FUZZY STABILIZER DESIGN FOR RENEWABLE ENERGY BASED DISTRIBUTION NETWORKS

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ABSTRACT

This research introduces an innovative combination of wind energy distributed generation (WEDG) system and fuzzy logic based controllers providing a high value unified response to distribution network customer's needs. This combination is uniquely placed to provide network customers with innovative integrated solutions making energy safer, more reliable, more efficient and more productive. .

INTRODUCTION

Now days, it is a general trend to cut the world's Co_2 emissions in half by 2050. However, electricity demand – a major source of Co_2 emissions will double by that date [1]. Of various alternative energy sources, wind energy is one of the most prominent source of renewable energy sources today. The increasing concerns to environmental issues demand the search for more sustainable electrical sources. Wind turbines are possible solution for the environmental friendly energy production as it is said to hit large integration in the near future [2]. The challenge is to achieve system functionality without extensive custom engineering, yet still have high system reliability and generation placement flexibility. Now days, it is a general trend to increase the electricity production using wind energy distributed generation (WEDG) systems. If these systems are not properly controlled, their connection to the utility grid can generate problems on the distribution network. Therefore, considerations about some technical barriers such as, power generation, safe running and network synchronization must be done before connecting these systems to the utility network [3]. WEDG systems have to overcome these technical barriers if it should produce a substantial part of the electricity.

In the wind energy based power system the challenge of any control strategy is to generate and deliver power as economically, safe, efficient, productive and reliable as possible while overcoming the aforementioned technical barriers [4-5].

The WEDG systems are conventionally equipped with automatic voltage regulators (AVRs) to improve the system performance. Unfortunately, AVRs adversely affect stability. Exposed to disturbances, such as wind variations, operating point variations and short circuits, power systems may exhibit unacceptable swing mode oscillations or loose synchronism. To damp and suppress these oscillations Power system stabilizers (PSS) are normally incorporated. Design and application of conventional PSS (CPSS) has been the subject of continuing development for many years [6]. Conventional power system stabilizers are based on linearized machine model with fixed system parameters and thus tuned at a certain operating point. However, WEDG systems are highly non linear systems. CPSS tuned at a certain operating point may not work properly for the actual plants. If the system drifts from the original operating point, the performance of a CPSS degrades significantly [7]. Alternative control techniques including self-tuning regulators, pole placement, pole shifting, and robust control have been investigated for the design of power system stabilizers. This involves obtaining a frequency response of the systems. There is a problem associated with it when noise is present [8-9].

In recent years, fuzzy-logic control has been proposed for power system stabilization problems. Fuzzy logic controllers are nonlinear controllers based on the use of expert knowledge. This knowledge is usually obtained by performing extensive mathematical modelling, analysis, and development of control algorithms for power systems.

This paper proposed a fuzzy-logic power system stabilizer (FLPSS) that overcomes the conventional power system stabilizer (CPSS) demerits. The proposed stabilizer is initialized using the small rule base of a FLPSS to ensure an acceptable performance. The rule base is then increased so that the stabilizer can cope with wide range of operating conditions. The proposed stabilizer results in a satisfactory performance as compared to the CPSS.

Section 2 demonstrates the theoretical and implementation issues related to the proposed FLPSS. Section 3 illustrates the performance of the FLPSS as it is applied to the wind energy distributed generation based distribution network. It also compares the FLPSS to the CPSS. The conclusions are driven in Section 5.

FUZZY-LOGIC-BASED PSS

The basic configuration of a pure fuzzy-logic controller is composed of four parts: the fuzzification, the knowledge base, the inference engine and the defuzzification; see figure 1. The fuzzification is the process of mapping the input crisp values into fuzzy variables using normalized membership functions and input gains. The fuzzy-logic inference engine deduces the proper control action based on the available rule base. The fuzzy control action is transferred to the proper crisp value through the defuzzification process using normalized membership functions and output gains [10]. The speed deviation, $\Delta\omega$; and the deviation in accelerating power (electrical power-mechanical power), ΔP; of the synchronous machine are chosen as the inputs. The use of accelerating power as an input to the power system stabilizer has recently received considerable attention due to its inherent low level of torsional interactions [11]. The output control signal from the FLPSS,U_{PSS}; is injected to the summing point of the AVR. Let the letters *N*, *Z* and *P* stand for the linguistic values negative, zero, and positive, respectively. Also, let the letters *B*, *M*, and *S* stand for big, medium, and small, respectively. Each of the FLPSS input and output fuzzy variables is assigned seven linguistic values varying from, Negative Big (NB) to Positive Big (PB). Each linguistic value is associated with a membership function to form a set of seven normalized and symmetrical membership functions for each fuzzy variable as shown in figure 2. The values X_{max} and X_{min} represent maximum and the minimum variation of the input and output signals. These values are selected based on simulation information. Let $X_{max}=-X_{min}$. The range of each fuzzy variable is normalized between -1 and +1 by introducing a scaling factor to represent the actual signal. The scaling factors are then optimized to minimize the summation of the square error of the speed deviation signal.

A symmetrical fuzzy rule set is used to describe the FLPSS behavior as shown in Table 1. Each entity in the table represents a rule of the form ''if antecedent then consequence'', e.g. the shaded rule in Table 1 is

if $\Delta\omega$ is *NB* and ΔP is *PB* then U_{PSS} is *Z*.

Symmetrical rule base is commonly used among researchers for monotonically increasing systems [11].

The activation of the i^{th} rule consequent is a scalar value (R_i) which is equal to the product of the two antecedent conjunction values. Using the center of gravity defuzzification method the appropriate crisp control is then generated [11].

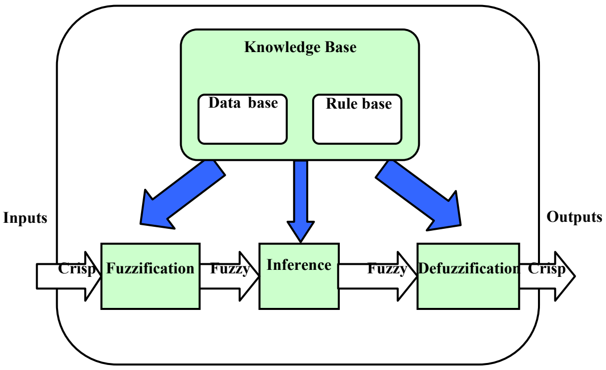

Fig.1 The basic structure of the fuzzy controller.

Let $\theta_1, \ldots, \theta_M$ represent the centroids of M membership functions that are assigned to U_{PSS}. Thus, for M rules, the output of the controller is.

$$U_{PSS} = \frac{\sum_{i=1}^{M} R_i \theta_i}{\sum_{i=1}^{M} R_i} = \theta^T \zeta \qquad (1)$$

where

$$\zeta = [\zeta_i \ldots \zeta_M]^T, \zeta_i = \frac{R_i}{\sum_{k=1}^{M} R_k}, and$$

$$\theta^T = [\theta_1 \ldots \theta_M].$$

The strength of the i^{th} rule is R_i. It is calculated based on interpreting the 'and' conjunction as a product of the membership values corresponding to the measured values of $\Delta\omega$ and ΔP. For example, the rule strength of the shaded rule in Table 1 is given by

$$R_i = \mu_{NB}(\Delta\omega) \times \mu_{PB}(\Delta P),$$

where μ_{NB} and μ_{PB} are the membership functions corresponding to the fuzzy sets *NB* and *PB*, respectively. In standard fuzzy systems, the values $\theta_1, \ldots, \theta_M$ are set once and kept fixed afterwards. One way to set $\theta_1, \ldots, \theta_M$ is to get the help of an expert in power system stabilization. The other alternative is to use Table 1 that can serve as a generic rule base for a lead (or PD) compensator. Consider Table 1 and assume the range of the control signal U_{PSS} is normalized, i.e. $U_{PSS} \in [-1, 1]$. Let also the membership functions be equally spaced. Then, the membership functions *NB*, *NM*, *NS*, *Z*, *PS*, *PM*, and *PB* will have their centeroids at *-1*, *-2/3*, *-1/3*, *0*, *1/3*, *2/3*, and *1*, respectively.

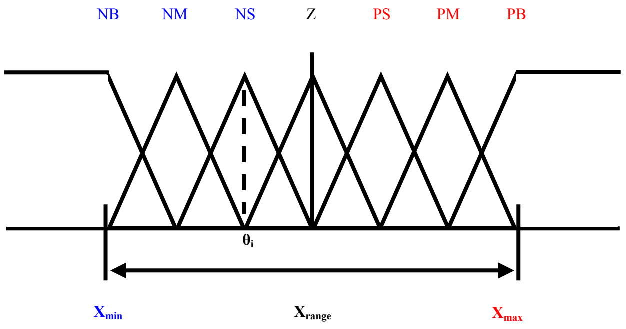

Fig.2 Fuzzy variable, Xi, seven membership functions.

Table 1: Fuzzy-logic PSS rules

		ΔP						
		NB	NM	NS	Z	PS	PM	PB
Δω	NB	NB	NB	NB	NB	NM	NS	Z
	NM	NB	NB	NM	NM	NS	Z	PS
	NS	NB	NM	NM	NS	Z	PS	PM
	Z	NM	NM	NS	Z	PS	PM	PM
	PS	NM	NS	Z	PS	PM	PM	PB
	PM	NS	Z	PS	PM	PM	PB	PB
	PB	Z	PS	PM	PB	PB	PB	PB

WEDG BASED NETWORK MODEL

A three-machine distribution system, as shown in figure 3, was used to test the proposed FLPSSs. The configuration was chosen to represent two physically far wind power plants and diesel power plant. The second wind plant (*G_3*) has much larger capacity than the first wind plant (*G_2*). Parameters for all generating units, transmission lines, loads and operating conditions are given in [12].

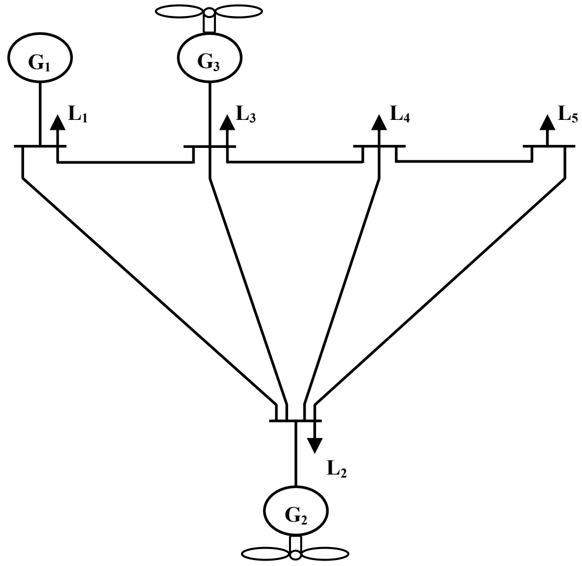

Fig.3 Schematic diagram of a five-bus three-machine power system.

SIMULATION STUDIES

In this section, we will investigate the performance of the proposed FLPSS as it is applied to the wind energy distributed generation based distribution network model. Firstly, the proposed FLPSSs will have to work together with the existing CPSSs. The purpose of the proposed distribution network test system is to illustrate that the proposed FLPSSs can work cooperatively with the existing CPSSs and also supersede a conventional PSS. Simulation results of the wind energy distributed generation based distribution network model system confirmed that the proposed FLPSS is capable of damping power system swing mode oscillations that follow disturbances and working cooperatively.

Only one FLPSS installed

The first wind plant (*G_2*) is of much smaller capacity than the second plant (*G_3*). It acts as a source of the local mode of oscillations when subjected to a disturbance. The proposed FLPSSs are installed on the first wind plant (*G_2*). A 0.3 p.u. step decrease in the wind speed input of the first wind plant (*G_2*) is applied at 0.5 s and the system returns to its original condition at 6s.

The proposed FLPSS damp the local mode oscillations very effectively. On the contrary, a conventional power system exhibits deterioration in the damping capability as shown in figure 4.

A FLPSS installed on the first wind plant (*G_2*) have little influence on the interarea mode oscillations. This is because the rated capacity of the first wind plant (*G_2*) is much less than that of the second wind plant (*G_3*). The interarea mode oscillations are introduced mainly by this large wind plant (*G_3*). To damp the interarea mode oscillations, the proposed FLPSSs must be installed on both the first and second wind plants as well.

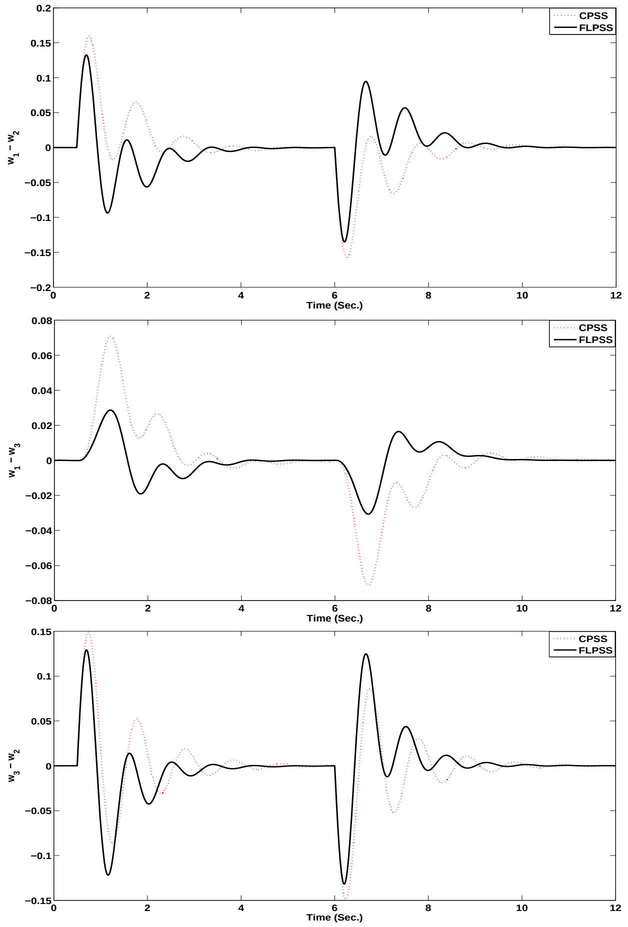

Fig.4 *System response to step decrease in wind with FLPSS installed on wind plant (G_2)*

Two FLPSSs installed

The proposed FLPSSs were installed on wind plant (*G_2*) and wind plant (*G_3*) to damp both the local mode and interarea oscillations. System response to a 0.2 p.u. step decrease in the wind speed input of the first wind plant (*G_2*) and 0.1 p.u. step decrease in the wind speed input of the second wind plant (*G_3*) is applied at 0.5 s and the system returns to its original condition at 6s was given in figure 5. It is very clear from figure 5 that both modes of oscillations were effectively damped.

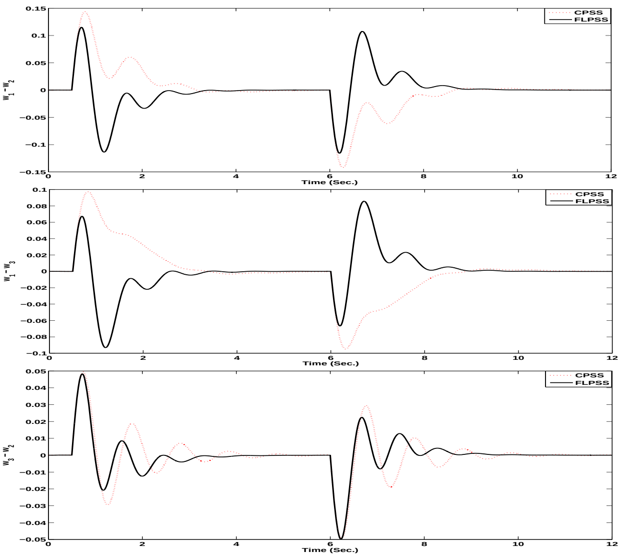

Fig.5 *System response to step decrease in wind with FLPSSs installed on wind plant* (G_2) *&wind plant* (G_3)

Three FLPSSs installed

The proposed FLPSSs were installed on wind plant (G_2), wind plant (G_3) and also diesel power plant. In this case, a sever test will be performed as follow: a 0.2 p.u. and 0.1 p.u. step decrease in the wind speed input of the first wind plant (G_2) and second wind plant, respectively. At the same time a three phase to ground fault occurred at the diesel power plant at 0.5s for 100ms. System response to that test was shown in figure 6. The proposed FLPSSs not only damp both modes of oscillations but also enhance the dynamic system response by reducing both the overshoot and settling time.

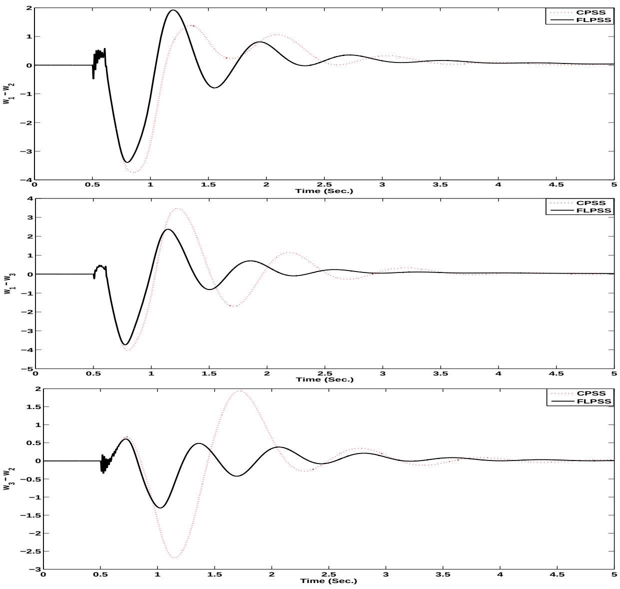

Fig.6 *System response to a three phase short circuit and step decrease in wind with FLPSSs installed on all plants* (G_1), (G_2) *&* (G_3)

CONCLUSIONS

The aim of this paper is to show the effectiveness of the FLPSS in damping multimodal oscillations and this had been illustrated on WEDG based distribution network that exhibits such a phenomenon. The results show that the proposed FLPSS can damp both modes of oscillations effectively. The results also show that the FLPSS can work cooperatively with the CPSS. This paper developed a unique worldwide capability to provide distribution network customers reduce costs, stay connected at all times and tap into an ultra pure, secure and uninterrupted power supply. It is evident from simulations results that the proposed innovative combination of WEDG system and FLPSS makes the energy safe, reliable, efficient, productive and Green.

Acknowledgments

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