DAMPER WINDING PHENOMENA OF SYNCHRONOUS GENERATOR UNDER UNBALANCED STEADY-STATE CONDITION: A CASE OF 500 KV EHV JAMALI SYSTEM

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ABSTRACT

The performance of three different damper winding configurations of a synchronous generator under unbalanced steady-state condition of the power system to which it is connected are investigated in this paper. This synchronous generator is a source of electrical energy generation system in the 500 kV EHV Jawa-Madura-Bali (or Jamali) System with untransposed transmission lines and many single-phase loads.

Induced currents of damper windings under the unbalanced steady-state system conditions, when the synchronous generator is equipped with and without damper winding, are measured and analyzed. Active windows with this model are developed using Matlab's Graphical User Interface (GUI) capability to examine the dynamic behavior of the machine after small perturbations, focusing on electromagnetically dynamic as affected by load unbalance. EDSA 2000 software is used to derive the generator's terminal inputs through load-flow analysis on the grid.

***Keywords**: Damper winding, Unbalanced steady-state condition, The 500 kV EHV Jamali, GUI, EDSA 2000*

INTRODUCTION

Many researcher have studied the performance of damper windings since their introduction to synchronous generator (Doherty and Nicle, 1926; Boldea, 2006)**.** However, the characteristics of damper windings and their effects on the dynamics of generator in the electric power system have yet to be sufficiently clarified **(**Matsuki *et* al, 1994). Moreover, study considering the experimental aspect of damper windings effect have been quite rare. The direct measurement of damper winding currents is quite difficult since the damper windings rotate with the rotor. Then, it has been generally difficult to realize the state of including damper in the practical generator to check the effects of the damper windings experimentally. Therefore, only simulation studies have been conducted to investigate them by including the generator parameters related to the damper windings in the analysis. But the simulation has a consequent it follows that the accuracy of results obtained by analytical techniques has been difficult to be checked, leaving a lot of uncertainties about the characteristics of damper windings.

A 820 MVA round-rotor synchronous generator model has been specially designed for investigating the characteristics of damper windings. A new method of measuring both induced currents and voltages in the damper bars has been developed. The damper bars are specially designed to be easily interconnected or disconnected to simulate the state of including or that of excluding damper effect. The performances of the damper windings under the power system oscillations are investigated analytically in this paper. The differences in performance between the machine with and without damper windings are discussed in terms of its induced currents of damper windings and generator terminal values such as electrical power output. The simulation was conducted on a one-generator connected to the 500 kV EHV Jamali System.

STUDY 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.

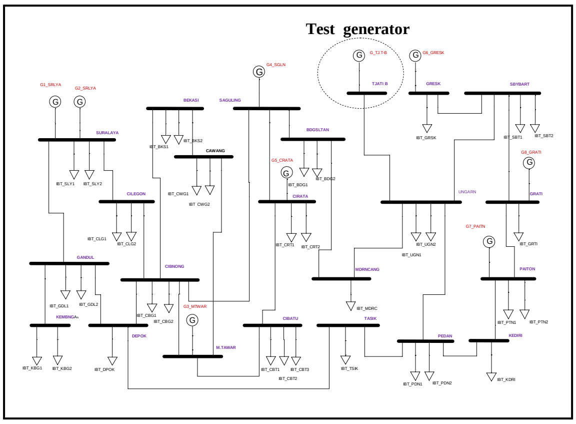


Fig. 1. The studied power system

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.

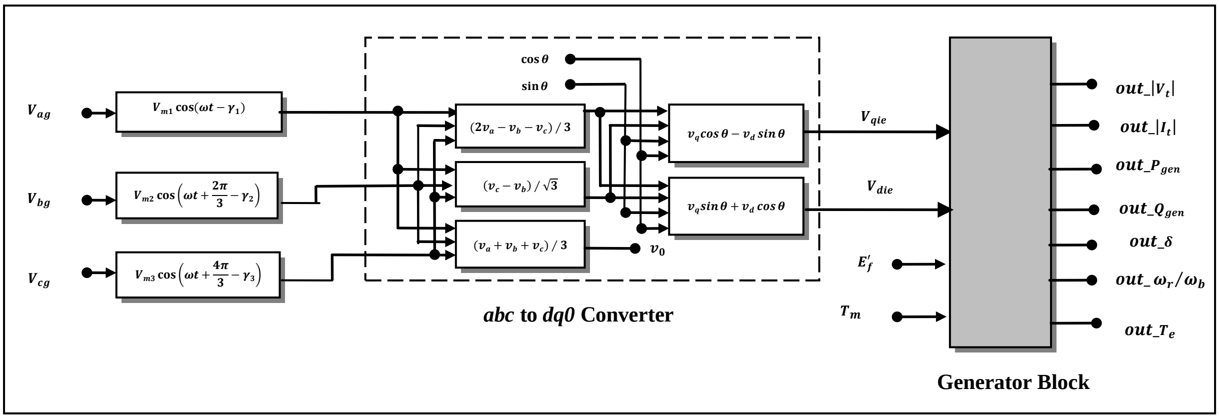


Fig. 2. Balanced generator with unbalanced inputs

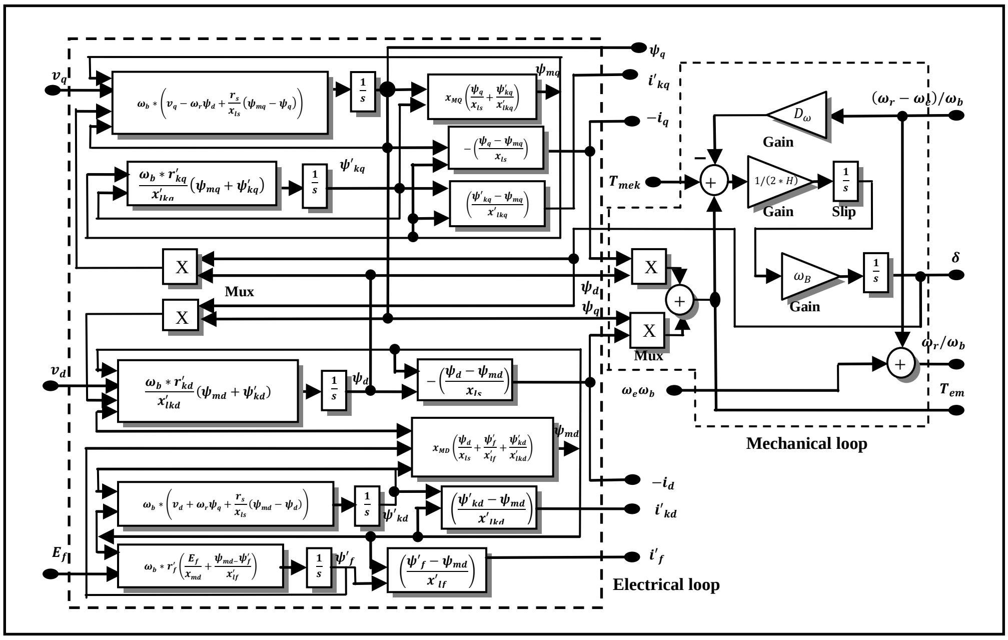


Fig. 3. The inside section of synchronous generator

The model of this generator is shown in Fig. 3**.** The generator has single damper per each axis winding**,** such *d*-axis and *q*-axis. Damper windings in the equivalent generator model can be used to represent physical *armotisseur* windings (Fig. 4).

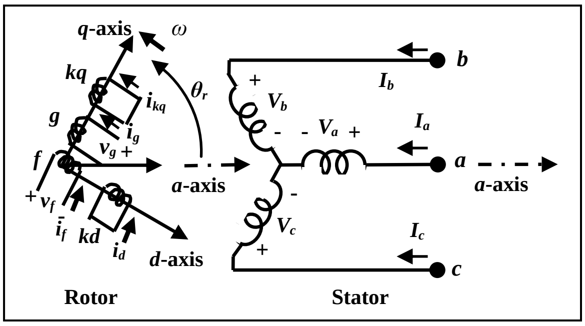


Fig. 4. Generator winding with armotiseur

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.

To investigate the effect of damper windings on generators under unbalanced steady state operation, a "hybrid" method by combination between unbalanced three phase load flow analysis and rotor's *qd0* reference frame of synchronous generator model which substitutes the model of generator in load flow analysis can be used.

A software package which applied Matlab's GUI facilities has been created for analysis damper winding phenomena of synchronous generator under unbalanced steady-state conditions (Fig. 5). As an example of using Matlab's 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. 6 and Fig. 7.

The verification of the generator model is judged through comparing between generator's respon by PSS Tecquipment NE9070 (Fig. 10) and by the proposed simulator under no load, balanced and unbalanced conditions, respectively.

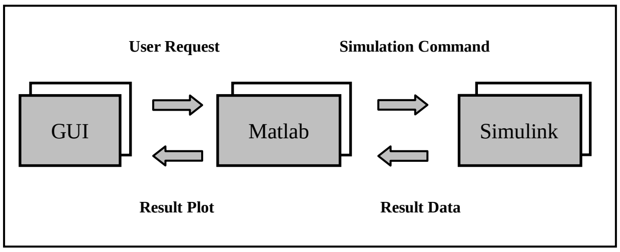


Fig. 5. Designed Simulator with GUI

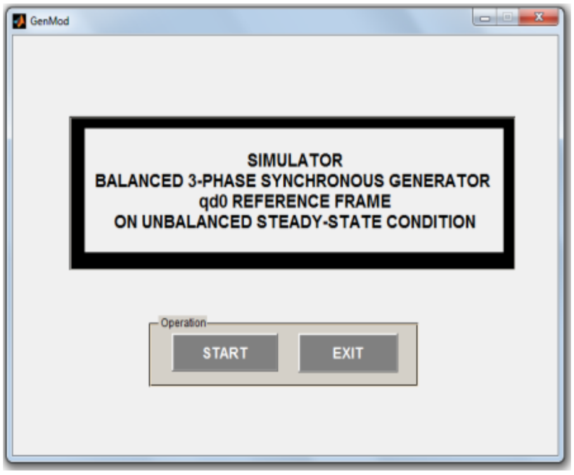


Fig. 6. The main window of the software tool

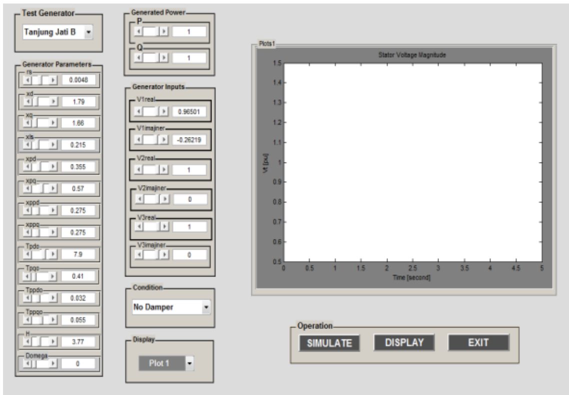


Fig. 7. The window of inserting the inputs for balanced generator and unbalanced inputs

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).

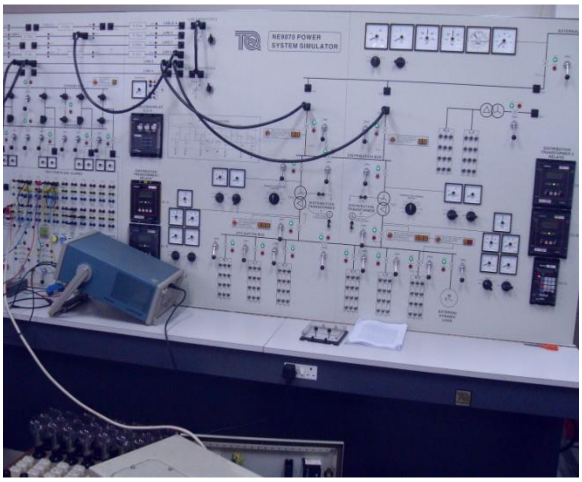


Fig. 8 . PSS Tecquipment NE9070

DEMONSTRATION

Using EDSA 2000 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*	$1\angle -15^{o}$
	b	$1\angle 120^{o}$
	c	$1\angle 240^{o}$
Connected the grid and load imbalance of 5%	*a*	$1\angle 0.3^{o}$
	b	$1\angle 120^{o}$
	c	$1\angle 240^{o}$

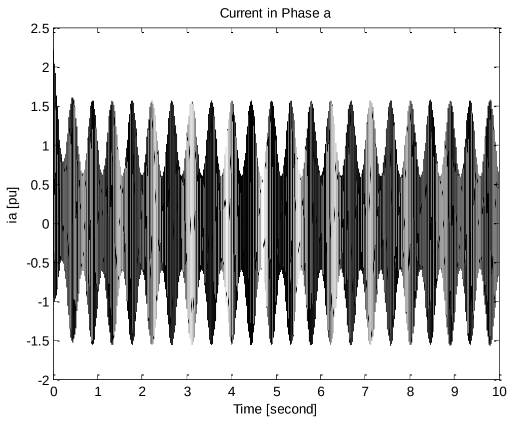
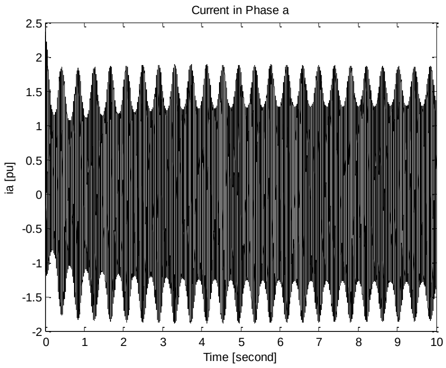
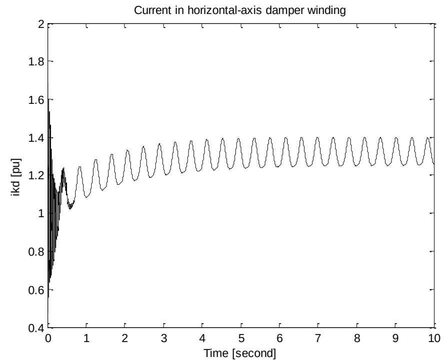


Fig. 14. Currents in phase-*a* of Tanjung-Jati-B of balanced loads and no-damper winding

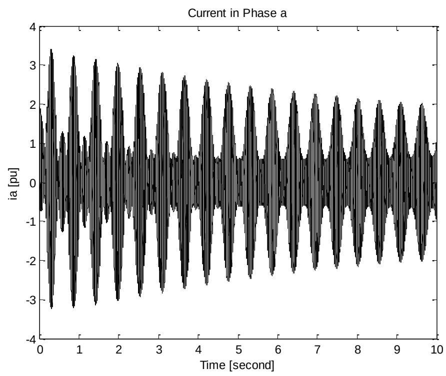


(a)



(b)

Fig. 15. Currents of Tanjung-Jati-B at balanced loads and *d*-axis damper winding:
a. in phase-*a* b. in *d*-axis damper winding



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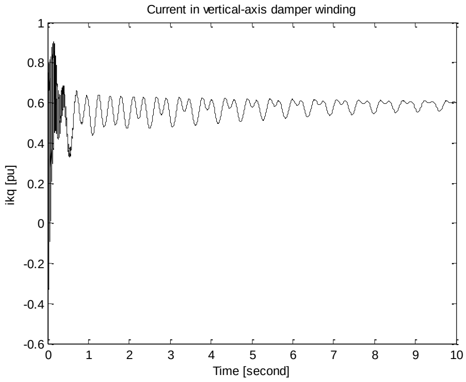
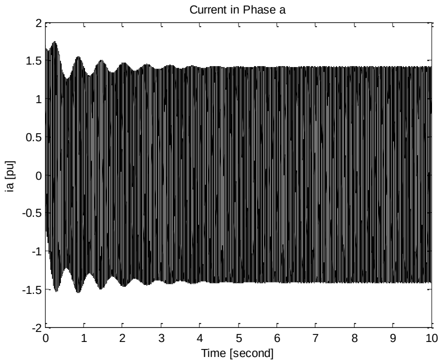


(b)

Fig. 16. Currents of Tanjung-Jati-B at balanced loads and *q*-axis damper winding:
a. in phase-*a* b. in *q*-axis damper winding



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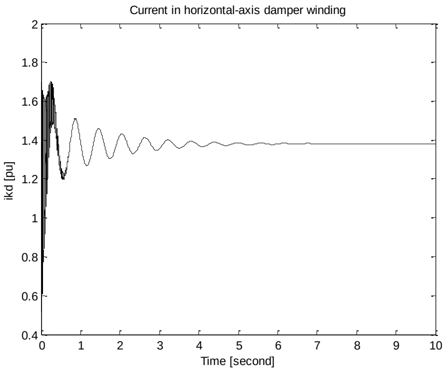

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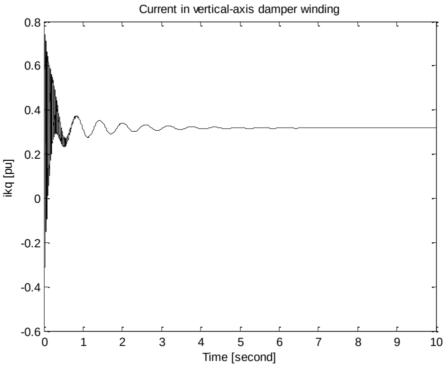

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Fig. 17. Currents of Tanjung-Jati-B at balanced loads and *d*-axis and *q*-axis damper windings:
a. in phase-*a*
b. in *d*-axis damper winding
c. in *q*-axis damper winding

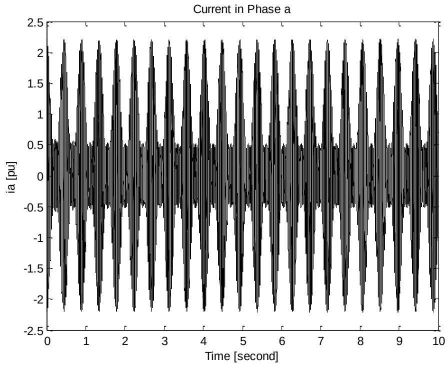
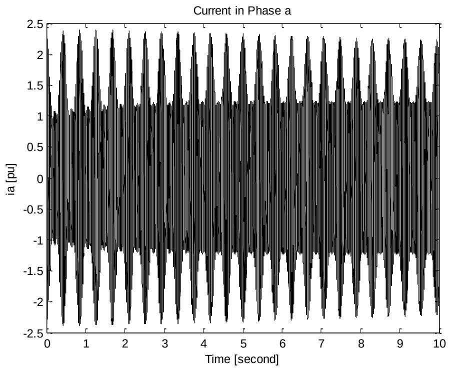


Fig. 18. Currents in phase-*a* of Tanjung-Jati-B of %5 of unbalanced loads and no damper winding



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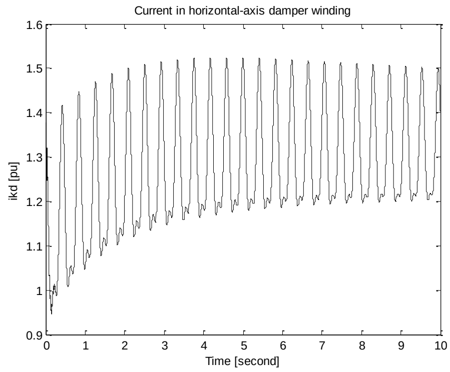
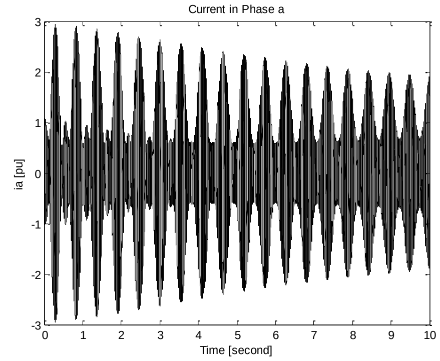


(b)

Fig. 19. Currents of Tanjung-Jati-B at 5% of un-balanced loads and *d*-axis damper winding:
a. in phase-*a* b. in *d*-axis damper winding



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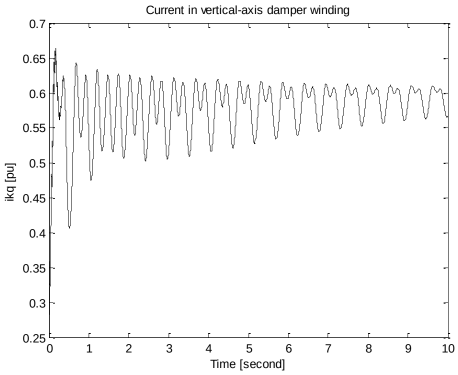
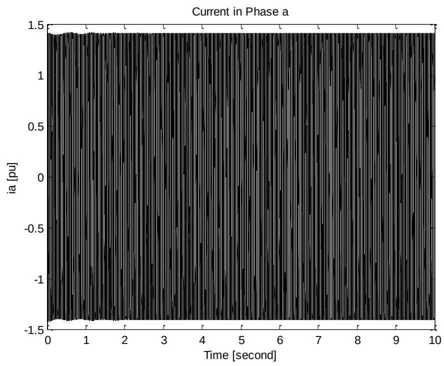


(b)

Fig. 20. Currents of Tanjung-Jati-B at 5% of un-balanced loads and *q*-axis damper winding: a. in phase-*a* b. in *q*-axis damper winding



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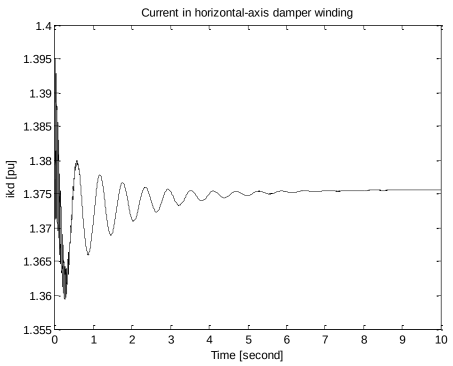

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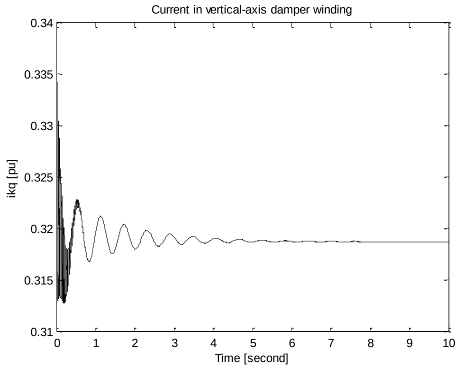

(c)

Fig. 21. Currents of Tanjung-Jati-B at balanced loads and *d*-axis and *q*-axis damper windings:

a. in phase-*a*
b. in *d*-axis damper winding
c. in *q*-axis damper winding

Figure 14 to Figure 21 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 phase-*a* of synchronous generator with tends to be sinusoidal form eventhough under 5% of unbalanced load by using the *d*-axis and *q*-axis damper windings, shown in Fig. 21.b . Meanwhile, the current in phase-*a* when generator applied the *d*-axis damper winding is much better compare to generator applied the *q*-axis damper winding. Moreover, the synchronous generator which do not apply the damper winding, wheter *d*-axis damper winding or *q*-axis damper winding, has a bad current in-phase's output.

CONCLUSION

A useful simulator for analysis "Damper Winding Phenomena of Synchronous Generator Under Unbalanced Steady-State Condition: A Case of 500 KV EHV Jamali System" has been presented in this paper. Two operation conditions of the synchronous generator, load balanced and load imbalance of 5% are mathematically modeled then simulated using Matlab.

The simulation results state that the using of damper windings at both *d*-axis and *q*-axis has significant effect on the outputs of generator dynamic during unbalanced steady state condition. Surprisingly, the using of *d*-axis damper winding exhibit the better output of generator currents in phases that by using of the *q*-axis damper winding.

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

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