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Fuzzy Controller For Reducing Oscillation On Large Power System

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Abstract

This paper describes a novel of power system stabilizer (PSS) based on fuzzy logic theory for damping electromechanic oscillations focusing on inter-area modes of South Sulawesi power grid. An innovative approach for the determination of associated domains considered with the fuzzy logic power system stabilizer (FLPSS) is obtained by computer simulations when subjected to small disturbances under stressed operating conditions. The digital simulation results show that proposed controller proves its effectiveness in term of calculation process rather than optimal power system stabilizer and improves system damping compare to lead-lag controller under MATLAB Simulink environment.

Keywords: *Fuzzy Logic Controller, Inter-area Modes, Oscillation, Stabilizer.*

1. Introduction

Power grid of South Sulawesi Indonesia as depicted in figure.1 stretches from Makassar to Mamuju through Pangkep - ParePare - Pinrang - Bakaru then through Jeneponto - Bulukumba - Sinjai - Bone - Soppeng – Sengkang. That system is the largest grid engineered by Perusahaan Listrik Negara or PLN, ***for east region of Indonesia***. PLN is the National Electric Company of Indonesia. During the last decades, the growth of South Sulawesi power grid is also the largest in east part of Indonesia; it's about 14,5 percent in average. According to PLN, power installed in 2010 is 623 MW for supply the total load of 541 MW through the length of 1,926 km of transmission lines.

The operation of such interconnected system can taking advantage of diversity of loads, availability of sources and fuel price in order to supply the electricity to the loads at minimum cost with a required reliability. However, as power transfers grow, the interconnected system becomes increasingly more complex to operate and the system becomes less secure. It may lead to large power flows with inadequate control, large dynamic swings among different part of the system which could produce instability of the system, and then create tendencies of less security and reduced quality of supply thus the potential advantages can not be utilized.

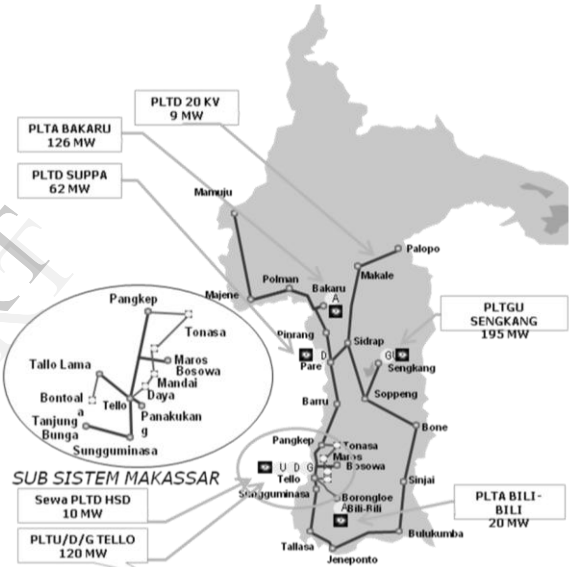


Fig. 1. 150 kV Grid Line of South Sulawesi Indonesia

This paper introduce the advantages of a novel FLPSS to reduce electromechanic-oscillation of South Sulawesi power grid in Indonesia which has weak ties structure. The poorly damped of oscillations typically occur in power systems with longitudinal structure or weak ties. The supplementary excitation controllers are used as additional feedback signals to enhance system damping and to improve the dynamic stability of power systems. These controllers are known as power system stabilizers. They have been widely used for years with many types.

Some of them depend on conventional control theory such as PI or lead-lag controllers that can not provide a total satisfactory response when the operating conditions change widely. These controllers have main trouble for weekly connected power systems as a trade off will appear at the design process between local-modes and inter-area modes.

Optimal controllers which are based on feedback signals from all or some states of the system will guarantee the damping of both local and inter-area modes. These controllers always suffer a lot from on-line iterative solution to Ricatti equation beside the many feedback gain channels.

Another type of controllers is the adaptive control, which can do the entire job, but it is time consumption for real-time system identification. Simulations associated with steady state stability are quite expensive in computational efforts, so these controllers can not be used for fast on-line assessments. Additionally many controllers such as self-tuning control, sliding-mode control and H-infinity control are a suggested solution to both local and inter-area modes of oscillation but they are not the perfect solution.

New types of controllers such as rule-based, neural networks and fuzzy logic controllers have been used in many power system applications. These types do not require any kind of computational complexity. That point is vital for multi-machine or large-scale system.

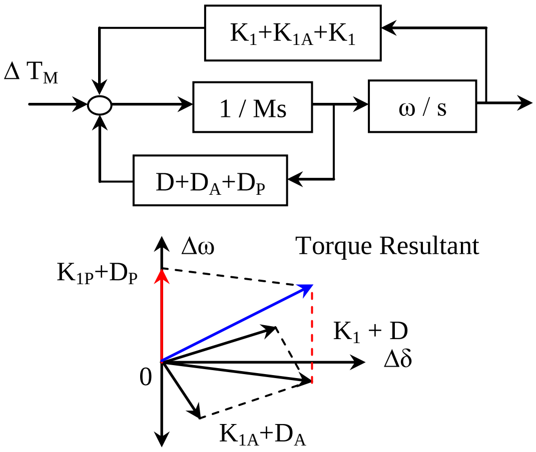
The controller proposed in this paper has advantages of its simplicity, systematic design and combine functions of AVR and PSS. The performance of this controller is investigated for South Sulawesi power grid during year 2012 which is starting with collecting data, modelling, simulation, analysis, interpreting and then results discussion. Simulation work is done at computer laboratory of electrical engineering department at the University of Atma Jaya Makassar using multi-machine detail model under MATLAB Simulink environment.

2. Basic Concept of PSS

Though a generator output power is decided by turbine mechanical torque but that output also can be changed by changing the excitation value transiently. PSS detects the changing of generator output power, control excitation value and reduced power swing rapidly. A PSS which is installed in the automatic voltage regulator of a generator could improve power system stability and has excellent cost performance compared to other modifications.

PSS is designed to work together with generator excitation system in order to produce positive damping torque to ensure system stability in which can be explain by torque vector diagram as figure 2. K_1 is syncronizing torque, K_{1A} is syncronizing torque by AVR and K_{1P} is syncronizing torque by PSS. Where D is damping torque D_A is damping torque by AVR and D_P is damping torque by PSS. In principle generic PSS has three components as seen on figure 3. They are washout, gain and phase compensation. The washout block serves as high pass filter with time constant high enough to allow signal associated with electromechanic oscillation to pass unchanged. The gain block determines the amount of damping introduced by PSS. Phase compensation block provides an approriate phase lead characteristics to compensate phase lagging between exciter input and generator electrical torque.

Fig. 2. AVR + PSS Torque Characteristic Diagram



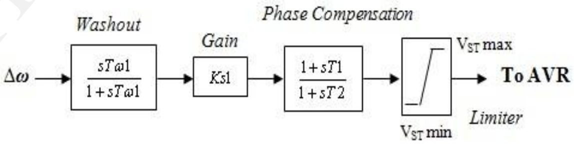


Fig. 3. Generic PSS Block Diagram

The input $\Delta\omega$ is rotor speed which came from the relation of change among mechanical power, electrical power and accelerating power as illustrated on diagram below.

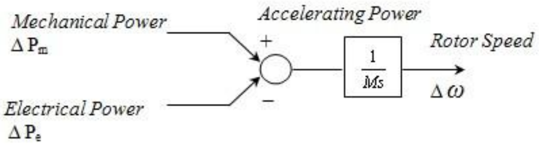


Fig. 4. Power and Rotor Speed Relation Diagram

PSS has three types of application. The most simple type is single input type such as ΔP, $\Delta\omega$ or Δf which maybe used for individual generator oscillates against the system with frequency of 1 Hz approximately and named local mode power oscillation. For this case ΔP type is more effective. The second type is used for the whole system oscillates with long distance and large power transfer system connection that known as inter-area mode power oscillation or long-cycle. In this case Δω or Δf is more effective. The third type PSS is used for complex power oscillation mode such as local mode and inter-area mode. In this case multiple input is more effective. For instance ΔP + Δω or ΔP + Δf type of PSS input. The connection of those three type of PSS is shown in figure 5.

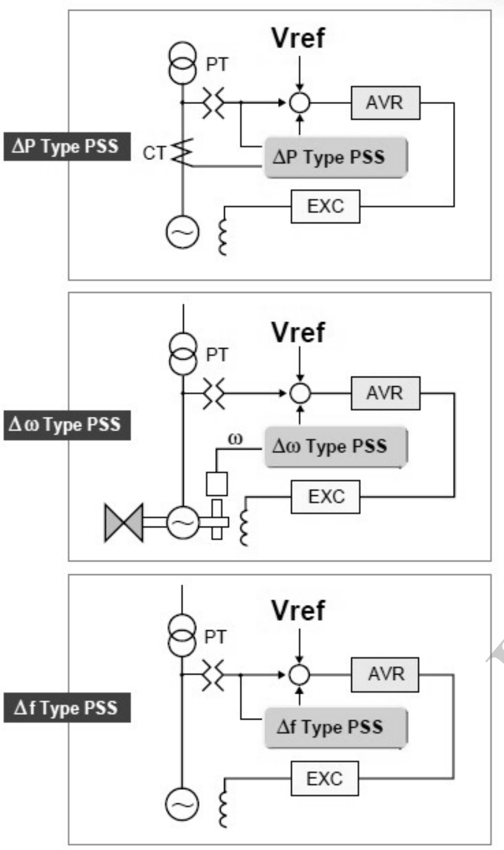


Fig. 5. Connection Diagram of PSS

3. Fuzzy Logic Controller

In this section the design of a novel PSS controller based on fuzzy logic theory is explored. With the goal of damping the oscillations associated with power systems under the effect of small signals for inter-area modes must be damped. A simple fuzzy controller based on the experience can damp only local modes. To damp inter-area modes of oscillation, the experience is difficult to be obtained. Thus the design process needs a systematic method for obtaining the rule base and domain ranges through optimal control theory.

3.1 Controller Stucture

The proposed controller uses triangular shaped fuzzy sets as nb: negative big, nm: negative medium, ns: negative small, z: zero, ps: positive small, pm: positive medium and pb: positive big, as in figure 6, the Max-Min inference method and the center of gravity deffuzification strategy. Two input signals are suggested, the generator speed deviation signal Δω and generator speed error change dΔω. The output signal UPSS is damping control signal as seen on figure 7. The point wise input controllers must be fuzzified (determination of their association to each defined fuzzy set in the domain).

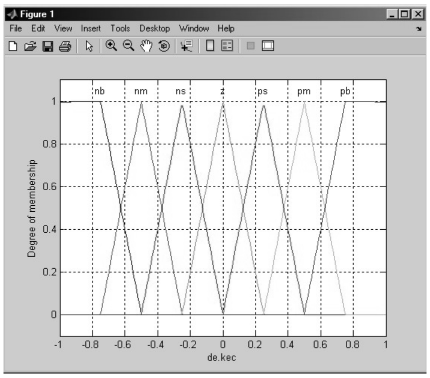


Fig. 6. Classified Fuzzy Sets

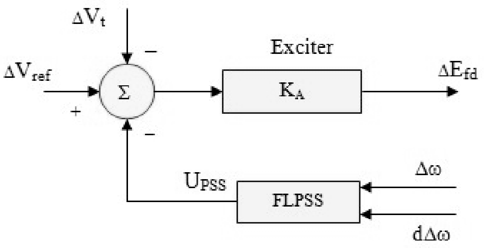


Fig. 7. Exciter and FLPSS Structure Diagram

3.2 Controller Training

The main properties to construct this controller are physical domains and rule base. Physical domains contain normalized counterparts, normalization and denormalization scaling factors and the ranges of fuzzy membership sets. The rule base defines the relationship between the fuzzy controller inputs and its output in fuzzy manner. Forty-nine rules for the proposed controller are to be extracted. These requirements for the proposed controller can be achieved using optimal controllers which guarantee the damping of inter-area modes. For the non-linear system described by the state space equation, the optimal control signal u that minimizes the performance index is a linear function in terms of the system state variable x as:

$$J = \frac{1}{2}\int_{0}^{\infty} (x^T Q x + u^T R u)\, dt \qquad (1)$$

$$u = Kx = -R^{-1}B^{T}Px$$

Q and R are the weighting matrices, K is the feedback gain matrix for the output u and P is the solution of the linear matrix Riccati equation :

$$A^T P + PA - PBR^{-1}B^T P + Q = 0 \qquad (2)$$

Physical domains can be calculated from the generated data for simulation by the optimal controller assuming different disturbances. For the rule base, the relationship between the fuzzy controller inputs and its output can be extracted from algorithm below.

Step1: simulate the optimal controller

Step 2: Save each sample value of (Δω, change in Δω, Upss)

Step 3: At each sample time t:
Δω ∈ the class with max membership among (ω_nb, ω_nm, ω_ns, ω_z, ω_ps, ω_pm, ω_pb) so at sample time Δω is ω_1 ... (a)

change in Δω ∈ the class with max membership among (dω_nb, dω_nm, dω_ns, dω_z, dω_ ps, dω_ pm, dω_ pb) so at sample time t , Δω is dω_1 ... (b)

This will form the contents of the rule-antecedent (If-part of a rule)
Upss ∈ the class with max membership among (u_nb, u_nm, u_ns, u_z, u_ps, u_pm, u_pb)
so at sample time t , Upss is u_1 ...(c)

This contents of the rule-consequent (then-part of the rule). And a total rule can be formed as:
From (a), (b) and (c) : the rule " If Δω is ω_1 and change in Δω is dω_1 then Upss is u_1 "

After generation rules, only small amount of samples can violate to the rule base. These samples are denied according to the results on table 1.

TABLE I
RULE BASE OF THE PROPOSED FUZZY LOGIC CONTROLLER

Speed Dev. Δω	**Speed deviation change dΔω**						
	dw-nb	dw-nm	dw-ns	dw-z	dw-ps	dw-pm	dw-pb
w-nb	u-nb	u-nb	u-nb	u-nb	u-nm	u-ps	u-z
w-nm	u-nb	u-nm	u-nm	u-nm	u-ns	u-z	u-ps
w-ns	u-nb	u-nm	u-ns	u-ns	u-z	u-ps	u-pm
w-z	u-nb	u-nm	u-ns	u-z	u-ps	u-pm	u-pb
w-ps	u-nm	u-ns	u-z	u-ps	u-ps	u-pm	u-pb
w-pm	u-ns	u-z	u-ps	u-pm	u-pm	u-pb	u-pb
w-pb	u-z	u-ps	u-pm	u-pb	u-pb	u-pb	u-pb

4. The Simulation, Results And Discussion

The single line diagram of the South Sulawesi power grid with 4 machine as shown in figure 8 is used to examine inter-area oscillation problem. The grid-ring is simplified and created especially for analysis study of oscillation problem under Simulink configuration. As shown in the single line diagram there are four generators, GEN1, GEN2, GEN3 and GEN4, and four 11.5/150 kV step-up transformers. There are 8 loads in the system except at bus no.7. The transformer and line impedances for the system are given in Appendix and also data of generators. Some of the set up parameters based on their preset value by MATLAB.7-Simulink is acceptable due to the lack of information.

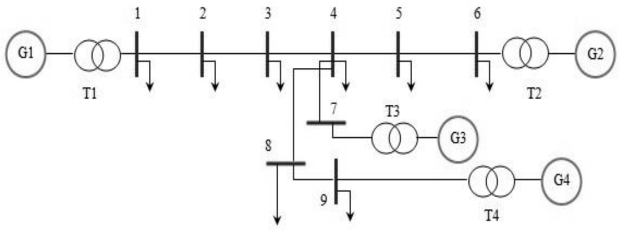


Fig. 8. Single Line Diagram of South Sulawesi Power Grid

This system exhibits seven electromechanical modes of oscillations. Three inter-area mode which the generating units in one area oscillates against those in the other area. The frequency of this mode varies from 0.35-0.75 Hz depending on operating conditions. And four local modes which represent oscillations generating units internally within each area against system. The loads are modeled as constant impedances. A 135 MW electrical power transfer from GEN1 of area#1 to area#2 of GEN2 and area#3 of GEN3 and GEN4 is the main case study which is very stressed operating point.

One set of fuzzy logic controllers (FLC) is used for each area. This set of controllers includes one FLC for the area and one FLC for each generator within the area. The test contains three inter-area. A comparison between the results of a lead-lag, optimal and fuzzy controllers due to different disturbances is presented below. A comparison between resultant performance of optimal and fuzzy controller is needed. So we present the results values for the relation among the controllers graphycally.

Models are simplifications thus there are relatively small numerical error and will not be valid exactly. However when used appropriately the simulation models provide an important results and useful information. Results of simulation are as follow:

Case #1. An increase of 5% in rotor speed at GEN1

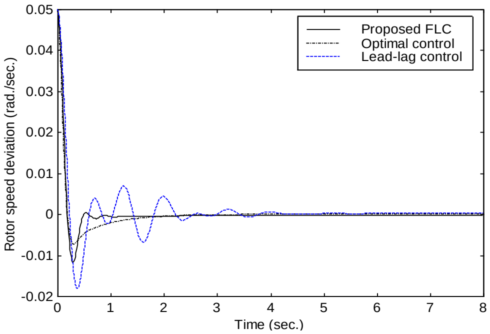


Fig. 9. Electromechanic-Oscillation on GEN1

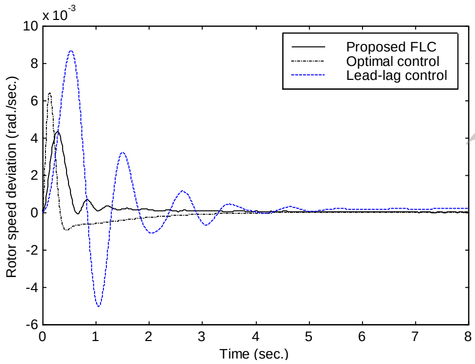


Fig. 10. Electromechanic-Oscillation on GEN2

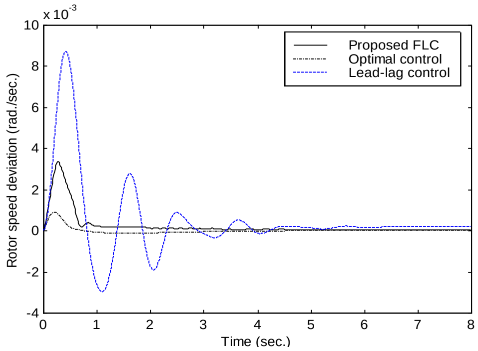


Fig. 11. Electromechanic-Oscillation on GEN3

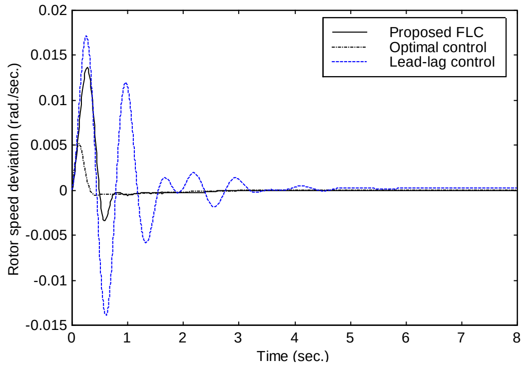


Fig. 12. Electromechanic-Oscillation on GEN4

The results for case #1 show that the fuzzy controller performance index ranges approximately from 7%-15% greater than optimal controller as different disturbances but more effective and efficient in terms of calculation process. Compare to lead-lag controller, the FLC much better to damp oscillations and the result is presented graphycally on figures above Fig.9 - Fig.12 of proposed FLC, optimal and lead-lag controller respectively.

Case #2. An increase of 5% in rotor speed at GEN2

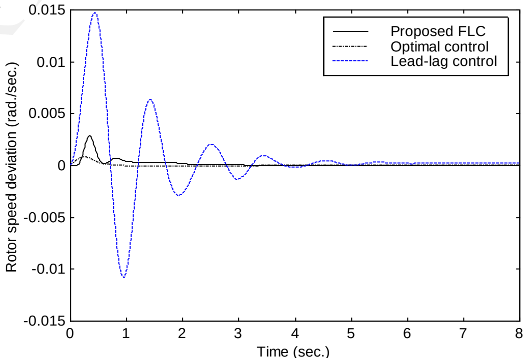


Fig. 13. Electromechanic-Oscillation on GEN1

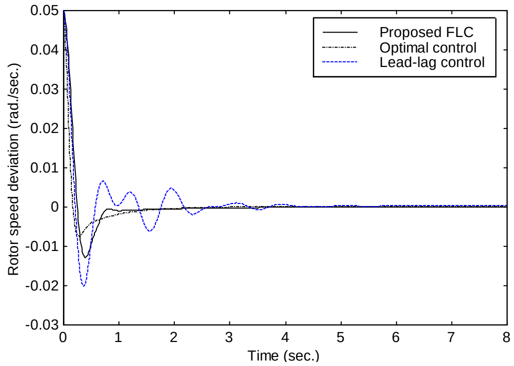


Fig. 14. Electromechanic-Oscillation on GEN2

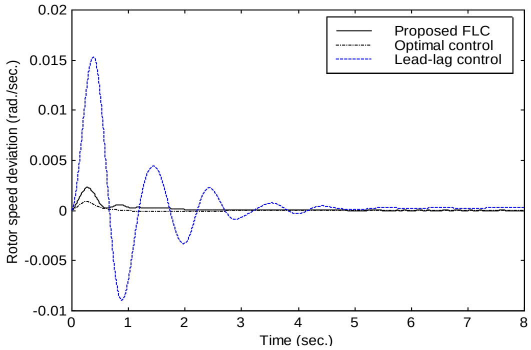


Fig. 15. Electromechanic-Oscillation on GEN3

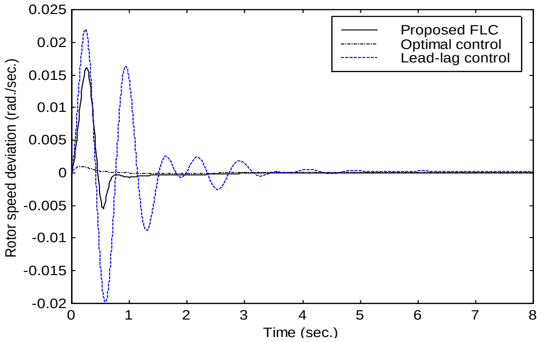


Fig. 16. Electromechanic-Oscillation on GEN4

The simulation results of case #2 above look similarly to case #1. Again the FLC shows its effectiveness. For case #3, an increase of 5% speed in rotor at GEN3 and #4, an increase of 5% speed in rotor at GEN4, look being almost the same if compare to case #1 and #2.

4. Conclusions

The work in this research involves fuzzy logic controller which is built based on data generated by an controller under MATLAB-Simulink environment. A systematic generation of fuzzy logic controller rule base and also input-output domain range has been investigated and tested on South Sulawesi power grid. It has found that the controller provides a more robust control over an excursion of the operating points versus optimal controller and lead-lag stabilizer. Most of the previous control methods either are not working sufficiently under whole range of operating conditions or they need complicated calculations as they require exact models. Decrease in calculations due to the fuzzy logic controller here is a fact.

Result of proposed controller has indicated damping increase and stability enhancement of inter-area modes and works nicely for South Sulawesi power grid in Indonesia in which certainly very useful for PLN as an alternative solution and policy for system stability.

Appendix

SYSTEM DATA

TABLE II
GENERATORS, LOAD AND TRANSFORMERS DATA

No	Bus Name	Generator	Transformer	Load
1	Sengkang	135 MW, 11,5 kV, Xd" = 0,17417 pu	210 MVA, 11,5/150 kV, X = 0,16929 %	30 MVA
2	Soppeng	-	-	40 MVA
3	Sidrap	-	-	20 MVA
4	Pare-pare	-	-	16 MVA
5	Pinrang	-	-	21 MVA
6	Bakaru	126 MW, 11,5 kV, Xd" =0,24 pu	130 MVA, 11,5/150 kV, X = 0,1683%	20 MVA
7	Suppa	80,4 MW, 11,5 kV, Xd" =1,9679 pu	90 MVA, 11,5/150 kV, X = 0,275%	-
8	Pangkep	-	-	93 MVA
9	Tello	180 MW, 11,5 kV, Xd" =1,4125 pu	240 MVA, 11,5/150 kV, X = 0,625%	133 MVA

Data Source: PT. PLN AP2B Sistem Sulawesi Indonesia

TABLE III
GENERATORS IMPEDANCE

No	Generator	Xd	Xd'	Xd''	X1	X0
1	GEN1	3,3527	0,2903	0,17417	0,2467	0,1016
2	GEN2	1,3200	0,3829	0,2400	0,2529	0,1557
3	GEN3	14,515	2,6867	1,9679	1,9679	0,8723
4	GEN4	5,2041	0,4388	1,4125	0,3010	0,1888

Data Source: PT. PLN AP2B Sistem Sulawesi Indonesia

TABLE IV
LINE TRANSMISSION IMPEDANCE

No	Line		Length	Total Impedance (Ohm)		
	from	to	(km)	R	X_L	Y/2
1	Sengkang	Soppeng	35.4	2.369	14.253	0.00004
2	Soppeng	Sidrap	53.8	6.348	22.809	0.00004
3	Sidrap	Pare-pare	19.1	2.254	8.097	0.00001
4	Pare-pare	Pinrang	26.4	3.123	11.192	0.00003
5	Pinrang	Bakaru	58.5	6.921	24.802	0.00004
6	Pare-pare	Suppa	7.5	0.885	3.180	0.00000
7	Pare-pare	Pangkep	90	10.647	38.155	0.00010
8	Pangkep	Tello	45.3	5.359	19.205	0.00005

Data Source: PT. PLN AP2B Sistem Sulawesi Indonesia

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