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SIMULTANEOUS COORDINATED TUNINGOF CES AND PSS FOR SINGLE-MACHINE USING GENETIC ALGORITHM

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ABSTRACT

This paper presents a new coordinated design between Power System Stabilizer (PSS) and Capacitive Energy Storage (CES) using Genetic Algorithm (GA). A GA will determines optimal parameters for PSS and CES by tuning parameters PSS and CES simultaneously. The optimization results can change the value of PSS and CES parameters which can also cause oscillation on the system. This problem is formulated as an objective function with limits consisting of damping ratio and damping factor. The approach is succesfully tested on single-machines generator models. The optimization results show that this method is effective enough to damp the oscillation, so as to give an idea of the dynamic stability of the single-machine system.

Keywords:*CES, PSS, Single-Machine, Genetic Algorithms*

1. INTRODUCTION

The power system stability has been considered as an important issue to protect power system operation.The pattern of load changes that occur so fast in aninterconnected system causes oscillations on each machine that connected to the system. These oscillations affect each other, so theinterconnected machineis interacted to reduce these oscillations in order to reach the stable condition [1][26].

The large oscillations cause system instability. This condition does not guarantee that the system will return to the steady-state condition. So many researchers developed various types of controllers to dampen these oscillations so the system back in a steady-state condition with a relatively short time after the fault [2] - [7]. This stability analysis focuses on dynamic stability caused by small disturbances, such as changesof theload when peak load condition.

CES (Capacitive Energy Storage) is a device for large power storage and release simultaneously.CES consists of the capacitor storage and Power Conversion System (PCS) with integratedcontrol and protection functions.The normal operating point of the capacitor can be arranged so that the maximum energy absorption equals to the maximum energy discharge. This condition makes CES is very effective in reducing oscillations caused by load changes [8-11], [23-24].

The PSS (Power System Stabilizer) installationas thecontroller has been shown in reference [3] intended to improve the controller performance in reducing oscillations.In its operation, the controller is working together with AVR (Automatic Voltage Regulator). These controllers are effectively used to dampen electromechanical oscillations. Therefore, this paper proposes the use of CES and PSS as an alternative method for reducing the system oscillation [12], [16-18], [20-22].

Generally, tuning parameters of PSS and CES are multimodal optimization problems. Therefore, most algorithms fail to get a fairly accurate solution, especially on large systems. Additionally, the optimization parameter limits make it harder to find the optimal solution. To solve all the above problems, this paper proposed.Genetic Algorithm (GA) to obtain optimal parameters that used as constants in the optimal coordination of CES and PSS operations simultaneously.

The genetic algorithm is an optimization method that imitates natural biological evolution metaphor [14], [24]. GA is used to solve nonlinear equations by finding random values and optimizing very complex problems. GA uses probabilistic transition rules in place of deterministic rules and addresses the population of potential solutions called individuals or chromosomes that develop iteratively. Each iteration of this algorithm is

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calleda generation. Development of solutions is simulated by fitness functions and genetic operators such as reproduction, mutation, and crossover.

In this paper, GA is presented for optimizing the use of PSS and CES in a single-machine infinite bus (SMIB) synchronous generator. The PSS and CES parameters are effectively tuned with GA to obtain sufficient damping for oscillations due to load changes. The attenuation to the oscillations occurring is used as an objective function. Then the attenuation is converted to a fitness function using the Integral Time Absolute Error (ITAE) method. ITAE optimizes the absolute error and completion time not achieved by other methods [27]. Then the fitness value that has been obtained will be evaluated to get the optimal oscillation damping value. Thus, system security can avoid unwanted incidents.

2. SYNCRONOUS GENERATOR MODEL

Single-machine generator model in this paper is shown in figure 1 [13]. This generator model is a synchronous generator modeling in detail, including its control components.Generally, there are two main controls on this generator modeling, Load Frequency Control (LFC) and Automatic Voltage Regulator (AVR). Both controllers maintain frequencies and voltages in stable conditions in accordance with their limitations when there is a load changing on the system. The active power change affects the rotor angle δ which will directly affect the frequency. While the change of reactive power will affect the voltage magnitude. The excitation system will keep the voltage stable, but it does not affect the LFC. LFC will work independently to maintain frequency stability due to active power change.

$$\frac{2H}{\omega_s}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - P_e \qquad (1)$$

With speed expressed in per unit, without explicit per unit notation,

$$\frac{d\Delta\omega}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \qquad (2)$$

Laplace Transform of equation (xxx) is

$$\Delta\Omega(s) = \frac{1}{2Hs}[\Delta P_m(s) - \Delta P_e(s)] \qquad (3)$$

By deriving the swing equation of the synchronous generator in equation (1) - (3) there is a corelation between the mechanical power of the generator *Pm* and the electrical power of the load *Pe* as shown figure (1).

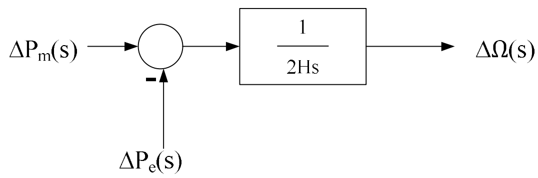

Figure 1. Mechanical power and the electrical power block diagram

2.1 LFC Model

LFC will keep the frequency stable at its limit. The frequency change will be known through the rotor angle change then the rotor angle error will be corrected. The error signal will be amplified and converted to active power. Then prime-mover will compensate for the change of active power. Figure (2) shows the LFC block diagram in the synchrous generator.

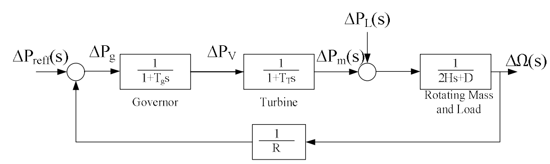

Figure 2. LFC block diagram

How sensitive the LFC to frequency changes depends on the frequency-sensitive load change DΔω, where D is the percent change of load divided by the percent change in frequency.

$$\frac{\Delta\Omega(s)}{\Delta P_L(s)} = \frac{(1+T_g s)(1+T_T s)}{(2Hs+D)(1+T_g s)(1+T_T s)+1/R} \qquad (4)$$

Change of -PL (s) as input and frequency deviation ΔΩ (s) as the output of blog diagram of LFC in figure (4). Close-loop transfer function between load changes -PL (s) and changes in frequency deviation ΔΩ (s) as equation (4).

2.2 AVR Model

The reactive power of the generator is controlled by the excitation system using AVR. AVR will maintain the voltage magnitude of the generator terminal at the specified limit. Figure (3) shows a simplified automatic voltage regulator block

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diagram.

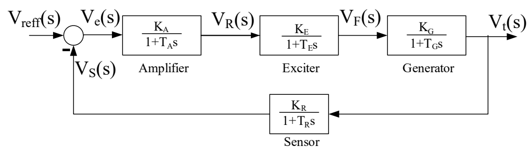

Figure 3. AVR block diagram

The addition of reactive power on the load will cause the voltage drop at the generator terminal. The voltage magnitude will be censored by the potential transformer (PT), then will be rectified to DC voltage by the rectifier. The DC signal will be compared with the set point so that the error signal will be compensated by the exciter so that the current on the generator field coil increases. The field current will amplify the emf on the generator so that the reactive power increases and the voltage return to the desired value.

$$\frac{V_t(s)}{V_{reff}(s)} = \frac{K_A K_E K_G K_R (1+T_R s)}{(1+T_A s)(1+T_E s)(1+T_G s)(1+T_R s)+K_A K_E K_G K_R} \quad (5)$$

Closed Loop transfer function between the terminal voltage generator Vt (s) to the reference voltage Vreff (s) is represented by equation (5).

3. CES (Capacitive Energy Storage)

CES consists of the capacitor storage and Power Conversion System (PCS) with control and integrated protection functions. Figure 4 shows the basic configuration of CES in electric power systems.Capacitor storage *C* consists of several discrete capacitors thatconnected in parallel. Resistance *R* connected in parallel to the capacitor*C* is leaking and dielectric losses of the capacitor bank at CES.Storage capacitor connected to the grid through the Power Conversion System (PCS), which consists of ac to dc rectifier and dc to ACinverter. Two sets of six-pulse bridge converter are used to reduce harmonics that occurred.The function of bypass thyristoris to provide a pathway for currents *Id* when converter failure occurs. DC breaker allows the currents *Id* to flow through resistor *RD,* theenergydisposal if the converter fails.Neglecting the losses, bridge voltage *Ed* is as equation (7).

$$E_d = 2E_{d0}\cos\alpha - 2I_d R_D \quad (7)$$

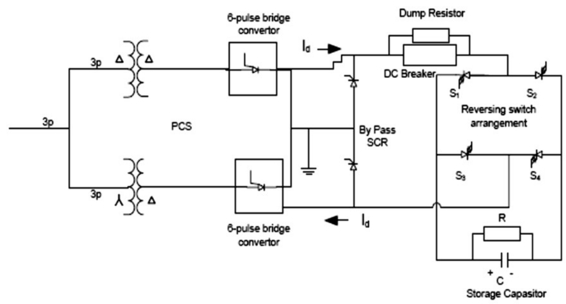

Figure 4. CES configuration

By changing the phase angle α with a range value from 0° to 180°the capacitor voltage *Ed* able to be varied from a maximum positive value until the maximum negative value [10].This conditions will make CES is very effective in reducing oscillations caused by load changes because the normal operating point of the capacitor can be arranged so that the maximum energy absorption equals the maximum energy discharge.If Ed_0 shows the initial voltage value, Edmax and Edmin shows the minimum and maximum voltage limits, then:

$$\frac{1}{2}CE_{dmax}^2 - \frac{1}{2}CE_{d0}^2 = \frac{1}{2}CE_{d0}^2 - \frac{1}{2}CE_{dmin}^2 \quad (6)$$

$$E_{d0} = \frac{[E_{dmax}^2 + E_{dmin}^2]}{2} \quad (7)$$

CES voltage must be returned to the initial value quickly, so after a fault occurs CES ready to work for the next fault. Therefore, the capacitor voltage deviation is used as a negative feedback signal in the CES loop control so so voltage recovery is achieved quickly as shown in figure 5 below.

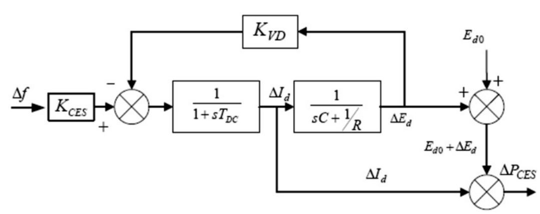

Figure 5. CES block diagram

K_{CES} is strengthening CES components can be arranged based on feedback *Δf*. Where*Δf* is the change in the frequency of each area of the power system. So that the current changes ΔI_d is,

$$\Delta I_{di} = \frac{[K_{CES}.\Delta f - K_{VD}.\Delta E_d]}{1+sT_{DC}} \quad (8)$$

With the capacitor voltage deviation ΔE_d are as follows:

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$$\Delta E_d = \left[\frac{1}{sC+\frac{1}{R}}\right]\Delta I_d \quad (9)$$

CES output power that released to the system during load changes are as follows:

$$\Delta P_{CES} = (E_{d0} + \Delta E_d).\Delta I_d \quad (10)$$

4. PSS (Power System Stabilizer) Models

PSS (Power System Stabilizer) operates in the generator excitation system by adding a control signal on the AVR (Automatic Voltage Regulator) to dampentheoscillations of rotorgenerator.The angular speed of the generator is generally used as an input signal from this device [3], [5]. Figure 6 shows a PSS modelling.

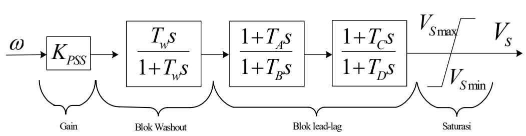

Figure 6. PSS block diagram

K_{PSS} is a gain component of the PSS that its value can be set. In lead-lag component, the phase can be adjusted by changing the value of T according to the needed phase values. T_A and T_B are $\sqrt{\alpha}/\delta$ and $1/\delta\sqrt{\alpha}$.

While the washout components prevent offset voltage on a steady state.With this transfer function on equation (11), PSS can be used to generate a positive damping torque which the magnitude and phasecan be regulated.

$$Vs = \frac{sK_{PSS}T_W}{1+sT_W}\frac{(1+\left(\frac{\sqrt{\alpha}}{\delta}\right)s)^2}{(1+\left(\frac{1}{\delta\sqrt{\alpha}}\right)s)^2} \quad (11)$$

This controller was effective, economical, and secure in the power system to dampen oscillations. However, this controller is not effectively used for large electric power systems that interconnected with the generator layout that far apart. Therefore, the oscillation interaera usually occurs in such a system [5].

2.3 CES and PSS Coordination

CES and PSScoordination in the system shown in Figure 7.CES dampen oscillations by detecting the frequency of feedback and then provide damping in the form of power CES (P_{CES}). While PSS dampen oscillations by detecting the frequency of feedback and then provide damping through the excitation system. Figure 7 shows the modeling of the generator by the addition of CES and PSS. In Table 1, have also shown some initial parameters of CES.

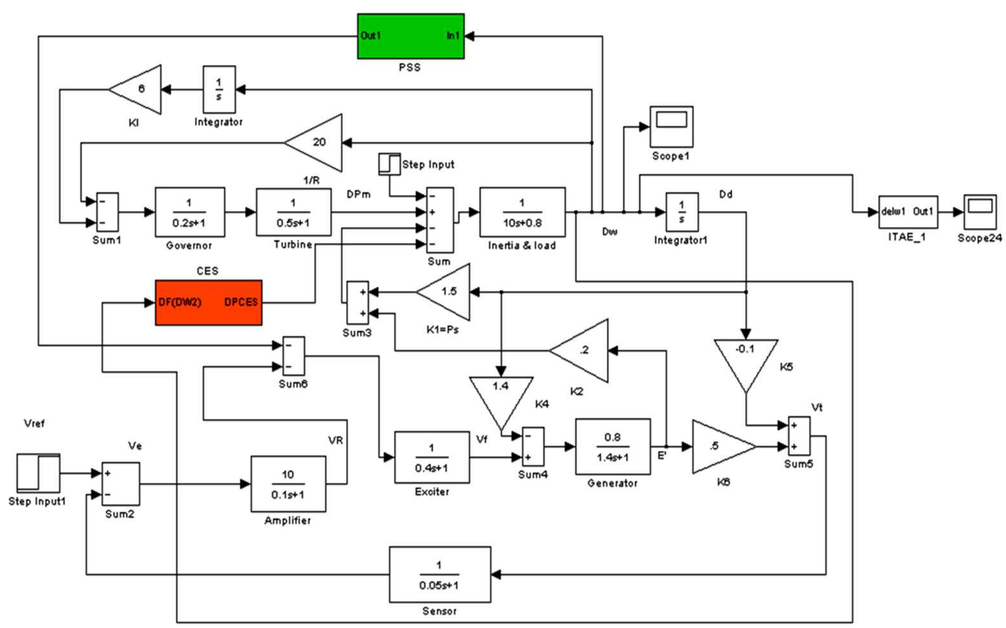

Figure 7. Generator modeling with the addition of CES and PSS

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Table 1: CES Parameter

CESParameter	Values
K_{VD}	-0.1
T_{dc}	0.05
C	1
T_{dc}	0.05
R	100
E_{d0}	2

5. GENETIC ALGORITHM FOR CES AND PSS COORDINATION

Nonlinearity and discontinuity system caused some optimization problems cannot be solved analytically.The appropriate method to solve these issues is the direct search method. The direct search method using a variety of ways to find appropriate solutions, such as random searches, or searches that inspired by the biological sciences such as genetic algorithms [14].

There are many variations in genetic algorithms, but specifically in this research proposed a genetic algorithm for optimization of CES and PSS in single-machine. A genetic algorithm is a search algorithm based on the mechanism of natural selection and natural genetics. In this research, there are six variables (K_{PSS}, T_w, T_A, T_B, T_C, T_D) which are encoded intoPSS chromosomes and six variable (K_{CES}, K_{VD}, T_{DC}, C, E_{d0}, R) encoded into CES chromosomes.Each chromosome contains a gene that encodes the information stored in the chromosomes. To resolve the above problems is used real number encoding by thevalue genes are in the interval of numbers between 0 and 1.

After the encoding scheme is determined, a genetic algorithm is initialized to a population by the N number of chromosomes. The gene that fills each chromosome randomly generated using a uniform distribution. Each chromosome will be encoded into a specific individual with the highest fitness. A new population is generated by using the mechanism of natural selection, selecting individuals in proportion to the value of fitness, and natural genetics are crossover and mutation. The steps genetic algorithm can be written as the figure 8.

For real number encoding, a gene 'g' is used to represent a real number between 0 and 1. By using a certain interval, the lower limit rb and the upper limit ra can be performed in the following formula:

$$x = r_b + (r_a - r_b)g \quad (12)$$

An individual is evaluated by a certain function as a measure of its performance. In nature evolution, individuals who have higher fitness will be alive while individuals that have low fitness will die.In this study, a solution searched to minimize the function h (minimization problem) so that the function $h$cannot be used directly.This is due to the rule that individuals with higher fitness values can survive in the next generation. Therefore the value of fitness that can be used according tothe equation:

$$f = \frac{1}{h} \quad (13)$$

that means that the smaller the value 'h', the greater the value 'f'. To avoid the value 'f' infinite due to the value of 'h' is equal to zero, should be added a number which is considered very small so the fitness value becomes:

$$f = \frac{1}{h+a} \quad (14)$$

The h function is a damping function obtained using the ITAE method. In this paper, the objective function (ITAE) is obtained using the equation (15).

$$h = \int_0^{\infty} t|e(t)|dt \quad (15)$$

After obtaining the value of fitness then will be ranked according to thefollowing equation:

$$f(i) = f_{max} - (f_{max} - f_{min})\left(\frac{R(i)-1}{N-1}\right) \quad (16)$$

where R (i) declare the i-th individual rank.The selection of two pieces of chromosomes as parents, which will be acrossovered, carried out proportionally based on the fitness value. The selection method that used in this research is the roulette wheel method. A chromosome with greater fitness value will substituteanother chromosome with lower fitness value. Crossover is done to avoid the early convergences. Each chromosome will choose its partner to do crossover randomly. The frequency of the crossover operator controlled by the value of Pc. In any population, as many as pc x the population_size, do the crossover. The higher the value of the crossover probability, then the sooner a new structure introduced in the population. In this research, crossover probability Pc used is 0.8.

Random mutations in a gene carried by a small probability. In this program, the probability of mutation is Pm = 0.3. The process repeated from the beginning for an every new population.

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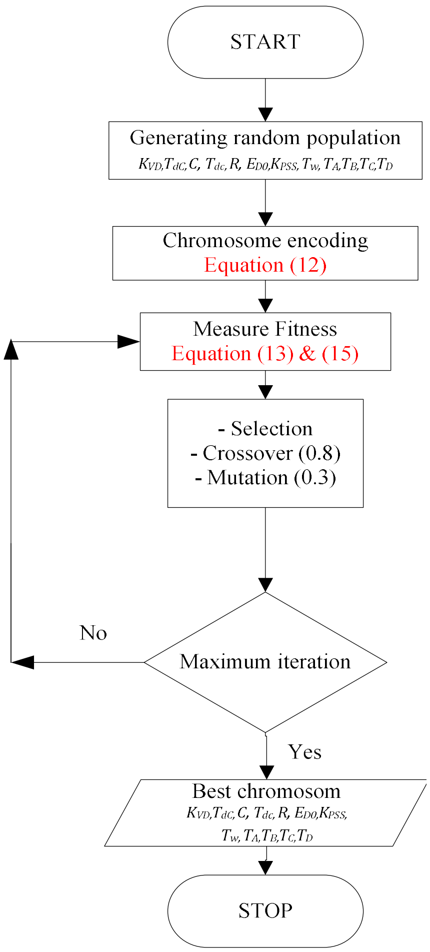

Figure 8. Genetic Algorithm for CES and PSS Coordination.

6. RESULTS AND DISCUSSION

Simulations were conducted to prove the suitability of the method. Table 2 is a parameter of the GA as a method to obtain optimal values of CES and PSS constants. Value optimization of system performance in each generation in the convergence-plot on a graph shown in Figure 5.

Table 2. Parameter DE

Gen	12
Population	100
Crossover Probability	0.8
Mutation Probability	0.3
Maximum Generation	300

Optimization value of the system performance on each iteration convergence-plot on a graph shown in Figure 7.

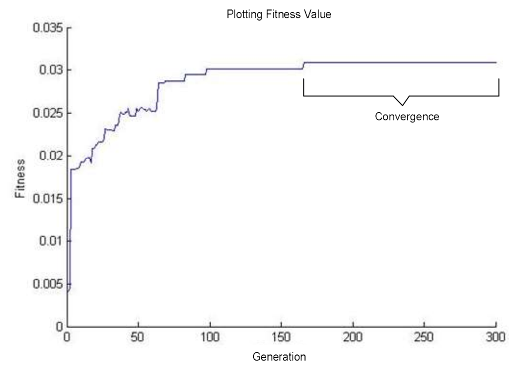

Figure 9. GA Convergence Graph

For the coordination of CES and PSS parameters using genetic algorithms, can be seen in the table below.

Table 3. Parameters of CES and PSS Coordination Using Genetic Algorithm

No.	CES Parameter		PSSParameter	
1	K_{CES}	0.8413	K_{PSS}	3
2	C	0.1197	T_w	0.6559
3	R	0.8367	T_A	0.9231
4	E_{do}	5	T_B	0.0416
5	K_{vd}	0.9111	T_C	0.9231
6	T_{dc}	0.0825	T_D	0.0416

These parameters will be used as control constants in CES and PSS operations. Thus, the performance of CES and PSS becomes optimum.

a. Frequency Changes Response

CES and PSS simulation application in a single-machineis optimized using Genetic Algorithms. To test the dynamic stability of the system, interruption of 1 p.u load change is given at 10th second. From the simulation obtained response of frequency change per unit (p.u) shown in Figure 8

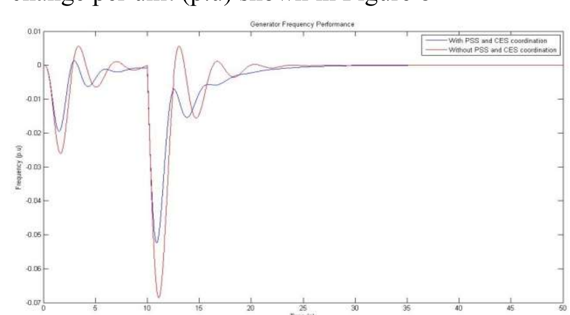

Figure 10. Frequency Change Responses Generator

From the picture above, the red graph shows the frequency response when an interruption occurs without CES and PSS installed. While the blue graph shows the frequency response using CES and PSS which has been optimized using GA algorithm. From the graph, it appears that with the addition of CES and PSS that have been coordinated and optimized using GA in the system causes the system performance against disruption becomes better. It can be seen from the reduction in the oscillation frequency of the system.

Overshoot frequency generator data in single-machine models are shown in the table below.

Table 4. Frequency Overshoot Value

WithoutController (pu)		CES and PSS (pu)	
max	Min	max	min
0.005608	-0.06857	0.001317	-0.0524

From the table above it can be seen that with the addition of CES and PSS in the system, making the frequency overshoot in the system becomes smaller.

b. Rotor Angle Responses

From the simulation results can also be analyzed for the rotor angle changes as shown in Figure 9.

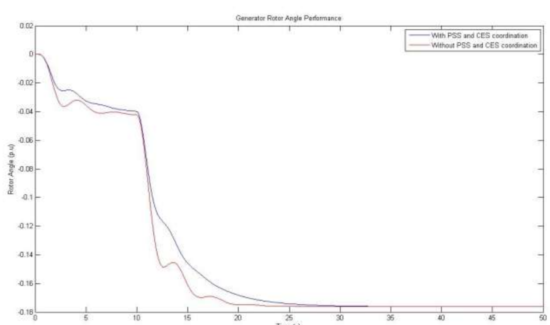

Figure 11. Rotor Angle Generator Response

From the picture above, the red graph shows the response of rotor angle when an interruption occurs without CES and PSS installed. While the blue graph shows the response of rotor angle using the CES and PSS. From both graphs can also be seen that the addition CES and PSS can reduce rotor angleoscillation due to a load changesdisturbance.Overshoot rotor angle data system single-machine generator are shown in the table below.

Table 5. Rotor Angle Overshoot Value

Without Controller (pu)			CES and PSS (pu)		
max	min	mean	max	min	mean
1.098×10^{35}	-0.176	-0.141	1.097×10^{35}	-0.176	-0.136

Table 5 also indicates that, with the addition of CES and PSS in the system, making rotor angle overshoot becomes smaller.

c. Voltage Responses

Analysis of simulation results of voltage parameters due to the installation of CES and PSS are shown in Figure 10.

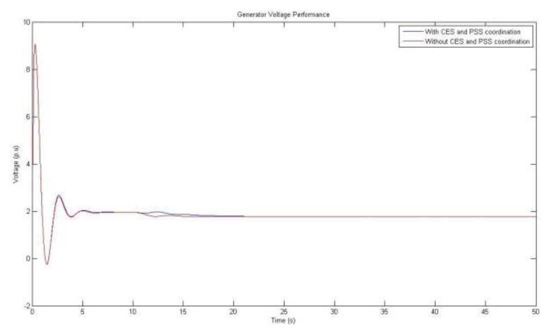

Figure 12. Generator Voltage Responses

Based on thefigure 10, the red graph shows the voltage response when an interruption occurs without CES and PSS installed. While the blue graph shows the voltage response using CES and PSS. These images show that CES and PSS installation can reduce the voltage oscillation. However, overshoot that occurs due to theinstallation of CES and the PSS in the system becomes larger.

Overshoot voltage data in single-machine generator models are shown in the table below.

Table 6. Voltage Overshoot Value

Without Controller (pu)		CES and PSS (pu)	
max	min	max	min
9.065	-0.2513	9.065	-0.2429

The table also indicates that, with the addition of CES and the PSS in the system, making voltage overshoot becomes smaller.

7. CONCLUSION

The results of proposed method showed that the installation of CES and the PSS in the single-machine generator models can reduce the oscillation due to load changes failure. The use of GA optimization algorithm parameters used as constants in the CES and PSS proved effective enough to get the optimum value so that the oscillation due to a disturbance becomes smaller. This will make the system safe from unwanted events. untuk kedepannya diharapkan penelitian ini dapat diimplementasikan pada sistem nyata.

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