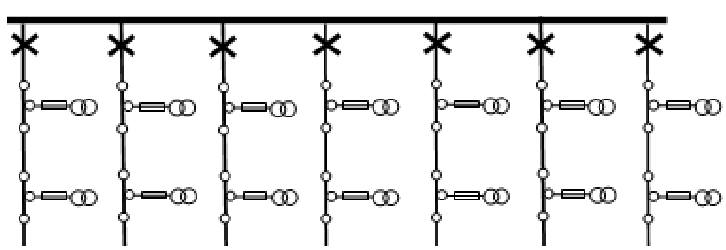

Figure 3. Radial Distribution System in MVN

The flow diagram of Medium Voltage Networks (MVN) can be seen in Fig. 4.

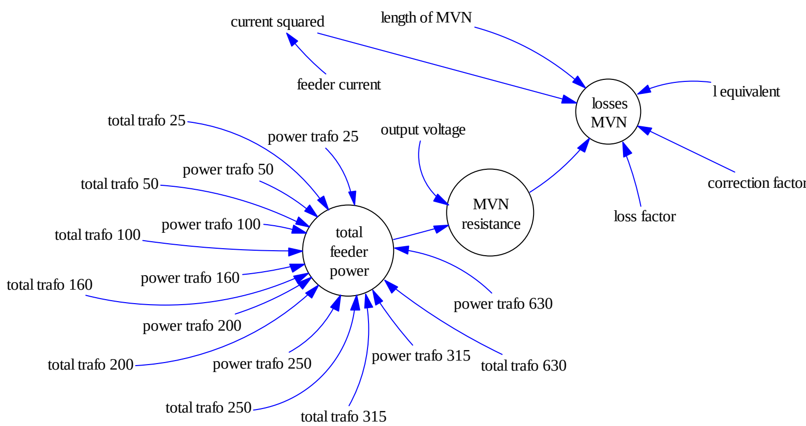

Fig.ure 4. MVN Sub-model

In this research, we set the simulation timing for 24 months (2011-2012) based on consideration that during the period, we can learn the system behavior. Result shows that MVN losses are distributed between 306.000 KWH and 374.000 KWH.

3.2. Low Voltage Networks (LVN)

An electric pole on home connection is a load point on Low Voltage Networks. LVN losses depend on several factors such as feeder current, length of LVN, LVN resistance, l equivalent, loss factor, and correction factor (caused by imbalance, resistance, temperature factors). The flow diagram of LVN sub-model can be seen in Fig 5. All these relationships are shown in Eq. (3). Result shows that LVN losses are distributed between 400.000 and 491.000 KWH.

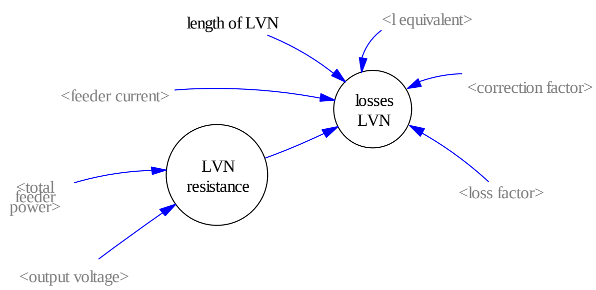

Figure 5. LVN Sub-Model

$$\text{LVN Losses} = 3 \times \text{feeder current}^2 \times (\text{Length of LVN} \times \text{LVN Resistance} \times L_{equivalent} \times LLF \times t) \times \frac{\text{Correction F}}{1000}$$

Eq. (3)

3.3. Model Validation

Model validation is required to check the model accuracy. A model will be valid if the error rate (E1) is less than or equal to 5% and the variance error (E2) is less than or equal to 30% [10]. The equation of error rate and error variance are shown in Eqs. (4) – (5).

$$E1 = \frac{|(\text{Average rate of Data}) - (\text{Average rate of Model})|}{(\text{Average rate of Data})}$$

Eq. (4)

$$E2 = \frac{|(\text{Standard Deviation of Data}) - (\text{Standard Deviation of Model})|}{(\text{Standard Deviation of Data})}$$

Eq. (5)

Regarding model validation, we utilized some variables such as Technical Losses, Non-Technical Losses, and Total Losses as variables that we used to check the model accuracy. The error rate and error variance of these variables can be seen in Table 1.

Table 1. Error Rate and Error Variance

Variable	Average Rate	Standard Deviation	Error Rate	Error Variance
MVN Losses			0.009	0.123
• Data	341025.7	16512.14		
• Model	337955.7	18552.02		
LVN Losses			0.027	0.012
• Data	431427.8	24340.01		
• Model	443392.5	24044.97		

As we can see from Table 2, it is shown that all the error rates and the error variance are less than 5% for the error rates and less than 30% for the error variance, which means that the model is valid. The data and model of MVN and LVN losses are presented in Fig. 6 and Fig. 7.

3.4. Scenario Development

Scenario represents all the possible outcomes in the future. It is usually conducted to improve the system performance. In this research, the scenario is conducted to reduce electricity distribution losses by increasing the cross sectional area in MVN and improving Cos Q through the placement of capacitor banks on MVN sites.

a. **Increasing Cross Sectional Area in MVN**

This scenario is developed by modifying the cross sectional area of MVN to be 3x150mm.The MVN resistance based on this scenario is determined by using Eq. (10)-(11).

MVN cross sectional area = 3 * 150 Eq. (10)

MVN ressistance = Cu inhibitory*length of MVN scn/MVN cs area JTM scn Eq. (11)

By increasing the cross sectional area, the MVN resistance can be reduced and consequently losses in MVN can also be reduced of around 200.000 KWH per month.

As the impact of this scenario, the additional cross sectional area in MVN will result in reducing losses in LVN of around 272.000 KWH per month.

b. Increasing Power Factor (Cos Q)

This scenario is developed to increase Power Factor (Cos Q) from 0.8 to 0.9. This scenario is implemented by adding capacitor banks in MVN site. The value of the capacitor banks can be determined by using Eq. 12. Result shows that by adding 38 kVAR of capacitor, the losses can be reduced of around 22%.

kVAR capacitor = (existing power pp* (TAN(ARCCOS(existing cos phi)) - TAN(ARCCOS (proposed cos phi))))/1000 Eq. (12)

We summarize all the scenario results in Table 2.

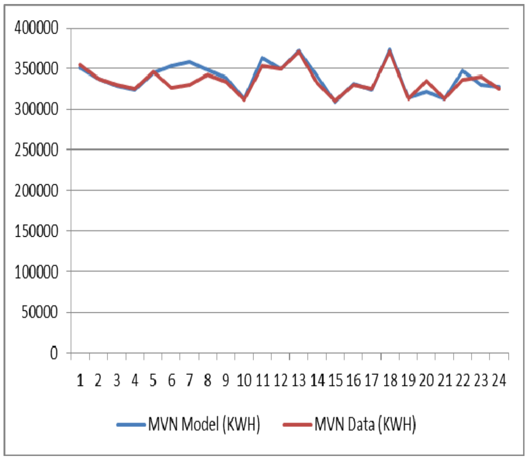

Figure 6. MVN Model and Data

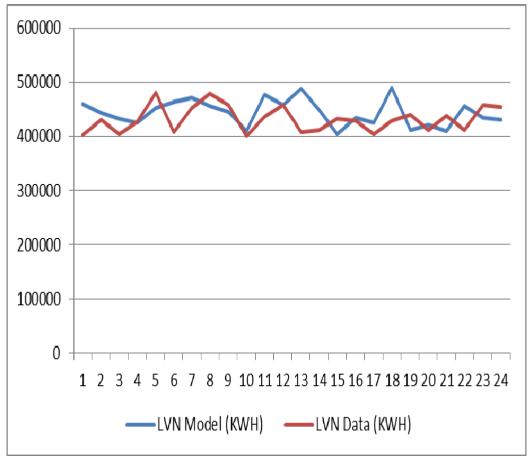

Figure 7. LVN Model and Data

Table 2. Scenario Results

Scenario Type	Result
Increasing Cross Sectional Area in MVN	MVN losses can be reduced of around 200.000 KWH per month.
Increasing Power Factor (Cos Q)	By adding 38 kVAR of capacitor, the losses can be reduced of around 22%.

4. CONCLUSION

This paper provides a framework to develop electricity distribution losses model to reduce electricity distribution losses based on system dynamics framework and insights to National State Electricity Company in achieving interoperability of electrical distribution network. In developing MVN model, we assumed MVN as one main feeder where the node is a distribution transformer placed in the main feeder which has the same the Load Density Factor (LDF) for the whole feeders. Meanwhile, LVN model is developed by considering that an electric pole on home connection is a load point on Low Voltage Networks (LVN).

This study could be considered as a pilot study to reduce electricity distribution losses in medium voltage networks and low voltage networks. Further research is required to reduce the electricity distribution losses through network reconfiguration.

ACKNOWLEDGEMENTS

First of all we would like to thank PLN Pamekasan for giving us an opportunity to have partnership and providing data and information required for the model development. We hope this research can provide knowledge and insights for researcher and academician in developing an system dynamics model to reduce. Furthermore, we also hope that the research results can provide some inputs for policy decision maker in deciding policies related to electricity distribution losses reduction.

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