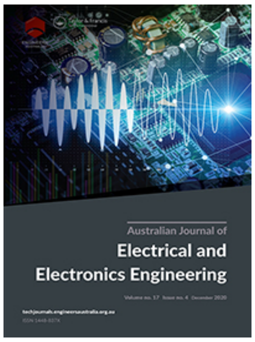

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Impact of the configuration and condition of the power system on the damping of low-frequency oscillations

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ARTICLE

Impact of the configuration and condition of the power system on the damping of low-frequency oscillations

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ABSTRACT

The current stage of power system development is characterised by the transformation from local electric power systems to global interconnections. It provides economic benefits, improves the reliability of power system operation and increases the quality level. However, such large interconnected systems have some technical and economical limitations, for instance, long distance transmission, and almost have a weak tie between the electric power systems. One of the main problems of the reliability of such large interconnected systems is low-frequency oscillations, which significantly reduces network capacity and leads to dynamic instability. Therefore, the analysis of the influence of various topologies and regime modes of electric power system to the low-frequency oscillations for the development of control actions and recommendations for their effective damping and reduction is relevant. In this paper, simulation and analysis was done by using of two-area electric power systems and using «EUROSTAG» software. The factors, such as the previous steady-state condition and the structure of the electric power system, affecting the damping properties of electric power system and the impact of the Back-to-Back High-Voltage Direct Current link based on voltage source converters to the damping of low-frequency oscillations were considered.

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KEYWORDS

Power system; low-frequency oscillation; simulation; damping

1. Introduction

Today a modern trend of electric power system (EPS) development is characterised by the transformation from local power system to global interconnections, using Flexible Alternating Current Transmission System (FACTS) devices and High-Voltage Direct Current (HVDC) technologies. It provides economic benefits, improves the reliability of power system operation and increases the quality level (Sitnikov et al. 2003; Buchholz, Povh, and Retzmann 2005). However, such large EPS has some technical and economical limitations, for instance, long distance transmission, and almost have a weak tie between interconnected parts of EPS. One of the main problems of the reliability of such large interconnected systems is low-frequency oscillations, which significantly reduces network capacity and leads to dynamic instability. Moreover, introduction of FACTS devices and HVDC technologies significantly change the structure of EPS and become it more sensitive to various disturbances, which leads to low-frequency oscillations of EPS's mode parameters (Prasertwong, Mithulananthan, and Thakur 2010; Avdakovic et al. 2009; Yu et al. 2016).

The low-frequency oscillations (usually frequency is about 0.1 to 3 Hz) are one of the potentially dangerous effects to operation stability of EPS, in particular, they can lead to small-signal instability and system break-up (Prasertwong, Mithulananthan, and Thakur 2010), significantly reduces the network capacity, which leads to a significant under-utilisation of network and under-supply of electricity to consumers. At the same time, active power oscillations are characterised by the appearance of alternating in sign loads on the shafts of synchronous generators, leading to equipment wear.

Currently, the low-frequency oscillation analysis is carried out mainly by monitoring data from Wide Area Measurement System, based on synchronised phasor measurement technology (Sattinger 2009). Phasor measurement units' data are received and processed by various modal analysis methods, in particular, Prony algorithm, Hilbert-Huang Transformation, for further identification of low-frequency oscillation parameters (Angelidis and Semlyen G, 1996; Shim, Nam, and Lim 2011).

The main tools for the damping of low-frequency oscillations are the power system stabilisers (PSS); however, the properties of HVDC Back-To-Back link based on voltage source converters (VSC B2B link) allow damping and reducing the zone of low-frequency oscillation distribution at the network level by creating a set of frequency-independent parts of the EPS (Farhang et al. 2014; Sorokin 2013; Grund et al. 1993).

However, for a theoretical and experimental substantiation and confirmation of these statements, it is necessary to conduct a wide range of studies. Due to the fact that natural experiments in EPS are unacceptable, only mathematical modelling can be means for carrying out of these studies.

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In this paper, the simulation and analysis was done by using two-area EPS and using «EUROSTAG» software. The factors, such as the previous steady-state condition and the structure of the EPS, affecting the damping properties of EPS and the impact of the VSC B2B link to the low-frequency oscillation damping were considered.

2. Influence of the EPS structure and condition on the low-frequency oscillation damping

The test scheme of EPS is represented in Figure 1. There are generators G-1, G-2, S-71 (slack bus), located in Area 1, and G-3, G-4, S-101 (slack bus), located in Area 2, respectively, connected to the transit 7–9, at the ends of which the loads are connected. This scheme considered two configurations: slack bus in two areas; slack bus in Area 1 and Area 2 (S-101 is disconnected). All generators are equipped by the PSS.

The structure of the EPS was changed by connecting/disconnecting S-101 in Area 2 (dotted line).

The following scenarios were considered:

- large disturbance: single phase short-circuit with during 0.12 s occurs on one of the line 7–8;
- small perturbations: load change in node 7.

Figure 2 show graphs of the power oscillations after a large disturbance in case with a small (86 MW) and large (707 MW) power flow through line 8–9.

According to these results, it can be noted that with a small value of the power flow, the generators oscillate in phase, with a large value, in antiphase. A number of researchers call this phenomenon sync of the low-frequency oscillations, distinguishing «+sync» and «-sync», when oscillations of generators or groups of generators relative to each other are in phase or out of phase, respectively, which should be taken into account when evaluating the damping (Shim, Ahn, and Choi 2017).

Similar experiments were carried out in case when only S-71 is used, the graphs are presented in Figure 3.

In this case, there is a more complex process: it can be noticed that all generators are involved largely in different components with different frequencies. In this case, it is not entirely correct to speak about the sync phenomenon due to the different oscillation frequencies;

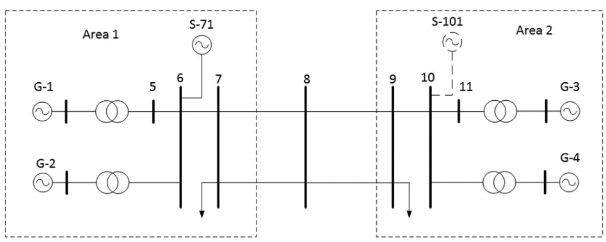

Figure 1. The test scheme of EPS.

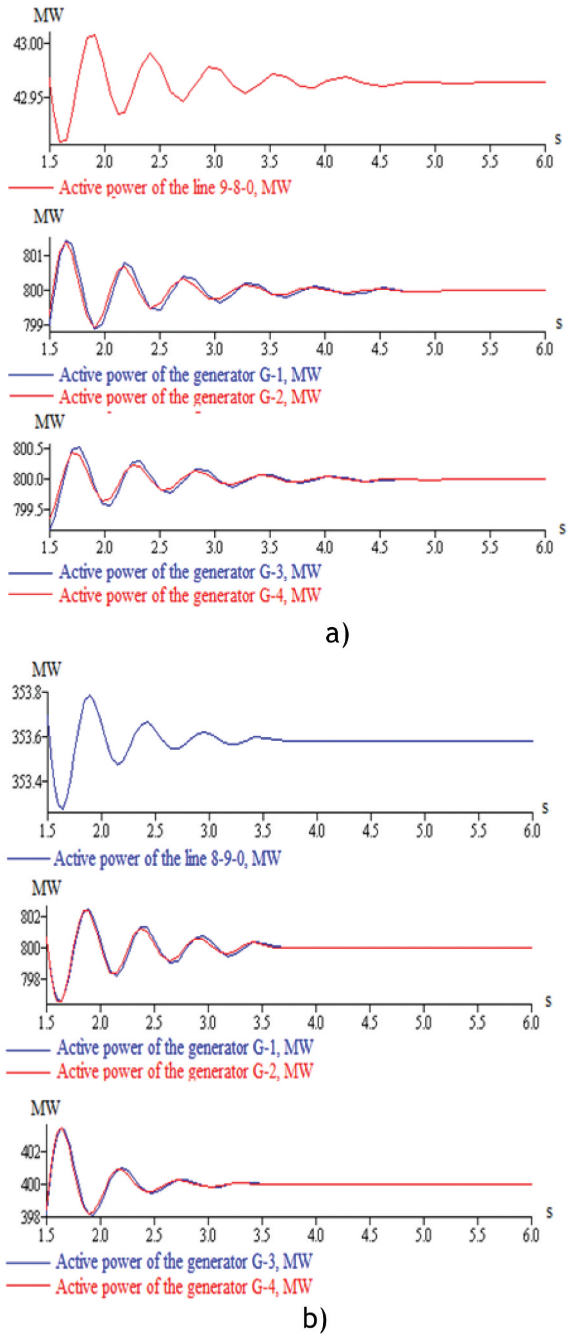

Figure 2. Plots of active power flow oscillations of one of the line circuits 8–9, generators of area 1 and area 2, in case when S-71 and S-101 are connected and initial flow value is about 86 MW (a) and 707 MW (b).

however, it can be noted that at the initial times, the oscillation phase of the oscillators behaves opposite to the case with S-71 and S-101. It should also be noted that in this case the amplitude of the oscillations of both the generators output and the power flow is greater, while the amplitude of oscillations of the generators in the Area 2 increases more strongly.

Then, experiments with large and small disturbances were performed for different values of the active power flow, for which the logarithmic damping decrement graphs were plotted versus the value of the power flow, which are shown in Figures 4 and 5.

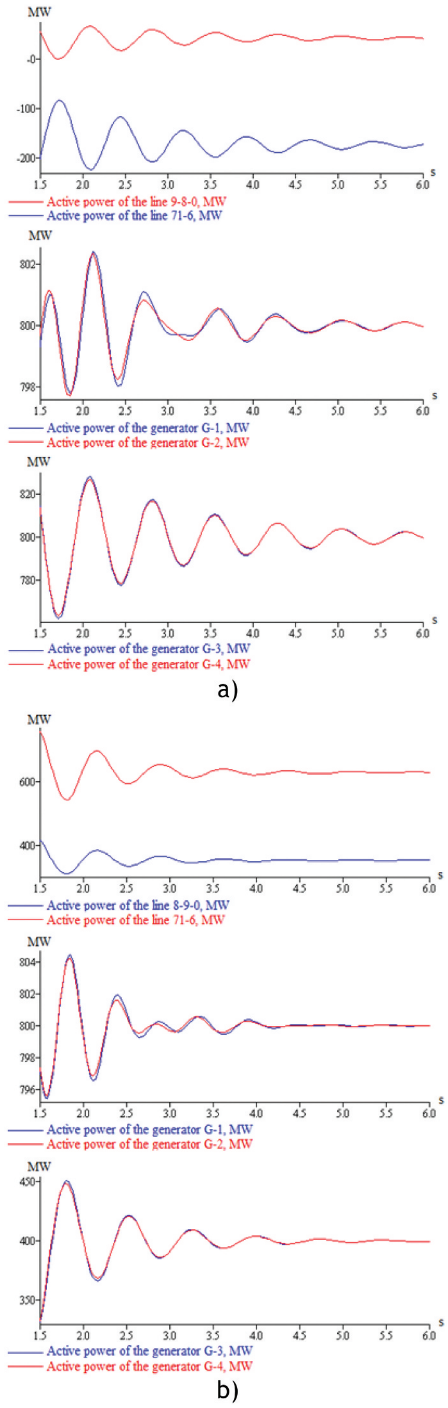

Figure 3. Plots of active power flow oscillations of one of the line circuits 8–9, generators of area 1 and area 2, in case when S-71 is connected and initial flow value is about 86 MW (a) and 707 MW (b).

According to these figures, it can be seen that in both cases with small perturbations, the logarithmic damping decrement decreases in absolute value. The same nature of the change is due to the fact that the system is linear.. In the case of large disturbances, the nature of the change is substantially different due to the different nonlinear properties of the system. It can also noticed that the presence of the minimum point of the graph in the case with S-71 and S-101 with power flow, corresponding to the change of type of sync of low-frequency oscillations.

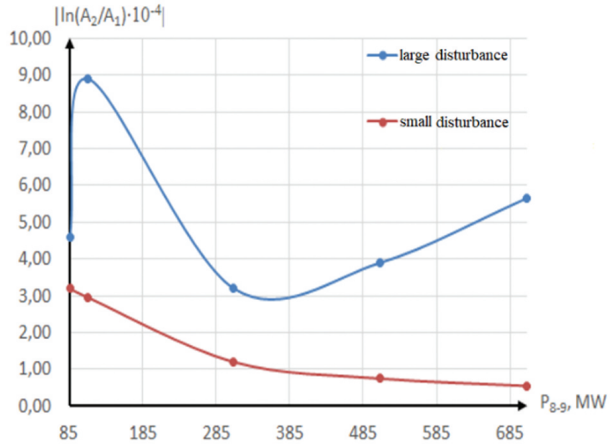

Figure 4. Plots of logarithmic damping decrement versus active power flow in the initial mode for S-101.

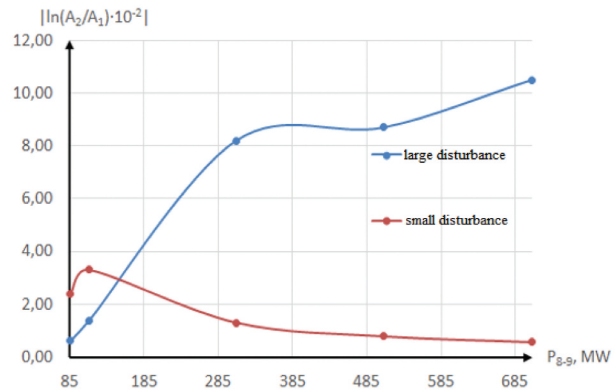

Figure 5. Plots of logarithmic damping decrement versus active power flow in the initial mode for S-71.

3. Influence of the VSC B2B link on damping of the low-frequency oscillations

To assess the impact of the VSC B2B link, the model of this device was included at substation 8. The VSC B2B link model in the Eurostag software (Standard models library 2008; Cole and Haut 2013) is realised based on the two dynamic controlled injectors, which deliver the consumed or produced power into the node (Figure 6).

Different macroblocks are used to realise an automatic control system, for instance, the control system of each converter includes Current Controller (CC) and Active and Reactive Power

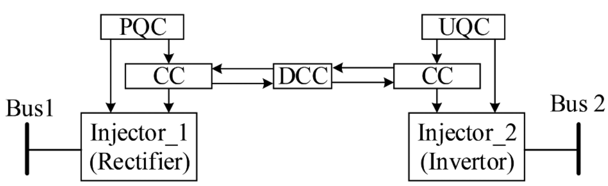

Figure 6. The structure of the VSC B2B link model.

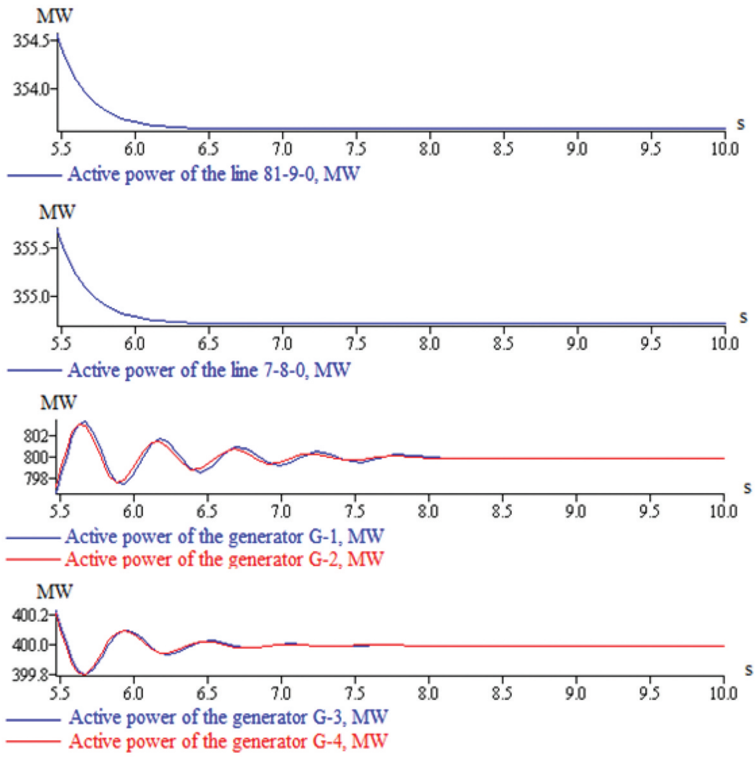

Figure 7. Oscillation plots of active power generators and flow control when using VSC B2B link.

Controller (PQC) macroblocks; thus, for other one, PQC macroblock is replaced by the DC Voltage and Reactive Power Controller (UQC). In the direct current circuit (DCC) macroblock, the direct current network equations are realised.

Similar results were observed for all cases. Figure 7 presents the results for the scheme with two stack buses and power flow in the initial mode of 707 MW under a large disturbance.

The result shows that there are no flow oscillations in the scheme – there are no interarea oscillations, only local oscillations of the generators are present in the areas, while the oscillations of the generators output decay faster than in a similar experiment without VSC B2B link due to the action of the active power regulator of VSC B2B link, and for the region where no disturbance, have a much smaller amplitude.

4. Conclusion

It is shown that both the initial steady-state mode of the EPS and its structure affect the damping of the low-frequency oscillations. For instance, it illustrates the obtained graphs of the logarithmic decrement of the active power flow: both cases with small perturbations, the logarithmic damping decrement decreases in absolute value; in the case of large disturbances, the nature of the change is substantially different due to the different nonlinear properties of the EPS.

The application of VSC B2B link allows reducing the zone of low-frequency oscillation distribution at the EPS by creating 'splitting at a direct current (no frequency)' of the two parts of the EPS. At the same time, due to the high-speed regulation of the active power transmitted through the VSC B2B link, it was possible to effectively damp local oscillations in the EPS part.

Disclosure statement

No potential conflict of interest was reported by the authors.

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