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Comparison Between The Optimal Application of Variable Structure Controller (VSC) and Power System Stabilizer (PSS) Using Particle Swarm Optimization (PSO) in Improving System Stability

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ABSTRACT

This paper is studying the improvement of the power system stability by optimal design of variable structure controller (VSC) and power system stabilizer (PSS) based on Particle Swarm Optimization (PSO) . Switching vector and the switching feedback gains optimal values of variable structure controller and optimal parameters of power system stabilizer are finding by using Particle Swarm Optimization (PSO). The variable structure controller and power system stabilizer parameters are tuned optimally to minimize the objective function of the problem . By Using each of optimal (VSC) and optimal (PSS) with the developed model of a single machine infinite bus power system and after comparison the simulation results of two controllers, The results of using the optimal VSC design shows it provides a simple method for arriving to the settings of the VSC and optimal VSC improved the power system stability best than PSS .

مقارنة بين التطبيق المثالي للمسيطر المتغير البنية(VSC) وجهاز موازنة منظومة القدرة (PSS)باستخدام امثلية الجسيمات (PSO) في استقرارية منظومة القدرة

الكلمات المفتاحية
استقرارية منظومة القدرة، السيطرة المتغيرة البنية، خوارزمية امثلية سرب الجسيمات.

الخلاصة

الهدف الرئيسي من هذا البحث هو دراسة تحسين استقرارية منظومة القدرة باستخدام تصميم مثالي لكل من الميســـطر المتغير البنية (VSC) و جهاز موازنة منظومة القدرة (PSS) المســـتند على الخوارزمية الامثلية (PSO) .وتم ايجاد القيم المثالية لاعدادات المســـيطرين باســـتخدام الخوارزمية الامثلية(PSO) واعتمد مبدأ الوصول الى التصميم الامثل للمسيطرين بالمناغمة الامثلية لتصغير دالة الهدف .تم اســـتعمال المســـيطر المتغير البنية و جهاز موازنة منظومة القدرة المثاليين مع النموذج الخطي لمنظومة قدرة ذات ماكنة واحدة وموصـــل عمومي لامتناهي.وبعد مقارنة النتائج الناتجة من اســـتعمال كل من(VSC) و (PSS) المثاليين مع منظومة القدرة. بينت النتائج ان المســـيطر المثالي المتغير البنية يقدم طريقة نظامية بســـيطة للوصـــول الى اعداداته وكذلك اكثر فعالية في تحســـين استقرارية منظومة القدرة من جهاز موازنة منظومة القد رة.

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Introduction

Power systems have evolved and expanded significantly so it need new ways to maintain the stability of its work. The stability of the power system analysis methods have evolved significantly in recent years, becoming a methods of stability control systems and the ability of the hottest topics in the operation of power systems. Therefore, the using of advanced control for improving the stability of power systems is necessary. There is a significant problem in the stability of power systems which is the excitation control of the synchronous machines and its very effective and important techniques to improve the stability of power systems .

Power system stabilizer (PSS) is used to improve damping in the vibrations power that occur due to disturbances and many types of faults in power systems. PSS's were considered more efficient appliances in damping oscillations and increase the stability of power systems [1]. Therefore, the PSS installed with generator that gives the background of nutrition that causes irregular and the stability of the signal in the excitation system [2]. The stability of power systems options are among the key issues in the main documented and energy efficiency systems process. The basic ingredients for a PSS device was considered in tuning of system ability in different studies [3]. Effects of low-frequency oscillation modes is usually reducing by PSS [4]. Some power system stations prefer to use conventional structure of PSSs , due to reliability and the tuning easiness [5]. System of Linear optimal excitation was designed on theory of LQR to improve stability of power system. This system proved to be able to enhance the stability of power system under disturbances in conditions compared with the traditional PSS[6]. Intelligent control that use the neural networks in PSS, was also applied to power system stabilization instead of the conventional PSS [7.8]. Fuzzy logic approaches were used in design PSS [9]. Different methods that include optimal control [10] , and variable structure control [11] were proposed for the design of PSS. The conventional way of design include the ability to convert a model system to a linear model around the appropriate point and then the process is linear control theory used in the design of conventional PSS but the power systems are usually nonlinear . Therefore adaptive control methods was suggested [12]. Variable Structure systems concepts is used in many applications including power systems [13], aerospace [14]. Design of PSS based on Variable Structure control is founded in [15] .

In this paper, variable structure controller (VSC) and Power System Stabilizers (PSS) designed by iterative heuristic namely , Particle Swarm Optimization (PSO) is applying to the famous model of linearized single machine system. The simulations are carried out using MATLAB and SIMULINK packages.

Modeling of Power System

In this paper, system of one machine and infinite bus (SMIB) is considered as shown in figure(1) below[16].

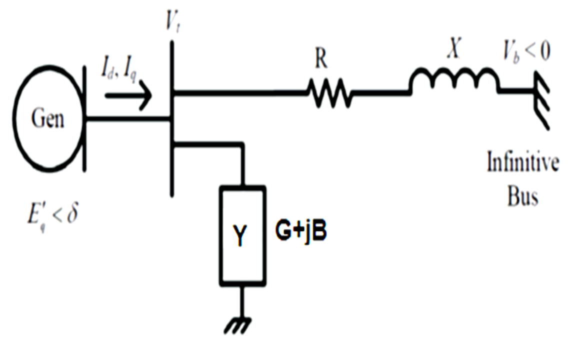

Figure 1: single machine infinite bus system

1. Model of Generator

The generator is represented by equations of the swing and internal voltage as below[17]:

$$\dot{\delta} = \omega_s(\omega - 1) \tag{1}$$

$$\dot{\omega} = (p_m - D(\omega - 1) - Pe) / M \tag{2}$$

$$\dot{E}q = (Efd\_id(xd\_x'd)\_E'q) / T'do \tag{3}$$

The output power of the generator is

$$Pe = vd\,id + vqiq \tag{4}$$

Where, p_m is input power ,p_e is output power; D is damping coefficient; M is inertia constant , ω is rotor speed , δ is rotor angle, E_{fd} is the field voltage; V_d is d- axis armature voltage , ν_q is q-axis armature voltage; T'_{do} is time constant of the open circuit field, i_d is armature current of d-axis, i_q is armature current of q-axis , x_d, is d-axis reactance, x'_d is the d-axis transient reactance of the generator.

2. Model of the Excitation System And PSS

The excitation system as shown in figure2. It can be represented by the following equations:

$$\dot{E}fd = \frac{kA(Vref - v + upss) - Efd}{TA} \tag{5}$$

$$v = (v^2d + v^2q)^{½} \tag{6}$$

Where, K_A is gain of the excitation system , V_{ref} is the reference voltage, $upss$ is signal of PSS, T_A is time constant of the excitation system

PSS is added to excitation system for improving damping vibrations in the generator rotor. The PSS will be very widely used lead-lag controller whose Transfer function is:

$$U = k\frac{ST_W}{1+ST_W}\left(\frac{1+ST_1}{1+ST_2}\right)\left(\frac{1+ST_3}{1+ST_4}\right)\Delta\omega \quad (7)$$

The PSS structure is shown in Fig. 2. The five parameters of PSS are gain K constants of time T1 toT4 which need to be optimal values to ensure optimal performance of the system under a different system faults and unrest.[18,19]

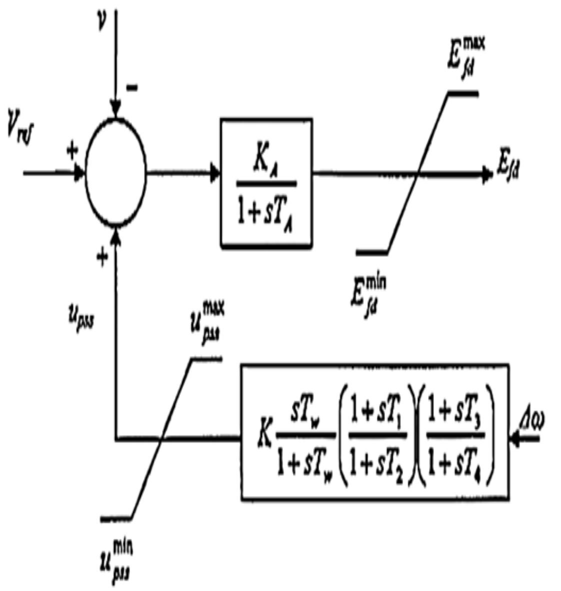

Figure 2:Block diagram of PSS and excitation System

3. Variable Structure Controller (VSC) Model

A block diagram of the VSC is shown in Fig. 3. The linear control system is described below:

$$\dot{Y} = AY + BU \quad (8)$$

Where

Y i- vector of dimensional state
U j- vector of dimensional control
A $i \times i$ matrix of system , B $i \times j$ matrix of input

The laws of VSC control (U) to the system of Equations (8) and (13) are given as below:

$$U = -\psi^T y = -\sum_{m=1}^{i}\psi_{nm} y_m \qquad m = 1,\ldots\ldots\ldots, j \quad (9)$$

then the gains of feedback are given as

$$\psi_{nm} = \begin{cases} \alpha_{nm}, \ if \quad y_m\sigma_n > 0; \ n=1,\ldots\ldots\ldots,j \\ -\alpha_{nm}, if \quad y_m\sigma_n < 0; \ m=1,\ldots\ldots\ldots\ldots,i \end{cases} \quad (10)$$

and

$$\sigma_n(Y) = S_n^T Y = 0, \quad n=1,\ldots\ldots\ldots, j \ [20] \ (11)$$

Where S^T is vector of switching surface and α is gain of the switching feedback, S_n are vectors of switching that conventionally determined through pole placement technology and it can be found in **[21]** .

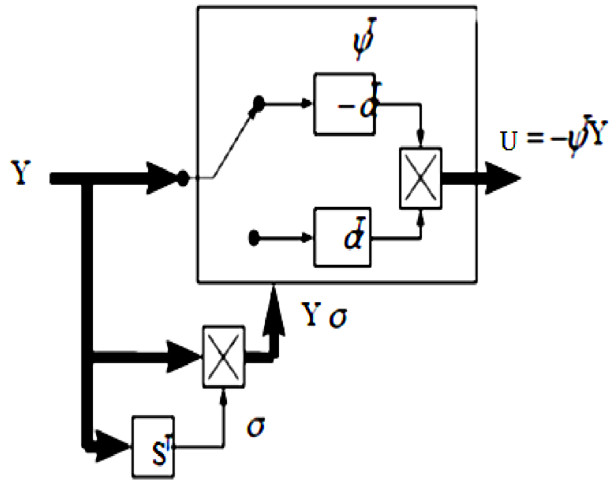

Figure 3:Block diagram of the VSC

4. Linearized Model Of Power System

The power system can be modeled as:

$$\dot{Y} = AY + BU \quad (12)$$

where A is the system matrix, Y is the state vector, B is the input matrix, and U the control vector and in state-space representation as in equation (13) below and the block diagram of power system in Fig. 4 ,

$$\begin{pmatrix} \Delta\dot{\delta} \\ \Delta\dot{\omega} \\ \Delta\dot{E}'_q \\ \Delta\dot{E}_{fd} \end{pmatrix} = \begin{pmatrix} 0 & \omega_b & 0 & 0 \\ \frac{-K1}{M} & \frac{-D}{M} & \frac{-K2}{M} & 0 \\ \frac{-K4}{T'_{do}} & 0 & \frac{-K3}{T'_{do}} & \frac{1}{T'_{do}} \\ \frac{-K_AK5}{T_A} & 0 & \frac{-K_AK6}{T_A} & \frac{-1}{T_A} \end{pmatrix} \begin{pmatrix} \delta \\ \Delta\omega \\ \Delta E'q \\ E_{fd} \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ 0 \\ K_A \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 0 \\ \Delta U \end{pmatrix} \quad (13)$$

T_A

Where U is the signal of conventional PSS (U_{PSS}) or VSC (U_{VSC}) and values of (*K1* to *K6*) acordinng to[16] is found as below :
$K1$ =0.6139 , $K2$ =0.8969, $K3$ =0.7118 , $K4$ = 0.6153, $K5$ = −0.1011 , $K6$ =0.7364.

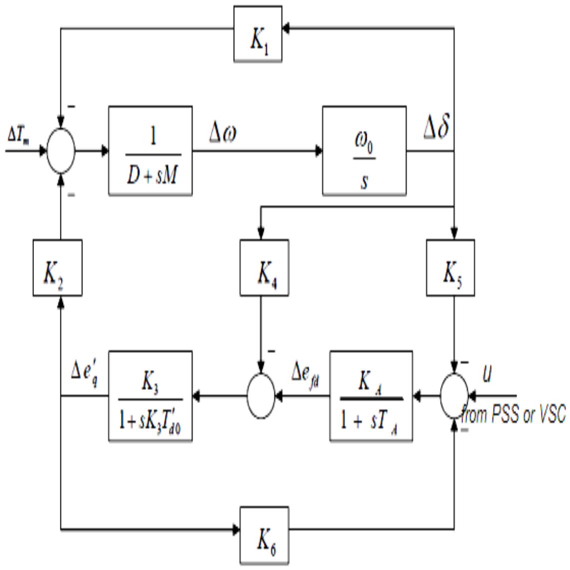

Figure 4:The linearized model of power system

Implementation

1. Objective Function

To select the best optimal settings of the VSC amd PSS that improving transient performance of power system using PSO Algorithm, the following objective function is proposed to minimised:

$$J=\int_0^\infty |\Delta\omega| .t.dt \qquad (14)$$

Its confirms on damping oscillations of the angular speed deviation using time multiplied by the absolute of the speed deviation

2.Particle Swarm Optimization (PSO)

The PSO is start with a set of random particles to conduct the search for the optimum point in each update generations, it updates the best values of particles and the swarm in each iteration . The *n*th particle is denoted by Xn = (xn1 ,xn2, . . . ,xnd). The fitness value of particle *n* (*fbest*) is also stockpiling as *fn = (fn1, fn2, . . . ,fnd)*. The global PSO has to follow better comprehensive value (*gbest*), and its position. The PSO At every step, change the velocity of every particle toward its *fbest* and *gbest* depending on to Eq. (14). The *nth* particle velocity is denoted by Vn= (vn1, vn2,..., vnd). Then the location of the *n*th particle updated depending on Eq. (15) and (16) **[22].**

$$vnd(t+1) = w * vnd\ (t) + b1 * rand(fnd(t) - xnd(t)) + b2 * rand(fgd(t) - xnd(t)) \quad (15)$$

$$xnd(t+1) = xnd\ + vnd(t+1) \qquad (16)$$

Where

$fnd\ = fbest$ And $fgd\ = gbest$

W is inertia weights , and

$$W = wintial - \left(\frac{\text{wintial} - \text{wfinal}}{\text{no. of max iteration}}\right) \text{no. of current iteration}$$

And figure 5 appear the PSO algorithm flowchart

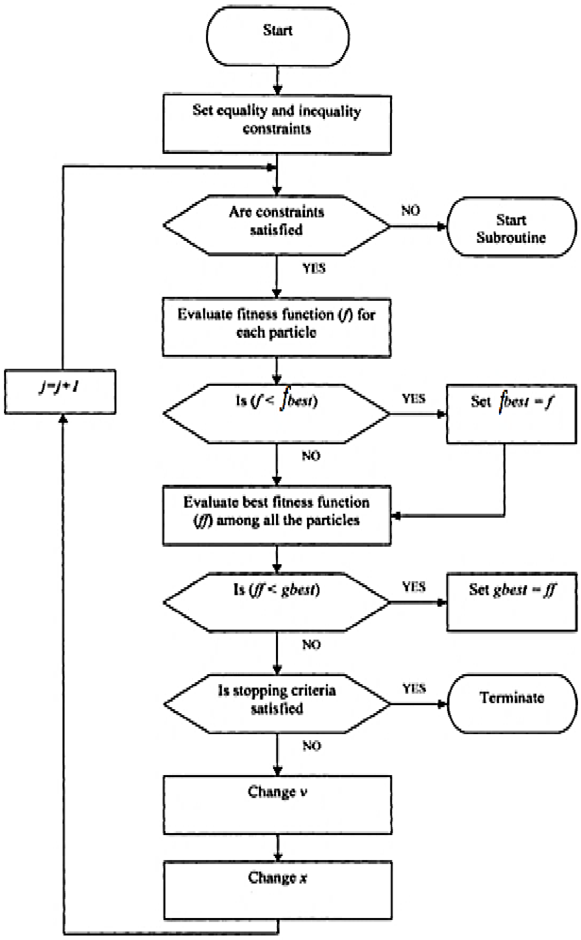

Figure 5: Flowchart of PSO algorithm

3. Optimal Design of PSS and VSC

The optimal design of PSS and VSC as shown in flowcharts in figure 6 and figure 7 respectively are used to get the best performance of the power system, The parameters of PSS and VSC are fine tuned by (PSO) [22], individually at condition of normal loading . PSO algorithm is used to find the optimal settings of the two stabilizers.

The optimum controllers parameters settings were searched to minimize the objective function above to raise the damping and this lead to improve power system stability

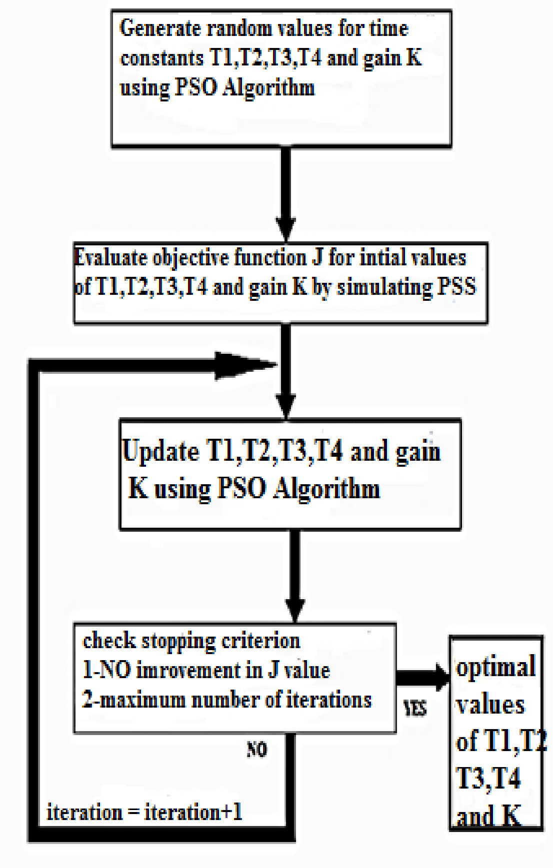

Figure 6: Flowchart of optimal PSS

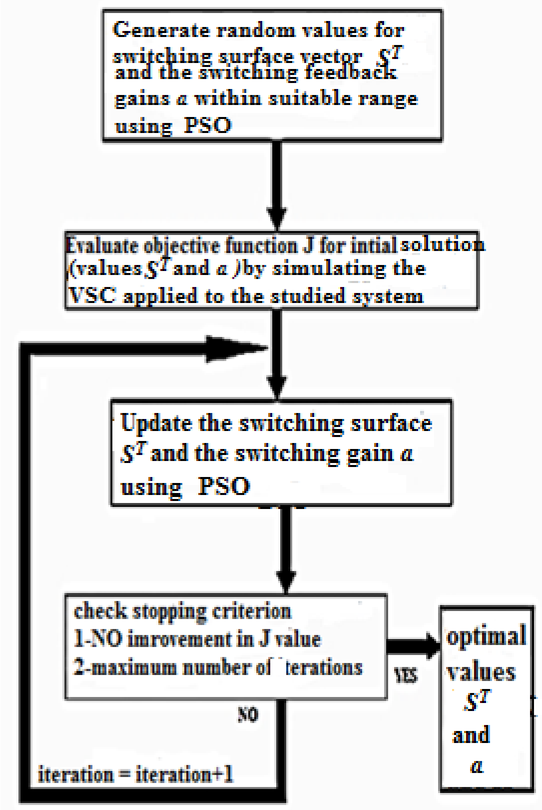

Figure.7: Flowchart of optimal VSC

4. he selected parameter of PSO ,PSS and VSC

1-The Selected Parameters of PSO as shown in table (1)

Table (1): Parameters of PSO

PSO parameters	Value
Swarm size	20
No. of Iterations	40
b1	2.0
b2	2.0
Wf	0.4
Wm	0.9

2-The Selected Parameters of PSS as shown in table (2)

Tabl (2): Parameters of PSS

Parameters	T_1	T_2	T_3	T_4	K
Min. value	0. 1	0. 1	0. 1	0. 1	1
max value	5	5	5	5	100

3- The Selected parameters of VSC [23]

The switching vector was designed by pole placement and was given to be

$C = [-13052 \quad -13 \quad 175 \quad 1\,]^T$

The values of the feedback gains obtained using $H\infty$ are

$\alpha = [\,-53.7168 \quad 0.9945 \quad 1.7125 \quad 0.0091]$

The Tuning and Simulation Esults

1.The Final Optimal Settings of PSS and VSC

The final optimum parameters for the two controllers are given below**:**

1-Optimal parameters that are found to PSS in table (3) below **:**

Table (3):Optimal Parameters of PSS

Parameter value	optimal
K	66.9983
T_1	0.7792
T_2	0.9874
T_3	0.5127
T_4	0.3035

2- Optimal parameters that are found to VSC

The optimal switching vector is found to be

$$C = [-33000 \quad -102.5431 \quad 112.4213 \quad 1]^T$$

and the feedback gains are

$$\alpha = [3.1923 \quad 2.3458 \quad 0.34119 \quad 0.13128]$$

,

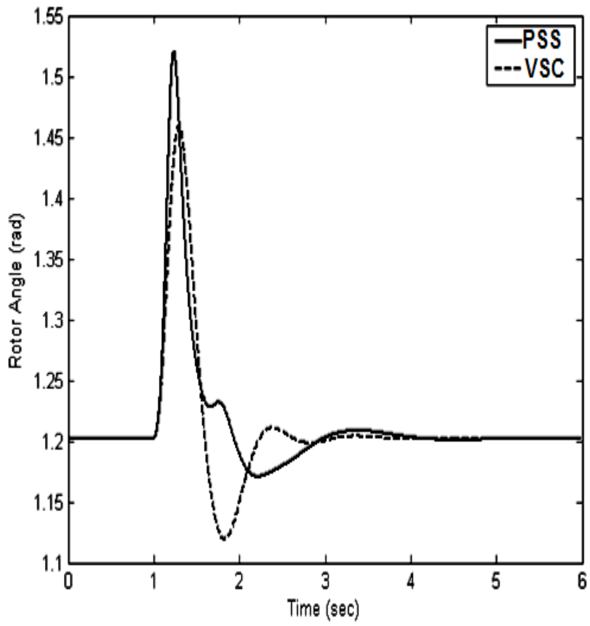

Fig 8: Response of generator rotor angle at nominal loading

4.2 Simulation of Non Linear Time Domain

The 6-cycle 3-φ fault on the infinite bus of the power system shown in Fig. 1 is considered for studies of nonlinear simulation with two operating conditions are shown in **Table 4**, for the purpose of study the effect of the two optimal controllers above when using individually with the power system. **Figures 8-11** shows the response of the rotor angle and the rotor speed deviation with above mentioned fault at conditions of nominal and light loading

Table(4):loading conditions

loading	Pe(pu)	Qe(pu)
1.nominal loading	1.0	0.015
2.light loading	0.3	0.015

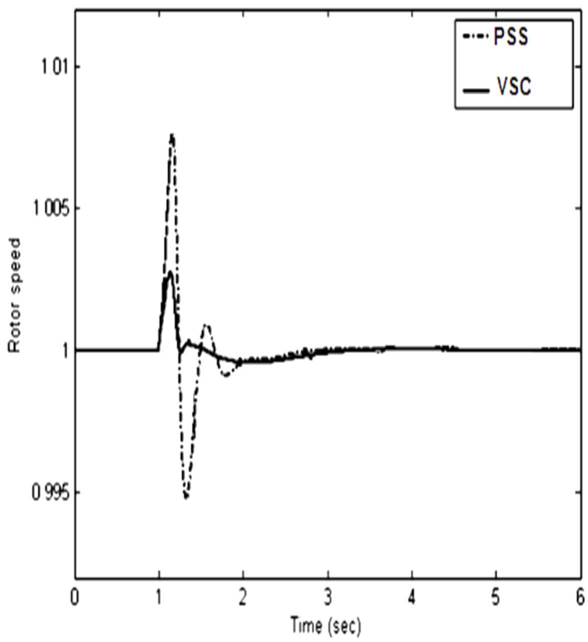

Figure 9: Response of generator rotor speed at nominal loading

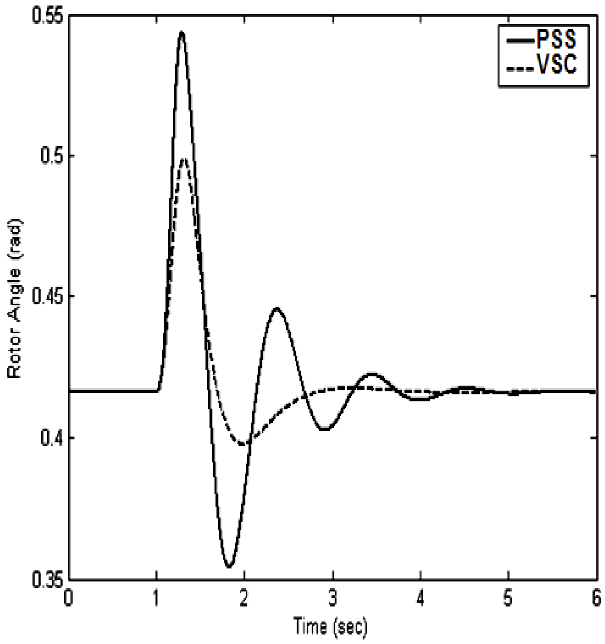

Figure10:Response of generator rotor angle at light loading

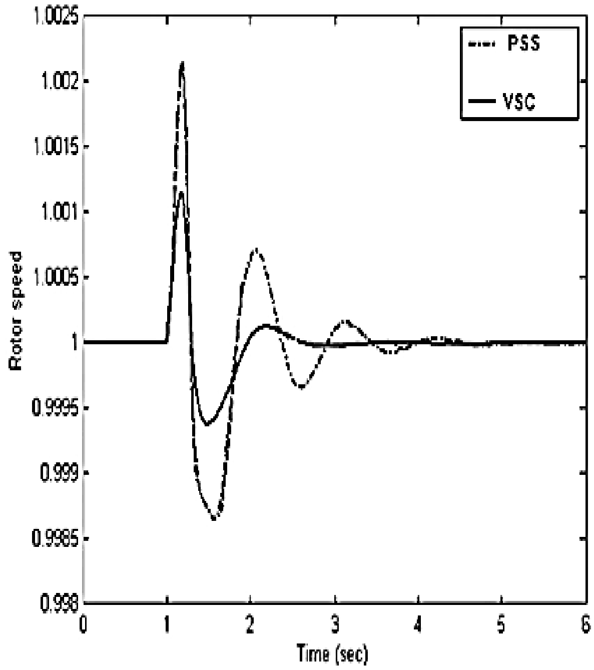

Figure 11: Response of generator rotor speed at light loading

3. Discussion of simulation results

From the above simultion results(**figures 8-11)** the following can be concluded:

1-The Optimal design of the SVC and PSS enabled the power system to maintain the stability after being subjected to six cycles fault on the infinite bus

2- The performance of optimal VSC better than optimal PSS in enhancing power system stability and when the operating point is changed it have robust behavior

Conclusions :-

One of the concerns of electric power engineers in recent years, is the design of suitable controller for improving the power system stability and dynamic performance of the electric power system. This paper addressed the improvement comparison of power system stability by using optimal design of variable structure controller (VSC) and power system stabilizer (PSS) which applied to power system of single machine and infinite bus. The design methods are utilize PSO algorithm to find the optimum parameters of the VSC and PSS. We can concluded from this study the following, A systematic ways and simple for optimal designing of VSC and PSS utilizing iterative heuristic optimization technique applied to power system dynamic problem, The two design methods of VSC and PSS formulated as an optimization problem and used PSO in the procedure of design, The two methods improved the dynamic behavior of the system and the results of simulation show that performance of the optimal VSC is better than the optimal PSS in improving power system stability

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Appendix

The Parameters of the studied system in figure. (1) as below[16]:

$M = 4.75$	$T'_{do} = 6$	$D = 0$
$w_b = 377$ rad /s;	$X_d = 1.7$	$X_q = 1.65$
$X'_d = 0.25$	KA = 100	TA = 0.05
$K_{pss}=1$;	$T_w=0.06$;	$\lvert U_{pss}\rvert \leq 0.3$ pu**;**
Xt=0.09	G=0.25	B=0.26
X = 0.5	R= 0	$V_t = 1.05$
$V_{b=}1.0$		