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Tuning the under excitation limiter and power system stabilizer in power system network

By

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Abstract:

Under excitation limiter is one of the standard auxiliary control devices in synchronous generators that it has been widely used since the advent of the automatic voltage regulator (AVR) for excitation control. Under-Excitation limiter usually used to prevent generators for going out the steady-state stability limited. The survey on power swing and rotor angle stability has accomplished in Shaheed Rajaee power station which is one of the biggest power plants with four units of 312.5 MVA in Iran.

In this paper, the 1st and 3rd order system model are designed and compared together. UEL can cause generator instability if this setting is inappropriate.
Show using the 1st order system model for designing the UEL can only be used when the PSS is activate and the absence of the PSS. However, it may cause to be instability and will be much better performance if the 3rd order model with PSS uses for designing of the UEL.

Keywords:

Under-Excitation controller, Power system stabilizer.

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1. Introduction:

The main function of the UEL is to prevent excessive armature end-core heating in a generator due to large flux. [1]. UEL is also used to prevent the generator from operating beyond its steady-state stability limit [4], [13].

The UEL are not expected to be operational under normal system conditions. During light load conditions, however, the generators may be forced to operate into the leading power factor region [9]. When this occurs, the limiters are necessary as they play an important role in ensuring that the generators can function safely [4]. Moreover, known one of the important control loops in power plant is power system stabilizer (PSS). It can add ratio damping rotor oscillations by sending suitable signal control to excitation system.

For studying and survey the effect of the UEL and PSS roles considerate the extended Heffron-Phillips model and frequency response analysis technique is applied.

2. System descriptions

Shaheed Rajaee station with four unit of 312.5 MVA is one of the biggest power plant that connect two part of 420KV network in West North and Center of country together. The simplified single line diagram of this power plant network is shown in Fig (1). The analysis can best be carried out using the small-signal power system model developed by Heffron-Phillips.

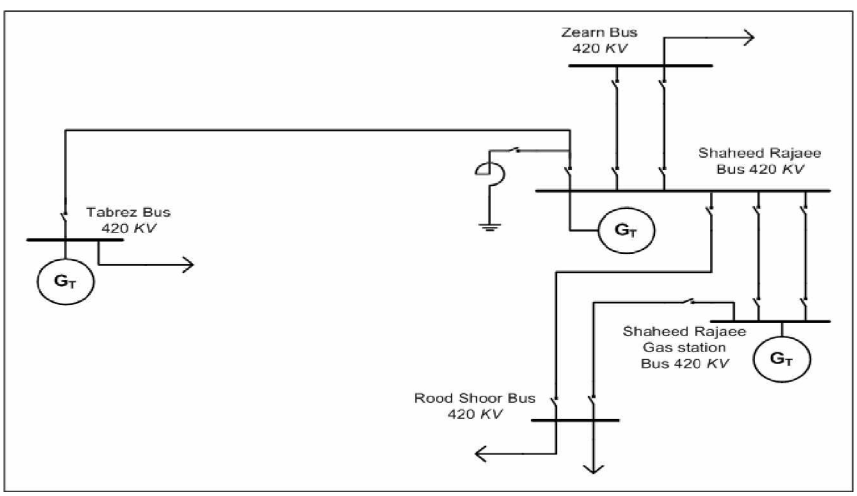

Fig (1): *Simplified Shaheed Rajaee Single line*

3. Analysis

The analysis can best be carried out using the small-signal power system model developed by Heffron and Phillips. Small-signal analysis is used because the corrective actions at the outputs of the PSS and UEL are limited so as to provide relatively small adjustments to the excitation level. [12]
The extended Heffron-Phillips model shows in Fig (2) so as the PSS and UEL controller signals added to AVR summing junction, meanwhile type and status coming signals of UEL and PSS are based on IEEE standard.
In this figure, G_{pss} and G_{uel} are PSS and UEL controller transfer function and detail of them has explained in Fig (3) and Fig (8) respectively.

Now, the state space equation will obtain with 1st order Exciter-AVR model and without consideration of PSS and UEL. These equations have depicted in (1) to (3). Reference [13] describes how the UEL can be incorporated into the generator-Excitation control loop. It shows that input to the UEL is given by equation (4).

$$\dot{X} = [A]X + [B]\Delta V_{ref} \tag{1}$$

$$X^T = \lfloor \Delta\delta \quad \Delta\omega \quad \Delta E_q' \quad \Delta E_{fd} \rfloor \tag{2}$$

$$[A] = \begin{bmatrix} 0 & \omega_B & 0 & 0 \\ -\frac{K_1}{2H} & -\frac{D}{2H} & -\frac{K_2}{2H} & 0 \\ -\frac{K_4}{T_{do}'} & 0 & -\frac{1}{T_{do}' K_3} & \frac{1}{T_{do}'} \\ -\frac{K_E K_5}{T_E} & 0 & -\frac{K_3 K_6}{T_E} & -\frac{1}{T_E} \end{bmatrix}, \quad [B]^T = \begin{bmatrix} 0 & 0 & 0 & \frac{K_E}{T_E} \\ 0 & \frac{1}{M} & 0 & 0 \end{bmatrix} \tag{3}$$

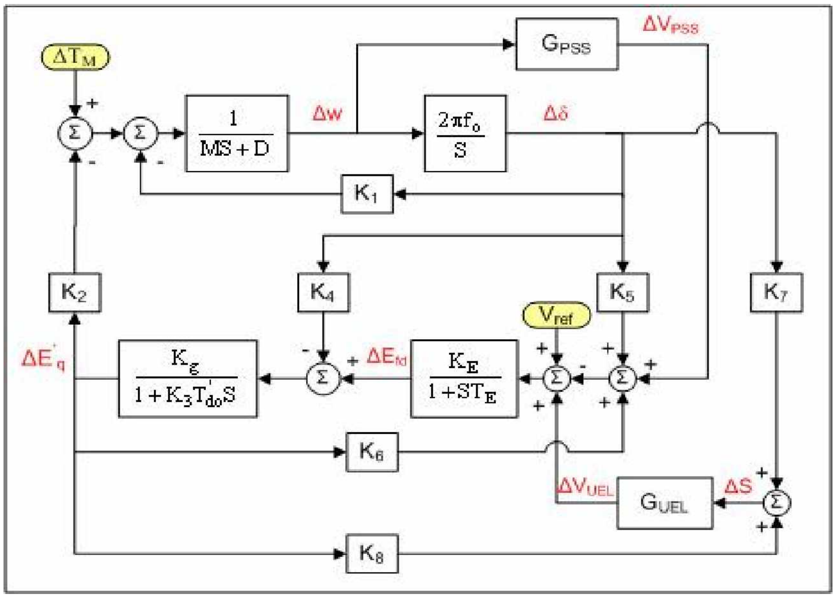

***Fig (2):** An extended Heffron-Phillips model.*

With applying the model's machine and linearize it around the specifying working point and substitute the linearity parameter into the equation (4) therefore this equation change to (5) so as the coefficients will obtain with equations (6),(7).

$$\Delta S = (V_{q0} + V_{d0})\Delta I_q + (V_{d0} - V_{q0})\Delta I_d + (I_{d0} + I_{q0})\Delta V_d + (I_{q0} - I_{d0})\Delta V_q \qquad (4)$$

$$\Delta S = K_7 \Delta\delta + K_8 \Delta E'_q \qquad (5)$$

$$K_7 = \frac{V_{do} I_{qo}(X'_d - X_e) + I_{qo}^2 X'_q X_e - V_{do}^2}{(X_e + X'_d)} + \frac{V_{qo} I_{qo}(X_e + X'_q) + I_{do}^2 X'_q X_e - V_{qo}^2}{(X_e + X'_q)}$$
$$- \frac{(V_{do} I_{do} + V_{qo} I_{qo})(X'_d X'_q - X_e^2)}{(X_e + X'_d)(X_e + X'_q)} - \frac{(V_{do} V_{qo} + I_{do} I_{qo} X_e^2)(X'_d - X'_q)}{(X_e + X'_d)(X_e + X'_q)} \qquad (6)$$

$$K_8 = \frac{V_{qo} + X_e I_{do} - V_{do} + X_e I_{qo}}{(X_e + X'_d)} \qquad (7)$$

Therefore the essential coefficients of Heffron-Philips model have obtained for designing the UEL controller which has describe in section 4.

It is well known that since the function of a PSS is to introduce a damping torque component, a logical signal to use for controlling the generator excitation is the speed deviation Δw. However, in practical power systems, the commonly-used input signal is the power deviation ΔP. As was explained in [14], the PSS transfer function Gpss, should have the appropriate phase lead to compensate for the phase lag between the exciter input ΔVref and the electrical torque ΔTe2.

The usual practice is to design the PSS so that it is only effective over a selected range of frequencies. Typically this is within the 0.5–2 Hz range. [11]

We well know, there are many different methods for designing the PSS. This paper does not concentrate for designing of PSS algorithm, but [11],[14] are one of the classical methods that has uses in this paper.

4. Design UEL

UEL acts to boost the generator excitation whenever the generator operation passes the steady state stability region or pushed the end-region heating limit. Therefore this controller under the normal condition working doesn't send any signal on AVR summing junction of the excitation system. The UEL schematic diagram is as shown in Fig (3), the first block contains a UEL limitation curve superimposed on the generator capability diagram and the second block is UEL controller.

The activity area of UEL is specified at C area in P-Q curve that is shown in Fig (3). If operating point of generator passes from this line and put on the left of this boundary UEL is activated and sends the corrective signal to the AVR summing junction to prevent from instability or rise of end-core heating stators machine.

In Fig (4) you can take compare between 1st and 3rd order system model with relation $\Delta S/\Delta V_{ref}$ transfer function.

Both of curves in Bode diagram are similar unless in break points that have been produced with 3rd order system model, so the 1st order system model can not defined all break points and it is one of the blind spot in this model.

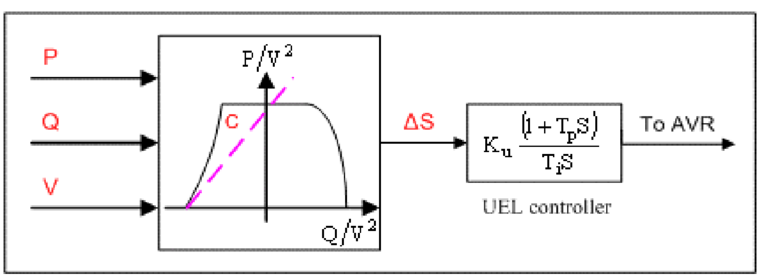

Fig (3): *UEL controller scheme.*

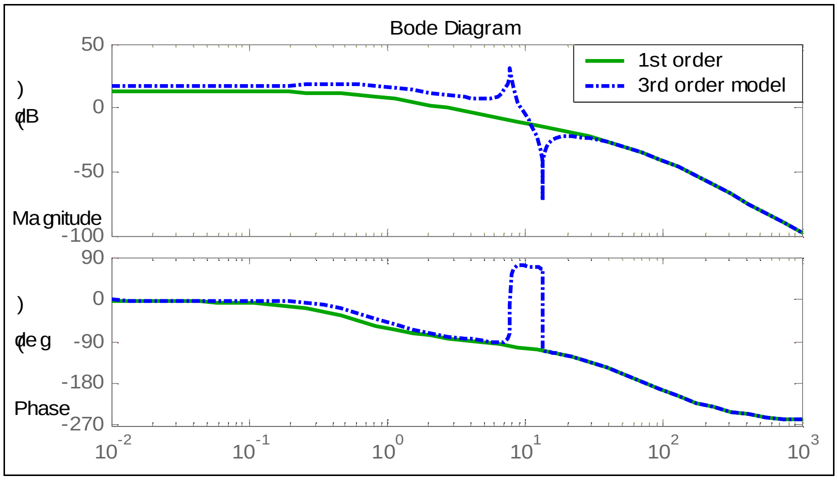

***Fig (4):** Bode plot of $\Delta S/\Delta V_{ref}$ of 1st, 3rd order system models.*

After adding the UEL in 1st order system, the open loop at cross over point S=jω, gain should be $G(S).G_{UEL}(S)=1$ and the phase degree in desired phase margin at cross over frequency should be -180+Φ.M

If separate the equation (9) to real and imaginary part and simplifies each component T_p and T_i will be derived equation (10).[11].

$$G(j\omega_c)\cdot G_{uel}(j\omega_c)=K_u\frac{j\omega_c T_p+1}{j\omega_c T_i}M_G e^{j\theta_G}=1e^{j(-180+\Phi.M)} \quad (8)$$

$$K_u\frac{j\omega_c T_p+1}{j\omega_c T_i}M_G(\cos\theta_G+j\sin\theta_G)=\cos(-180+\Phi.M)+j\sin(-180+\Phi.M) \quad (9)$$

$$T_p=\frac{\cos(\Phi.M-\theta_G)}{-\omega_c\sin(\Phi.M-\theta_G)},\quad T_i=\frac{KM_G}{\omega_c\sin(\Phi.M-\theta_G)} \quad (10)$$

5. Case study

Our survey based on the one of the biggest power plant which not only joins some states of Iran together but also with injection of active and reactive power has important role in the network.

Shaheed Rajaee power plant has four with nominal capacity 312.5(MVA) and type of them are turbo-generator. These units are equipped with brush less excitation system to control terminal voltage of the generators; type of this AVR is shown in Fig (5). Machine and exciter's system properties are given respectively in Table (1). With assume, While generator is working at 0.6*(p.u)*, -0.4*(p.u)* and fault appearance on reactor causes the reactor connected to over head lines tripe so machine operating shall move perforce to 0.6*(p.u)*, -0.6*(p.u)* so as this operating point is similar as region that UEL controller have to be activate.

In continue we intend to design the Under Excitation Limiter (UEL) controller with 1st order system model and compare it with 3rd order system model. According with approach designing described in section 4, the 1st and 3rd order system model for designing of UEL controller has shown in Table (2).

Table (1): *Specification of Shaheed Rajaee generator.*

Generator	AVR	Transformer & Line
M = 6.4 *(s)* T'do = 8.78 *(s)* X_d = 4.53 *(p.u)* X'_d = 0.4 *(p.u)* X'_q = 1.89 *(p.u)*	K_d = 27 T_d = 0.01 K_e = 72 K_f = 0.066 T_f = 2 K_{cc} = 0.055	20/400 *(Kv)* Δ/Y X_T =0.1 *(P.u)* X_L=0.48 *(p.u)*

Table (1): *Compare 1st, 3rd order UEL parameters.*

Design UEL with 1st order system model	Design UEL with 3st order system model
ω_c= 2.62 *(rad/s)* K_p= 5 T_p= 58.5 *(s)* T_i= 294.9 *(s)*	ω_c= 7.5 *(rad/s)* K_p= 5 T_p= 0.28 *(s)* T_i= 18.33 *(s)*
$G_{uel} = 5\dfrac{58.5S+1}{294.9S}$	$G_{uel} = 5\dfrac{0.28S+1}{18.33S}$

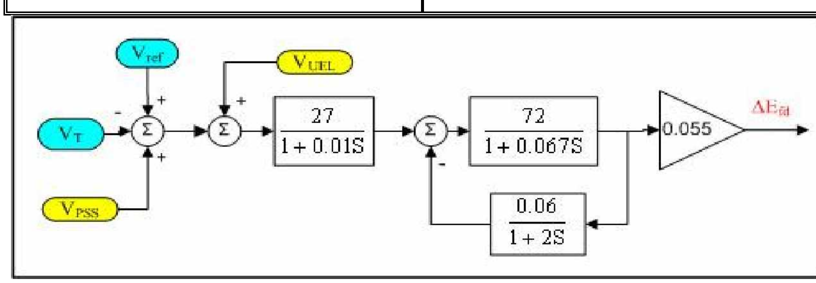

Fig (5): *Shaheed Rajaee AVR Model.*

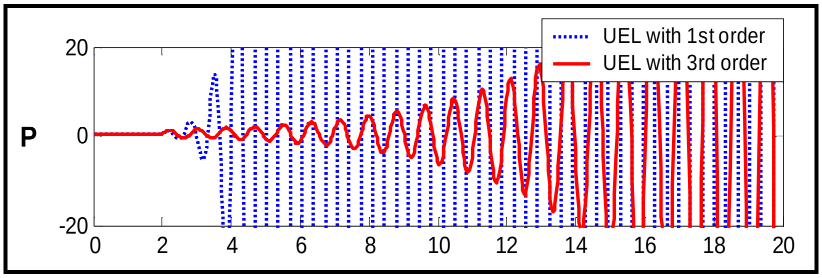

Fig (6): *Active power deviation without PSS consideration.*

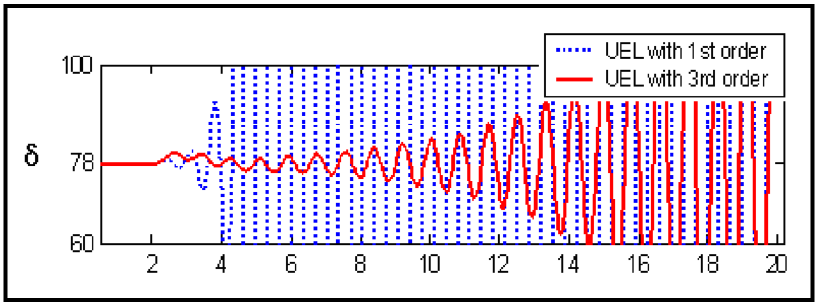

Fig (7): *Rotor angle deviation without PSS consideration.*

Now, four important synchronous generator analysis bases on to compare the designing UEL controller with 1st and 3rd order system models, these functions are Active and Reactive power, Speed and Rotor angle deviation.

In Fig (6) and Fig (7) show step response when the PSS is turn off. It is clearly design UEL controller with 1st and 3rd order without the PSS hadn't been effected because this operating point has the electromechanical oscillation mode which can not damp with just this controller and using the PSS moreover the UEL controller is necessary.

The PSS controller is tuned with the largest negative torque damping in Over Excitation region at 0.85*(p.u)*, 0.2*(p.u)* operating point. Model and parameters' PSS conventional controller is shown in Fig (9).

Although in Fig (4) the frequency response has compared to the 1st and 3rd order system models together about $\Delta S/\Delta V_{ref}$, but have to take care this matter using the only UEL controller in this point can be cause to taken out the system stability and apply the PSS controller as well as UEL is necessary.

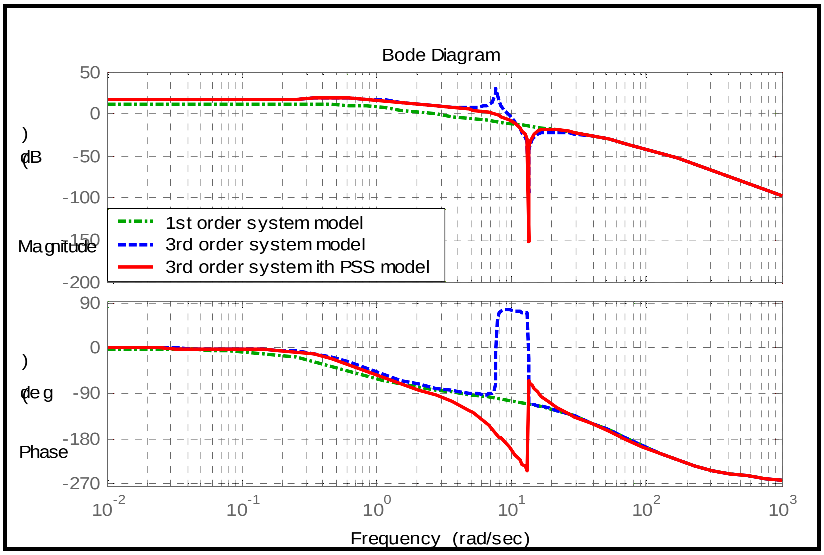

Fig (8): *Compare* $\Delta S / \Delta V_{ref}$ *transfer function of the 1st, 3rd and 3rd order.*

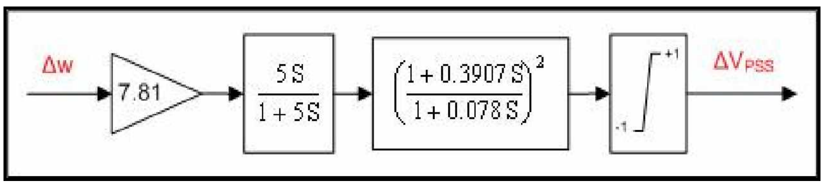

Fig (9): *Power system stabilizer Model*

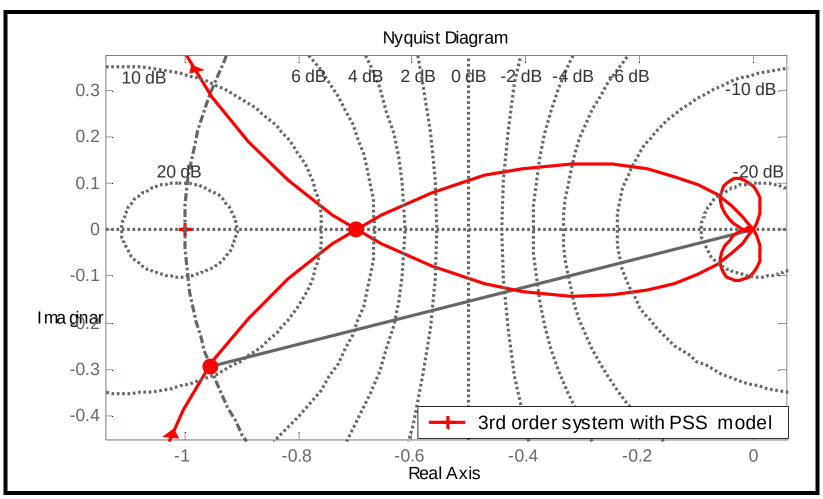

Fig (10): *Zoom in Nyquist diagram about (-1,0).*

Therefore, frequency response for present this problem and compare it when the PSS controller add to the machine has shown with and without PSS on 1st and 3rd order system model in Fig (8).

It is clearly, the PSS action in low and high frequency is like as the main model with UEL controller except the break points that PSS obligate the unstable poles move toward stability point also confirm this claimed with Nyquist diagram that shown in Fig (10). In this diagram obviously derive that the phase and gain margin are positive.
After designing of UEL and PSS controller, the Nyquist diagram and Frequency Response are represented in later, now intend to examine the 1st and 3rd order system model Step response after the PSS add into these models which has situated in Under-Excitation area nearby the unstable limitation boundary. The step response of four main generator's parameter has depicted in Fig (11), Fig (12).

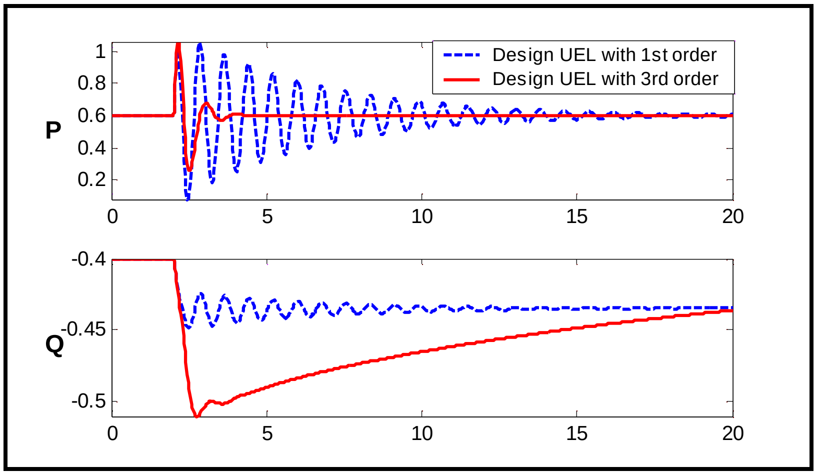

Fig (11): *The step response of Active and Reactive Power*

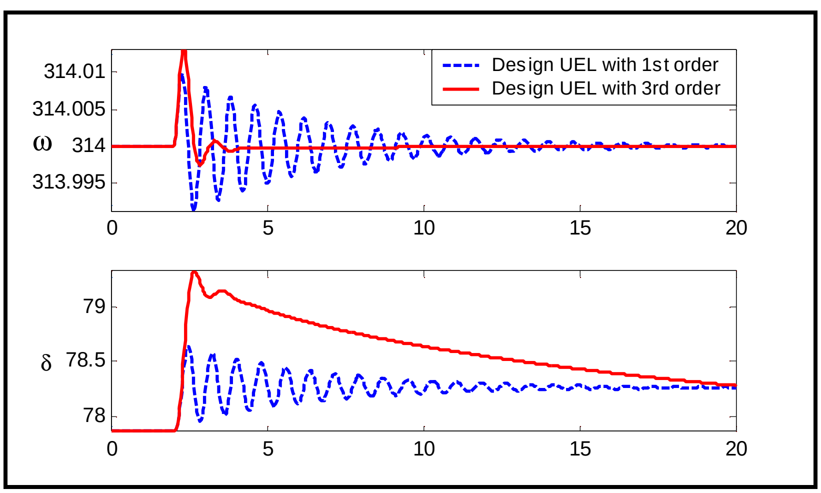

Fig (12): *The step response of Speed and Rotor angle.*

6. Conclusion

This paper considers the relationship between the Under Excitation action and Power system stabilizer. Parameters tuning of Under Excitation controller has done with based on frequency response technique on 1st and 3rd order system model.[paper 5]

The boundaries nearby the limited instability are critical regions that using the UEL is not only enough for prevent of go out the limitation, not only must be use the PSS in these areas, but also the suitable tuning of them is necessary.

7. Reference:

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