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AMANGALDI KOOCHAKI[1], ATILA SKANDARNEZHAD[1], YAGHOOB MOHAMMADMORADI[1], SOLGUN SALIMI[1]

Department of Electrical Engineering, Aliabad Katoul Branch, Islamic Azad University, Aliabad Katoul, Iran (1)

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Multi-Machine Power System Fuzzy Stabilizer Design using Cuckoo Search Algorithm

***Abstract**. Nowadays, fuzzy controllers have achieved an important role in different systems and their superiority over the classical control methods has been proved. In this study, the power system stabilizer is used to damp the power system oscillations based on the fuzzy logic controller. A three-phase to ground-fault test is done during a period of 10 ms to evaluate power system behaviour between the area of two distinct points. Simulation results show that the system is unstable without a stabilizer. It has also been determined that the fuzzy stabilizers have high ability to damp the system oscillations in comparison with classical stabilizers so that system oscillations are damped with higher speed and lower amplitude. Also in this study, the Cuckoo search algorithm is used to optimize the fuzzy stabilizer inputs and improve its performance. The results show that the optimizations of stabilizer parameters improve their damping performance.*

Streszczenie.** W artykule opisano algorytm typu Fuzzy logic wykorzystany do tłumirnia oscylacji w systemie zasilania.Wykoyowany jest test systemu między dwoma odległymi punktami. W porównaniu z klasycznymi sterownikami zaproponowany sterownik oscylacje tłumione sa szybciej i skuteczniej.* ***Wykorzystanie algorytmu typu Cuckoo do tłumienia oscylacji w systemie z wieloma źródłami.

Keywords: Power system stabilizer, Classic stabilizer, Fuzzy stabilizer, Cuckoo optimization algorithm.
Słowa kluczowe: stabilizacja systemu zasilania, fuzzy logic – logika rozmyta, algorytm Cuckoo.

Introduction

The stability is known as the one of the important issues of safe operation of power system so that more global power outages due to power system instability reveal the importance of this issue [1]. Today, in the most modern power systems, the power system stabilizer is used to increase damping and enhance system dynamic stability [2]. Experience has shown that classic stabilizers have not good performance against system variations in its operating points. Therefore, a stabilizer must be designed that in accordance with the aforementioned variations, its parameters should be varied and adapt itself to new conditions. Therefore, attention has been drawn to smart approaches and the use of optimization algorithms. In the last literatures, many control strategies based on the theory of optimal control, adaptive control and robust control methods by researchers have been proposed to overcome the disadvantages of conventional stabilizer. Several methods based on the optimal control theory [3-5], robust control [6], adaptive control [7], neural network [8], smart evolutionary approach [9], particle swarm [10], cultural algorithm [11], immune algorithm [12], and the frog leap algorithm [13], are used to design the stabilizer.

In this paper, the studied power system is modelled and then designing of power system stabilizer based on Optimized Fuzzy Logic Controller using Cuckoo Search Algorithm is presented.

Modeling of the studied system

Figure 1 shows a four-machine two-area system that is used to study the power system stability and stabilizer design.

The conventional third-order model of generators is as follow [10-11].

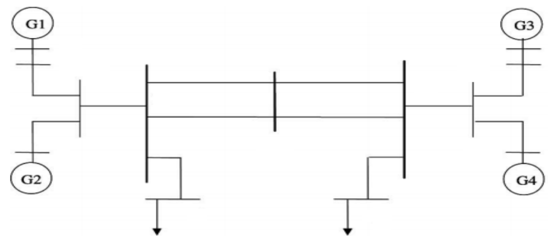


Figure1. Structure of studied network

Table1. The generator model values

$\frac{d\delta}{dt} = \omega - \omega_s$	(1)
$\frac{d\omega}{dt} = \frac{1}{2H}\left[-D(\omega-\omega_s)+T_m-T_e\right]$	(2)
$\frac{dE'_q}{dt} = \frac{1}{T'_{do}}\left[-E'_q+(x_d-x'_d)i_d+E_{f}\right.$	(3)
$\frac{dE'_d}{dt} = \frac{1}{T'_{qo}}\left[-E'_d+(x_q-x'_q)i_d\right]$	(4)
$\frac{dE_{fd}}{dt} = \frac{1}{T_A}\left[-E_{fd}+K_A(V_{ref}-V_t)\right]$	(5)

where E'_d , E'_q are the EMF's of stator, E_{fd} is the field voltage of stator, X_d , X_q are the synchronous reactance's, and X'_d , X'_q are the transient reactance's in d-q axis. In addition, I_d , I_q are the stator currents , τ'_{do} and τ'_{qo} are the open circuit time constants , P_e is the output electrical power of generator and D is the damping ratio. The model of Conventional Power System Stabilizer (CPSS) is shown in Figure 2. where the generator speed is usually used as the input signal. The CPSS is mathematically formulated as follows.

where Δω is the speed deviation in P.U. The CPSS consists of a washout filter and a dynamic compensator [13-14]. The output signal is fed to the excitation system as a supplementary input signal. The high pass washout filter is employed to reset the steady state offset in the PSS output. The value of time constant (Tw) is usually fixed and is considered as 10 s in this study. Also T1 − T4 and K_{PSS} show the time constants and the gain of two stages lead–lag compensator respectively. Then, the design problem will be to obtain K_{PSS} and T1 − T4.

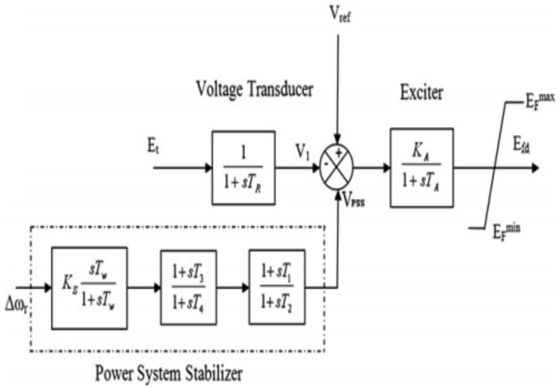


Figure 2. The conventional PSS structure.

$$U_{PSS} = K_{PSS} \frac{ST_W}{1+ST_W} \frac{1+ST_1}{1+ST_2} \frac{1+ST_3}{1+ST_4} \Delta w \quad (6)$$

Designing OF FUZZY System Stabilizer

In this paper, the self-tuned fuzzy controller is used to damp the power system inter-area oscillations. Figure 3 shows the fuzzy controller structure [15-16].

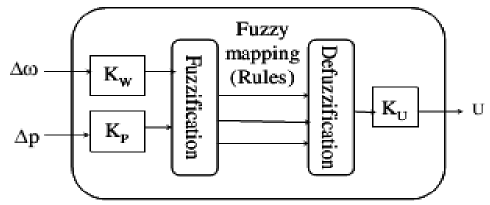


Figure 3. Fuzzy controller structure.

According to Figure 3, input signals to the fuzzy controller are the rotor speed oscillations dw and generator active power oscillations dp. The control signals generated by fuzzy stabilizer are injected into generator AVR system. The purpose of this stabilizer is enhancement of synchronous generator damping. In order to apply proper control, triangular membership functions as seven fuzzy functions are respectively considered as the Figure 4 for active power oscillations and rotor speed oscillations.

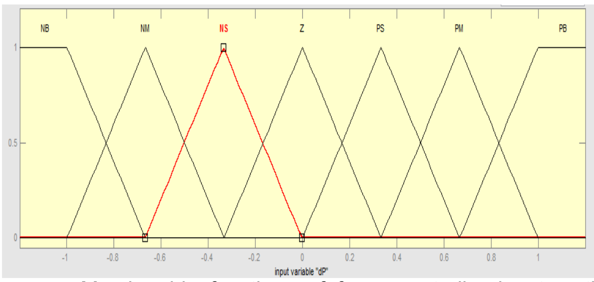


Figure 4. Membership functions of fuzzy controller input, active power and rotor speed oscillations

As seen in Figure 4, the inputs dw and dP are affected by k_w and k_p and The output of the fuzzy controller is multiplied by k_u. Selecting the values for these coefficients depends on system working conditions and must be carefully selected to ensure FPSS performance. The membership functions of fuzzy controller output are presented by Figure 5 as the control signal.

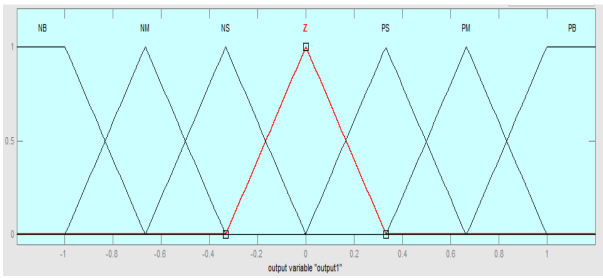


Figure 5. The membership functions of fuzzy controller output signal

Fuzzy rules considering the membership functions for decision are presented based on the Table 2 according to controller inputs.

Table 2. Fuzzy rules of FPSS

Speed deviation \ Reactive power	NB	NM	NS	ZE	PS	PM	PB
NB	ONB	ONB	ONB	ONB	ONS	ONS	OZE
NM	ONB	ONB	ONM	ONM	ONS	OZE	OPS
NS	ONB	ONM	ONM	ONS	OZE	OPS	OPM
ZE	ONM	ONM	ONS	OZE	OPS	OPM	OPM
PS	ONM	ONS	OZE	OPS	OPM	OPM	OPB
PM	ONS	OZE	OPS	OPM	OPM	OPB	OPB
PB	OZE	OPS	OPM	PSB	OPM	OPB	OPB

Optimization of Stabilizer

The CPSS against the system variations in the various operating points of system is not proper. Thus, by using optimization techniques the performance of stabilizer should be ensured in damping of power system oscillations with optimal determination of its parameters. In this paper, the cuckoo search algorithm is used to optimize the parameters of the CPSS and FPSS. Cuckoo search algorithm inspired by the lifestyle of the cuckoo bird in 2009 by Shin Ouyang, and Deb Savsh has been developed. Cuckoo search algorithm is based on a kind of cuckoo life. This algorithm has been developed by flying levy Instead of Isotropic random walk. Cuckoo search algorithm is fully described in [17]. The main steps of cuckoo search algorithm can be expressed as follows.

Step 1, →
Specify current place of residence of cuckoos randomly
Step 2, →
Assign a number of eggs to each cuckoo.
Step 3, →
Specify the laying radius of each cuckoo.
Step 4, →
Cuckoos are laying on the host nests in their lay radius.
Step 5, →
Eggs that are identified by the host birds are destroyed
Step 6, →
Cuckoo eggs that have not been identified are grown.
Step 7, →
Evaluate the place of residence of new cuckoos.
Step 8, →
Specify the maximum number of cuckoos that are in a place to live and eliminate those that are in unsuitable places.
Step 9, →
cluster the cuckoos using k-means clustering method and specify the best group of cuckoos as the objective place of residence.

Step 10, →
New cuckoo's population are moving to the objective location.
Step 11, →
stop if the stop condition has been established, otherwise, go to step 2.

The optimization objective function is defined as follows in this study [10-11]:

$$Objective = \int t \left| \Delta\omega_1 + \Delta\omega_2 + \Delta\omega_3 + \Delta\omega_4 \right| dt \tag{7}$$

In the above equation Δω is the generator speed oscillation. The time constants of phase compensator and gain of compensator are considered as the optimization parameters. Range of optimization variables of CPSS are presented in Table 3.

Table 3. Range of optimization variables of CPSS [10-11]

Parameter	K_{pss}	T_1
Min Value	1	0.01
Max Value	20	1

In continue, optimization of FPSS is presented. Coefficients K_W and K_P in FPSS have a key role in the efficiency and increasing of system damping and select the appropriate values for the coefficients is very important. In this paper to strengthen the performance of the fuzzy controller in damping of fluctuations, the preprocessors parts of fuzzy controller are optimally selected. In this study, the values of K_W and K_P are optimally selected by cuckoo search algorithm in a special range. The objective function of equation (7) is considered similar to the optimization of the CPSS to determine the optimal values of K_W and K_P. the variations range of the fuzzy controller preprocessor coefficients is presented in Table 4.

Table 4. Variations range of the fuzzy controller preprocessor coefficients

Parameter	K_w	K_P
Min Value	1	0.1
Max Value	20	1

In this study, setting of cuckoo search algorithm options is obtained based on the experience and a specific method has not been used to obtain these parameters. Cuckoo search algorithm parameters are listed in Table 5.

Table 5. Cuckoo search algorithm parameters

Parameter	Value
Number of cuckoo	10
Max iteration	20

After running the cuckoo search algorithm the optimal values of parameters and coefficients of classical and fuzzy controller are obtained as shown in Table 6.

Table 6. Optimal values of parameters of classical and fuzzy PSS

Stabilizer	CPSS	FPSS
Optimal value	K_{stab}=18.047 T_1=0.1054	K_p=5.878 K_w=0.2675

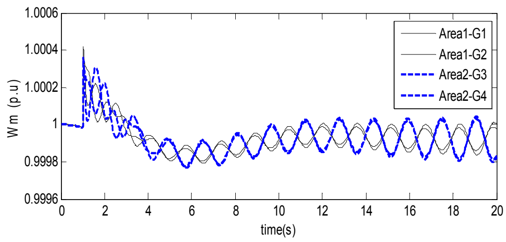
Simulation Results

In this paper, damping of power system inter-area oscillations is studied using the power system stabilizer on the 4-machines two-area power system. The studied system is simulated by the Matlab/Simulink software environment as the Figure 8. The power system consists of two similar areas, which are connected by a weak transmission line. Each area is made up of two connected power plant units which have the 900 MVA rated power and 20 kV rated voltage. The rated voltage of transmission line is 230 kV and normally with no reactive power, 413 MW is transferred from first area to the 2nd area.

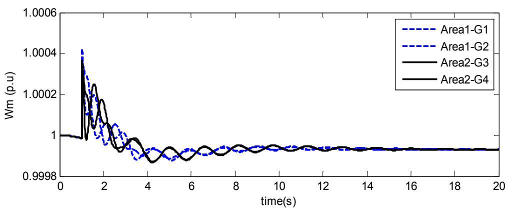
Studied system parameters including generators, transformers and lines parameters are available in [19]. The amounts of AVR voltage regulator parameters and classic power system stabilizer are respectively presented in [19] too.

To evaluate the ability of the power system stabilizer in damping of low frequency oscillations of 4-machines 2-area power system, generators speed oscillations, voltage of buses 1 and 2 of system on both sides of the transmission line and inter-area transferred power from bus 1 to bus 2 are evaluated. To create oscillations and check the system stability, a 3-phase to ground short circuit fault is used in the transmission line between two areas with duration of 10 ms at time of first second to test the ability of each stabilizers. In the Figures 6 and 7, the rotor mechanical speed of each generator and inter-area transferred power are respectively represented without stabilizer and with CPSS and FPSS. As can be seen, the power system has oscillations without damping in the fault occurrence time and time of fixing fault, without stabilizer. With CPSS and with fault occurrence the system is again converted into two island areas but because of using stabilizer the synchronization of two areas is retrieved again. In addition, results from FPSS show that the fuzzy stabilizer in comparison to CPSS has high speed and damping and the power system oscillations has been reduced.

In continue, the results of stabilizers optimization are presented. Figure 8, shows the results of system inter-area transferred power is presented before (CPSS and FPSS) and after optimization (optimal CPSS and optimal FPSS). According figure 8, it can be said that the optimal FPSS has less oscillations and is damped with higher speed in comparison to other stabilizers.



(a)



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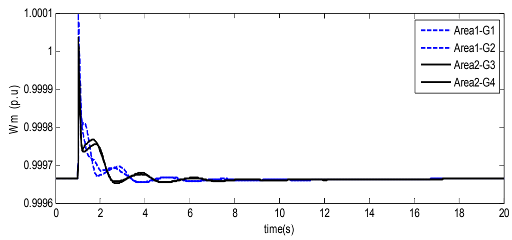
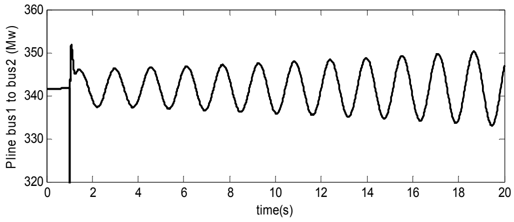


(c)

Figure 6. the mechanical speed of each generator: a) without stabilizer, b) with CPSS, c) with FPSS



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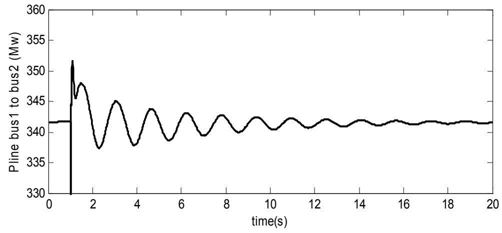

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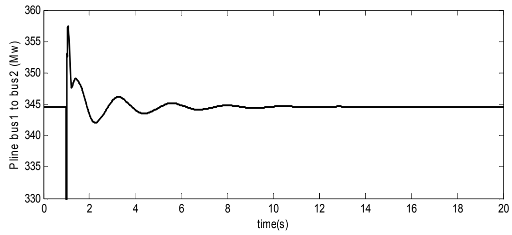


(c)

Figure 7. the inter-area transferred power:
a) without stabilizer, b) with CPSS, c) with FPSS

It is also clear that the optimization of FPSS by using the cuckoo algorithm has caused that its oscillations are significantly reduced. Therefore, stabilizer optimization has improved its performance on the power system oscillations damping process.

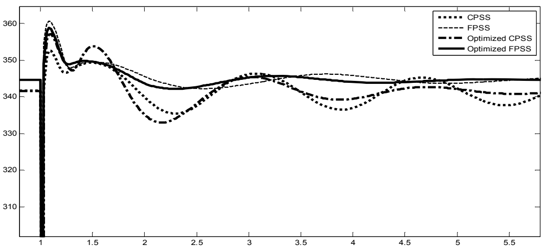
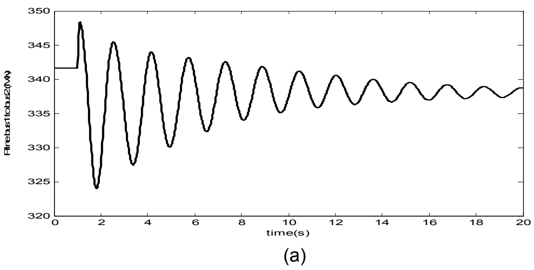
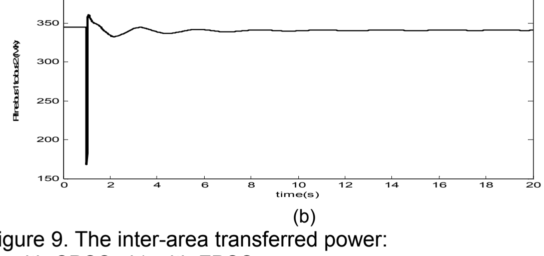


Figure 8. the inter-area transferred power oscillations before and after optimization with CPSS and FPSS.



(a)



(b)

Figure 9. The inter-area transferred power:
a) with CPSS , b) with FPSS

In continue, the reference voltage of generator 1 is increased from 1.03 to 1.05. in this state, the ability of stabilizers to the system conditions variation can be better tested. The results of fuzzy and classic stabilizers including the transferred power oscillations are shown in figure 9. Also in this state, the obtained results show the high ability of fuzzy stabilizer in damping of inter-area power oscillations that is the fuzzy stabilizer has less oscillations and damps the power system oscillations with higher speed.

6. Conclusion

In this paper, damping of 4-machines 2-area power system with low frequency oscillations are studied by supposing the occurrence of a 3-phase fault. The generators speed oscillations and inter-area transferred power oscillations are also detiled. The simulation performed in different states such as: without stabilizer, with CPSS, with FPSS and with optimal FPSS. The results show that the stabilizers which are based on the fuzzy controllers have more ability to stabilize the power system oscillations in comparison to CPSS. Also, results reveal that the optimization of stabilizer parameters has a main role on its performance to damp the system oscillations.

Authors
Amangeldi Kochaki, koochaki@aliabadiau.ac.ir
Faculty Member of Electrical Engineering,
Department of Electrical Engineering, Aliabad Katoul Branch, Islamic Azad University, Aliabad Katoul, Iran.
Atila Skandarnezhad, eskandarnejad@aliabadiau.ac.ir
Faculty Member of Electrical Engineering,
Department of Electrical Engineering, Aliabad Katoul Branch, Islamic Azad University, Aliabad Katoul, Iran.
Yaghoob Mohammadmoradi,
MohammadMoradi@aliabad.ac.ir
Faculty Member of Electrical Engineering,
Department of Electrical Engineering, Aliabad Katoul Branch, Islamic Azad University, Aliabad Katoul, Iran.
Solgun Salimi, solgun_salimi@yahoo.com
M.S. Student of Electrical Engineering,
Department of Electrical Engineering, Aliabad Katoul Branch, Islamic Azad University, Aliabad Katoul, Iran.

* The correspondent E-mail is:
Koochaki@aliabadiau.ac.ir

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