A Hybrid Newton-Raphson Unbalanced Three-Phase Loadflow and Rotor's *qd0* Reference Frame of Syncronous Generator Model as An Alternative Tool for Studying The Impact of Unbalanced Loads on Power Angle Change of Three Phase Synchronous Generator Connected the Power System Grid

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Abstrak *- Isu tentang dinamika sistem tenaga sering dipelajari dengan melihat respon dinamis generator yang terhubung dengan grid listrik, dengan interaksi keduanya menjadi fokus pertimbangan. Paper ini menguraikan kajian khusus tentang dampak beban takseimbang dari grid terhadap perubahan sudut rotor generator sinkron dalam kondisi mapan dengan bukti-bukti kuantitatif. Karena interaksi dinamis biasanya ditandai oleh karakteristik interaksi oleh kedua struktur-grid dan variabel status terkait maka penggambaran akurat tentang perilaku dinamis dari generator sinkron dalam kondisi takseimbang dapat dilukiskam oleh model nonlinier diferensial - aljabar kompleks. Pada paper ini, tool alternatif untuk mempelajari perilaku dinamis dibentuk dari hibrid aliran daya tiga fasa tidak seimbang Newton-Raphson dan kerangka referen qd0 rotor generator sinkron. Window aktif dengan model generator ini didasarkan pada kerangka referen qd0 dan dikembangkan menggunakan Graphical User Interface (GUI) Visual berkemampuan memeriksa sudut rotor dari mesin setelah kemunculan gangguan kecil dengan fokus pada elektromagnetik dinamis yang dipengaruhi oleh beban takseimbang. Aliran daya tiga fasa takseimbang Newton-Raphson digunakan untuk memperoleh masukan terminal generator melalui analisis aliran beban pada grid. Hasil penelitian menunjukkan bahwa terjadi pengaruh yang signifikan dari beban takseimbang terhadap sudut daya.*

Kata kunci: *Beban takseimbang, kondisi mapan, GUI, Aliran daya takseimbang Newton-Raphson, kerangka referen qd0 rotor*

Abstract *– The issues considering power system dynamics are often studied by looking at the dynamic responses of generators connected through the power grid, taking their interactions into consideration. This work decribes a specific study on the impact of unbalanced loads of the grid on rotor angle change of synchronous generators under steady state condition with quantitive evidence. Since the dynamic interactions are usually characterized by both grid-structure-related and status-related variables, an accurate portrait of the dynamic behavior of synchronous generators under unbalanced conditions can be described by a complex nonlinear differential-algebraic model. In this paper, an alternative tool for studying such dynamic behaviour was created by hybrid Newton-Raphson unbalanced three-phase loadflow and rotor's qd0 reference frame of synchronous generator. Active windows with this generator model based on qd0 framework were developed using Visual's Graphical User Interface (GUI) capability to examine the rotor angle of the machine after small perturbations, focusing on electromagnetically dynamic as affected by load unbalance. Newton-Raphson unbalanced loadflow was used to derive the generator's terminal inputs through load-flow analysis on the grid. The results showed that the significant influence of unbalanced loads occured in power angle.*

Keywords*: Unbalanced load, Steady-state condition, GUI, Newton-Raphson unbalanced loadflow, rotor's qd0 reference frame.*

INTRODUCTION

The dynamics of the power system centered on the interaction dynamics generator connected to grid power systems. This is known as a dynamic interaction generally characterized by a combination relation grid structure and variables related to status. Variables related to the structure of the grid is usually a time invariant variables, such as the impedance of the transmission line, the location and type of generators and loads. While related variables are variables whose status varies according to the working steady state conditions, such as bus voltage, power angle, and angular speed of the generator.

To analyze the power system in the steady state needed a power flow analysis or load flow. As for the view angle changes synchronous generator power we need a complete mathematical model of balanced synchronous generator operated under unbalanced steady state condition. This needs a synchronous generator model which has a completely enough framework for analyzing the small-signal dynamic performance of power systems under unbalanced conditions.

Until now there is no attractive theoretic mathematics models of synchronous generators used to analyze this kind of problems mentioned above. The presented study considers several typical synchronous generators which are connected to 500 kV EHV Jamali System, Indonesia. The study is carried out through the "hybrid" method by combination between unbalanced load-flow Newton to analyze the grid and determine the inputs of the test generator and the rotor's *qd0* reference frame of synchronous generator model to substitute the loadflow generator's model. The verification of the proposed model was checked by comparing it with a Tecquiment NE9070 simulator.

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 simulation method of synchronous generator dynamic. The example and analysis are presented on Section IV. Section V presents the final conclusion obtained with the present study.

STUDY SYSTEM

The studied power system is the 500 kV EHV Jamali System 8 autonomous grids of Indonesia network 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) (ESDM, 2003). 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 model of this generator is shown in Fig. 2 and 3**.**

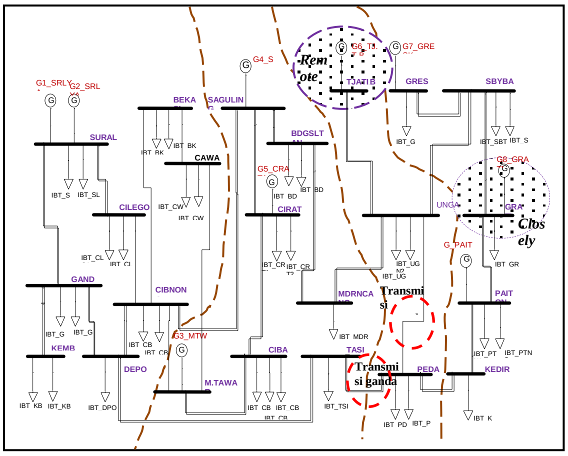

Fig. 1. The studied power system

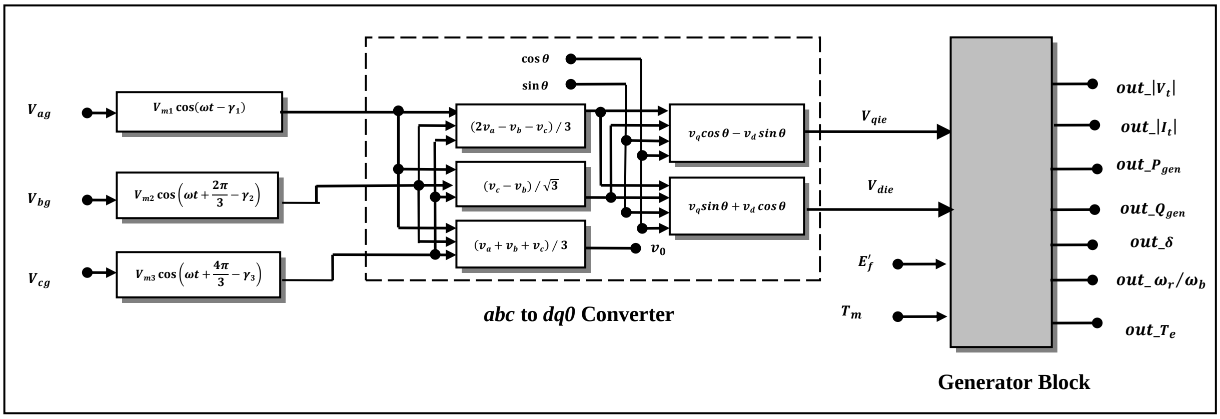

Fig. 2. Balanced generator with unbalanced inputs

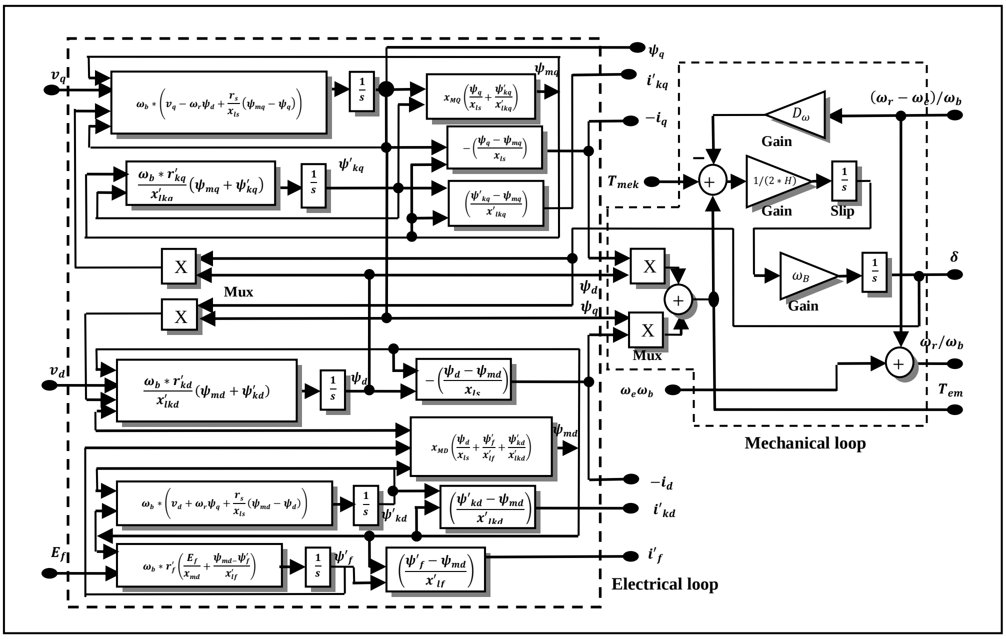

Fig. 3. The inside section of synchronous generator

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 (Boldea, 2006).

A software package which applied GUI facilities has been created for analysis of power angle change of synchronous generator under unbalanced steady-state conditions (Fig. 4). As an example of using GUI capabilities, menu and plotting commands are implemented in a script file to provide interactive windows. The main menu, which is displayed after running the file, are shown in Fig. 5 and Fig. 6.

The verification of the generator model is judged through comparing between generator's respon by PSS Tecquipment NE9070 (Fig. 7) and by the proposed model under balanced and unbalanced conditions, respectively.

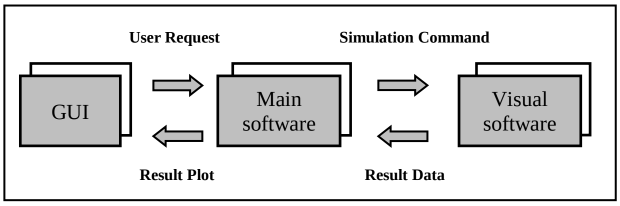

Fig. 4. Designed Simulator with GUI

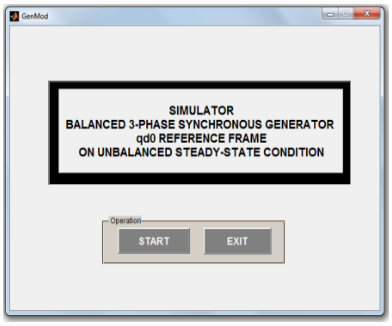

Fig. 5. The main window of the software tool

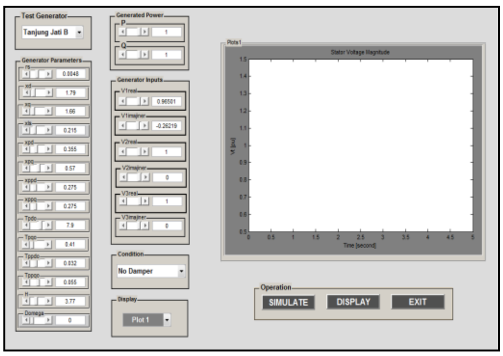

Fig. 6. The window of inserting the inputs for balanced generator and unbalanced inputs

The verification of the generator model is judged through comparing between generator's respon by PSS Tecquipment NE9070 (Fig. 8) and by the proposed simulator under no load, balanced and unbalanced conditions, respectively (Sugiarto *et al*, 2013).

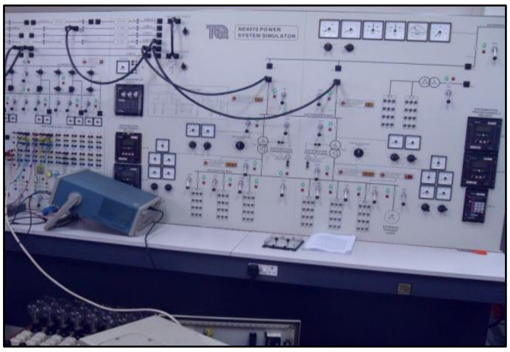

Fig. 7 . PSS Tecquipment NE9070

DEMONSTRATION

Using Newton-Raphson unbalanced three phase loadflow software program one can get the flow calculation results from Fig. 1. Table 1 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 balanced load condition.

Table 1. Values of generator terminal voltage

CONDITIONS OF SYNCHRONOUS GENERATOR	PHASE	TANJUNG JATI B VOLTAGE [P.U]
CONNECTED THE GRID AND LOAD BALANCE	*A*	$1\angle -17^{o}$
	B	$1\angle 103^{o}$
	C	$1\angle 223^{o}$
CONNECTED THE GRID AND LOAD IMBALANCE OF 7.5%	*A*	$1\angle -17.4^{o}$
	B	$1\angle 102.6^{o}$
	C	$1\angle 223.6^{o}$

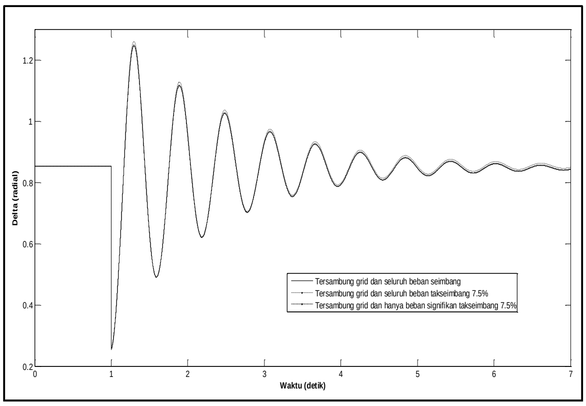

Fig. 8. Power angle of Tanjung Jati B's generator at balanced and unbalanced loads

Figure 8 represents power angle of Tanjung Jati B's generator under balanced and unbalanced load conditions. There is an interesting phenomenon which has been occured. At steady state conditions, the Tanjung Jati B's generator produces δ (power angle) of 1.248 rad in a balanced condition. If the grid is loaded by 7.5 % of unbalance, power angle becomes 1.251 rad. An interval of achievement of steady or t_SS conditions of 3.5 seconds (at 2 % error steady conditions).

CONCLUSION

A useful simulator for analysis power angle change of synchronous generator under unbalanced steady state sonditionhas been presented in this paper. Two operation conditions of the synchronous generator, load balanced and load imbalance of 7.5% are mathematically modeled then simulated using visual software.

The simulation results state that power angle has been changed on the generator dynamic during balanced and unbalanced steady state condition.

The developed tool is made easy to use by providing an active link with the simulated models using some of GUI functions. The given examples demonstrate helpfulness of the developed tool for analyzing power angle of synchronous generator connected to the grid and under unbalanced steady state operation

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