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THE ANALYSIS OF LOCAL OSCILLATION IN THE GAS TURBINE GENERATOR CONNECTTO POWER GRID SYSTEMS USE LINEAR OBSERVER

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Abstract:

The low frequency oscillation in the electrical generator connect to power grid is an important problem to control systems, especially in the gas turbine generators with high speed. The oscillation makes affect to life time, finance of operating and effect of energy process. There are many cause of the oscillation in governor speed control of power plants. They use PSS to do damping low frequency oscillation in recently [11], [12], [13], [14], [22], [23]. So PSS usually does process with delay cycle time, therefore it makes effect isn't good result. This paper presents a method using linear in the gas turbine generator, which connects to power grid. By observe affect action of local oscillation of the power, study finds key point of oscillation time. From that, we take out decision to do prediction of damping in system and supply signal in to PSS to reduce damaging of this oscillation. Simulation results explain difference action of the system with linear observer and system without linear observer.

Keywords: *Hydropower Plants; Speed Control System; Magnetic Excitation; Power Grid; Gas Turbine; Power Plant; Damping; Low Frequency Oscillation; Linear Observer.*

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1. Introduction

The Local Plant Mode Oscillations (LPMO) is a special mode operation of the connection plant to grid systems. In that, there are grid connecting models of electrical plants as hydraulic power plants, heating power plants, sunlight plants, wind plants etc. The plants connect to grid to loads and make a big power system. This is a complex circuits system with elements R, L, C and sources. They make an online energy store system and usually have oscillation in system. The oscillation has to make unstable states and do difficulty for relays protection systems. If system happens oscillation nearly agenerator then they will make low frequency signal to rotor and does obstacle for turbine-generator system.

In LPMO, a generator oscillates with the rest of the system at 1.0 - 2.0Hz. The speed variation of the transmitter is shown in figure1[10].

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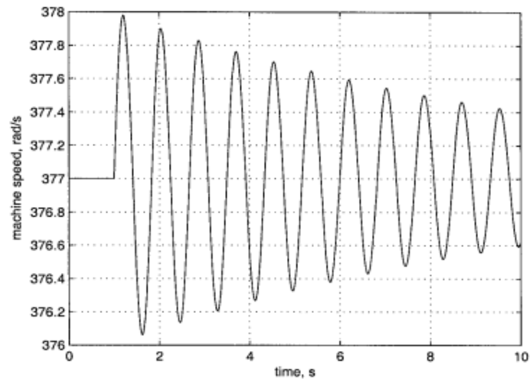

Figure 1: A local oscillation in the power system

The effect of oscillation is propagated to the generator and connected to the grid, which usually occurs when the system has significant power fluctuations such as closing or cutting loads on the grid. If the grid has a very large capacity, it will be immune to this power fluctuation. Conversely, if the load is near a transmitter or low power grid, it will cause reverse power fluctuations on the generator. create local oscillation. The rest of the system is usually simulated as a constant voltage source whose frequency is thought to remain constant. This is called the Single Machine Infinite Bus model (SMIB). The damping and frequency vary according to the requirements of the machine and the impedance between the motor and the bar bus voltage is infinite. The oscillation can be eliminated by a single or double PSS (Power System Stabilizer) input which supplies the reference voltage regulation of the Automatic Voltage Regulator (AVR) with the appropriate phase and pulse increased compensation [Lee, 1992].

2. Modelling of System

We consider complex system as fig. 2. In that, turbine is a gas turbine with Rowen's model [2]. The mechanical power transmits to generator through gear drive with assume inertia torque is very big in the system. We have equation of Speed governor as follow:

$$W_{SG} = \frac{K_1(T_1 s + 1)}{T_2 s + Z} \tag{1}$$

Signal of W_{SG} will be choice LVS value, which has equivalent set up value to start fuel system. LVS shall choice error of acceleration or speed or temperature to make signal control fuel valve.

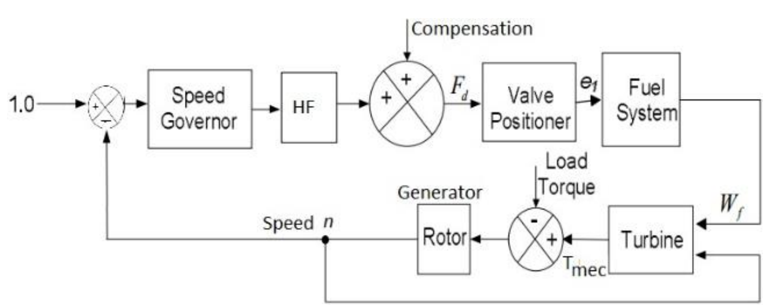

Figure 2: A basic model of gas turbine generator plant

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From Rowen's model [3], [4], we have modelling of the fuel valve system as figure 3.

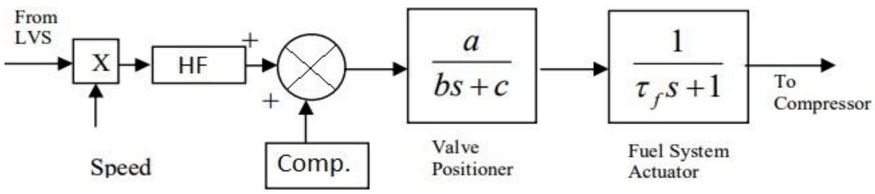

Figure 3: Modelling of the fuel valve structure

For compressor, we have two parts: turbine exhaust system delay (ESD) and compressor discharge (CPD). The ESD supplies exhaust to thermocouple and CPD supplies turbine torque. For compressor, we have modelling as follow:

$$\dot{W}_c = \dot{m}\left[h(T_{in}) - h(T_{out})\right] \tag{2}$$

For torque:

$$T_{out} = T_{in} + \frac{T_{in}}{\eta_{c,\mathrm{ins.}}}\left(p_{Rc}^{\frac{\gamma-1}{\gamma}} - 1\right) \tag{3}$$

$$T_{in} = K_P\omega + \frac{P_{in}}{\eta_{c,\mathrm{ins.}}}\omega_{gear} \tag{4}$$

For combustion model [4], [5]

$$V_{cc}\frac{d\rho}{dt} = \dot{m}_{\mathrm{air}} + \dot{m}_{fuel} - \dot{m}_{fuelgas} \tag{5}$$

$$\frac{d\left(\dot{M}_{cc}\dot{U}_{cc}\right)}{dt} = \dot{m}_{\mathrm{air}}h_{\mathrm{air}} + \dot{m}_{fuel}LHV - \dot{m}_{fuelgas}h_{fuelgas} \tag{6}$$

$$\eta_{cc} = \frac{1}{m_{fuel}.LVH}\left(\dot{m}_{out}h_c\left(T_{out}\right) - \dot{m}_{in}h_c\left(T_{in}\right)\right) \tag{7}$$

For turbine

$$\dot{W}_T = \dot{m}\left[h(T_{in}) - h(T_{out})\right] \tag{8}$$

$$\tau_T = \dot{W}_T / \omega \tag{9}$$

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$$T_{out} = T_{in} - T_{in}\eta_{c,\mathrm{ins.}}\left(1 - p_{RT}^{\frac{1-\gamma}{\gamma}}\right) \tag{10}$$

For rotor of generator, this is an inertial object and controlled by strain torque, which from turbine. While rotor does a rotation, then it strained by forces and torques as follow:

$$T_{rot} = \frac{dP_{rot}}{dn_{rot}} = J_{rot}\frac{dn_{rot}}{dt} + T_{load} + T_{damp} + T_{loc} + T_{aux} \tag{11}$$

In that,

- T_{rot} is a torque of mechanism power;
- J_{rot} is a inertial torque of rotor;
- T_{load} is a torque of power load (active power);
- T_{damp} is a torque by damping from low frequency oscillation and PSS supplies;
- T_{loc} is a torque from local structure of rotor;
- T_{aux} is an auxiliary torque of unknown and uncertain values.

We have:

$J_{rot} = m_{rot} r_{rot}^2$, m_{rot} and r_{rot} are weight and radius of the rotor.

$T_{damp} = J_{rot}\dfrac{d^2\delta}{dt^2}$, δ is a small load angular with low frequency.

$T_{loc} = \sum_{\upsilon=7}^{m}\dfrac{2\sqrt{2}k_{\upsilon}wB_{m\upsilon}l}{Z_{\upsilon}}$ is a high order frequency torque and asymmetrical rotation.

The converter from T_{mec} to speed n of rotor as:

$$G_{rot} = \frac{1}{J_{rot}s} \tag{12}$$

There is an important problem for this system. That’s an analyzing of the damping signals. We can’t capture some first cycle of low frequency. We usually observe oscillation signals with big delay, more than ten cycles of low frequency. So when we capture oscillation signals then we have signals as fig. 1. If we have an observer to find oscillation signals soon then we can cancel low frequency oscillation after some cycles. However, the speed of rotor is very big in the heat power plant, so we can’t use indirect observe with long delay time. In this study, we use direct observer with high sensitive function as advanced linear observer. We assume the sample time is very small than cycle of damping. So we can measure new full signals at first cycle. The signals of power oscillation, speed and small load angular are important for observation process. They supply unit control to PSS to improve compensation of power to reduce low frequency oscillations in the system.

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3. Model of Linear Observer

We design linear observer by form:

$$\begin{aligned}\dot{\mathbf{x}} &= \mathbf{Ax}+\mathbf{Bu}\\ \mathbf{y} &= \mathbf{Cx}\end{aligned} \tag{13}$$

With $\mathbf{x}\in R^{nx1}$is a vector of the states (measurement), $u\in R^{rx1}$ is a vector of input signal and $y\in R^{mx1}$is output signal, **A** and **B** are transfer matrix and weight matrix. **C** is an output states matrix. We assume this a controllable and observable system. To increase accuracy, we do addition feedback matrix:

$$\mathbf{x} = -\mathbf{P}\hat{\mathbf{x}} \tag{14}$$

With $\mathbf{P}\in R^{nxn}$ and nonsingular matrix. We define output error: $\mathbf{e} = \mathbf{y} - \hat{\mathbf{y}}$ and $\hat{\mathbf{x}}$ is an estimation value of the **x** with start point $\hat{\mathbf{x}}(0)$ and $\hat{\mathbf{y}}$ is an estimation output vector of the **y**. We propose a model as fig.4.

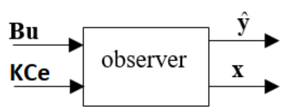

Figure 4: A model of the observer

Reply (14) into (13) with output error, will have:

$$\begin{aligned}\dot{\hat{\mathbf{x}}} &= \hat{\mathbf{A}}\hat{\mathbf{x}}+\hat{\mathbf{B}}\mathbf{u}\\ \hat{\mathbf{y}} &= \hat{\mathbf{C}}\hat{\mathbf{x}}\end{aligned} \tag{15}$$

The target of observer is calculating **x** to error **e** to zero.In the (15), with $\hat{\mathbf{A}} = \mathbf{P}^{-1}\mathbf{AP}; \hat{\mathbf{B}} = \mathbf{P}^{-1}\mathbf{B}; \hat{\mathbf{C}} = \mathbf{CP}$. Reply them into (15) and combine variable, we have:

$$\begin{cases}\left(s\mathbf{I}-\hat{\mathbf{A}}\right)\hat{\mathbf{x}} = \hat{\mathbf{B}}\mathbf{u}\\ \hat{\mathbf{y}} = \hat{\mathbf{C}}\hat{\mathbf{x}}\end{cases} \Rightarrow \begin{cases}\hat{\mathbf{x}} = \left(s\mathbf{I}-\hat{\mathbf{A}}\right)^{-1}\hat{\mathbf{B}}\mathbf{u}\\ \hat{\mathbf{y}} = \hat{\mathbf{C}}\hat{\mathbf{x}}\end{cases} \tag{16}$$

We could see:

$$\mathbf{e} = \mathbf{Cx} - \hat{\mathbf{C}}\hat{\mathbf{x}} \Rightarrow \mathbf{x} = \mathbf{C}^{-1}\left(\mathbf{e}+\hat{\mathbf{C}}\hat{\mathbf{x}}\right) \tag{17}$$

Equations (16) and (17) take out output values of the observer. The problem is what you do to error goes to zero in the (17). Combine (16) and (17), we have:

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$$\mathbf{e} = \mathbf{Cx} - \hat{\mathbf{C}}\left(s\mathbf{I} - \hat{\mathbf{A}}\right)^{-1}\hat{\mathbf{B}}\mathbf{u} \Rightarrow \mathbf{x} = \mathbf{C}^{-1}\left(\mathbf{e} + \hat{\mathbf{C}}\left(s\mathbf{I} - \hat{\mathbf{A}}\right)^{-1}\hat{\mathbf{B}}\mathbf{u}\right) \quad (18)$$

We choice **P**is a diagonal matrix with positive elements and reply into (16). From input vector, we calculate output signal by (17), (18) and then reply results into (16) to decide output of the observer. If error value isn't a zero then we increase or reduce values of the elements of the **P** matrix.

There is a problem for observer to reduce error while observer estimates signals. Studies propose theorem as follow:
Theorem:
If we choice estimation value of **x**satisfy condition:

$$\hat{\mathbf{x}} = \hat{\mathbf{C}}^{-1}\mathbf{y} + \hat{\mathbf{C}}^{-1}\mathbf{M}\int \mathbf{e}\,dt \quad (19)$$

Then observer in (16) will have output error signals reduce to zero.
Proof:
We build a candidate function as follow:

$$V = \frac{1}{2}\dot{\mathbf{e}}^{\mathbf{T}}\mathbf{H}\dot{\mathbf{e}} + \frac{1}{2}\mathbf{e}^{\mathbf{T}}\mathbf{K}\mathbf{e} \quad (20)$$

With **H, K** are thediagonal positive decision matrixes. We clearly see that V is a positive function, which describes total of kinetic energy and potential energy of system. So we have:

$$\dot{V} = \dot{\mathbf{e}}^{\mathbf{T}}\mathbf{H}\ddot{\mathbf{e}} + \mathbf{e}^{\mathbf{T}}\mathbf{K}\dot{\mathbf{e}} = \sum_{i=1}^{m}\left(\dot{e}_i h_i \ddot{e}_i + e_i k_i \dot{e}_i\right) = \boldsymbol{\varepsilon}^{\mathbf{T}}\dot{\mathbf{e}} \quad (21)$$

With $\boldsymbol{\varepsilon} = \left[h_1\ddot{e}_1 + e_1 k_1; \ldots; h_m\ddot{e}_m + e_m k_m\right]^T$. From (20) if we choice $\varepsilon_i = -l_i\dot{e}_i$, $l_i>0$; i=1..m then $\dot{V} < 0$. That is:
$\ddot{e}_i = -\frac{k_i + l_i}{h_i}\dot{e}_i \Rightarrow \ddot{\mathbf{e}} = -\mathbf{M}\dot{\mathbf{e}}$; $\mathbf{M} \in \mathrm{R}^{\mathrm{mxm}}$ and this a diagonal matrix with positive elements. From (19) we have:
$\ddot{\hat{\mathbf{x}}} = \hat{\mathbf{C}}^{-1}\ddot{\mathbf{y}} + \hat{\mathbf{C}}^{-1}\mathbf{M}\dot{\mathbf{e}} \Rightarrow \ddot{\mathbf{y}} - \hat{\mathbf{C}}^{-1}\ddot{\hat{\mathbf{x}}} = -\mathbf{M}\dot{\mathbf{e}}$
From (17) we can see: $\ddot{\mathbf{e}} = \ddot{\mathbf{y}} - \hat{\mathrm{C}}^{-1}\ddot{\hat{\mathbf{x}}}$. Analysis elements of **M** become:

$$m_i = \frac{k_i + l_i}{h_i} > 0 \text{ then } h_i\ddot{e}_i + k_i\dot{e}_i = \varepsilon_i = -l_i\dot{e}_i \quad (22)$$

Reply this result into (21) we have:

$$\dot{V} = \boldsymbol{\varepsilon}^{\mathbf{T}}\dot{\mathbf{e}} = \sum_{i=1}^{m} -l_i\dot{e}_i^2 < 0 \quad (23)$$

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That is true$e_i \rightarrow 0$ with finite time.

In that, **y** and **e** are vectors, which could measure by sensors. From (19) and (16) we will choice values of elements m_i of **M** matrix after two cycles of the signal **y**.

4. Simulations

We use real model of power plant as follow

Rated power: 110MW; Rated speed of turbine: 3600rpm; Rated speed of rotor: 360rpm; Inertial of rotor: 3800kgm^2; Turbine temperature: 950^{0}C; Delay time: 1.5s; Response time: 3.5s; Stabilization time: 5.6s; Dead band: 2%

We build a simulation model and then estimate results to compare.

Define vector x = $[x_1, x_2, x_3, x_4]^T$ with x_1 is a temperature, x_2 is a speed of rotor, x_3 is an active power and x_4 is a reactive power at a head of the generator. Modelling of the generator as in [2] for active power and reactive power. There is a problem of the connect to grid of generator, so we also decide model of the active load.

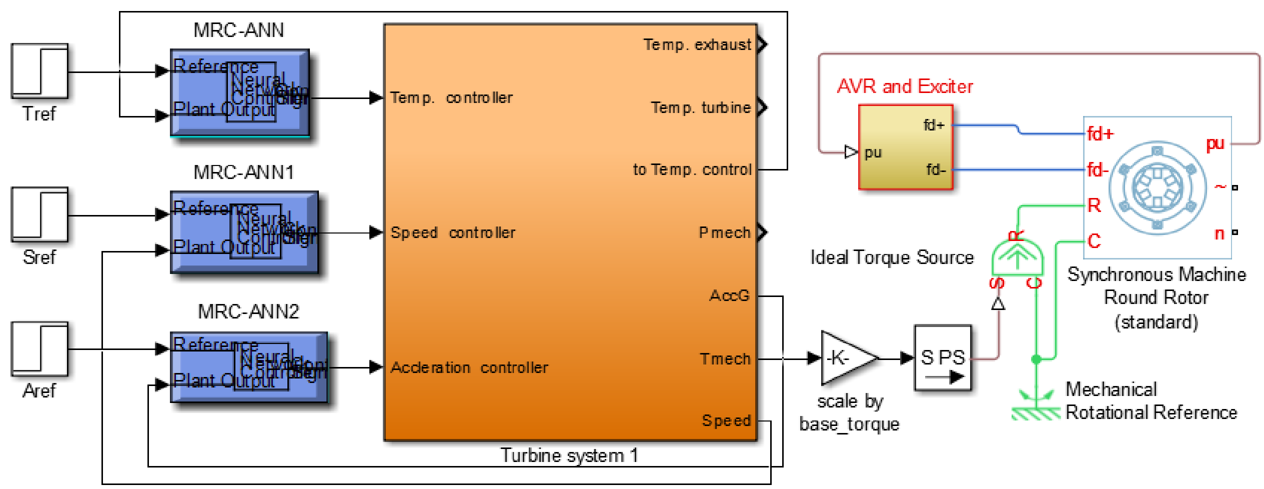

Figure 5: Model of turbine and generator

To observe, we measure output signal from head of generator, frequency at connecting points. Set input signal is speed of the rotor (x_2) and use (16) to observe output. Start values of **P** are unit and they will approach to real values.

The equations from (1) to (11) used to build modeling of the turbine and generator as figure 5. The load of generator made by structure of long power line, power system and load with change values.

To teach to ANN, we use reference model are second-order elements with fix parameters.

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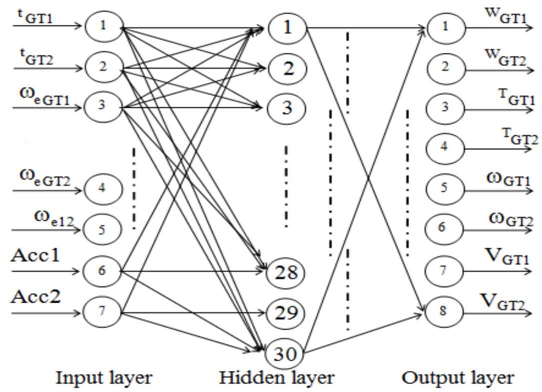

Figure 6: The structure of ANN to control observer

We set three input signals are temperature, speed and acceleration. After finished teaching, we continue simulate system with ANN process. We use ANN to control estimation parameters of PSS. Design controller ANN with DBF model as figure 6, in that we use hidden layers with fifteen numbers. Simulation results as figure 7.

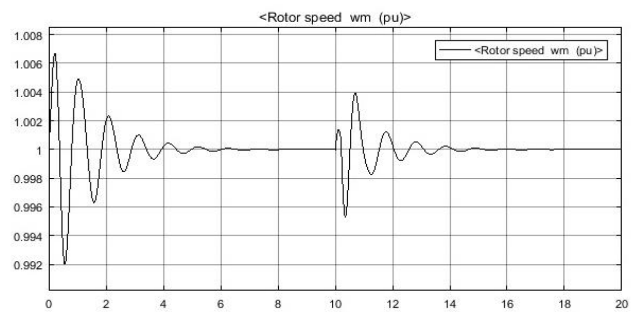

Figure 7: The change speed when change power load

At zero time, we start system with normal load, we can see change of power and oscillation of the speed. By control of the controller ANN, system has stabilization good. So at 10 second, we make change power on the poles of generator, then damping will appearance and make low frequency oscillation. This state will turn-off after some seconds.

Now we use observer to see oscillation of the speed of rotor. We have results as figure 8.

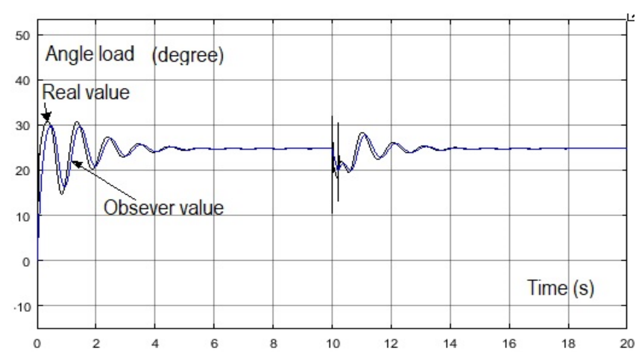

Figure 8: Result of observer for load angle

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In the figure 8, we see values of the design observer always cling real values. It is a main mean of the issue, so we need minimum error of the measurement. We have result of the speed of rotor as figure 9. In that, measurement unit has been used unique.

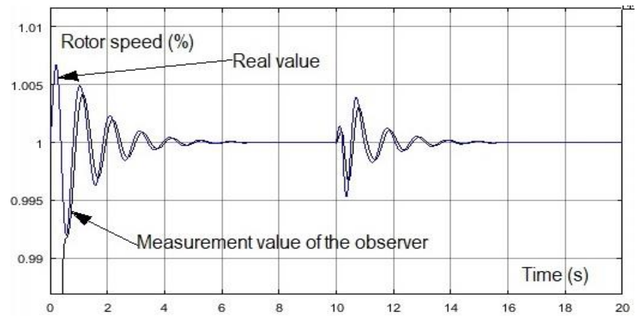

Figure 9: Result of the speed measurement

The result of the figure 9 illuminates an online accuracy measurement of the observer. The values of the measurement will store in the controller and make compensation values to PSS to control electrical power to reduce damping. Because we only interest measurement to do prediction, so we don’t explain controller design, so it is very important for system.

By calculate values, we have accuracy of the measurement smaller than 1.5% with delay time after one cycle. This is a good result because an insurance of the overlap control signals. So this results are guarantee for action of PSS. We could choice window function to design filter of observer before transfer to controller by this data set.

5. Discussion

The low frequency oscillation in generator is an important problem. The fee of repair and guarantee every year are very big for power plants. The fee will reduce if you reduce damping to make long life of generators. To do this issue, we have to do prediction damping. This study has made out a good linear observer. Some problems as following:

- Design width of the observe windows and profile of the windows.
- Decide cause of the low frequency oscillation to arrange rank of the control in system. If they have causes then we could have to estimate levels by sensors and process in the system.
- To do complete buffer communication between observer and PSS to make adaptive signal compensation.
- To do soon prediction to control compensation power into stator of generator. This action shall make inverse toque to anti oscillation.

6. Conclusion

The PSS is an important in power plants, they have main role to do stabilization power by made damping at the head of the generator, they always happen at every day. Because the fee to repair is big, about 10% of the total decay, so the reduce repair will increase effect of plants. There are studies prediction low frequency oscillation to do damping, so they have not complete. The

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electric heat plants are important power system, so we need study to reduce broken of the plants. Although this is a study of heat turbine, we also apply linear observer into hydraulic power plants and others.

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