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Identification of the Most Effective Supplementary Signal in Damping a Particular Power System Mode of Instability

By

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Abstract:

Previous works in the field of power system stability adopting the concept of supplementary signal were mostly dedicated to stabilize all system modal instabilities. In this paper a study is made to identify the particular type of supplementary signal most-effective in increasing the damping introduced to the excitation system over a specific power system mode of instability. To this end, a series of MATLAB algorithms were developed and the results obtained yielded a set of supplementary signals to be introduced to the excitation of a single machine infinite bus-bar power system. The effect on increasing damping over a particular system mode is evaluated. The outcomes from extensive case studies confirmed the validity of the proposed approach.

Keywords:

Supplementary signal, modal interaction, power system stability, signal processing.

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1. Introduction:

In the past two decades, numerous approaches were directed towards using supplementary signals derived either directly or indirectly from the machine state variables for the purpose of enhancing the system modal damping introduced by the voltage control loop during transient periods [1-5]. Power system instability can take one of several forms such as mechanical instability (hunting mode), electrical instability (self excited oscillation) and electromechanical instability (subsynchronous resonance); as well as other forms [6-10].

Classification of supplementary signals can be listed as follows: derivatives of machine terminal voltage, machine rotor current and/or its derivatives, machine active power P or machine reactive power Q and their derivatives and finally machine rotor angular speed deviation ω and its derivative signal ($\Delta\omega$) [11,12]. The latter is known as power system stabilizer, PSS, and is the one most widely used to increase the effectiveness of the AVR in controlling power system instability. The outcomes of such approaches remain restricted by the exciter and machine field constraints [13].

This work presents a comprehensive computational study, carried out using a set of MATLAB algorithms, to evaluate and assess the effect of the above mentioned supplementary signals in enhancing the effectiveness of the control loop in damping out modal instabilities which may occur in power systems. The study addresses each supplementary signal as linked to a specific type of modal instability. This is achieved through three basic measures namely:

1. Selecting the appropriate supplementary signal to modulate the response of the AVR for the effective control of the selected form of instability.
2. Devising a signal processing strategy to blend the selected supplementary signal to be fed with the existing control system to achieve an inphase signal reinforcement.
3. Tuning the controller parameter, through optimization algorithms, to best suite suppressing the actual form of instability.

2. Problem Formulation:

In addition to the system power frequency, generated under steady normal operation, other unwanted oscillations may arise due to changes in system configuration or switching causing stability problems [6,7]. The modes of instability in power systems are usually manifested in two basic forms:

Instability with monotonic nature; which may occur due to unbalance either through power surplus or deficiency between generation and delivery.

Instability with oscillatory nature; caused by the exchange of energy between either like or unlike energy forms i.e. electrical to electrical exchange or electrical to mechanical exchange etc…. The range of frequency of oscillation can fall into two major domains: the first domain of oscillation resides in the supersynchronous zone where all modal interactions falling into this domain are well damped and do not provoke stability problems [14]. On the other hand the second domain of oscillation is of subsynchronous nature and can be subdivided into self excited oscillation, subsynchronous resonance, hunting mode and inter-area oscillations etc…...and may cause stability problem and even damage of system components. In this domain ultra low range of subsynchronous oscillation where very low subsynchronous frequency are encountered, with frequency ranging below 1Hz and is attributed to the instability due to rotor masses oscillating in unison against the mass of the infinite system or due to the inter-area oscillation between two large pools of energy connected through a relatively weak tie line. Here, although the magnitude of these oscillations may not be of pronounced nature, yet they are poorly damped causing the oscillations to become persistent [15].

Attention in this paper will be basically focussed on selecting the most effective signal, altogether with defining the feeding methodology the feeding methodology of this signal to the voltage control loop augmented by the optimal tuning of the controller parameters to achieve the suppression and control over a given unstable mode.

3.Systems under Study

Three basic power system configurations were selected to generate the modes of instability and to test the suggested approach for effective control are listed as follows:

1. A single machine connected to an infinite system through a step up transformer and a tie line as shown in fig.(1) to model for the machine power angle instability.
2. A single machine connected to an infinite system through a step up transformer and a series compensated tie line as shown in fig.(2) to exemplify for the problem of self excited oscillation .
3. A single machine with a multimass rotor representation is connected to an infinite system through a step up transformer and series compensated tie line as shown in fig.(3) to provoke the subsynchronous resonance phenomena and test the proposed suppression approach.

The study routine will be performed testing various supplementary signals when system is undergoing either a small perturbation or a large scale disturbance and the results presented in this paper are the ones that has yielded best damping and thus the ones that can reduce the probability of system instability and enhance stability limit to its utmost level.

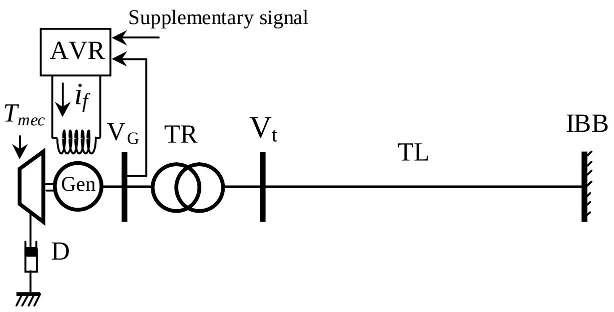


Fig.(1) *System A Single machine infinite bus bar*

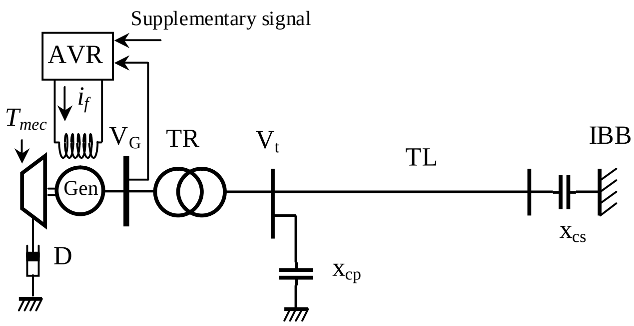


Fig.(2) *System B Single machine infinite bus bar with compensated tie line*

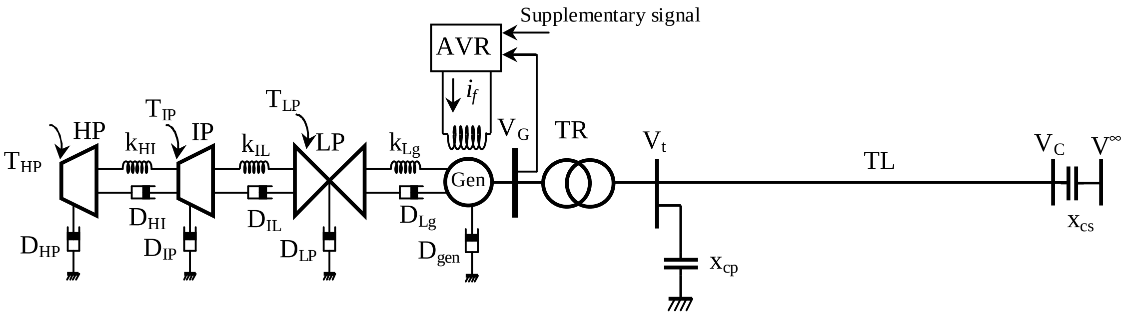


Fig.(3) *System C Single machine infinite bus with multimass shaft representation and compensated tie line*

4. Selection and Conditioning of the Supplementary Signal(Expanding the Power Angle Stability Limit)

In this study the fast acting static exciter (thyristor based) model is adopted and the block diagram representation for this model is shown in fig.(4) [13,16]. All generating units equipped with such excitation system, necessitate supplementary stabilizing signals to suppress the mechanical oscillations. Here the stabilizing signal is derived from rotor angular speed deviation (PSS); needless to say that PSS must provide enough phase compensation over the expected range of oscillation frequencies. For design purposes of conventional power system stabilizer (CPSS), its transfer function is in the form of:

$$\mathbf{G}_{\mathbf{PSS}}(\mathbf{s}) = \mathbf{K}_{\mathbf{PSS}}\left(\frac{\mathbf{1}+\mathbf{sT_1}}{\mathbf{1}+\mathbf{sT_2}}\right)^{\mathbf{k}}$$

where k denotes the number of phase compensation blocks and T_1, T_2 are the time constants that must be set to provide damping over the range of frequencies at which oscillations might occur. System parameters and controller are given in Appendix A.

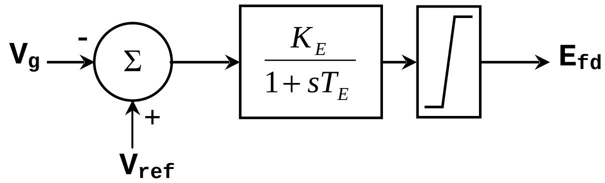


Fig.(4) *Type IV automatic voltage regulator (AVR)*

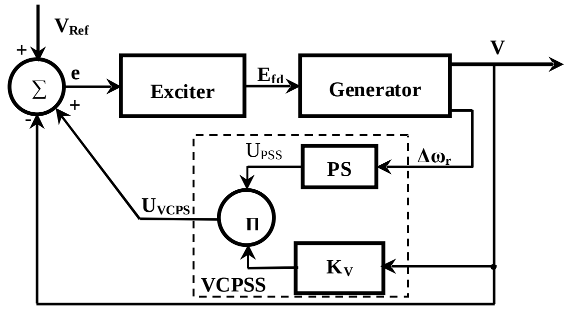
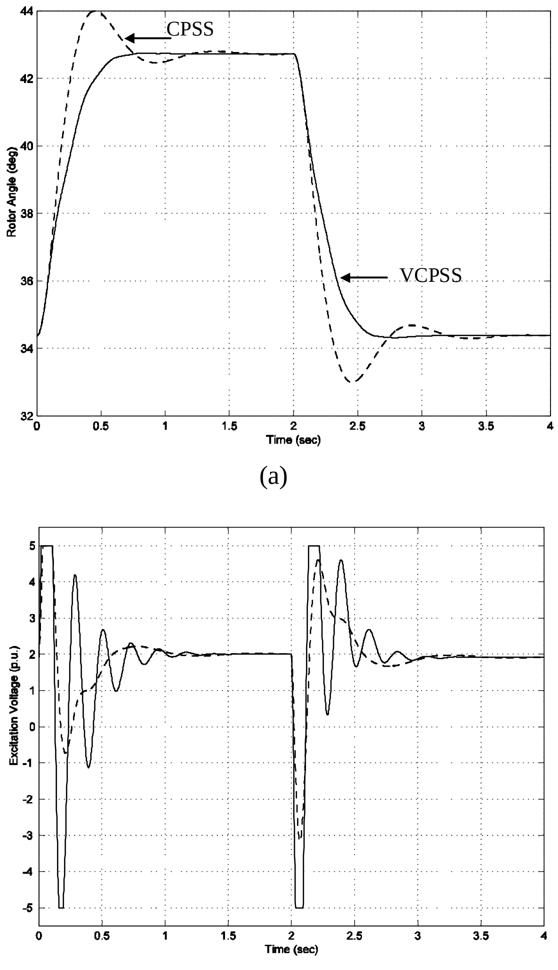


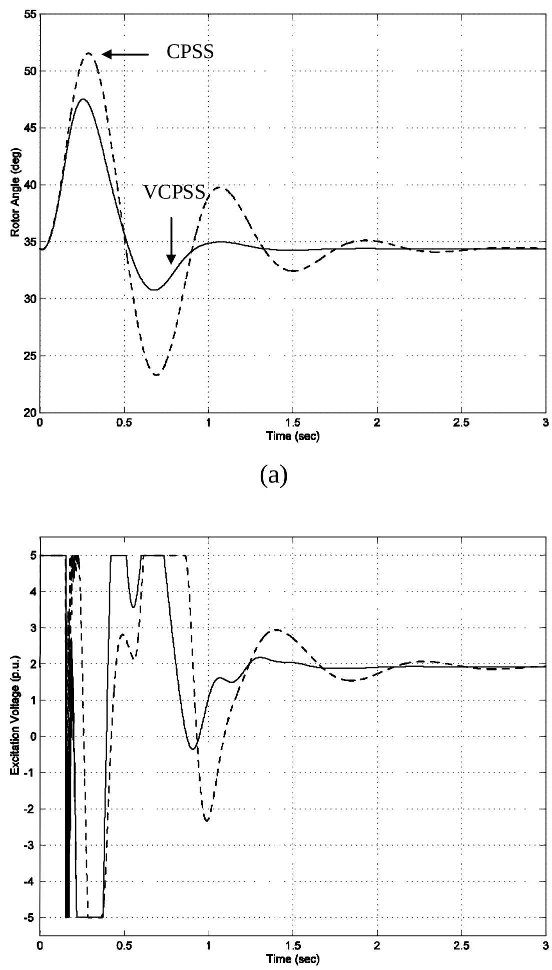
Fig.(5) *Voltage controlled PSS stabilizer (VCPSS)*



(a)

(b)

Fig.(6) *Time variation in rotor power angle(a) and excitation voltage (b)due to a 10% increase in T_{mech}; with full recovery after 2 sec*



(a)

(b)

Fig.(7) *Time variation in rotor power angle(a) and excitation voltage (b)due to a three-phase short circuit at the HT terminals of the power transformer with system restored after a 150 msec*

In fig.(5) the block diagram of a voltage controlled PSS stabilizer where the machine voltage is engaged with the supplementary signal to produce a signal U_{VCPSS} that will provoke the exciter response immediately after the occurrence of a disturbance as it can be seen from the excitation response shown in fig.(6) and fig.(7).

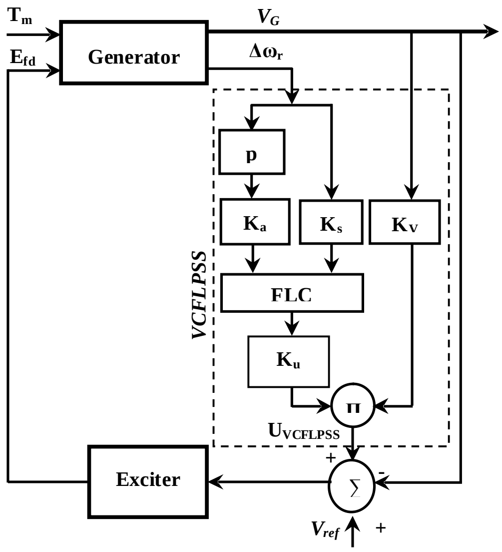


Fig.(8) *Block diagram for VCFLPSS*

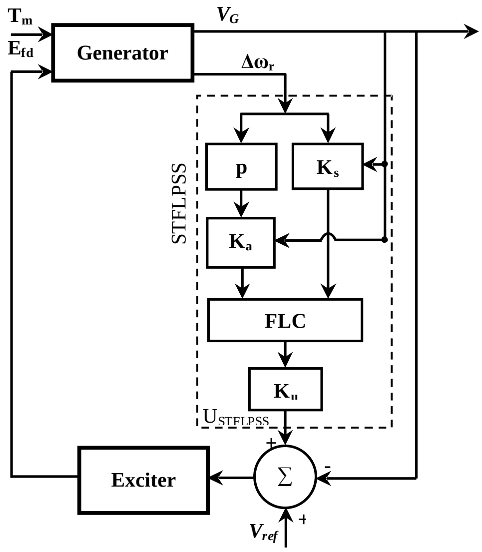


Fig.(9) *Block diagram for STFLPSS*

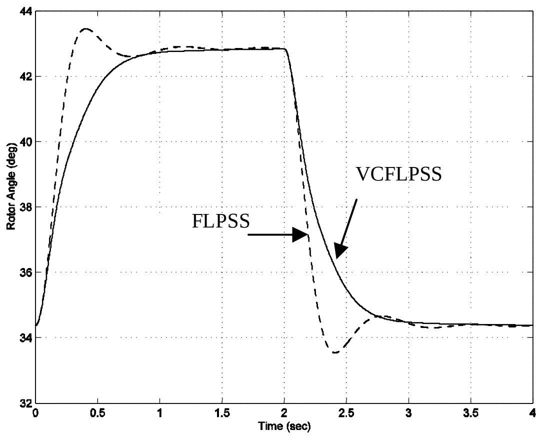


Fig.(10) *Time variation in rotor power angle (a) and excitation voltage (b)due to a 10% increase in T_{mech}; with full recovery after 2 sec*

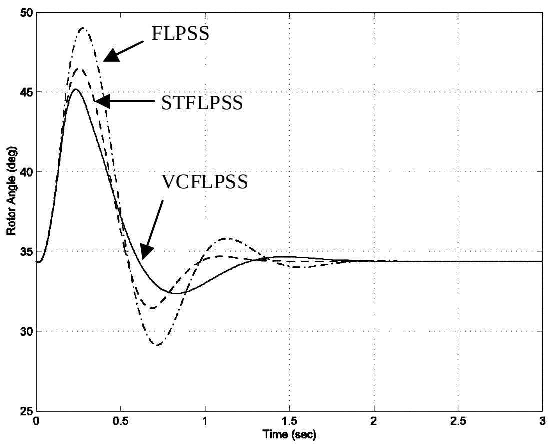


Fig.(11) *Time variation in rotor power angle(a) and excitation voltage (b)due to a three-phase short circuit at the HT terminals of the power transformer with system restored after a 150 msec*

The adoption of fuzzy logic technique to the power system stabilizer operation has noticeably enhanced the performance of the voltage control system. In fig.(8) and fig.(9) the block diagrams of the voltage controlled fuzzy logic power system stabilizers (VCFLPSS) and the self tuned fuzzy logic power system stabilizer (STFLPSS) respectively are presented. The performance of both VCLFPSS and STFLPSS are presented in fig.(10) when the system undergoing a small disturbance and in fig.(11) when the system is subjected to a severe three-phase short circuit with a fault duration of 150 msec. The use of STFLPSS has expanded the system stability limit to withstand a fault duration of 432.5 msec, while the figure was limited to 346 msec with the conventional (VCPSS) delivering an increase in the transient stability limit by 25% over the (VCPSS).

5. Selection and Conditioning of the Supplementary Signal (Control of the Self Excited Oscillations)

The concept of self excited oscillations is related to the low X/R ratio in tie line interconnecting a plant to the remaining part of the system [8,17]. This form of instability causes the occurrence of electrical oscillations thereby generating mechanical oscillatory torques. Various approaches to the prevention of the self excited oscillation were, earlier, suggested such as line filters, by pass filters or attempting to control the phenomena using static VAR compensators, excitation voltage control, and reactive power switching [17]. To date all these measures have proven to produce limited damping on this form of instability. The concept of using field control with reactive power as supplementary signal termed negative damping stabilizers, NDS, has produced encouraging results [17]. The adoption of GAs approach, to decide for the optimum controller’s parameters, has boosted the efficacy of the NDS controller [18]. The power system adopted for the study is given in fig.(2). The system data and controllers parameter are given in Appendix B. The time variation in reactive power picture in the post-disturbance period is shown in fig.(12.a) and fig.(12.b) for both small and large perturbations. The build up of self excited oscillations is quite clear.

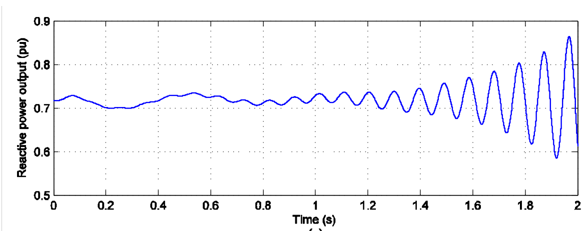


Fig.(12.a) *Reactive power output when system is subjected to 10% reduction in Tmech for 100msec*

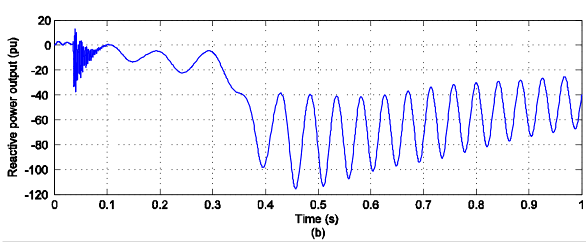
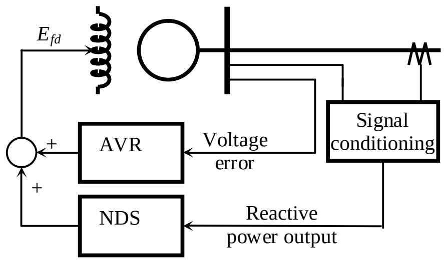


Fig.(12.b) *Reactive power output when system is subjected to 10% reduction in Tmech for 100msec*



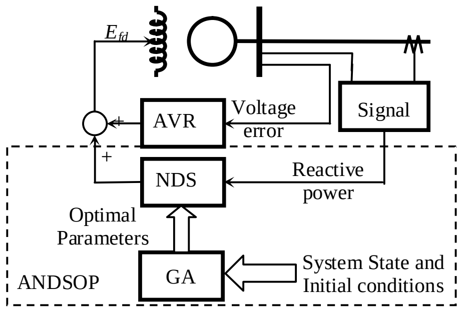
(a)

Full excitation system

$$\Delta Q \rightarrow \boxed{\frac{k_1 s}{1+sT_1}} \rightarrow \boxed{\frac{k_2 s}{1+sT_2}} \rightarrow U_{NDS}$$

(b)

Fig.(13) *Negative damping stabilizer*



(a)

Full excitation system with GA parameter optimization

$$\Delta Q \rightarrow \boxed{\frac{1}{1+s}} \rightarrow \boxed{\frac{k_1 s}{1+sT_1}} \rightarrow \boxed{\frac{k_2 s}{1+sT_2}} \rightarrow U_{NDS}$$

(b)

Fig.(14) *ANDSOP controller transfer function*

In fig.(13) the block diagram of a conventional negative damping stabilizer (NDS) is presented; while fig.(14) shows the functional diagram of an adaptive NDS with computed optimal parameters using GAs.

Table I *Eigenvalues for systems B with 90% compensation level and different voltage control supplementary signal*

Modes			Constant Excitation	Fast Acting Static Exciter	Exciter with NDS	Exciter with ANDSOP
Stator Modes	**Network Modes($\omega_{sync}+\omega_{n1}$)**		-6.3193 ± j 2607	-5.9334 ± j 2607.8	-5.9334 ± j 2607.8	-5.9324 ± j 2607.9
	Network Modes($\omega_{sync}+\omega_{n1}$)		-8.0104 ± j 1852.6	-7.2143 ± j 1851.1	-7.2143 ± j 1851.1	-7.3323 ± j 1851.1
	Electrical Mode($\omega_{sync}+\omega_{n2}$)		-4.1568 ± j 688.05	-4.1276 ± j 688.13	-3.3882 ± j 687.9	-4.1103 ± j 688.17
	Electrical Mode($\omega_{sync}-\omega_{n2}$)		+3.0308 ± j 65.894	+0.75664 ± j 71.601	-6.6615 ± j 73.027	-1.584 ± j 64.712
Rotor Modes	**Mech. Mode**	**Hunting Mode**	-1.7551 ± j 11.672	-1.4271 ± j 11.505	-1.545 ± j 11.533	-2.0486 ± j 11.121
	Electric Modes	**Field & Control Mode**	-0.36144	-23.3 ± j 26.11	-10.329 ± j 37.238 -57.671 -18.021	-11.273 ± j 49.068 -1.584 ± j 0.5251 -42.854
		D-axis Mode	-33.58	-90.423	-92.319	-90.943
		Q-axis Mode	-16.965	-14.008	-12.715	-15.809

Using the eigenvalue analysis technique, a comparison is made between the system characteristic roots when undergoing small disturbance encompassing the following voltage control cases: absence of any control action, control with fast acting exciter, conventional negative damping stabilizer excitation and finally the adaptive negative damping stabilizer with optimum parameters at a level of series compensation of 90%, where the system is in deep instability, the results obtained in table I show that the simple excitation system failed to stabilize this phenomena.

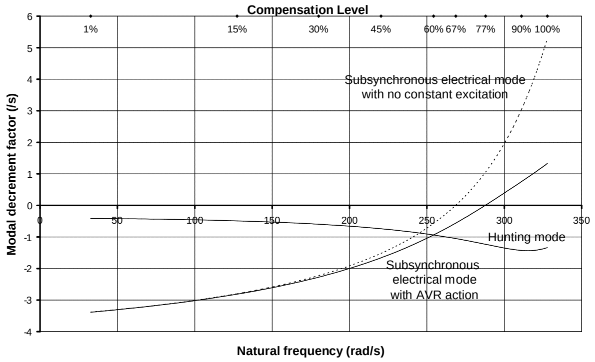


Fig.(15) *Locus of the (ω_{sync}-ω_n)mode for values of 0.1< x_c< 1 with no control and with conventional Fast acting AVR control*

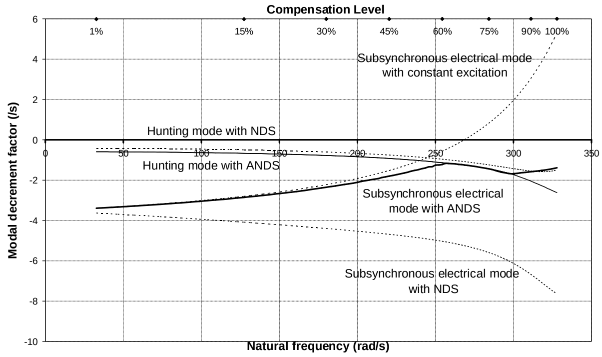


Fig.(16) *Locus of the (ω_{sync}-ω_n)mode for values of 0.1< x_c< 1 with NDS and ANDSOP control*

The small perturbation model of the adopted power system was repeatedly solved for values of 1% < x_c< 100% of the line series reactance and locus of the damping of the electrical mode and hunting mode are plotted in fig.(15) against the resulting natural angular frequency for the cases of constant excitation and conventional AVR. The results obtained exhibit self excited oscillation instability. Similarly in fig.(16) with NDS and ANDSOP where system stability was maintained over the range of compensation. Furthermore, in fig.(17) and fig.(18) system suffered into instability except for the case of ANDSOP controller.

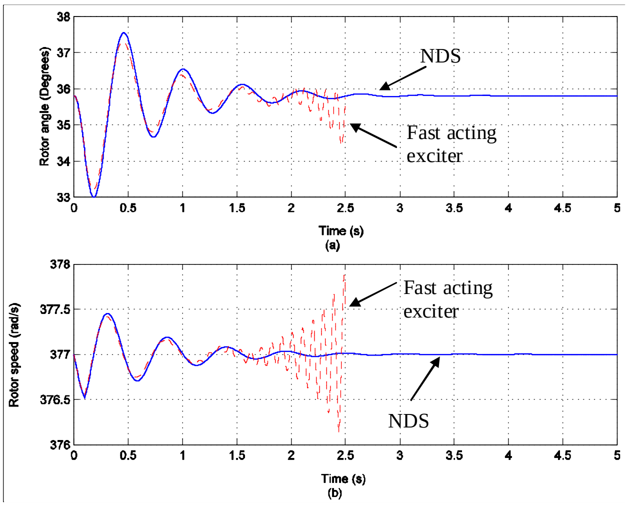


Fig.(17) *Time variation in rotor angle and angular speed due to a 10% reduction in T_{mech} for 100msec at 90% compensation level*

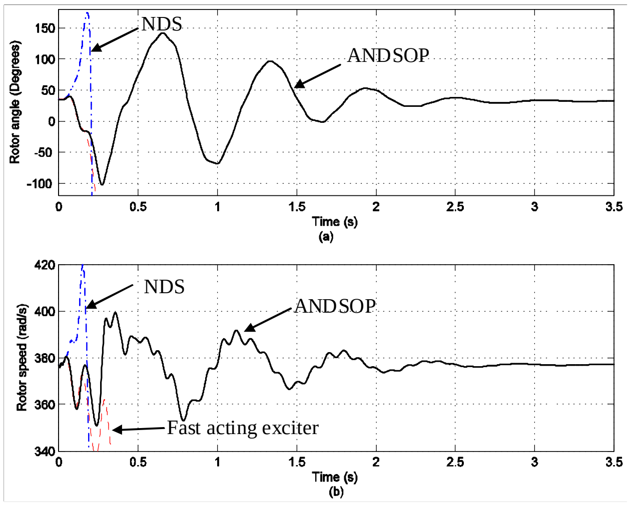


Fig.(18)*Time variation in rotor angle and angular speed due to a 3ϕ- short circuit at the high tension side of the power transformer for a period of 35msec at 90% compensation level*

6. Selection and Conditioning of the Supplementary Signal (Control of the Subsynchronous Resonance Phenomena)

In a power system with series compensated lines the electrical system will exhibit oscillations at its natural frequency, as the level of compensation is usually in the vicinity of 80% of the line series inductance. Thus an electrical oscillatory mode will develop at side band frequencies ($\omega_{sync}+\omega_n$) and ($\omega_{sync}-\omega_n$) the latter obviously fall in the subsynchronous range and may coincide with one or more of the mechanical natural modes causing electromechanical instability leading to material fatigue and eventually to shaft failure. This is referred to subsynchronous resonance phenomena [10,19].

In fig.(19) the shaft mode shapes of the four masses turbine generator rotor are presented where there basic mechanical natural frequency are 308.5, 209.2, 127.9 and 9.75 rad/sec. Referring to the dotted line box the low pressure turbine and generator rotor masses maintained an antiphase swinging relation in the mode 3, mode 2 and mode 1; thus the difference between the angular speed of this masses will be taken as the supplementary signal to be fed to the excitation system through the usual PSS lead/lag function and the control thus formed is termed the modified power system stabilizer (MPSS).

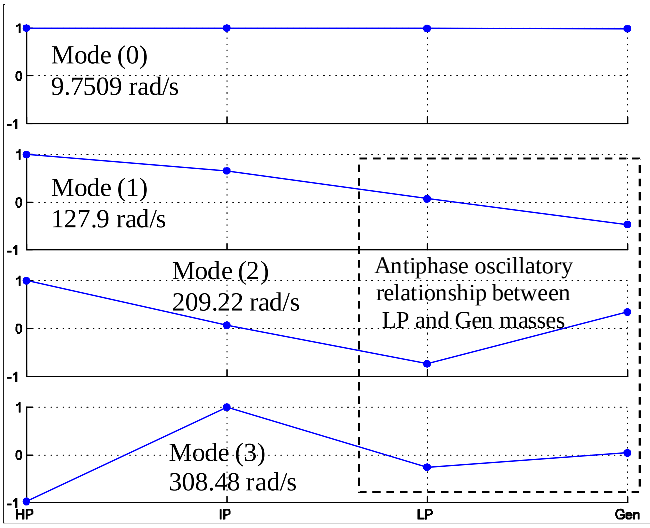


***Fig.(19)** Mechanical mode shapes and natural frequencies*

Mechanical modes with natural frequency near the synchronous speed are normally stable, as they belong to a mechanical mode shape where all rotor masses are oscillating in antiphase to each other at an angular frequency of 308.48 rad/sec. On the other hand mechanical modes in the mid range of the subsynchronous domain are characterised by a group of masses oscillating against each other producing either one point of torsional location (mode1) or two points of torsional locations (mode 2) along the length of the shaft. Mechanical modes in this range of oscillation are prone to instability and are usually subjected to encounter the subsynchronous resonance phenomena.

At lower range of subsynchronous oscillations all rotor masses will swing in unison against the mass of the infinite system, this mode is referred to as mode 0 or hunting mode and usually exhibits poor damping and may cause machine fall out of synchronism.

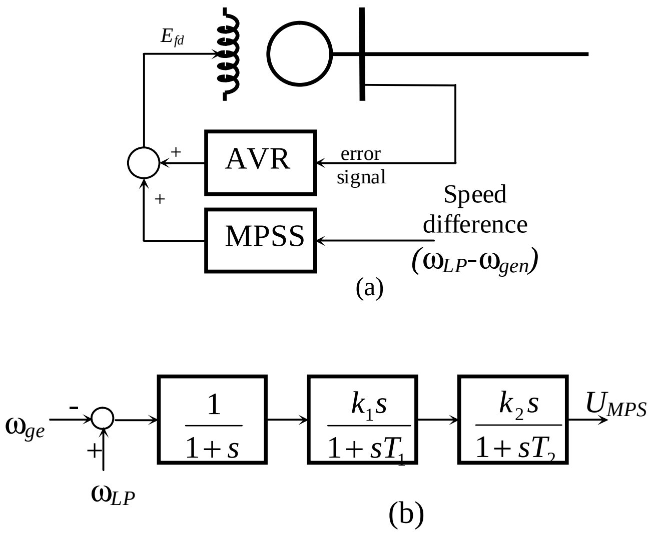


Fig.(20) *Generator with AVR and MPSS*
(a) Full system block diagram
(b) Suggestion MPSS transfer function

Unlike the situation with conventional PSS controllers, where the supplementary signal is derived from the generator rotor angular speed deviation from the synchronous angular speed, the idea behind the suggested modified PSS controller as previously mentioned resides in selecting its supplementary signal to be proportional to the angular speed difference between the rotor mass and the antecedent low pressure turbine mass. The excitation system with the proposed modified PSS (MPSS) transfer function are shown in fig.(20). The supplementary signal loop consists of a two stage high-pass filters to ensure that the controller will not affect the machine hunting mode and a single stage low-pass filter to block the supersynchronous frequency components of the input signal. The output of the proposed controller is fed directly to the AVR output rather than the voltage error in the normal PSS.

The small perturbation model of the power system shown in fig.(3) and system data and controller parameters are given in Appendix B was developed and repeatedly solved using the eigenvalue technique for values of line series compensation in the range of 1% < x_{cs}< 100% of the line series reactance and the results obtained at x_{cs} equal 26% of line series compensation where the coincidence between the electrical mode (ω_{sync}-ω_n) and the mechanical mode 2 is presented with various excitation models in table II. Similarly the coincidence between the electrical mode (ω_{sync}-ω_n) and the mechanical mode 1 at x_{cs} equal to 58% of series compensation are shown in table III.

Also the effect of the conventional PSS was successful in controlling the instability at the mechanical mode 2 when undergoing a small perturbation; yet it failed to do so at the coincidence frequency with mode 1. Evidently, the damping introduced by the MPSS controller has maintained all mechanical mode stable over the full range of variation in x_{cs}.

***Table II** Eigenvalues for the power system with 26% series compensation*

			Excitation Control	
	Mode	**Constant Excitation (No Control)**	**PSS**	**MPSS**
Stator modes	Network Modes($\omega_{sync}+\omega_{n1}$)	-6.3409±j2602.1	-6.05±j2603.4	-6.0571±j2603.4
	Network Modes($\omega_{sync}-\omega_{n1}$)	-8.0511±j1847.8	-7.3884±j1845.3	-7.4024±j1845.4
	Electrical mode ($\omega_{sync}+\omega_{n2}$)	-3.9461±j544.58	-3.9348±j544.61	-3.9602±j544.5
	Electrical mode ($\omega_{sync}-\omega_{n2}$)	-4.4431±j209.12	-3.0213±j211.41	-2.9201±j198.49
Rotor modes	Mechanical mode (3)	-1.2923±j308.84	-1.2934±j308.84	-1.3097±j308.87
	Mechanical mode (2)	1.4666±j209.07	-0.25257±j207.64	-1.0±j220.84
	Mechanical mode (1)	-0.36223±j128.12	-0.25265±j127.06	-4.9705±j123.89
	Mechanical mode (0)	-0.6814±j10.208	-0.25256±j10.858	-1.0±j10.234
	Excitation system modes	-0.25518	-29.607±j51.657 -61.139 -0.28845 -0.25257	-19.315±j54.633 -25.38 -5.7935 -1.0
	D- axis damper mode	-32.241	-77.986	-81.626
	Q-axis damper mode	-10.033	-9.7479	-10.018

***Table III** Eigenvalues for the power system with 58% series compensation*

			Excitation Control	
	Mode	**Constant Excitation (No Control)**	**PSS**	**MPSS**
Stator modes	Network Modes($\omega_{sync}+\omega_{n1}$)	-6.3302±j2604.5	-5.9964±j2605.6	-5.9995±j2605.6
	Network Modes($\omega_{sync}-\omega_{n1}$)	-8.0307±j1850.2	-7.3089±j1848.2	-7.3167±j1848.2
	Electrical mode ($\omega_{sync}+\omega_{n2}$)	-4.0768±j627.01	-4.0601±j627.08	-4.068±j627.05
	Electrical mode ($\omega_{sync}-\omega_{n2}$)	-6.209±j127.28	-2.8387±j130.76	-1.4337±j113.62
Rotor modes	Mechanical mode (3)	-1.2923±j308.84	-1.2927±j308.84	-1.3013±j308.85
	Mechanical mode (2)	-0.57249±j209.06	-0.62454±j209.12	-1.0201±j209.97
	Mechanical mode (1)	5.1014±j127.29	1.2535±j125.49	-1.0955±j138.33
	Mechanical mode (0)	-1.0346±j11.054	-0.2535±j10.28	-1.2015±j11.226
	Excitation system modes	-0.2909	-27.514±j42.15 -0.55151±j0.2423 -0.15624	-23.174±j44.998 -47.202 -1.1438 -1.0001
	D- axis damper mode	-32.717	-85.269	-85.589
	Q-axis damper mode	-11.932	-11.705	-11.399

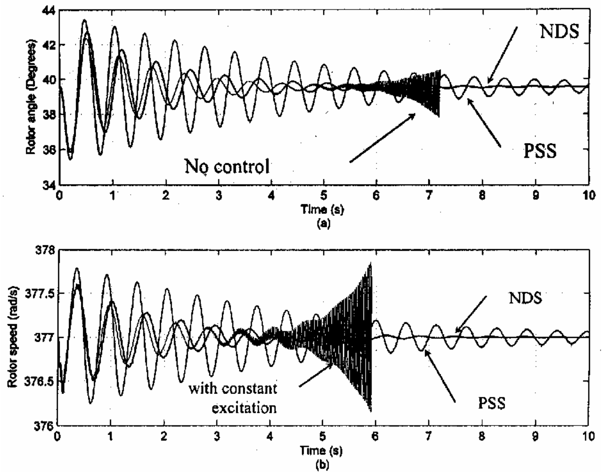


Fig.(21) *Time variation of the machine rotor angle (a) and angular speed (b) for a 10% reduction in T_{mech} at 26% compensation level and system restored after 100 msec for the cases of constant excitation, PSS and NDS controllers*

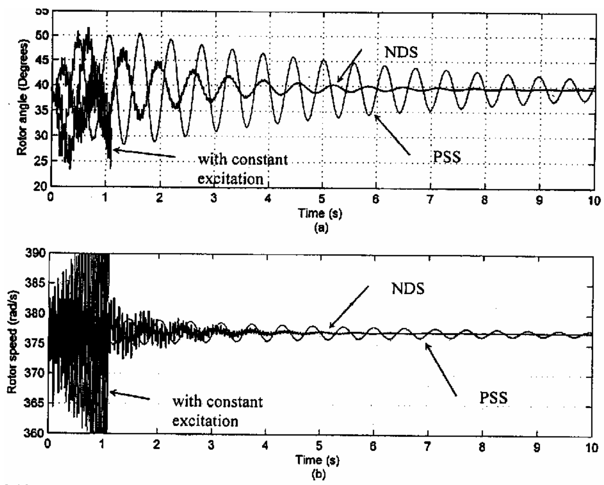


Fig.(23) *Time variation of the machine rotor angle (a) and angular speed (b) for a three-phase short circuit at 26% compensation with system regaining its original state after 80 msec for the cases of constant excitation, PSS and NDS controllers*

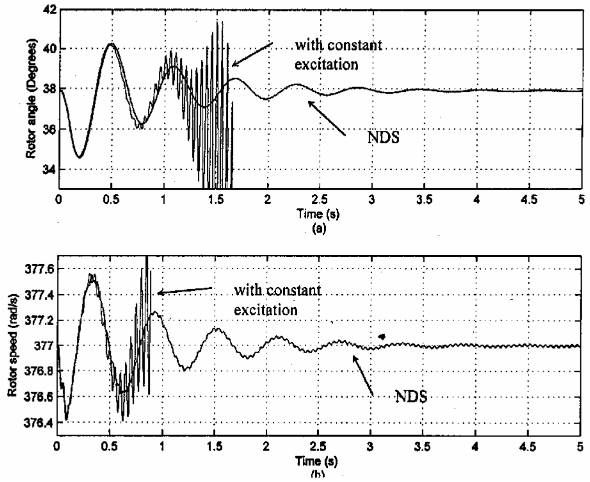


Fig.(22) *Time variation of the machine rotor angle (a) and angular speed (b) for a 10% reduction in T_{mech} at 58% compensation level and system restored after 100 msec for the cases of constant excitation and NDS controller*

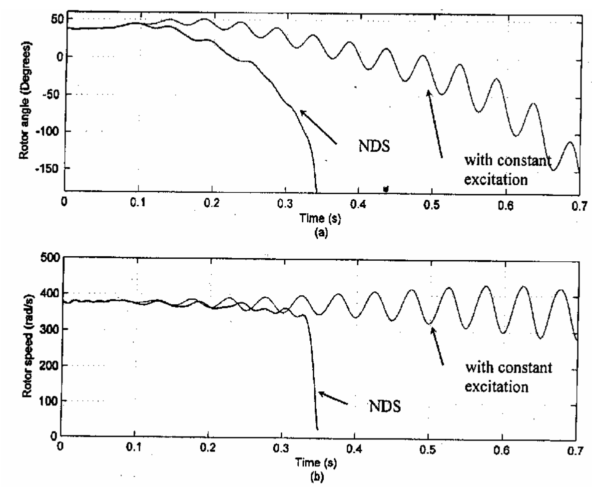


Fig.(24) *Time variation of the machine rotor angle (a) and angular speed (b) for a three-phase short circuit at 58% compensation with system regaining its original state after 80 msec for the cases of constant excitation and NDS controller*

The set of results presented in fig.(21) and fig.(22) confirm the potential of the NDS over the PSS as far as the case of small perturbation is concerned. For the case of large scale disturbance results shown in fig.(23) and fig.(24) subsynchronous oscillation where not properly damped.

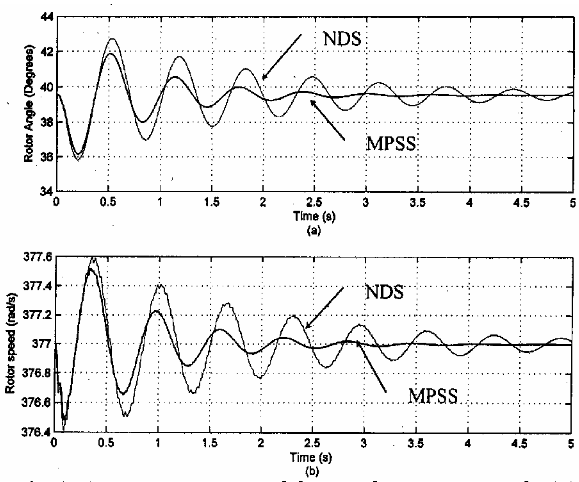


Fig.(25) *Time variation of the machine rotor angle (a) and angular speed (b) for a 10% reduction in T_{mech} at 26% compensation level and system restored after 100 msec for the cases of NDS and MPSS controllers*

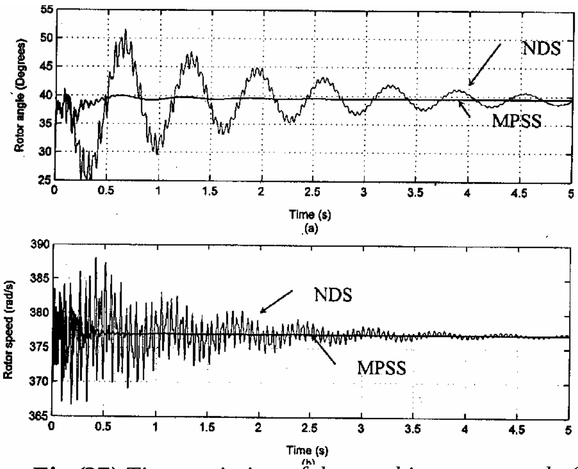


Fig.(27) *Time variation of the machine rotor angle (a) and angular speed (b) for a three-phase short circuit at 26% compensation with system regaining its original state after 80 msec for the cases of NDS and MPSS controllers*

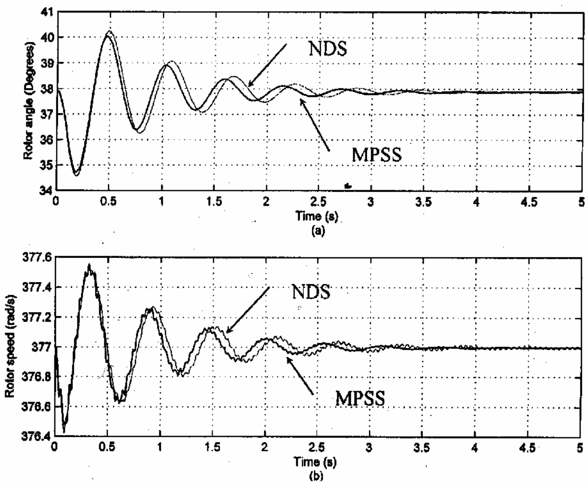


Fig.(26) *Time variation of the machine rotor angle (a) and angular speed (b) for a 10% reduction in T_{mech} at 58% compensation level and system restored after 100 msec for the cases of NDS and MPSS controllers*

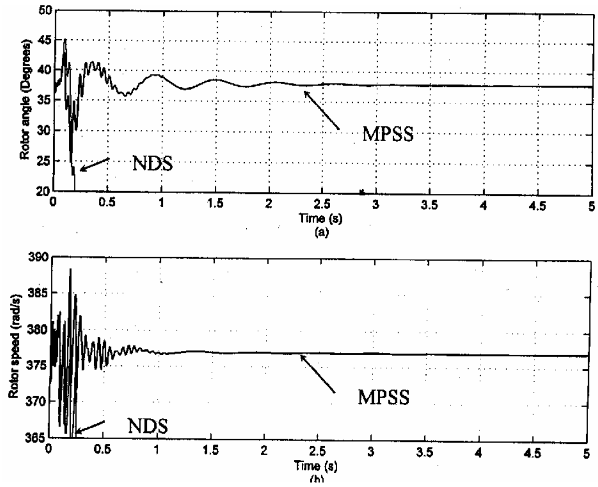


Fig.(28) *Time variation of the machine rotor angle (a) and angular speed (b) for a three-phase short circuit at 58% compensation with system regaining its original state after 80 msec for the cases of NDS and MPSS controllers*

From fig.(25), fig.(26), fig.(27) and fig.(28) where the system was subjected to both a small perturbation and a large scale disturbance only the MPSS controller did maintain system stability under both cases of compensation at x_{cs} = 26% and x_{cs} = 58%.

6. Conclusion:

- A set of MATLAB algorithms was developed to identify the particular type of the most effective supplementary signal to be introduced to the excitation system to damp out the specific power system mode of instability.
- Through these algorithms, it was made possible the selection and conditioning of the supplementary signals to control the self excited oscillation, the subsynchronous resonance and to expand the power angle stability limit.
- Through selecting the optimum controller parameter, the efficacy of the selected supplementary signal has contributed in enhancing the power angle stability limit.
- For the case of controlling the self excited oscillation it has been demonstrated that the optimal selecting the controlling parameter through adopting the GAs technique did stabilize the self excited oscillation resulting from severe short circuit condition.
- As for subsynchronous resonance phenomena the adequate choice of supplementary signal did stabilize the impertinent subsynchronous resonance oscillation using a modified version of PSS termed here MPSS. This has been achieved through selecting a supplementary signal based on the difference in the angular speed between the low pressure turbine/generator rotor inertias.
- In all the above work a particular signal conditioning strategy was implemented, together with the selection of supplementary signal and optimizing the controller parameters, to suppress the self excited oscillation and to expand the power angle stability limit.

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Appendix A:

1. **Generators Data**

$R_a=0.0029$ $R_{kq}=0.0073$ $X_{la}=0.18$ $X_{lkq}=0.05$ $R_{fd}=0.00081$

$X_{md}=1.38$ $X_{lfd}=0.089$ $X_{mq}=1.08$ $R_{kd}=0.0076$ $X_{lkd}=0.025$

$H=2.75$ $\omega_o=377\ rad.sec^{-1}$

2. **Transformer and Transmission System Data**

$R_{tr}=0.008$ $X_{tr}=0.2$ $R_{TL} = 0.02,$ $X_{TL}=0.2,$ $X_{cp}=10$

3. **Fast Acting Static Exciter Parameter**

$K_E=400$ $T_E=0.02$

4. **Conventional Power system Stabilizer Transfer Function**

$$G_{PSS}(s) = 17.5 \times \frac{1+0.162s}{1+0.025s}$$

5. **Voltage-Controlled Power System Stabilizer Parameters**

$Kv=0.956.$

6. **Fuzzy Logic Controller FLPSS**

$K_s=0.045$ $K_a=0.00165$

7. **Voltage-Controlled Fuzzy Logic Stabilizer (VCFLPSS)**

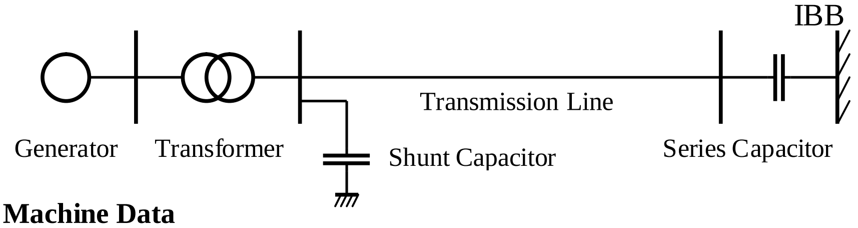
$Kv=0.756.$

Appendix B:

Data of The Single Machine Infinite Busbar Power System NDS and MPSS controllers

1- System Electrical Data

All data are given in per unit with base voltage of 500kV and base power of 10GW



Machine Data

x_d =1.5 x_{ad} =1.31 x_{fd} =1.42 x_{kd} =1.4

x_q =1.49 x_{aq} =1.29 x_{kq} =1.34

r_a =0.0015 r_{fd} =0.00063 r_{kd} =0.0153 r_{kq} =0.00207

Transformer Data

x_{tr} =0.135 r_{tr} =0.003

Transmission Line Data

x_{tl} =1.205 r_{tl} =0.025 x_{cp} =10 $0.1205 < x_{cp} < 1.205$

Exciter Data

k_e =400.0 T_e =0.01

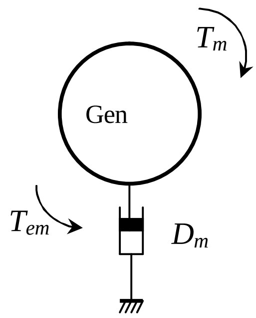
System Operating Conditions

V^∞ =1.0 P =0.8 Q =0.6 ω_s =377rad/s

2. System Mechanical Data

2.A. Single Mass Model

H =2.62 s D_m =1.0



2.B. Lumped Multi-Mass Shaft Model

All system data are identical to the system shown in appendix A except for mechanical data given below

D_{HP} =0.4 D_{IP} = 0. 3 D_{LP} = 0.3 D_{Gen} = 0.0

D_{HI} =0.4 D_{IL} = 0.4 D_{LG} = 0.4

K_{HI} = 47.0 K_{IL} =61.0 K_{LG} =74.0

H_{HP} =0.1883s H_{HIP} = 0.3351s H_{LP} =0.7562s H_{Gen} = 1.0s