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Power System Stabilizer Model Using Artificial Immune System for Power System Controlling

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Abstract

This paper presents power system stabilizer (PSS) model using artificial immune system (AIS) for power system controlling. PSS is a device that can be used to improve the damping of power system during low frequency oscillations. This study proposed the use of AIS algorithm for tuning the PSS parameter. AIS-based PSS has been successful in controlling the multi-machine under study. For multi-machine system consists of four machines, the application testing on the machine M1 to short circuit symmetrical three-phase, AIS-based PSS found that that good design results in this study. Overall, AIS-based PSS, Delta w PSS and Delta Pa PSS gives relatively good results in reducing oscillation system variables of which transfer electrical power, changes in angular velocity generator, and the generator terminal voltage. AIS-based PSS have the performance relatively better than Delta w PSS and Delta Pa PSS in terms of ability to reduce oscillation and speed of reaching a state of instability. Based on testing can be seen that AIS-based PSS rapidly deliver good results compared Delta w PSS and Delta Pa PSS primarily on the state of the system.

Keywords—Power System Stabilizer, Artificial Immune System, transient stability, damping oscillation, multi-machine power system.

INTRODUCTION

Electrical power systems are often operated in critical situations that may lead to instability problems and in worst-case blackouts [1]-[3]. Large interruptions have historically occurred in many of electric power systems around the world, especially in Indonesia [4]-[6]. This may lead to panic and state of emergency in the society, something to be avoided. Because of today climate change, the Indonesian governments have decided that at least 23 % of the energy production must come from renewable energy sources by 2025 [7]-[12]. In operation, the electrical power system is often impaired the short circuit faults, either permanent or temporary. The short circuit fault can cause a deviation in the variables of the electric power system, such as voltage, frequency, and others. This variable deviation may affect the stability of the power system. The stability in the power system is defined as the ability of the system to maintain synchronization at the time of interruption and after interruption occurs [13] – [15].

Power System Stabilizer (PSS) is a device that serves to maintain the stability of the electric power system [16]. In power systems, the PSS used to mitigate system damping of low-frequency oscillations is an important control objective for optimization design. For tuning of linear parameters of PSS such as gain and time constants, the conventional tuning processes are based on the linear approaches such as the eigenvalue analysis have been used [17]. However, by focusing only on a small signal state, the dynamic damping of oscillation performance immediately following a large disturbance is often degraded. The output limits of PSS can provide a solution to balance theses competing effects. In particular, these limit values of PSS parameters attempt to prevent the machine terminal voltage from falling below the exciter reference level while the speed is also dropping, which means that it can improve the reduced transient recovery after a disturbance [18].

PSS action is to expand the limits of the large multi-machine power system stability by delivering synchronous machine rotor oscillation damping via the excitation generator [19]. Damping of oscillation is provided by an electric torque applied to the rotor in line with variations of speed. On the other hand, the use of artificial intelligence-based method has a lot of help in the field of large electrical power systems [20]-[24]. The use of artificial intelligence-based method is not only limited to the field of image processing [25]-[29]. In the last two decades, various methods have been applied to PSS design in order to improve performance of the overall power system. Most of the PSS design is used in the power system was developed based on the classical linear control theory [30]-[31]. The linear control refers to a linear model of the electric power system configuration that is fixed value. Therefore, the PSS with fixed parameters are often called the conventional PSS. The conventional PSS is able to function at its optimum for a particular operating condition and is not effective for the operating conditions change drastically [32]-[37]. Therefore, in this study will be elaborated models of artificial immune system based algorithm for PSS design in order to overcome the problem of transient stability of the multi-machine power system. In this approach, it is conducted linearized model of the machine on interconnected electric power system. With this approach, it is expected to be obtained by a relatively simple method and suitable for overall power system conditions that are very varied.

POWER SYSTEM STABILIZER

In power system, large electric power system is generally a multi-machine system connected to an infinite bus. By electric power system in growth, the more vulnerable to interference, especially interference short-circuit. One effect is the oscillation of power that will cause the system out of the area of stability and can result in an even worse as a total blackout. The probability of occurrence of short circuit in transmission line for the various types of interference that is to disruption by 5% for three-phase fault, two-phase to ground fault by 10%, phase to phase fault by 15%, and one phase to ground fault by 70%.

Generally, the stability of electric power system is characterized into both steady state stability and transient stability. Transient stability associated with the major interruption that occurs suddenly, like a short circuit, line disconnection, and removal or disconnection of the load. Then, the steady state stability associated with the ability of the power system to return to the conditions of its operating point after a small disturbance or rejection such as changes in power or load smoothly. The steady state stability is also named “dynamic stability”. Small changes in load will result in a change in the angular velocity of the rotor, resulting change in machine terminal voltage. The angular velocity will swing around speed and voltage synchronous machine terminal converging around its rating voltage.

In the large multi-machine system, a system is said to be dynamically stable if there is after disturbance the difference in the angle of the rotor head at a certain finite value. If there is a difference between the rotor angles progressively enlarged then the system is unstable. Due to changes in the load on dynamic stability studies are relatively small, the multi-machine power system model used in this study is a non-linear models were linearized. Small change in load on the multi-machine power system is a matter that could not be avoided and it is always the case. Therefore, it is necessary to design a power system controller that can maintain the power system remains stable, commonly called Power System Stabilizer (PSS).

The basic function of PSS is to expand the limits of stability by modulating the generator excitation to produce oscillation damping rotor synchronous motor. The power oscillation usually occurs within a frequency range of about 0.2 to 3.0 Hz, and can interfere with the power rotor frequency. Therefore, the ability of the system to transmit electrical power can be deteriorated. In order to damp these oscillations, PSS must be able to produce electric torque according to the rotor speed changes. One example of the application of PSS in addressing the stability of the power system is shown in Figure 1.

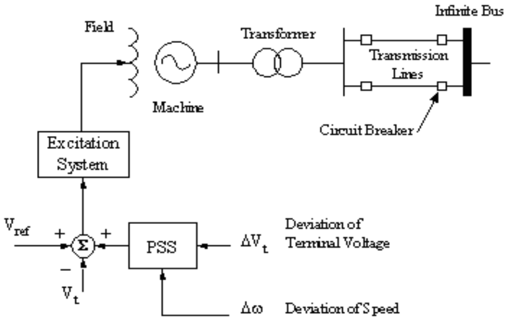

Figure 1. Application of PSS in a machine

One example of PSS models is refers to the IEEE 421.5 standard, known as Multi-Band Power System Stabilizer (MB-PSS), as shown in Figure 2. In the PSS model has applied three kinds of filters are low-pass filter, intermediate-pass filter, and high-pass filter, which serves to damp the local oscillation, the oscillation between networks, and global oscillations. By the PSS, the effect on the stability of the signal due to changes in the turbine power can also be suppressed.

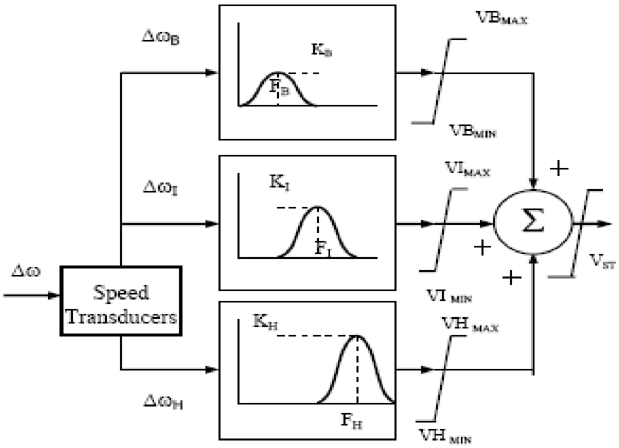

Figure 2. Diagram block of a MB-PSS Stabilizer

ARTIFICIAL IMMUNE SYSTEM

Artificial immune system theory is used to explain the basic response of the immune system by being adaptive to antigen stimulation, as described in Figure 1. This theory states that the only cells able to recognize antigens that will proliferate, while other cells are ignored. Clonal selection operates on B cells and T cells in cell B, when the antibody binds to the antigen then activated and differentiated into plasma cells or memory cells. Prior to this process, B cell clones are produced and undergo somatic hyper-mutation. The result obtained diversity in the population of B cells to plasma cells produce antibodies antigen-specific works against antigens. Memory cells remain with host antigens and promote secondary response quickly.

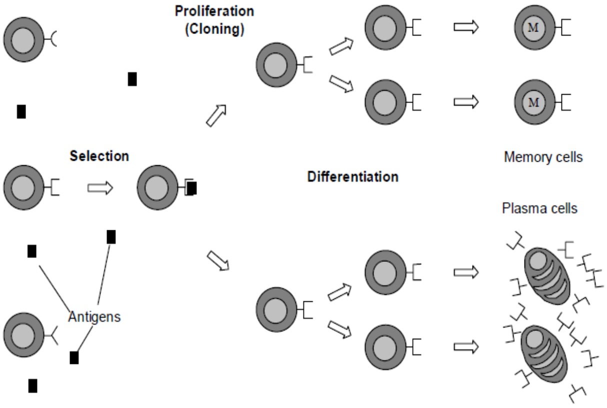

Figure 3. The principle of artificial immune system

The main features of the clonal selection of artificial immune system theory are:

a. new cells are duplicates of those parents (clone) which is charged with the rapid mutation mechanism height (somatic hyper-mutation),
b. elimination of the new different lymphocyte making it the self-reactive receptors,
c. proliferation and differentiation takes place through contact adult cells with antigen, and
d. the persistence of illegal clones, resistant to early elimination by self-antigen, as the basis of the auto-immune disease.

The analogy with natural selection fit the reality that is the strongest candidate into most cells recognizes antigens, or in other words, into cells most triggered. To workings of this algorithm, population or repertoire of receptors should be diverse enough to recognize any form of foreign cells. A mammalian immune system contains a heterogeneous repertoire of about 10^{12} lymphocytes in humans, and the rest of B cells (stimulated) can display about 10^5-10^7 identical like-antibody receptor. Repertoire has been believed complete means that he can recognize the shape of any cell.

In [11], they have proposed the clonal selection algorithm named ClonalG for learning and optimization. They discussed the main features of the theory of clonal selection and develop algorithms include the maintenance of a set of specific memory, selection and cloning antibodies are most stimulated, death antibody non-excitatory, maturation affinity and selection of re clones are balanced against affinity antigen, and the generation and maintenance of a set of antibodies.

The main steps of clonal selection of artificial immune system method are described in the following algorithm.

```
Input: Ab, gen, n, d, L, β;
Output: Ab, f
1.    for t = 1 to gen,
1.1   f := decode (Ab); vector f contains all
      affinity antibodies that bind to the
      antigen
1.2   Abn := select (Ab, f, n);
1.3   C := clone (Abn, β, f);
1.4   C* := hypermut (C, f);
1.5   f := decode (C*);
1.6   Abn := select (C*, f, n);
1.7   Ab := insert (Ab, Abn);
1.8   Abd := generate ( d, L ); randomly
      generate antibody d along L
1.9   Ab := replace (Ab, Abd, f);
      end;
2.    f := decode (Ab); Decode functions are
      supposed to encode Ab and evaluation
      for values decode.
```

Affinity between antibody and antigen can be defined using different techniques such as matching rules and a measure of distance. One common technique used is the Euclidean distance, which is suitable when using a real-valued vector representation.

METHODOLOGY

In this work, there is a multi-machine power system that are consists of two fully symmetrical areas. The areas are linked together by two 230 kV power transmission lines of 220 km length. It was specifically designed to study low frequency electromechanical oscillations in large interconnected multi-machine power systems. In this model, there are four machines which are interconnected in a system. Despite its small size, it mimics very closely the behavior of typical multi-machine power systems in actual operation. The multi-machine power system circuit diagram in this study is shown in Figure 5. The multi-machine power system of IEEE standard consists of 4 generator 10 bus by interference on the transmission line.

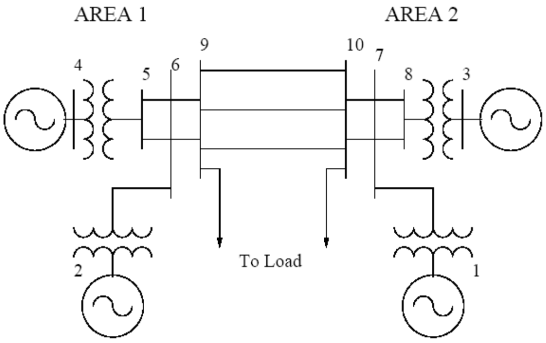

Figure 4. Multi-machine power system of IEEE for 4 generator 10 bus by interference on the line

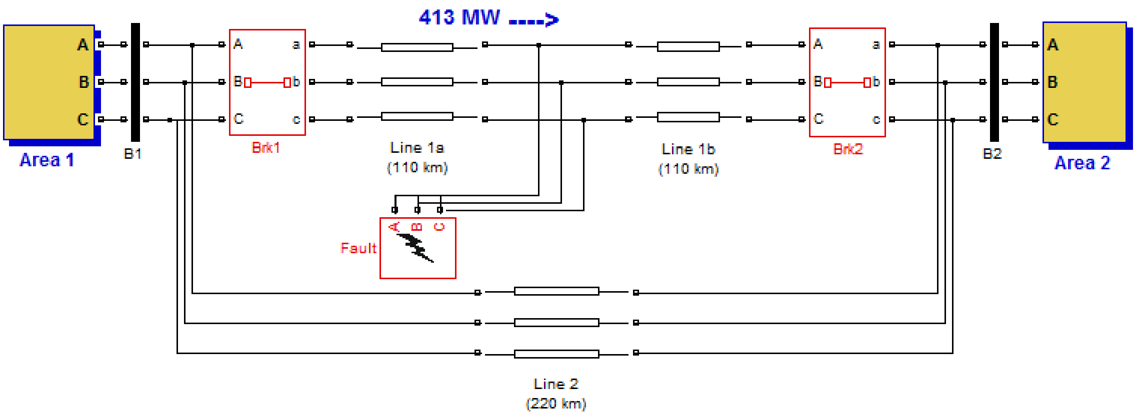

Figure 5. A multi-machine power system under study

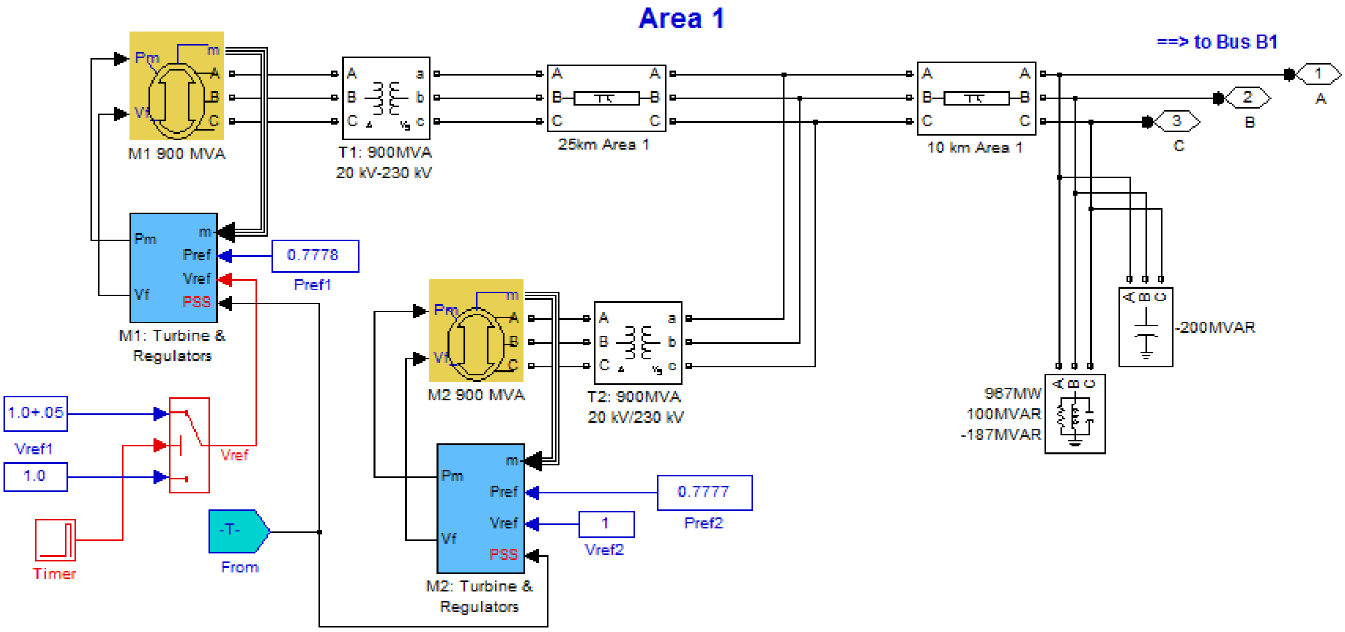

Figure 6. Components of area 1 of multi-machine power system under study

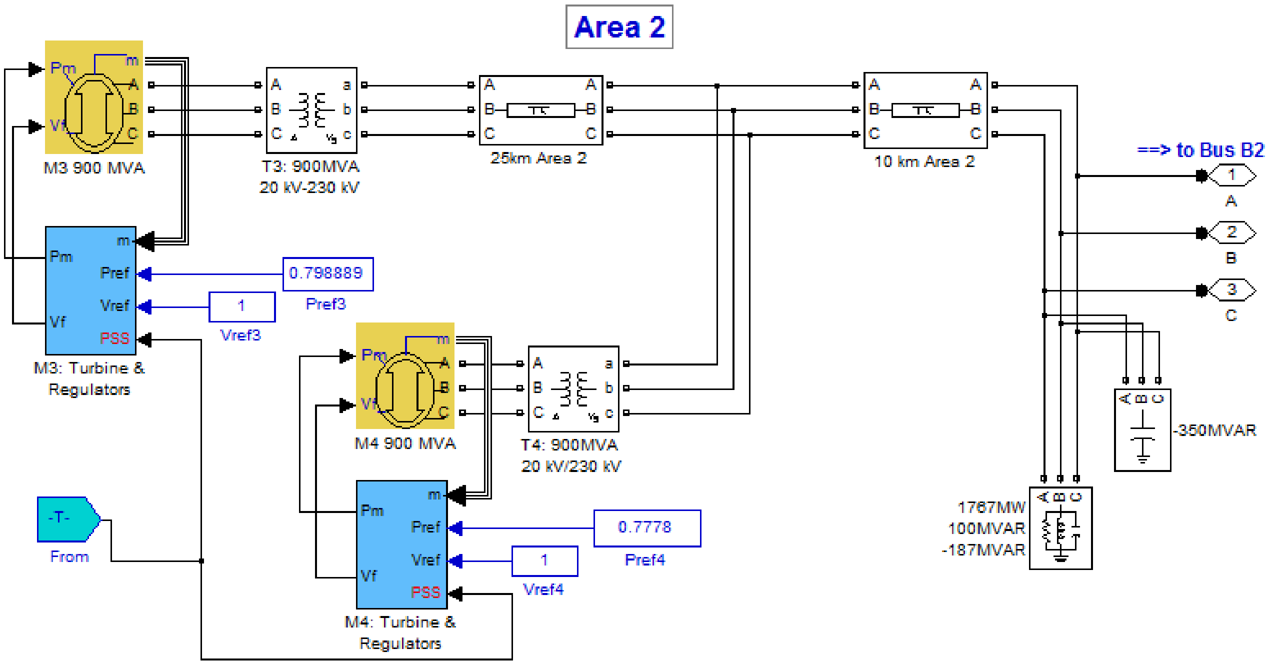

Figure 7. Components of area 2 of multi-machine power system under study

The load of the system is represented as constant impedances and split between the two areas in such a way that area 1 is exporting 413MW to area 2. The system is somewhat stressed, even in steady-state, because the surge impedance loading of a single line is about 140 MW. The reference load-flow with machine M2 considered the slack machine is such that all generators are producing the active power about 700 MW each. In this study, the losses of transmission and generation may vary depending on the detail level in transmission line and generator representation. The multi-machine power system under study is shown in Figure 5. Figure 6 shows components of area 1 of multi-machine power system while Figure 7 shows components of area 2 of multi-machine power system under study.

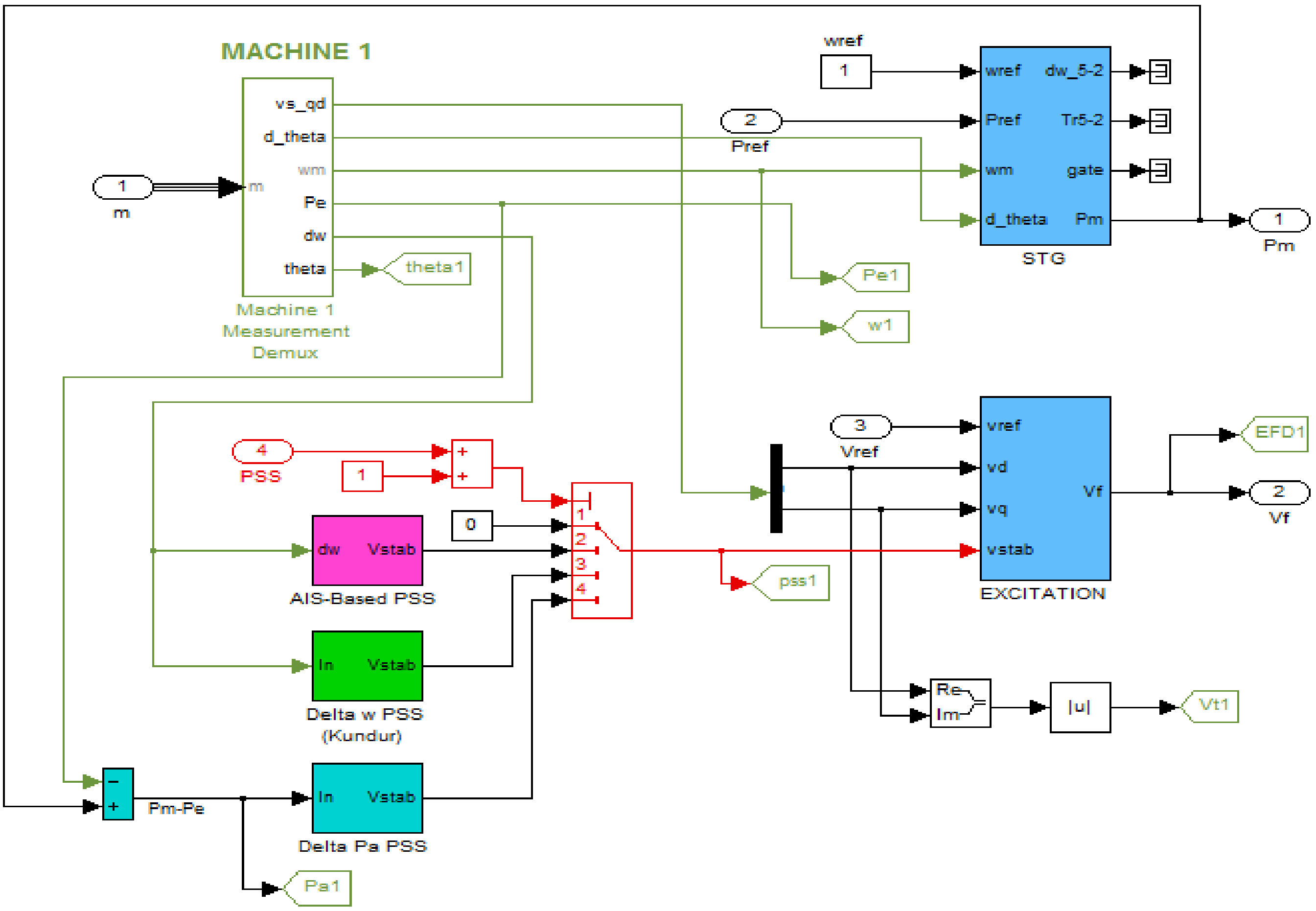

Figure 8. Model of PSS in Machine 1 of area 1 of multi-machine power system under study

RESULTS AND DISCUSSION

Multi-machine Power System Analysis for Small Signal

In this study, multi-machine power system analysis for small signal is performed. In order to understand behavior of the network, the open-loop responses to a 5%-magnitude pulse, is applied for 12 cycles at the M1 voltage reference. This simulation is started by opening the timer controlling the M1 voltage reference and changing the factor of multiplication of the transition times vector from 100 to 1. Then, the transmission line fault should be deactivated by changing from 1 to 100 the factor of multiplication of the transition time vector in the fault device and transmission line breakers. After that, the signals responses are visualized by opening the scopes of "Machine" and "System" scopes on the main diagram as shown in Figure 5.

The signals of the system scope have been shown in Figure 9 while the signals of the four machine scopes have been shown in Figure 10. All signals of the Figure show undamped oscillations leading to un-stability. A modal analysis of acceleration powers of machines shows the three dominant modes, i.e.:

a. Mode of interarea-mode (fn = 0.66Hz , z = -0.028) involving the whole area 1 against area 2. This mode is clearly observable in the tie-line power displayed in scope of "System".

b. Area 1 for local mode (fn = 1.14Hz, z = 0.09) involving this area's machines against each other.

c. Area 2 for local mode (fn = 1.17Hz, z = 0.09) involving machine M3 against M4 (the smaller the inertia then the greater the local natural frequency).

If the breakers "Brk1" and "Brk2" are setting in an open position, then one of the two tie-lines is removed. Therefore, it is possible to reach steady-state stable equilibrium point with the same generation and load patterns. The phenomenon is called a post-contingency network. It is easy to initialize using the Machine and Load-Flow Initialization. An analysis in modal type for the network's responses to the same 5% of magnitude pulse, it was applied for 12 cycles at the voltage reference of M1 reveals that. At this time, the two local modes has been remain basically unchanged in both frequency and damping (fn=1.10Hz, z=0.09 in area 1 and fn=1.18Hz, z=0.09 in area 2). The mode of interarea shifts to a much lower frequency with unstable condition (fn = 0.45Hz, z = -0.017).

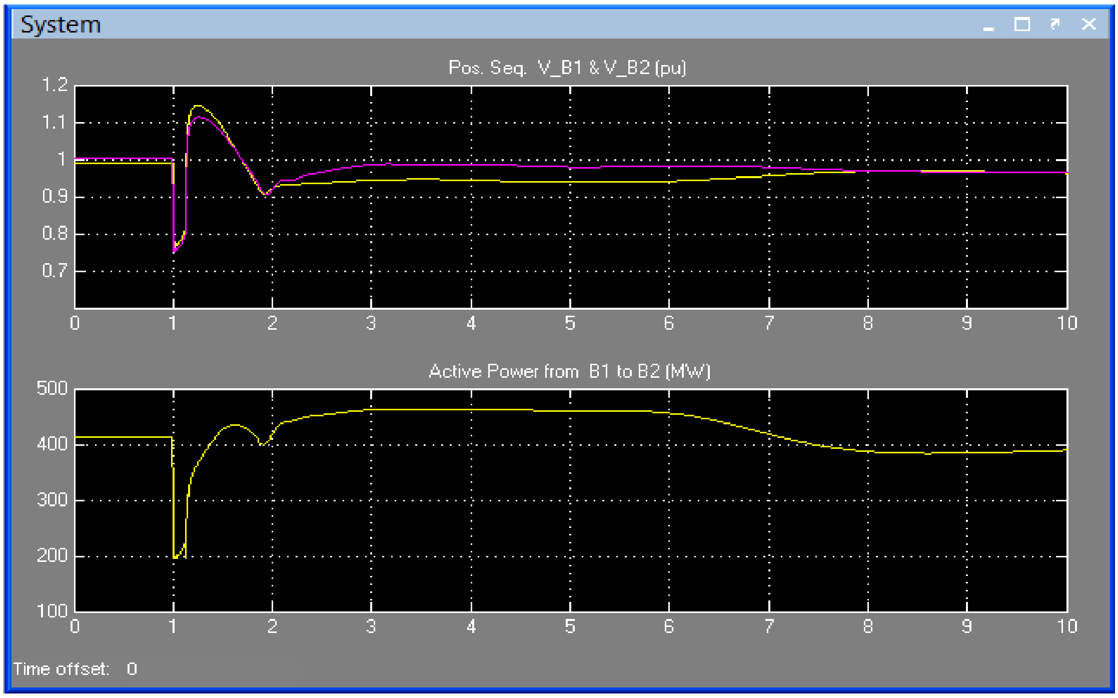

Figure 9. The signals of the system scope under simulation

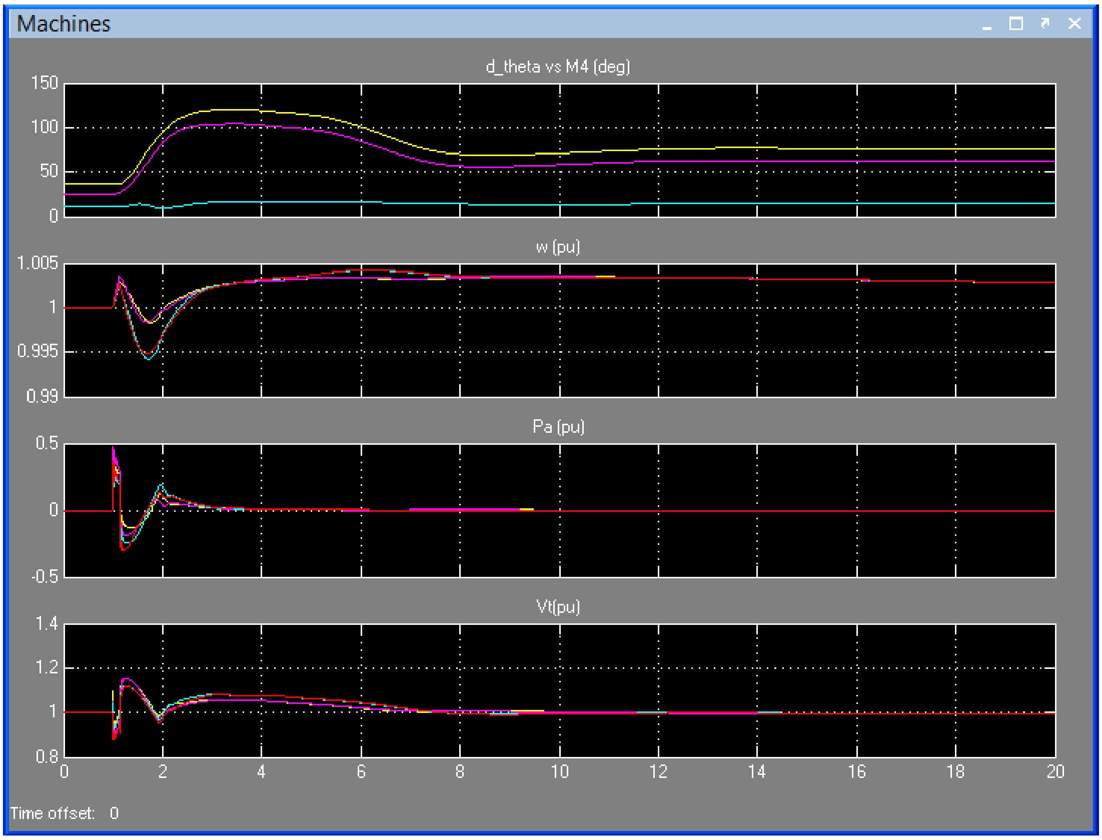

Figure 10. The signals of the machine scope under simulation

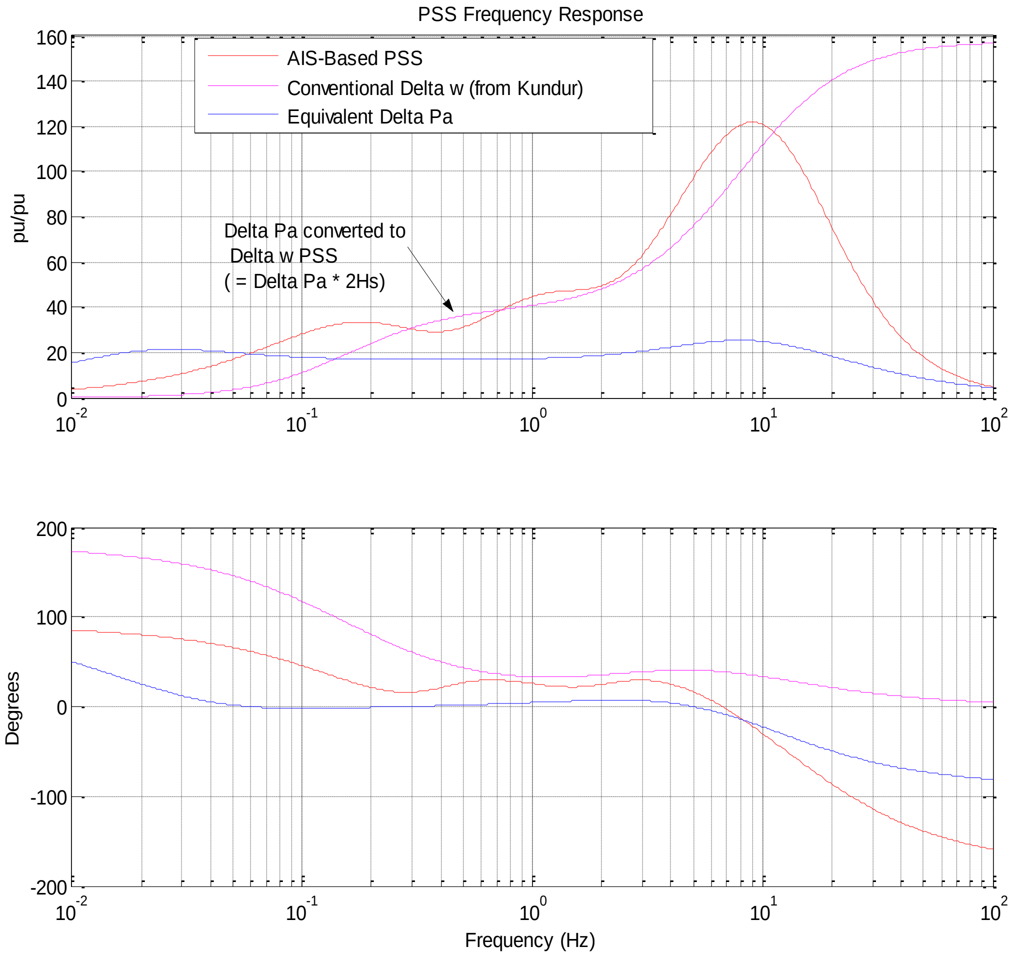

Figure 11. Bode plot of all PSS under simulation

Tuning of PSS for Multi-machine Power System

The AIS-based PSS setting in this research was built in simulink-matlab software. As a comparison to the AIS-based, it has been simulated another PSS scheme, i.e. delta w PSS and delta Pa PSS, as shown in Figure 8. The results of bode plot of all PSS scheme is shown in Figure 11. The setting of Delta w PSS settings are from Kundur [18]. The PSS settings have two changes i.e. a gain increase from 20 to 30 and the addition of a 15-ms transducer time constant. The frequency responses of these PSSs can be seen on Bode Plot of the PSS in Figure 11. From the figure, it can be seen that the AIS-based PSS is effectively flat around 20-40 degrees in the frequency range of interest.

For Delta w PSS, it has an overall poor phase shape, especially around 1-2 Hz. Therefore, there makes it unable to cope with faster local or inter-machine modes in multi-unit power plants. For Delta Pa PSS, it has a good combination of strong gain and phase advance above 0.3 Hz. The PSS type is unpractical at low frequency where it shows a 180 degrees phase advance, which actually has a destabilizing effect despite the rather small low-frequency gain.

Small-Signal Performance Assessment of PSS

In this section, the small-signal performance assessment of PSS is examined. In order to simulate the small-signal closed-loop system responses of the PSS, the transition time vector of the breakers and fault devices on the main diagram should be disabled by multiplying it by 100. After that, the timer block controlling the reference of voltage of machine M1 is activated in the same way by removing any multiplication by 100, i.e. by changing 100 to 1. Select the PSS to be simulated by setting PSSmodel = 1,2,3. Then, start the simulation and record the output variables. Most of the variables such as the terminal voltage and machine speed are stored in matrices W and Vt (see inside the "Machines" and "System" blocks on the main diagram for other variables). This procedure was repeated for the three PSSs for comparison. In order to see the comparisons, so double click on icon Show results: Step on vref of machine M1. The results of 12-cycle pulse of 5% of voltage reference magnitude of machine M1 is shown in Figure 12. The figure contains four plots, i.e. the top plot shows the power transfer from area 1 to 2.

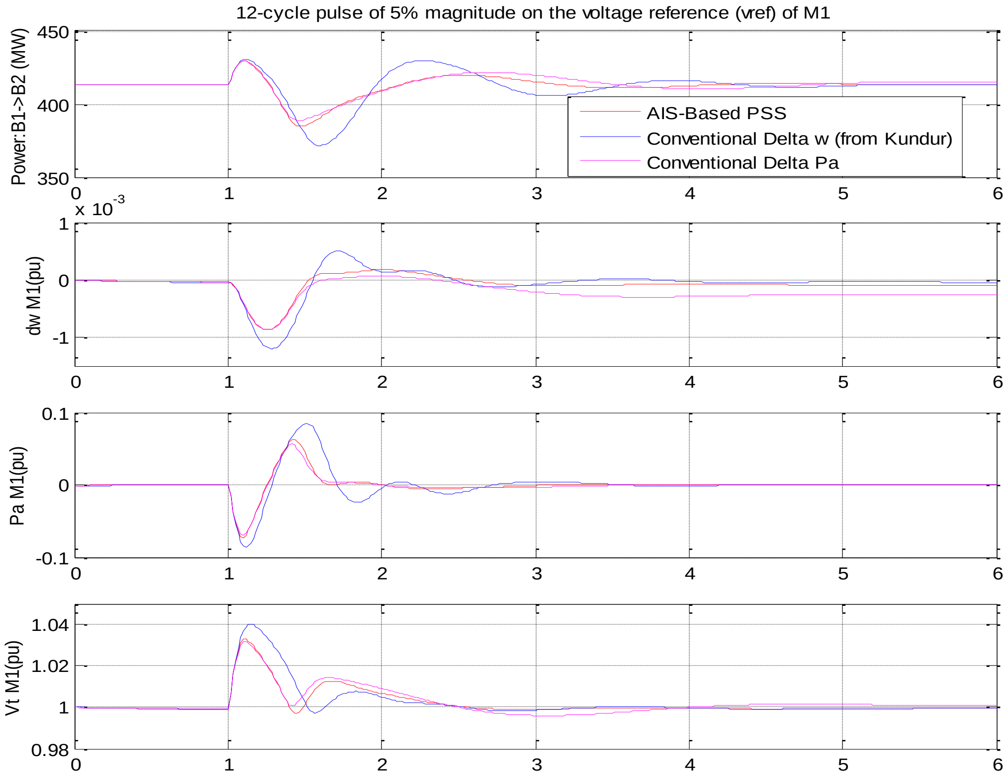

Figure 12. 12-cycle pulse of 5% of voltage reference magnitude of machine M1

CONCLUSIONS

In our study, AIS-based PSS has been successful in controlling the multi-machine under study. For multi-machine system consists of four machines, the application testing on the machine M1 to short circuit symmetrical three-phase, AIS-based PSS found that that good design results in this study. Overall, AIS-based PSS, Delta w PSS and Delta Pa PSS gives relatively good results in reducing oscillation system variables of which transfer electrical power, changes in angular velocity generator, and the generator terminal voltage. All PSS can work well in order to stabilize the system which is basically unstable system. However, AIS-based PSS have the performance relatively better than Delta w PSS and Delta Pa PSS in terms of ability to reduce oscillation and speed of reaching a state of instability. Based on testing can be seen that AIS-based PSS rapidly deliver good results compared Delta w PSS and Delta Pa PSS primarily on the state of the system.

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