INVESTIGATION OF POWER SYTEM STABILIZER PERFORMANCE IN FREQUENCY STABILITY OF POWER SYSTEM INTEGRATED WITH WIND POWER

NGHIÊN CỨU HIỆU QUẢ CỦA CÁC BỘ ỔN ĐỊNH HỆ THỐNG ĐIỆN TRONG ỔN ĐỊNH TẦN SỐ CỦA HỆ THỐNG ĐIỆN CÓ TÍCH HỢP ĐIỆN GIÓ

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Abstract:

The energy transition is implementing in various different industries at a global scale. In particular, the shift from traditional fossil fuel-based power generation technology to renewable energy sources-based ones plays a pivotal role in this process. In many countries including Vietnam, the level of penetration of wind power sources is increasing, on the one hand, contributing to meet the demand of the load, on the other hand and modifying the related technical issues in power systems. The fluctuation of output power of wind power sources following the variation of the wind speed is great challenging to the guarantee of power system stability. This paper introduces research results on the effectiveness of power system stabilizers (PSSs) in improving small signal stability. First, the 9-node IEEE power system is modified with the participation of a wind power source. The operation of PSS that is equipped at a traditional power plant was then investigated in the conditions that there are fluctuations in load and the output of wind power system. The obtained results show different efficiency of PSS types in power system stabilization.

Keywords:

Power system stabilizer, Wind power, Integrated power system, Power system stability.

Tóm tắt:

Quá trình chuyển dịch năng lượng đang diễn ra trong nhiều lĩnh vực khác nhau và ở quy mô toàn cầu. Trong đó, sự chuyển dịch công nghệ phát điện từ nguồn điện sử dụng năng lượng hóa thạch truyền thống sang nguồn điện sử dụng năng lượng tái tạo đóng vai trò nòng cốt. Ở nhiều quốc gia trong đó có Việt Nam, mức độ thâm nhập của các nguồn điện gió ngày một tăng, một mặt đóng góp vào việc đáp ứng nhu cầu của phụ tải, mặt khác làm thay đổi các vấn đề kỹ thuật liên quan trong hệ thống điện. Sự dao động công suất phát của các nguồn điện gió theo tốc độ gió là thử thách lớn trong duy trì ổn định hệ thống điện. Bài báo giới thiệu kết quả nghiên cứu về hiệu quả của các bộ ổn định hệ thống điện (PSSs) trong ổn định do nhiễu loạn. Trước hết, hệ thống điện mẫu IEEE 9 nút được hiệu chỉnh với sự tham gia của nguồn điện gió. Hoạt động của các bộ PSS đặt tại nhà máy điện truyền thống sau đó được khảo sát trong điều kiện có sự biến động của tải và công suất phát của điện gió. Kết quả thu được cho thấy tính hiệu quả khác nhau của các bộ PSS trong ổn định hệ thống điện.

Từ khóa:

Bộ ổn định hệ thống điện, điện gió, hệ thống điện tích hợp, ổn định hệ thống điện.

1. INTRODUCTION

The transition from fossil fuel-based energy to renewable-based energy, with low or zero carbon emissions, is taking place in many countries all over the world. Especially after the 26th UN Climate Change Conference of the Parties (COP26), in November 2021, many countries have pledged to reach net-zero emissions by 2050. The aim of COP26 presidency is to keep the rise in global temperature to 1.5C [1].

In fact, wind power development continues to show impressive statistics in 2022 with 78 GW of new installed capacity worldwide [2]. According to the Global Wind Energy Council (GWEC) forecast, global new installed capacity could exceed 100 GW in 2023 and at 680 GW in the next five years. Besides the benefits in meeting the demand of the power system load, the integration of wind power causes technical problems due to the variation in their generating capacity. One of those effects is to cause frequency fluctuations in the power system. To mitigate this impact, many technical solutions related to the control process of the wind power systems themselves and other elements in the power system have been applied additionally.

In this study, the performance of PSSs with the generic model and a standard type of PSS4B is investigated. The input signal used is the rotor speed deviation or active power difference between the mechanical and electrical powers.

The remainder of the paper is organized as follows. Section 2 introduces the overview of the PSS. Next, the modification of 9-bus IEEE power system with the addition of a wind power system is shown in Section 3. Simulation results and discussion are then presented in Section 4. Some conclusions are finally given in Section 5.

2. POWER SYSTEM STABILIZER (PSS)

Power system stabilizer (PSS) provides an additional signal to the excitation system to damp generator rotor oscillations and to improve power system stability. The input signals to the PSS may include shaft speed, frequency, and power measured at the generator terminal. As the PSS is applied, fluctuations in the power system are damped and system stability can be improved. Especially, using PSS is an effective method of improving small-signal stability of power system.

To damp the fluctuation, PSS generates an electric torque according to the rotor speed deviation. Figure 1 shows the generator with is voltage regulator through the exciter [1]. The input of the voltage regulator is added to the signal from the PSS, which is the frequency, speed or the difference between the mechanical and electrical powers.

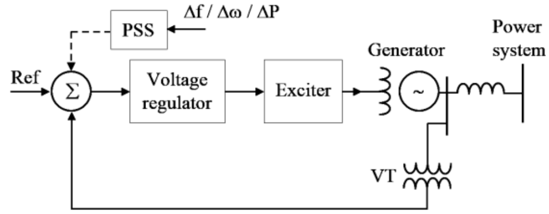

Figure 1. The addition of PSS to the input of voltage regulator and exciter

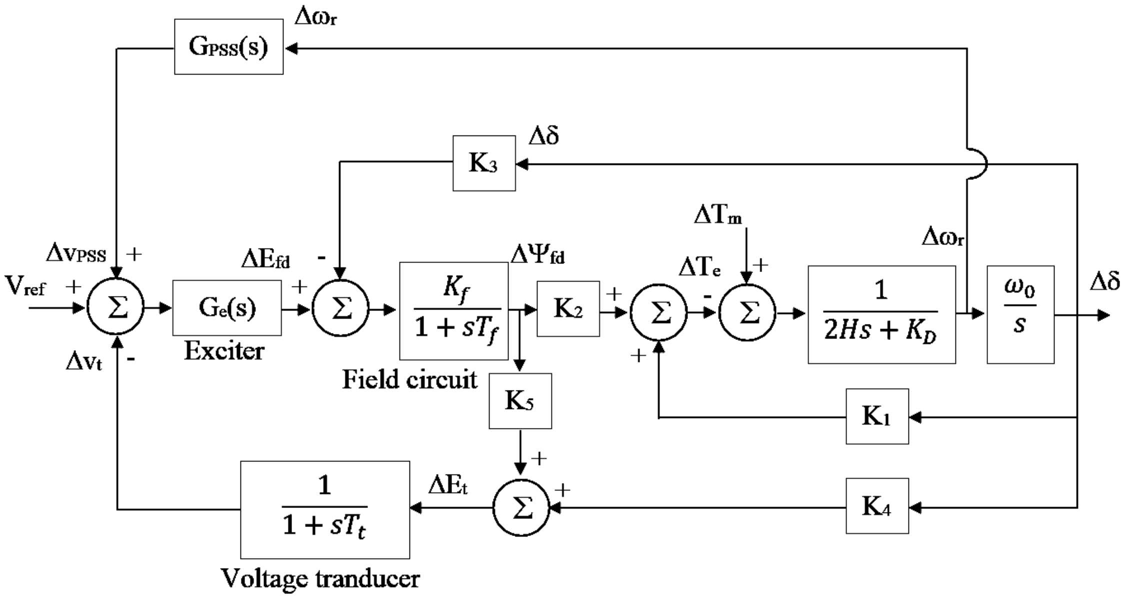

Figure 2. Block diagram of exciter and the automatic voltage regulator (AVR) equipped with PSS

Figure 2 show the block diagram of the exciter and AVR with the participation of PSS [2]. In the diagram, $G_e(s)$ is the transfer function of the exciter and AVR, for the thyristor-based type, the transfer function is a constant. The IEEE Type PSS4B is equipped with external inputs, e.g. the speed and electrical power.

3. MODIFICATION OF IEEE-9 BUS WITH WIND TURBINE

The IEEE-9 bus power system [3], [4] shown in Figure 3 is selected to investigate the role of PSS in mitigating the variation of load as well as the output of wind power system. The model of round rotor type thermal generators and their exciter, which is combined with IEEE type 1 voltage regulator, is adopted from [2], and that of wind turbine is referred to [5] and [6].

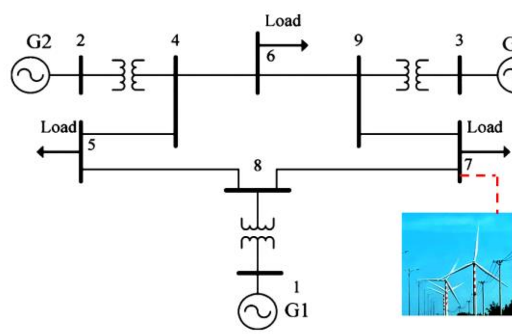

Figure 3. IEEE 9-bus power system (WSCC 3-Machines 9-Bus system)

Moreover, a wind power system is connected to the bus of node 7. All the rated powers of three machines are modified to 100 MVA in which the machine 1 is connected to the slack bus 1.

The machine connected to bus 3 has the exciter and AVR with additional input of PSS. In this study, three following types of PSS will be simulated: IEEE Type

PSS4b (PSS_1) with the input of rotor speed deviation ($\Delta\omega$); generic PSS with the input of $\Delta\omega$ (PSS_2) and generic PSS with the input of active power difference (PSS_3) [2]. Selection of these PSSs has merit for a number of reasons. First, integrating traditional PSSs in the form of program code into modern digital voltage regulators is a solution with the cost that is not as large as FACTS equipment based ones. Second, PSS_2 and PSS_3 represent the types with typical input of rotor speed deviation or active power, respectively. Moreover, PSS_1 is with multiband dedicated to the low-, intermediate-, and high-frequency modes of oscillations. If the structure and parameters are selected appropriately, the performance of generic PSSs is comparable with other solutions [7]. Furthermore, the combination of this PSS with droop control of wind system will sufficiently show certain change in the effect in damping of frequency oscillation.

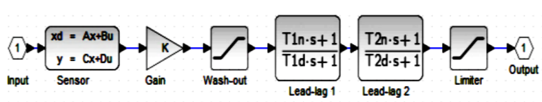

Figure 4. Major elements of PSS

For the multi-band power system stabilizer or IEEE Type PSS4b, the input is the rotor speed deviation. The generic model PSS introduced in [2] has the major elements shown in Figure 4 with the input of the rotor speed deviation or the difference between the mechanical power of the turbine (P_m) and the electrical power (P_e) of the generator.

4. SIMULATION RESULTS AND DISCUSSION

Simulation is developed with two different penetration levels of the wind power: 10% and 30%; the total capacity of system load is 315 MW and 115 MVAr. It must be underlined that after any disturbance, which causes the deviation in frequency of power system, the secondary frequency control function of the governor of units assigned is activated to regulate output power to recover the system frequency into the permitted range according to national grid codes [8], for instance [49,5; 50,5] Hz (power networks that have not been stable after single incidents) in Vietnam.

However, in this study, to investigate the impact of PSS under the variation of output of wind turbine, such operation is not considered.

In fact, wind turbine is commonly required to support power system in the frequency control. Accordingly, the control scheme of the wind turbine is designed to be able to mobilize the spare power into frequency control with the droop characteristics similar to that of traditional generators:

$$\Delta P = -\frac{\Delta f}{R} \tag{1}$$

As a result, it is possible to create the characteristic as shown in Figure 5.

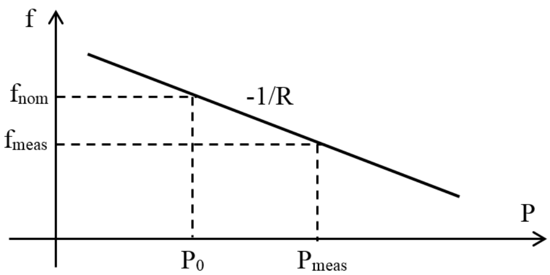

Figure 5. Droop characteristic of the wind turbine

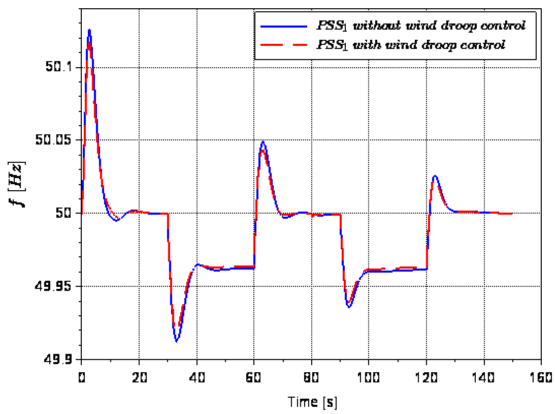

Figure 6. The effect of droop control in the wind turbine on the system frequency

Once the droop control is applied to the wind power system, the frequency response can be improved, as can be seen in Figure 6.

Figure 7 shows the response of system frequency following the load variation at time instants of 40 s, 60 s, 90 s and 120 s. The output signal of PSS is enabled and added to the input of the AVR during the period from 80 s to 140 s.

It is seen that the PSS affects obviously on the response of the frequency with smaller drops during the transient periods. In addition, its impact seems to be independent from the penetration level of wind power.

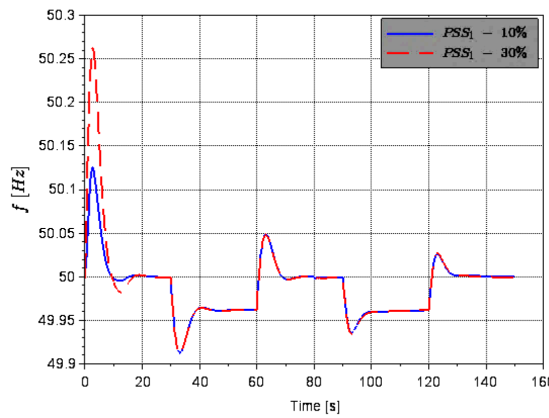

Figure 7. Response of the frequency under 10% and 30% penetration of wind power

Following this, simulation of the power system with three above-mentioned types of PSS is repeated. As can be seen in Figure 8, all of PSSs have the positively impact on the response of the frequency.

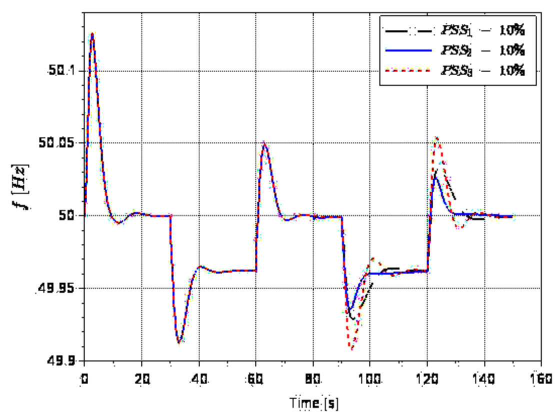

Figure 8. Comparison of frequency responses with the utilization of different PSS types during the variation of load power

PSS with the input of rotor speed deviation seems to provide better mitigation on the fluctuation of frequency during the transient periods in comparison with that with the input of active power difference.

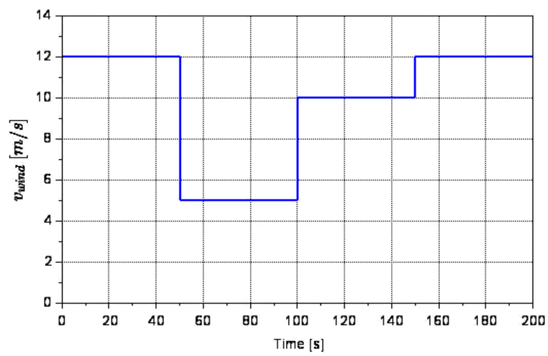

Figure 9. The variation of wind speed

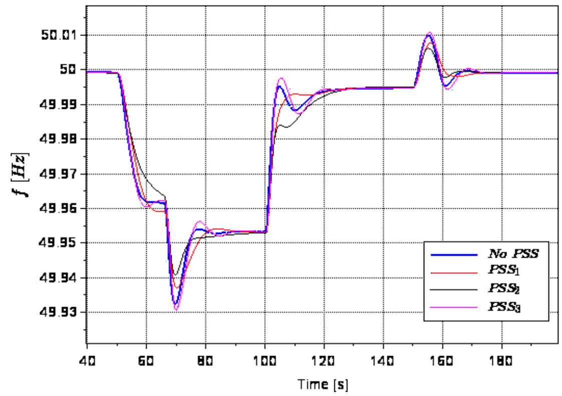

Figure 10. Comparison of frequency responses with the utilization of different PSS types during the variation of wind speed

The generic structure PSS with main elements shown in Figure 4 and the input of rotor speed deviation outweighs the other in terms of the magnitude and transient period of the fluctuation, see the dotted black curve in Figure 8.

PSS typed PSS4b of IEEE (PSS_1) provides robust response following the disturbances by wind speed change, see Figure 9. Meanwhile, PSS_2 seems to give slower response. The PSS_3 does not appear to have a positive effect on oscillations caused by the variations in wind speed.

4. CONCLUSION

The performance of some types of PSS in limiting fluctuations due to load variation and generating capacity of wind power plants was investigated. PSS typed PSS4b of IEEE provides great performance with robust response following the disturbances. Furthermore, the control within the wind power system itself has shown to assist in mitigating the disturbance caused by the aforementioned fluctuations.

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