THE EFFECTS OF SIGNIFICANT UNBALANCED THREE PHASE LOADS OF 500 kV EHV JAMALI SYSTEM ON ITS GENERATING UNIT UNDER STEADY STATE OPERATION

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Abstract

A method is described for determining dynamic solutions for electrical steady-state that accompany unbalanced disturbances on synchronous generator connected to the 500 kV EHV Jamali System. The system can be modeled as a balanced synchronous generator's model based *qd* reference of frame with unbalanced voltage inputs. Meanwhile, the load locations having significant effect on the test generators are obtained by using the electricity tracing method. Two unbalanced steady-state conditions of the grid are obtained by setting significant IBTs (or inter bus transformers), the Jamali's grid loads, into load imbalance of 5% and 7%. Finally, the feasibility of the proposed model and method are validated by numerical results.

Keywords: unbalanced disturbance, 500 kV EHV Jamali System, *qd* reference of frame, IBT.

1. INTRODUCTION

Many studies regarding unbalanced steady state operating conditions of synchronous generators as a generating unit have done using the analytical methods. The characteristic of the unbalance comprises unequal voltage-magnitudes at the fundamental system frequency and fundamental phase-angle deviation. One of its causal factors is the appearance of unbalanced loads of the generator. In seriously unbalanced systems, the overheating of the machineries may be caused by negative sequence current; meanwhile, zero sequence current may cause improper action of the protective relaying (Birt *el,* 1976).

In Megahed and Malik (1999), it has been understood to calculate unbalanced short-circuits of synchronous generator under steady state condition. Analysis based on mathematical theory which includes single line-to-neutral fault and the line-to-line fault, is been utilized.

But according to Peng (2011), the other problem of the unbalance when the system is connected the grids has not been thoroughly solved. Most of researchers analyze the small signal dynamic performance of synchronous generator connected to the load under any unbalanced operation conditions only focus on the distributed generating case and *single machine infinite bus* or SMIB.

The load-flow program can be used to analyze unbalanced steady-state problems of synchronous generator as long as more realistic synchronous generator model is implemented (Acha, 2005). So the goal of this study is to design a complete mathematical model of balanced synchronous generator operated under unbalanced steady state condition and also can accommodate the load-flow analysis to determine values of generator's terminal inputs when the changing loads happened in the grid connected to it. To determine a significant loads on the 500 kV EHV Jamali, the electricity tracing called the *common method* can be used.

This work is organized as follows. A brief explanation about the concepts and algorithms involving the unbalanced condition of balanced synchronous generator is defined on Section I. Section II presents the studied system. The example and analysis are presented on Section IV. Section V presents the final conclusion obtained with the present study.

2. STUDIED SYSTEM

The studied power system is the 500 kV EHV Jamali System that comprises 4-regions, such as Banten-Jakarta (Region 1) , West Java (Region 2), Central Java-Yogyakarta (Region 3) and East Java-Bali (Region 4). It also has 71 line nodes, 27 lines of inter buses and 9 generator nodes, as shown in Fig. 1. In this system, Paiton's bus is the swing node and others are the PV nodes. System capacity is 100,000 MVA. The Test generators are Tanjung Jati B.

The synchronous generator used in this study is a 820 MVA. 4-pole, 50 Hz, round-rotor generator, which is connected to the 500 kV EHV Jamali System through a 18 kV parallel transmission line.

The scheme definition is unbalanced condition. According to this plan, using EDSA 2000 software program based Newton-Raphson method we can get the flow calculation results in Fig. 2. By using the *common* method, the Jamali System can be divided into 13 commons, such as 6 commons of supplied energy

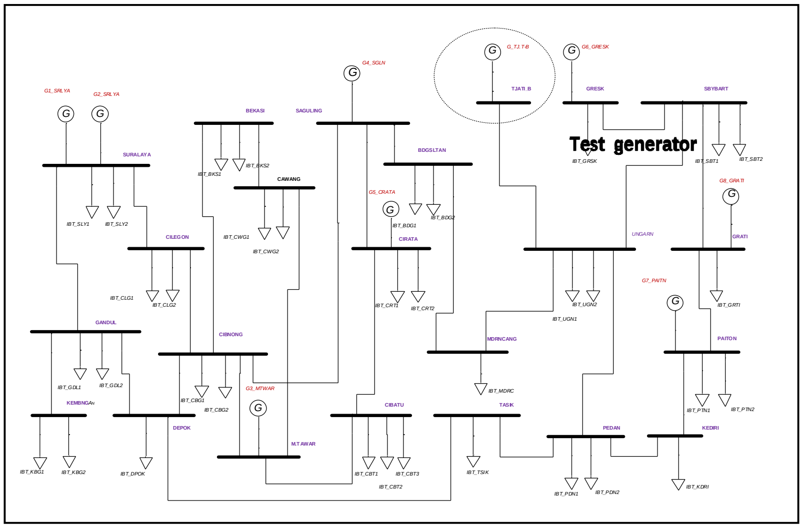


Fig. 1. The studied power system

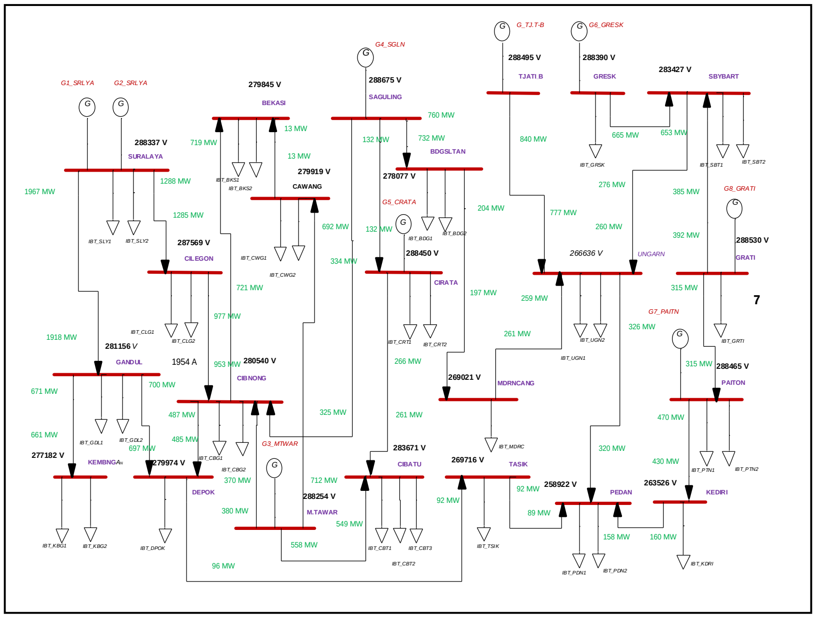


Fig. 2. Distribution of flow calculation results

by generator from the one bus and 7 commons of supplied energy by generator from different buses, shown in Fig. 3.

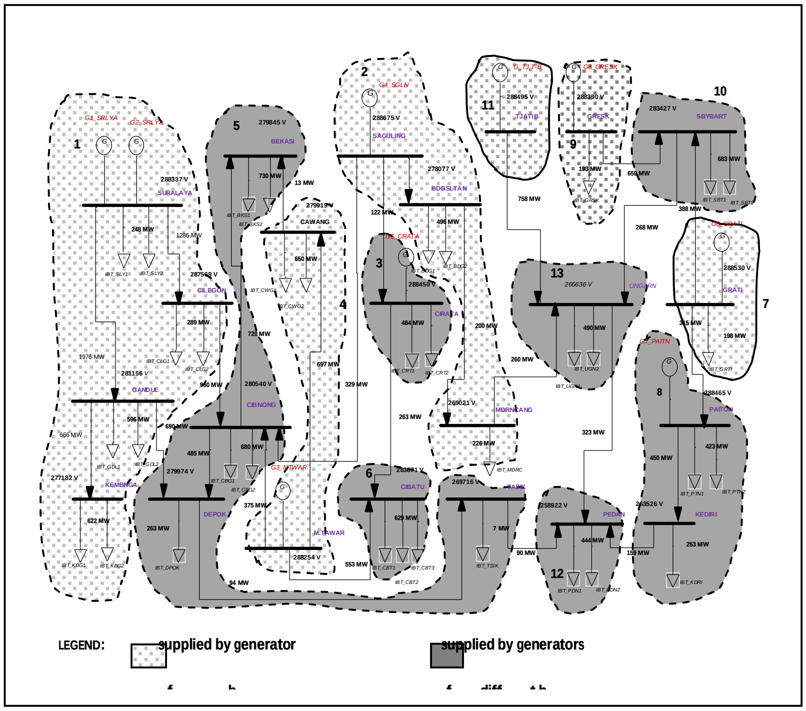


Fig. 3. *Flows* and *commons* under balanced condition

The calculation of each generator into flows and loads can be done using Eq. (1) (Kirschen and Strbac, 1997, 1999).

$$C_{ik} = \frac{\sum_j F_{ijk}}{I_k} \tag{1}$$

where C_{ij} and C_{ik} are contribution generator *i* into loads and outflow of the *common j* dan k, respectively. F_{jk} and F_{ijk} are the flows at the *link* between *common- j* and *k* and the flows at *link* between *common j* and *k*, respectively.
Using combination between Eq. (1) and Fig.3, it is obtained the contribution factor of test generator. (Tabel 1).

The model of this generator is shown in Fig. 4 and Fig.5**.** The generator has two-dampers. Damper windings in the equivalent generator model can be used to represent physical *armotisseur* windings.

Table 1. Contribution factor of test generator

Common Number	**Percentage of Contribution [%]**
	Generator of Tanjung-Jati B
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	100
10	62.94
11	0
12	33.28
13	58.94

The mathematical description or model develop is based on concept of an ideal synchronous generator. The fields produced by the winding currents are assumed to be sinusoidal distributed around the air-gap. This assumption of sinusoidal field distribution ignores the space harmonics, which may have secondary effects on the machine's behavior. It is also assumed that stator slots cause no appreciable variation of any of the rotor winding inductances with rotor angle.

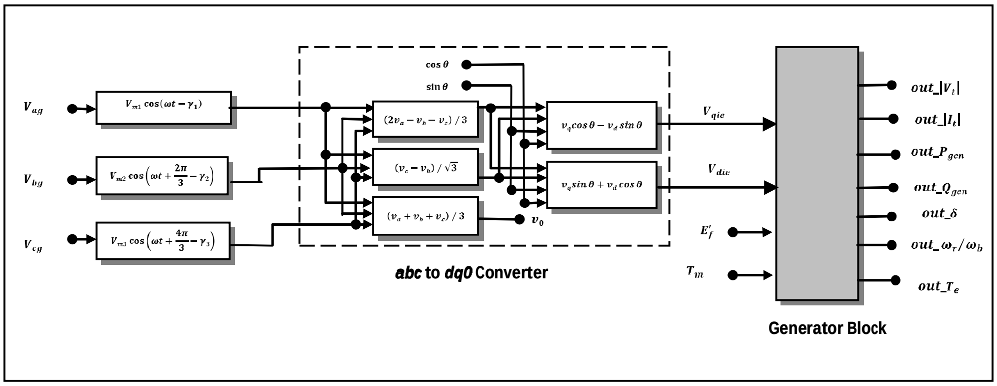


Fig. 4. Balanced generator with unbalanced inputs (Sugiarto *et al*, 2013)

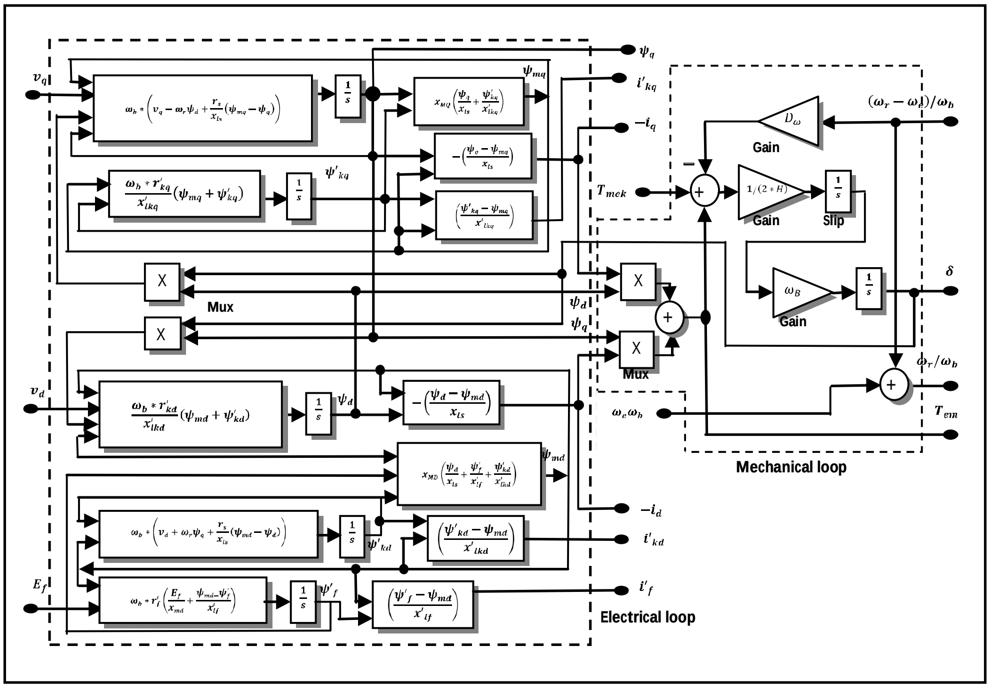


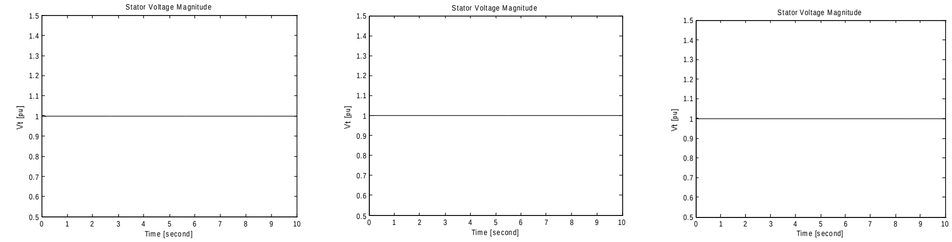
Fig. 5. The inside section of synchronous generator (Sugiarto *et al*, 2013)

3. DEMONSTRATION

Table 2 presents inter-phase voltage values of the test generator terminal, before and after loading condition. It is shown that under unbalanced loads condition, the phase angles of terminal generator voltage are deviated from its balanced value. The biggest deviation occurs when the grid operates under 7% of unbalanced load condition.

Table 2. Values of Tanjung Jati B's generator terminal voltage

Conditions of Synchronous Generator	**Phase**	**Tanjung Jati B Voltage [p.u]**
Connected the grid and load balance	a	$1\angle -15^{O}$
	b	$1\angle 120^{O}$
	c	$1\angle 240^{O}$
Connected the grid and load imbalance of 5%	a	$1\angle -15{,}1^{O}$
	b	$1\angle 120^{O}$
	c	$1\angle 240^{O}$
Connected the grid and load imbalance of 7%		$1\angle -15{,}2^{O}$
		$1\angle 120^{O}$
		$1\angle 240^{O}$

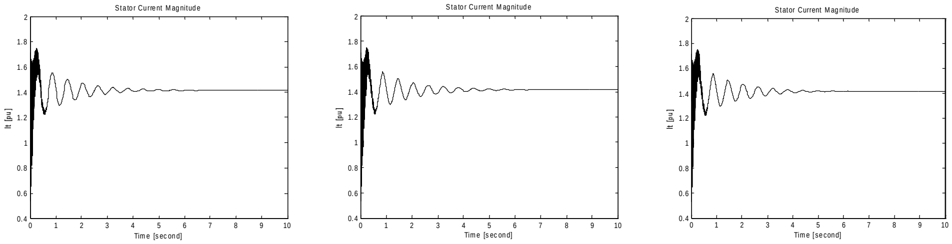


all of balanced loads

5% of significant unbalanced loads

7% of significant unbalanced loads

Fig.6. Stator voltages of Tanjung Jati B

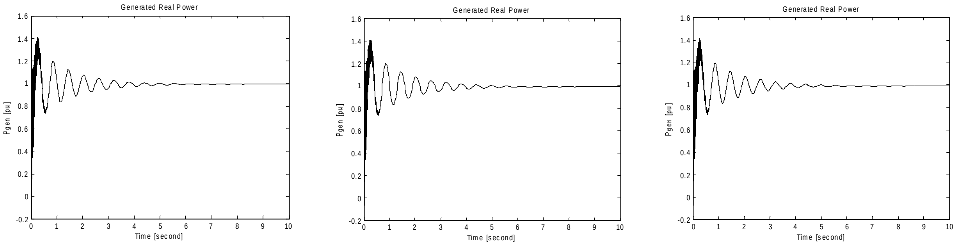


all of balanced loads

5% of significant unbalanced loads

7% of significant unbalanced loads

Fig.7. Stator voltages of Tanjung Jati B

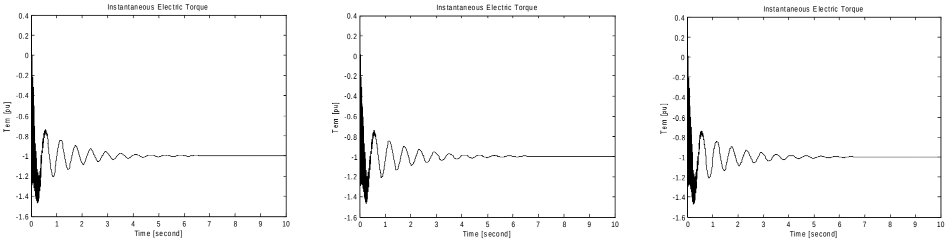


all of balanced loads

5% of significant unbalanced loads

7% of significant unbalanced loads

Fig.8. Generated real power of Tanjung Jati B

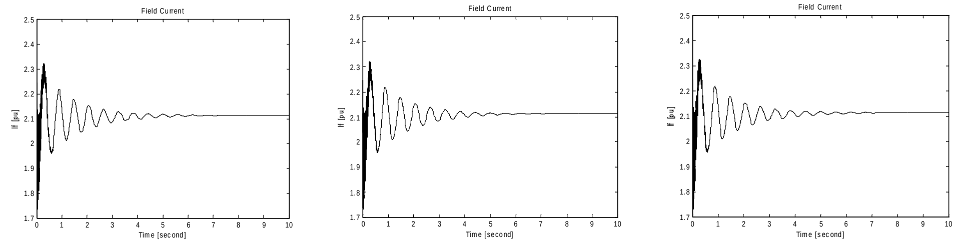


all of balanced loads

5% of significant unbalanced loads

7% of significant unbalanced loads

Fig.9. Electrical torque of Tanjung Jati B

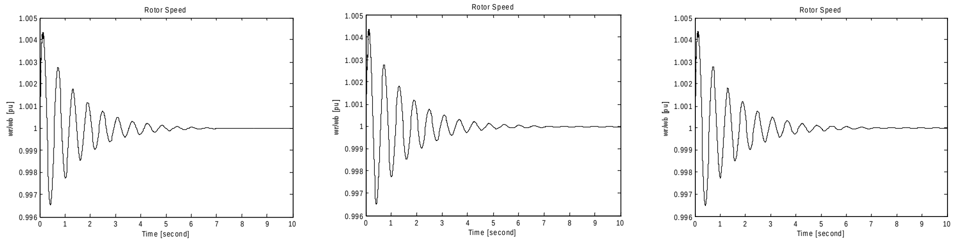


all of balanced loads

5% of significant unbalanced loads

7% of significant unbalanced loads

Fig.10. Field currents of Tanjung Jati B

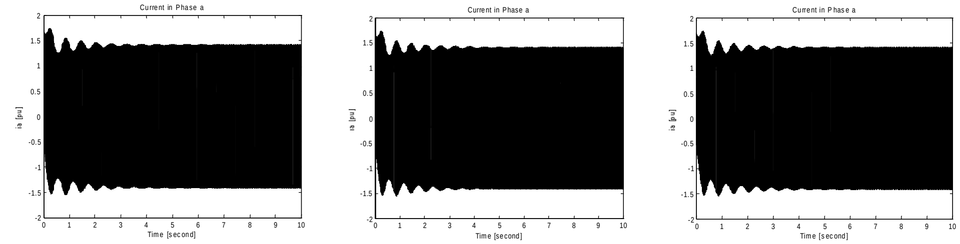


all of balanced loads

5% of significant unbalanced loads

7% of significant unbalanced loads

Fig.11. Rotor speed of Tanjung Jati B

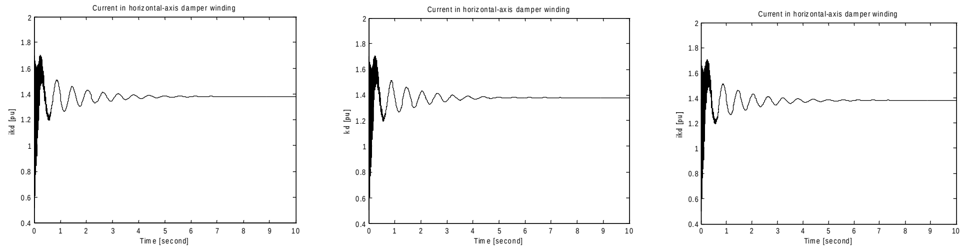


all of balanced loads

5% of significant unbalanced loads

7% of significant unbalanced loads

Fig.12. Currents in fase-*a* of Tanjung Jati B



all of balanced loads

5% of significant unbalanced loads

7% of significant unbalanced loads

Fig.13. Currents in *d*-axis damper winding of Tanjung Jati B

Figure 6 to Figure 13 represent all of currents of Tanjung Jati-B's generator under balanced and unbalanced load conditions. There is an interesting phenomenon which has been occured. The waveform of current in dynamic variables of synchronous generator under balanced loads for all IBT has similar form with 5% and 7% under unbalanced loads at IBT Suarabaya-Barat, IBT Ungaran and IBT Pedan.

4. CONCLUSIONS

By numerical siumulation, combination among unbalanced three-phase Newton-Raphson load-flow, the rotor's *qd0* reference frame of synchronous generator model and electricity tracing method can be used to reflect the dynamic of synchronous generator under unbalanced steady state operation. Two operation conditions of the synchronous generator, load balanced and load imbalance of 5% are mathematically modeled.

At Tanjung Jati B a test generator, with the increasing percentage of unbalance at all loads, the dynamic of synchronous generator might be simillar compares to its condition when the unbalance operation occurred at only 3 significant loads, which are IBT Surabaya Barat, IBT Ungaran, and IBT Pedan.

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