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REFINEMENT OF POWER SYSTEM STABILIZER

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Abstract: A fractional-order power system stabilizer (FoPSS) is introduced to control the frequency and the terminal voltage deviation in a power system connected to an infinite bus. FoPSS yields satisfactory results when there is drastic load change in long transmission lines. MATLAB/Simulink simulation is used to show the improvement of system's performance when FoPSS is used. FoPSS is more superior to the classical integer-order power system stabilizers (IoPSS)

Keywords—

FoPSS	Fractional order Power System Stabilizer
IoPSS	Integer order Power System Stabilizer
PSS	Power System Stabilizer
q-axis	Quadrature Axis
d-axis	Direct Axis
FOC	Fractional Order Controller
AVR	Automatic Voltage Regulator

I. INTRODUCTION

The PSS compensates the local and inter-area mode of frequency oscillations that appears in power systems connected to long transmission lines. These oscillations could go up to ±1 Hz off the nominal value. The stability analysis of power systems using adaptive or sliding mode techniques is not straightforward especially when it comes to online tuning. For instance, different techniques of sequential design of PSS's were adopted to damp out inter area mode of oscillations one at a time. However, this approach may not lead finally to an overall optimal choice of PSS parameters; the stabilizers designed to damp one mode can produce adverse effects in other modes.

A classical integer-order lead PSS with a washout component is usually used to stabilize power systems. Since most of these controllers have at least five parameters to tune, and exhibit narrow band phase compensation around a desired operating point, there is a need to implement more robust PSS with fewer number of parameters to adjust.

Fractional-order controllers exhibit a flat phase response that depends on the fractional-order dynamics. The flat phase characteristics yield a robust FoPSS, which makes it capable of accommodating wider range of disturbances than the IoPSS.

II. FRACTIONAL-ORDER POWER SYSTEM STABILIZERS

A FoPSS was successfully implemented to control a single machine connected to an infinite-bus system [1]. The FoPSS enjoys a memory effect, which exhibits a satisfactory performance in most practical applications. In spite of the design complexity of the FoPSS, this feature gives the fractional-order compensators a leading edge over their integer-order counterparts. A typical FoPSS may be described by the following transfer function:

$$G_f(s) = \frac{(K_W\, s)^{\alpha}}{((s\tau)^{\alpha}+1)}\left(\frac{((s\tau_1)^{\alpha}+1)}{((s\tau_2)^{\alpha}+1)}\right)^2 \qquad (1)$$

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where $s^{\alpha} = \pounds\{\frac{d^{\alpha}}{dt^{\alpha}}\}$ is the Laplace operator of the fractional derivative of order α; $\alpha < 0 \leq 1$, where, $T_{j;\, j} = 1, 2 \ldots 4$, while T_W and K_W are real constants Obviously, as $\alpha = 1$, $G_f(s) \rightarrow G_I(s)$.

For completeness, the Laplace transform of a fractional-order derivative of $f(t)$ of order n-1 < α ≤ 1 is given by :

$$\pounds\{D_t^{\alpha} f(t)\} = s^{\alpha} F(s) - \sum_{k=0}^{n-1} s^k [D^{\alpha-k-1} f(t)]_{t=0}; \quad (2)$$

Clearly, if the signal $f(t)$ is initially at rest, then , $\pounds\{D_t^{\alpha} f(t)\} = s^{\alpha} F(s)$ which will be assumed throughout this work.

Due to the memory effect of the fractional-order dynamics, a single-stage FoPSS of the form:

$$G_F = K\left(\frac{((s\tau_1)^{\alpha}+1)}{((s\tau_2)^{\alpha}+1)}\right)^2 \quad (3)$$

will be sufficient to stabilize an interconnected system. $s^{\alpha}K_w/((s^{\alpha}\tau)+1)$. The large bandwidth exhibited by (3) can replace the washout component

In order to implement a finite-dimensional FoPSS, one may replace the fractional-order integrator, $1/s^{\alpha}$, (s^{α} in the case of a differentiator), by a finite-order transfer function. The half-order integrator, $1/s^{\alpha}$, can be replaced by:

$$1/_{s^{0.5}} = \frac{15.8489(s+0.0389)(s+0.2512)(s+1.585)(s+10)(s+63.1)}{(s+0.01585)(s+0.1)(s+0.631)(s+3.981)(s+25.12)(s+158.5)}$$

Consequently, the FoPSS in (3) can be rewritten as:

$$G_{Fi}(s) = \frac{\tau_1^{\alpha}[N(s)+\tau_1^{\alpha}D(s)]}{(\tau_2^{\alpha}-\tau_1^{\alpha})+\tau_1^{\alpha}[N(s)+\tau_1^{\alpha}D(s)]} \quad (4)$$

where τ_1, τ_2 and K are the controller parameters that will be selected to provide sufficient damping signals to the power system.

III. MODEL 2.1

To reduce the modelling complexity, while still retaining key generator dynamics effects. The sub-transient effects that produce a demagnetizing effect due to a change in the rotor by the damping winding are neglected in this model. However, the transient effects of the damping windings are still taken into account. The following simplifying assumptions are made in Model 1.1.

$$\tau''_{d0} \rightarrow 0,\ X''_d \rightarrow X'_d,\ E''_q \rightarrow E'_q$$

1) *Block Diagram Modeling of Synchronous Generator*

The stator resistance is assumed to be negligible.

The following equations in the *s*-domain characterize Model 2.1.

$$\Delta P_e(s) = K_1\Delta\delta(s) + K_2\Delta E''_q(s) - K_{2d}\Delta E''_d(s) \quad (5)$$

$$\Delta E_t(s) = K_5\Delta\delta(s) + K_6\Delta E''_q(s) + K_{6d}\Delta E''_d(s) \quad (6)$$

$$\Delta E''_q(s) = K_3\Delta E_{fd}(s) - K_4(s)\delta(s) \quad (7)$$

$$\Delta E''_d(s) = K_{4d}(s)\delta(s) \quad (8)$$

$$\Delta P_e(s) = K_1\Delta\delta(s) + K_2\Delta E''_q(s) - K_{2d}\Delta E''_d(s) \quad (9)$$

$$\Delta\omega(s) = \frac{1}{2Hs}[\Delta P_m(s) - \Delta P_e(s) - D\Delta\omega(s) \quad (10)$$

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$$\Delta\delta(s) = \frac{\omega_0}{s}\Delta\omega(s) \qquad (11)$$

This model is defined by equations (5)–(10). The transfer matrix representation of (11) is obtained, where

2) System coefficients and transfer functions

$$K_1 = \frac{V_{\infty d0}^2}{X_d^{"}+X_d} + \frac{V_{\infty q0}^2}{X_q^{"}+X_{tl}} - I_{q0}V_{\infty d0} + I_{d0}V_{\infty d0}$$

$$K_2 = \frac{V_{\infty d0}}{X_d^{"}+X_{tl}}$$

$$K_2 = \frac{V_{\infty q0}}{X_q^{"}+X_{tl}}$$

$$K_3(s) = \frac{1}{D(s)}\,(1+\tau'_{d0}s)(X_q^{"}+X_{tl})$$

$$K_4(s) = \frac{V_{\infty d0}}{D(s)}\,[(X_d - X_d^{"}) + \{(X'_d - X_d^{"})\tau'_{d0} + (X_d - X'_d)\tau_{d0}^{"}\}s$$

$$D(s) = \tau'_{d0}\tau_{d0}^{"}s^2(X_d^{"}+X_{tl})\,\tau_{d0}^{"}\{(X_d^{"}+X_{tl}) + (X_d - X'_d)\} + \qquad \tau'_{d0}(X'_d+X_{tl})]s + (X_d + X_{tl})$$

$$K_{4d}(s) = \frac{C_{4d}}{1+\tau'_q s} \qquad C_{4d} = \frac{(X_q - X_q^{"})}{(X_d+X_{tl})}.V_{\infty q0}$$

$$K_5 = [\frac{E_{td0}}{E_{t0}}.\frac{X_q^{"}V_{\infty q0}}{X_d^{"}+X_{tl}} - \frac{E_{tq0}}{E_{t0}}.\frac{X_d^{"}V_{\infty d0}}{X_d^{"}+X_{tl}}]$$

$$K_6 = [\frac{E_{tq0}}{E_{t0}}.\frac{X_{tl}}{X_d^{"}+X_{tl}}]$$

$$K_6 = \left[\frac{E_{td0}}{E_{t0}}.\frac{X_{tl}}{X_q^{"}+X_{tl}}\right] \qquad \tau'_q = \frac{(X_q^{"}+X_{tl})}{(X_q+X_{tl})}.\tau_{q0}^{"}$$

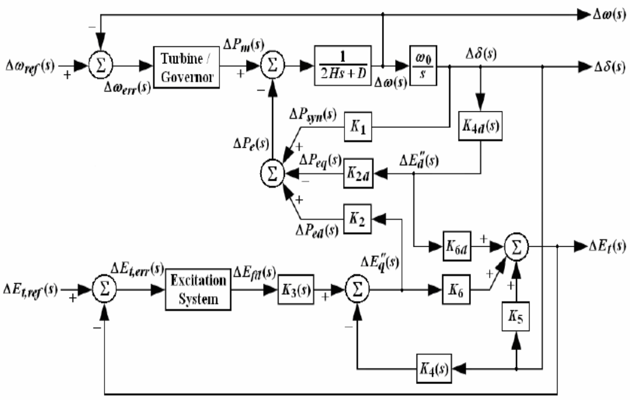

Fig 1 Block Diagram for the model

3) *Stabilization with an AVR*

Excitation system is a key element in the dynamic performance of any electrical power generator. Since accurate excitation is of great importance in bringing the machine into synchronization, and since an AVR malfunction could

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destabilize the overall system. It is needed to investigate the effect of both stabilizers onto the system with and without an AVR.

IV. NUMERICAL RESULTS

The maximum amount of phase needed depends on the fractional order of the FoPSS. Cascading more than one power system stabilizer would yield the amount of phase required to stabilize the system. The performance of the system is investigated using MATLAB/Simulink environment. It is assumed that the system with the exciter is working properly and a 0.05 p.u. step change in both ΔV_{ref} and T_m is applied to it at t=0.5s and t=2s, respectively. The IoPSS implemented is [3]:

$$G_I(s) = \frac{10s}{(1+10s)}\frac{(1+0.568s)}{(1+0.0227s)}\frac{(1+0.568s)}{(1+0.0227s)}$$

For fractional-order controllers, two lead FoPSS is cascaded and followed by a limiter without a washout component to form a complete FoPSS controller

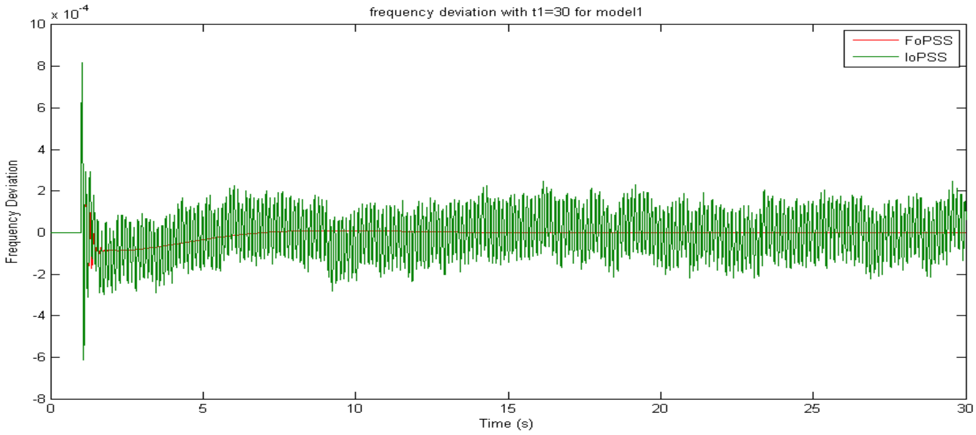

Fig 2 Frequency deviation due to 0.05 p.u. step change in both V_{ref} and T_m when D = 2, τ_1 = 30, τ_2 = 1

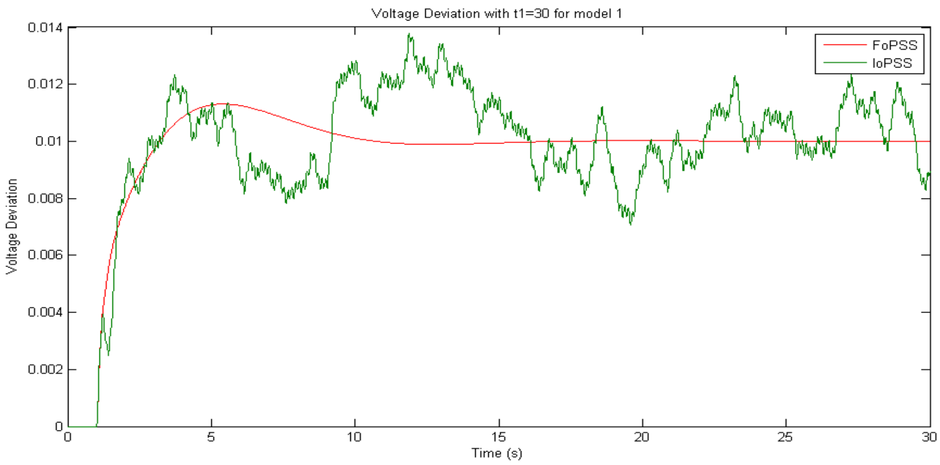

Fig 3 Voltage deviation due to 0.05 p.u. step change in both V_{ref} and T_m when D = 2, τ_1 = 30, τ_2 = 1

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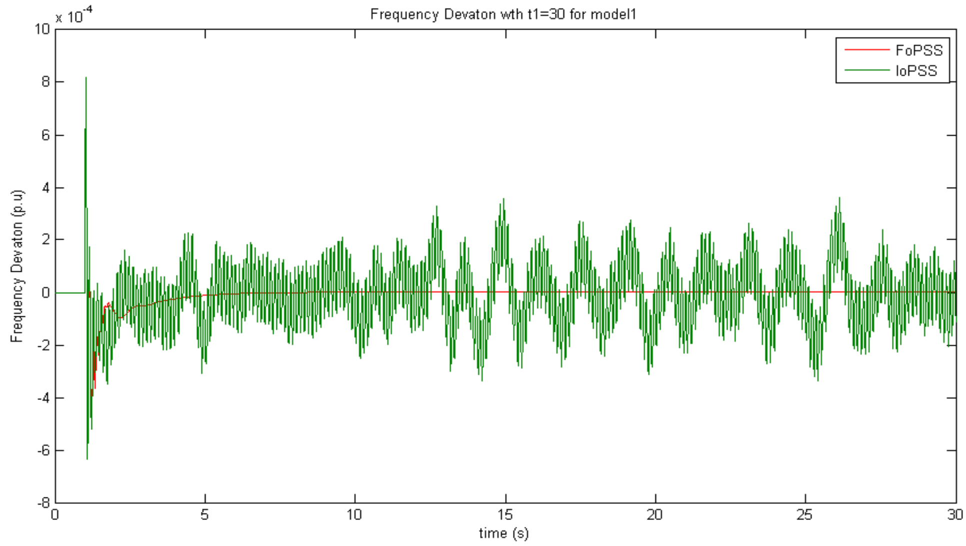

Fig 3 Frequency deviation without an AVR when D = 2, $\tau_1 = 30$, $\tau_2 = 1$

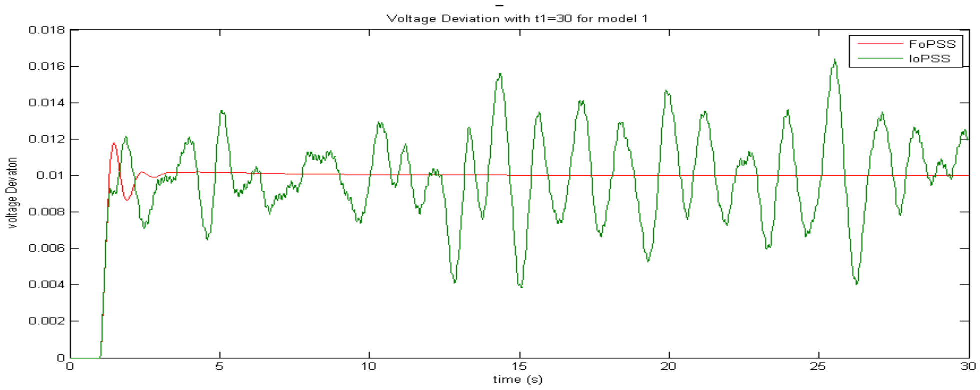

Fig 4Voltage deviation without an AVR
when D = 2, $\tau_1 = 30$, $\tau_2 = 1$

V. Conclusions

The FoPSS improved the performance of the infinite bus system and achieved a faster and smoother performance than its integer-order counterpart. Frequency and terminal voltage deviation over sever conditions were quickly absorbed when using FoPSS. FoPSSs has a larger bandwidth than its integer-order counterpart, and is expected to accommodate wider range of operating conditions. The increase in order in the case of FoPSS can be compensated by implementing already existing fast processors.

APPENDIX

Parameters for Model 2.1

$K_{2d} = 1.4198$, $C_{4d} = 0.5864$

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$$K_{4d} = \frac{0.5864}{1 + 0.159s} \qquad K_{6d} = 0.2563$$

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Table I Synchronous Machine Parameters

Variable	Value	Variable	$X_{tl} = 0.4\ p.u$
X_d	1.445p.u	P_g	0.256p.u.
X'_d	0.316p.u.	δ_∞	0.92p.u.
X''_d	0.179p.u.	V_∞	40.24^0
τ'_{d0}	5.26s	$V_{\infty 0}$	0.9741p.u.
τ''_{d0}	0.028s	$V_{\infty d0}$	0.70228p.u.
X_q	0.959p.u.	E_{t0}	0.83862p.u.
X''_q	0.162p.u.	E_{tq0}	0.49556p.u.
τ''_{d0}	0.159s	I_0	0.51678p.u.
R_a	0	I_{q0}	0.61064p.u.
f_0	50	P_g	0.256p.u.

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Table II Transfer function approximation of fractional-order integrators with 2 dB maximum error.

α	$H(s) = N(s)/D(s) \approx 1/s^{\alpha}$
0.1	$\frac{1584.8932(s+0.1668)(s+27.83)}{(s+0.1)(s+16.68)(s+2783)}$
0.2	$\frac{9.4328(s+0.05623)(s+1)(s+17.78)}{(s+0.03162)(s+0.5623)(s+10)(s+177.8)}$
0.3	$\frac{39.8107(s+0.04)(s+0.3728)(s+3.3)(s+29.94)}{(s+0.02)(s+0.193)(s+1.73)(s+138.9)}$
0.4	$\frac{35.4813(s+0.03831)(s+0.261)(s+1.778)(s+12.12)(s+82.54)}{(s+0.01778)(s+0.1212)(s+0.8254)(s+5.623)(s+38.31)(s+261)}$
0.5	$\frac{15.8489(s+0.0389)(s+0.2512)(s+1.585)(s+10)(s+63.1)}{(s+0.01585)(s+0.1)(s+0.631)(s+3.981)(s+25.12)(s+158.5)}$
0.6	$\frac{107989(s+0.04642)(s+0.3162)(s+2.154)(s+14.68)(s+100)}{(s+0.01468)(s+0.1)(s+0.6813)(s+4.642)(s+31.62)(s+215.4)}$
0.7	$\frac{9.3633(s+0.06449)(s+0.578)(s+5.179)(s+46.68)(s+416)}{(s+0.01389)(s+0.1245)(s+1.116)(s+10)(s+89.62)(s+803.1)}$
0.8	$\frac{5.3088(s+0.1334)(s+2.371)(s+42.17)(s+749.9)}{(s+0.01334)(s+0.2371)(s+s+4.217)(s+74.99)(s+1334)}$
0.9	$\frac{2.2675(s+1.292)(s+215.4)}{(s+0.01293)(s+2.154)(s+359.4}$