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Real Power Generation Scheduling to Improve Steady State Stability Limit in the Java-Bali 500 kV Interconnection Power System

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***Abstract*—**This paper will discuss about an active power generator scheduling method in order to increase the limit level of steady state systems. Some power generator optimization methods such as *Langrange,* PLN (Indonesian electricity company) Operation, and the proposed Z-Thevenin-based method will be studied and compared in respect of their steady state aspects. A method proposed in this paper is built upon the thevenin equivalent impedance values between each load respected to each generator. The steady state stability index obtained with the REI DIMO method. This research will review the 500kV-Jawa-Bali interconnection system. The simulation results show that the proposed method has the highest limit level of steady state stability compared to other optimization techniques such as Lagrange, and PLN operation. Thus, the proposed method can be used to create the steady state stability limit of the system especially in the peak load condition.

***Keywords*—**generation scheduling, steady-state stability limit, REI Dimo, margin stability

I. INTRODUCTION

POWER systems are becoming heavily stressed due to the increased loading of the transmission lines and the difficulty of constructing new transmission systems as well as the difficulty of building new generating plants near the load centers. All of these problems lead to the steady state stability problem in the system. There have been a number of incidents in the past years which were diagnosed as steady state stability problems caused by the increased loading and decreased stability margin. The stability margin may be defined as the distance between the loading of the system and the maximum loading limit of the system.

There are different measures against voltage instability in real-time and in the planning and the design stage of a power system. The real- time measures can be of preventive or corrective nature. To prevent immediate loss of voltage stability, corrective actions are needed. Preventive measures are then implemented to improve the steady state stability margin of the system. The preventive and corrective control of steady state stability mainly constitute one or more of the following options: rescheduling real power generation, changing load tap changer (LTC) settings, adjusting phase shifter angles, reactive compensation and load shedding [2]. In the present paper, generator real power rescheduling is considered as the means for enhancing steady state stability of a power system. The method proposed in this paper is built upon the Thevenin equivalent impedance between each load and each power generator. From the steady state stability review, power generators with lower impedance to the power load or the closest one, will have a higher level of stability compared to those with higher impedance. This situation occurs as a result of maximum power transmission to the power load increased, hence, the limit level of the steady state stability increased as well. Power generators with the closest impedance to the load will be operated at the maximum level, followed by other generators. This arrangement should be made by referring to the sequence of Thevenin impedance values. Through this approach, the level of system stability will increase.

There are a number of works reported in the literature regarding the use of generation rescheduling to enhance steady state stability of a power system. In Cutsem (1995), sensitivities of the reactive power generation with respect to the demand are calculated, to determine the generators to be rescheduled. The potentially dangerous contingencies are identified using the Eigen values of the linearized Jacobian matrix that includes the effect of LTCs on steady state stability of the system, and then control actions are taken to improve the steady state stability margin. The corrective and preventive actions against voltage instability are determined in Wang et al. (1998), using optimization. The control cost is taken as the objective function to be minimized. In Feng et al. (2000), direct equilibrium tracing approach is used to examine the steady state stability of the system. The best control actions are found by sensitivity analysis; and linear optimization is used to coordinate the control actions. Different possible control actions considered are rescheduling of real power generation, generator secondary voltage control, addition/removal of shunt capacitance, shunt reactive power compensation and load shedding. Generation rescheduling and load curtailment are used in Capitanescu and Cutsem (2002) as preventive control against voltage in- stability for multiple contingencies.

Most of the available methods of generation rescheduling for steady state stability enhancement use optimization to determine the correct amount of rescheduling needed to drive the operating point away from the potentially dangerous

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situation. The effect of change in control variables on the steady state stability of the system is usually included in the optimization process in the form of linearized sensitivities of the steady state stability margin with respect to the parameters of interest. Derivation of an accurate analytical expression for the sensitivities for multiple contingencies is a challenging task (Capitanescu and Cutsem, 2002). In the present research, an enhanced radial basis function network (RBFN) proposed in Chakrabarti and Jeyasurya (2007) is used to develop an alternative method of computing the sensitivities for different network topologies condition.

II. PROBLEM DESCRIPTION

Economic dispatch is very important to be considered in the planning and operation of power systems. However, the application of economic operation pattern sometimes makes the system less secure stability. This study aimed to see the effects of optimization methods to the stability of steady state power system. Power scheduling method using PLN operation, will be compared with the Lagrange method will be proposed in this paper is Thevenin impedance method. The influence of economic dispatch in steady state stability analysis be concerned in this paper. It is describe that Dimo REI equivalent method will be used to analyze the steady state stability index. The computation of the reactive power criterion $\frac{dQ}{dV} < 0$ instead of evaluating the eigenvalues of the dynamic Jacobian determinant results in an increase of the computational speed by at least one order of magnitude and is at the core of the fast and relatively accurate technique developed by Paul Dimo [6,7,8]. Dimo's method, which has been successfully implemented and is currently used in several SCADA/EMS installations to compute the system loadability limits in real time and to continuously monitor the distance to instability [12,22,23,27,28].

At the time of the generation pattern changes, there will be changes to the steady state stability index. With equation (1), the stability index for each change of the generation operation can be calculated [1].

$$\frac{d\Delta Q}{\mathrm{dV}} = \sum_m \frac{Y_m E_m}{\cos\delta_m} - 2\left(\sum_m Y_m + Y_{load}\right)V \tag{1}$$

where:

E_m = internal voltages of the machines (assumed to remain constant, unaffected by small adjustments made under steady-state stability conditions)
δ_m = internal angles of the machines with reference to the voltage V on the load bus (either fictitious or actual)

The value of steady state index that obtained from equation (1) describe the condition of system stability. The pattern of active power generation obtained from the PLN, Lagrange optimization and Z Thevenin be compared, where the best pattern of steady state stability.

III. METHODOLOGY

A.Establish Z Thevenin Matrix

For example: A power system consists of three generators and three loads. Illustration of the system can be described in figures (1).

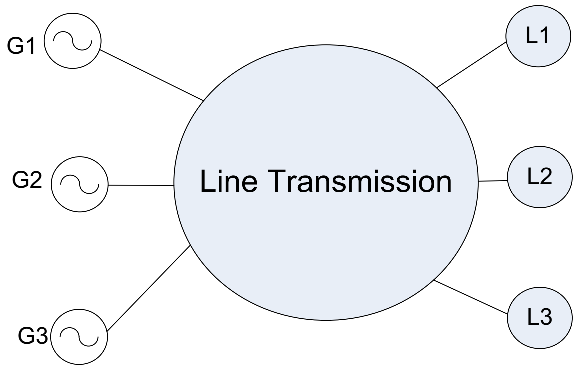


Fig. 1 System Illustrations Schema

Current and voltage equations are formed :

$$[I] = [Y][V]$$

or

$$[V] = [Z][I]$$

The sequence of bus number started from generator bus to load bus.Furthermore, the matrix of voltage system is obtained as follows:

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & Z_{13} & Z_{14} & Z_{15} & Z_{16} \\ Z_{21} & Z_{22} & Z_{23} & Z_{24} & Z_{25} & Z_{26} \\ Z_{31} & Z_{32} & Z_{33} & Z_{34} & Z_{35} & Z_{36} \\ Z_{41} & Z_{42} & Z_{43} & Z_{44} & Z_{45} & Z_{46} \\ Z_{51} & Z_{52} & Z_{53} & Z_{54} & Z_{55} & Z_{56} \\ Z_{61} & Z_{62} & Z_{63} & Z_{64} & Z_{65} & Z_{66} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix}$$

To determine Z thevenin between G2 generator and L3 load, then the value of I_1=I_3=I_4 =I_5 =0, this is due to G1 and G3 generator are not supplying current. Similarly, L1 and L2 load.
Voltage equation becomes :

$$\begin{bmatrix} 0 \\ V_2 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & Z_{13} & Z_{14} & Z_{15} & Z_{16} \\ Z_{21} & Z_{22} & Z_{23} & Z_{24} & Z_{25} & Z_{26} \\ Z_{31} & Z_{32} & Z_{33} & Z_{34} & Z_{35} & Z_{36} \\ Z_{41} & Z_{42} & Z_{43} & Z_{44} & Z_{45} & Z_{46} \\ Z_{51} & Z_{52} & Z_{53} & Z_{54} & Z_{55} & Z_{56} \\ Z_{61} & Z_{62} & Z_{63} & Z_{64} & Z_{65} & Z_{66} \end{bmatrix} \begin{bmatrix} 0 \\ I_2 \\ 0 \\ 0 \\ 0 \\ I_6 \end{bmatrix}$$

or :

$$[V_2] = [Z_{21}][0] + [Z_{22}][I_2] + [Z_{23}][0] + \cdots + [Z_{26}][I_6] \tag{2}$$

$$[V_2] = [Z_{22}][I_2] + [Z_{26}][I_6] \tag{3}$$

Current magnitude $[I_6] = [-I_2]$, because the total current coming out of the generator equal to the total current flowing to the load but with different directions.

Then obtained:

$$[V_2] = ([Z_{22}] - [Z_{26}])[I_6] \tag{4}$$

Thevenin circuit from power source G2 to the load L3 can be described as follows:

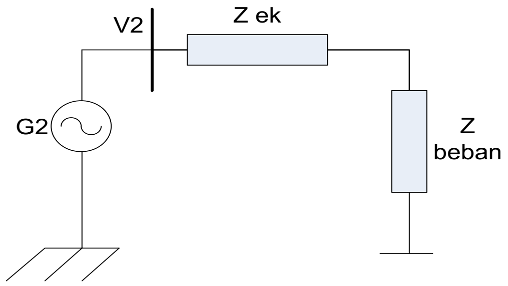


Fig 2. Thevenin Circuit

$$[V_2] = ([Z_{ekv}] + [Z_{beban}])[I_2] \tag{5}$$
$$[Z_{22}] - [Z_{26}] = [Z_{ekv}] + [Z_{beban}] \tag{6}$$

Thus obtained:

$$[Z_{ekv}] = ([Z_{22}] - [Z_{26}]) - [Z_{beban}] \tag{7}$$

TABLE I
CORRELATION BETWEEN LOAD AND GENERATOR IMPEDANCE

Load\Gen	*G1*	*G2*	*G3*
L1	*Z11*	*Z12*	*Z13*
L2	*Z21*	*Z22*	*Z23*
L3	*Z31*	*Z32*	*Z33*

Where: Z11=Z12=Z13=Z21=Z22=Z23=Z31=Z32=Z33 are thevenin impedance. From this matrix load operation pattern (L1, L2, L3) for which the generators are operating at maximum can be determined.

Suppose L1 load into the system, which will operate the plant is a plant which has a maximum value of Z Thevenin smallest (from the matrix above)

III. RESULT AND DISCUSSION

From the simulation obtained value of steady state stability limit (SSSL) for every plant optimization methods. In the figure 3, shows that the Thevenin equivalent method have value of SSSL greatest value in a row followed, Lagrange, PLN.

Z Thevenin method is capable of improving the condition of the system stability. So this method is necessary especially at peak load operating conditions that are closed to unstable condition. In table 2, looking for operations using Z Thevenin obtained the SSSL value is 18.126 MW. Followed by the Lagrange method (17.497 MW), and PLN (16.319 MW).

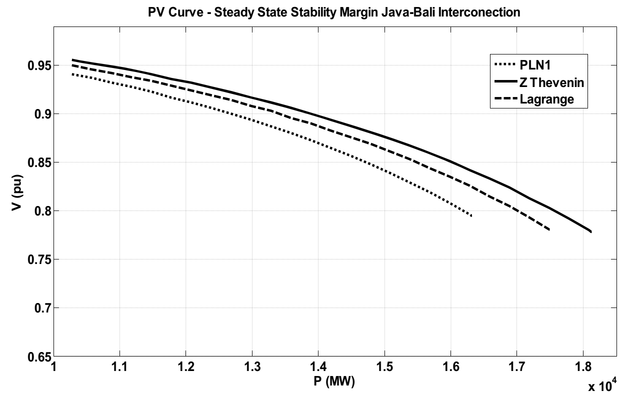
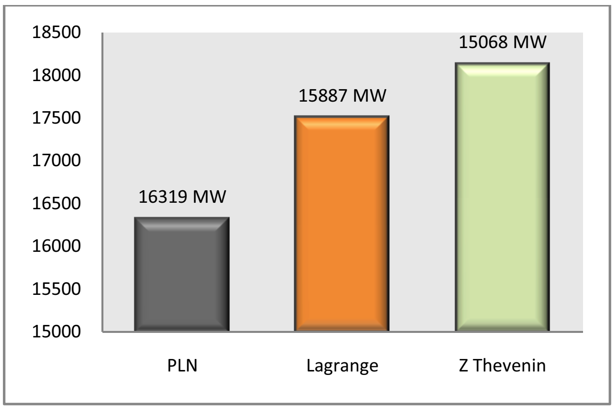


Fig. 3 PV curve of Java-Bali interconnection system for Different Optimization Methods

TABLE II.
COMPARISON OF STEADY STATE STABILITY LIMITS FOR DIFFERENT METHODS



Limit the maximum loading is influenced by the value of impedance between the load and generator. If the impedance value is smaller, the maximum power transfer will increase. This relationship can be seen in the following equation:

$$P = \frac{E_s E_R}{X_T} \sin(\delta_s - \delta_R) \tag{8}$$

Using Thevenin impedance method, plant operations adjusted impedance value between the generator and the load point to point. Generator which has the smallest impedance values, would be prioritized for maximum operating other plants was followed by a large impedance values obtained.

P value will increase with the increasing level of value and the value of XT and an increasingly small.

In the figure 4, the relationship of P to changes in the value of d and e obtained by the relationship that, the lower the value of d and e are large value would raise steady state stability limit. Of all the rigorous optimization method in this study, the Thevenin impedance method has the lowest value of d and e of the largest value so that the steady state stability limit for this method to be greatest.

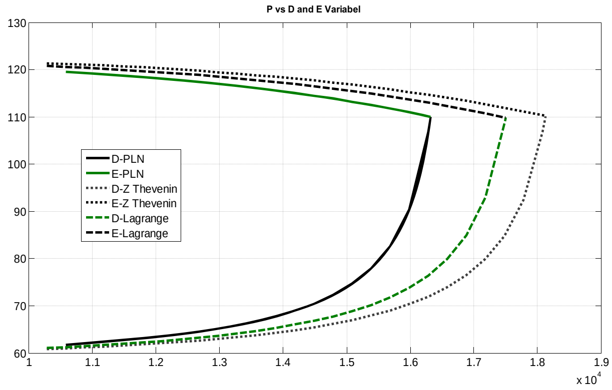


Fig. 4 P vs D and E Variabel

In the fig. 5, the slope of the slope between changes in the stability of the power to change the index will provide information about the stability of the steady state. Using the Z Thevenin method is obtained the slope of a large slope so that any changes will cause changes in load power greater stability.

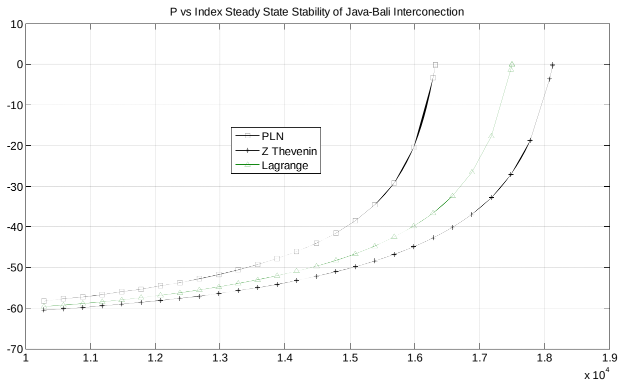


Fig. 5 P vs Index Stability

The relationship between changes in voltage to changes in the value of stability index can be seen in the figure 6. From the figure show that the changes produce the same voltage rate of change of the stability of the different indices. Thevenin impedance drop method has the lowest stability index decreased to decrease the voltage. This provides information that in the event of voltage drop caused by the load on the Load Center caused a decrease in the stability index that is not too large when compared to other optimization methods. So that at steady state stability studies, using Thevenin impedance operation will be able to improve the condition of the system stability.

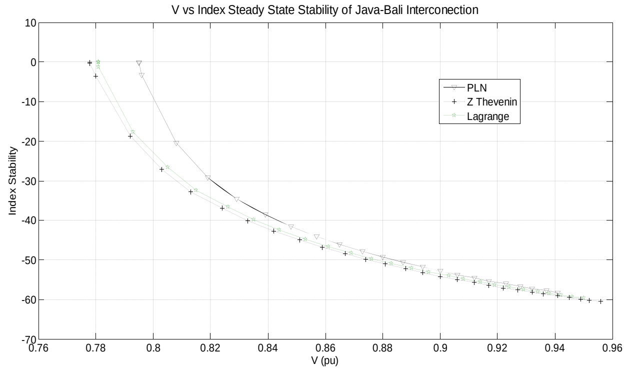


Fig. 6 Voltage vs Index Stability

This load limit is obtained from the Java-Bali system model into the form of Dimo REI equivalent.

$$\frac{d\Delta Q}{\mathrm{dV}} = \sum_m \frac{Y_m E_m}{\cos\delta_m} - 2\left(\sum_m Y_m + Y_{load}\right)V$$

From the equation above, to determine the pattern of economic relations to be represented on the stability index value $\frac{d\Delta Q}{\mathrm{dV}}$ is determined by changes in the parameters V and $\cos\delta_m$. The closer the distance load to the power plant that supplies the value $\cos\delta_m$ will be greater because of the difference angle bus send and receive the smaller, the result will be worth the value of d $= \sum_m \frac{Y_m E_m}{\cos\delta_m}$ and e = $2\left(\sum_m Y_m + Y_{load}\right)V$ will be smaller and greater value. The small value of d and the value of e, resulting in the distance to d = e or $\frac{d\Delta Q}{dV} = 0$ become more distant. So this method can increase the limit stability system. To see the effect of the value of d and e of the steady state stability limit can be seen in the figure 6.

Determination of stability power reserve and voltage stability reserve can be determined using the following equation:

$$Power\ Stability\ Reserve = \frac{P_{max} - P_{base\ case}}{P_{base\ case}} \times 100\%$$

$$Voltage\ \ Stability\ Reserve = \frac{V_{max} - V_{base\ case}}{V_{base\ case}} \times 100\%$$

On the table III, thevenin impedance seen that the method has a better security level. Stability margin is left for the initial loading conditions to the unstable conditions of about 76.29% followed by Langrange Method 70.17%, and PLN 58.71%

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TABLE III
COMPARISON OF RESERVE POWER SYSTEMS

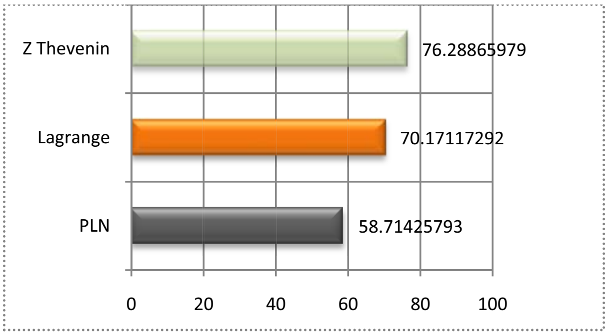
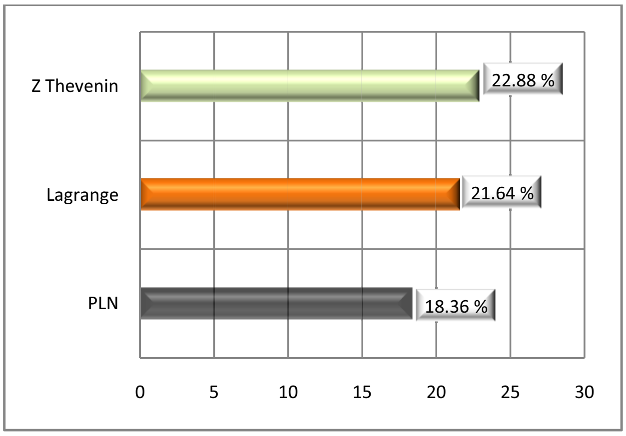


TABLE IV
COMPARISON OF VOLTAGE POWER SYSTEMS



From the table IV, shows that the Thevenin impedance method has a margin of greater voltage stability. This margin is very influential in the phenomenon of voltage collapse. The greater the margin is the distance to the further condition of voltage collapse

IV. CONCLUSION

From the simulation results shows that the generation rescheduling method proposed in this paper, is able to improve steady state stability index when compared with other methods such as the economy dispatch Merit Order (PLN operation) and Lagrange. This can be seen from the increase in steady state stability limit. This method is expected to be implemented at the peak load operation or at special events require a better level of security. With already in implementations Dimo REI method on real-time monitoring systems in several countries, it is expected that the method proposed in this paper becomes an additional tool to facilitate the generation rescheduling from the study of steady state stability

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