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COMBINED POSICAST AND PHASE ADVANCE CONTROLLER FOR A SUPERCONDUCTING GENERATING UNIT

Dr. Heba A. Khattab
Electrical Engineering Department, Faculty of Engineering
Shebin El-Kom, Menoufiya University, Egypt
h74.khattab@yahoo.com

Abstract

Recently, power system engineers have faced numerous difficulties in adding new power stations and transmission lines to face the continuous need of electrical power. In the future, superconducting generators (SCGs) are expected to be the most suitable solution for the previous problem. This paper presents the design and implementation of Posicast Input Command Shaping(PICS) which is combined with phase advance controller in the governor control loop for a SCG against infinite bus system. This is to improve the system performance, enhance its stability and reduce the exhibiting oscillations. To achieve a high degree of accuracy, a detailed non-linear system model is considered including SCG, governor, turbine, controllers, transmission lines and non-linear constrains. The performance of the SCG equipped with the phase advance controller has been studied and the results were obtained in a comparative form with others obtained when PICS is used under different faults (3-phase short circuit for 120ms and 10% step increase in the mechanical input) and over a wide range of operating conditions.

حاليا يواجه مهندسو نظم القوى الكهربية مشاكل عديدة لاضافة محطات توليد وخطوط نقل جديدة لمواجهة الطلب المتزايد على الطاقة الكهربية. لذلك فى المستقبل يتوقع أن تكون المولدات فائقة التوصيل هى الحل المناسب لتلك المشكلة نظرا لمميزاتها العديدة. هذا البحث يقدم تصميم وتطبيق حاكم لتقليل الاهتزازات المتوقعة. والحاكم المقترح(POSICAST) هو دائرة لاعادة تشكيل اشارة الدخل ويضاف مع دائرة التحكم الموجودة(PHASE ADVANCE) فى دائرة منظم البخار حيث أنه يعتبر المسار الوحيد للتحكم فى الألة فائقة التوصيل. وللحصول على دقة عالية فى النتائج تم استخدام نموذج غير خطى تفصيلى لكل أجزاء النظام(المولد و الحاكم و خطوط النقل والتوربينة). تم دراسة أداء النظام فى وجود الحاكم المقترح وبدونه تحت ظروف التشغيل المختلفة وعندما يتعرض النظام لبعض الاضطرابات مثل قصر ثلاثى الأوجه على أحد خطوط النقل أو زيادة فى الدخل الميكانيكى. والنتائج تشير الى أن الحاكم المقترح يحسن من أداء النظام فى ظروف التشغيل المختلفة من حيث زيادة الخمد وسرعة عودة متغيرات النظام الى قيمها الأولية.

1. Introduction

Over the years, there has been a continuous need for increasing generation of electrical power to cater the ever growing of power demand. The continuous progress in up-rating the generators with different machine parameters reduces the stability margin and adversely affects the system performance. SCGs are possible alternative to overcome the foregoing problems. This is due to the several advantages of SCGs over conventional synchronous machines such as higher efficiency, possibility of generating at transmission line voltages, smaller size and weight in addition to its contribution to stability improvement of power systems[1].

At the same time, these machines are adversely characterized by their low inertia and low inherent damping. So, special attention and consideration must be taken when dealing with SCGs. Problems associated with the stability and control of SCGs have been under extensive investigations since the late of 70's. The main problem is that SCGs have almost zero resistance of field winding which leads very long field time constant[2]. So, excitation control, which is very effective in conventional generators, becomes ineffective in improving the dynamic performance of SCGs. So, the governor control loop is considered as the only available loop for improving the machine performance. However, the governor control loop in nature provides relatively lower positive damping. Therefore, additional signals need to be used to provide extra damping for the SCGs. Considerable attention has been directed to the application of controller to improve the performance of SCGs[3-5].

The most common power system controllers are conventional, modern and artificial intelligent control techniques. Various conventional controllers have been employed to control the SCG such as phase advance, flexible controller and proportional- integral and derivative(PID)[6-9]. The design of these controllers was based on linear control theory, to obtain models which describe the system dynamics about an equilibrium operating point. SCGs are highly nonlinear systems and non linear control is not will established. Therefore, controllers with fixed parameters which insure good performance under a certain operating condition may be not suitable for other conditions[6-9]. Fuzzy logic controller(FLC) and artificial neural network(ANN) have been applied for SCG to improve the performance of the low inherent damping and maintain better performance under a wide range of operating conditions [10-14].

The previous mentioned control systems were designed based on specific techniques with the aid of turbo generator linear zed models. The designed controllers are then implemented without any quantitative measure to precisely control the turbo generator output. Alternatively, this paper introduces a new technique to improve the turbo generator performance via a control parameters obtained by reshaping the input signal to obtain the required damping characteristics of the turbo generator output. This technique represents a new trend to power system controller design based on tailoring the required control signals for achieving the required damping characteristics. The Direct search method technique represent an important step in reshaping a system performance to fit an experimental data and may be used to tailor the required input control signal. This method, however, requires complex computation and convergence may not be guaranteed[15,16]. Posicast Input Command Shaping technique was successful in reshaping the control signal to damp mechanical oscillations. Posicast control originally introduced in the late 1950s and further studied in the early 1960s. The main idea of this method is to split control input into direct and delayed signals. When such control signal is applied to the process, the direct and delayed signals counteracts and attenuate oscillations at the process output and consequently the desired damping characteristics can be obtained. Also, this technique can be implemented in both time-domain and frequency domain analysis [17-19].

The objectives of this paper is to use the PICS technique to reshape the transient response of the superconducting generating unit for obtaining the required damping characteristics. The technique proposed in this paper is based on using the phase advance network to design control for the governor loop of the SCG and then using PICS to reshape the input control signal. The performance of the studied power system with phase advance has been studied and the results are obtained in comparative form with others obtained when PICS is added.

2. System Representation

The studied power system is consisted of SCG connected to an infinite bus via a transformer and a double-circuit transmission line, as shown in Fig. (1). The SCG is driven by a fast response turbine with fast valving routine. The turbine governor model represents a 3-stage reheat turbine with fast acting electro-hydraulic governor fitted to both the main and interceptor valves. The non-linear differential equations for the studied system are as follows[7,9,11]:

$$\Psi_{\mathrm{f}} = \omega_0 \left(E_{\mathrm{fd}} \frac{R_{\mathrm{f}}}{\mathrm{X_{fd}}} - \mathrm{i_f}\,\mathrm{R_f} \right) \tag{1}$$

$$p\Psi_d = \omega_o \left(V_d + \mathrm{i_d}\,\mathrm{R_a} + \Psi_{\mathrm{q}} \right) + \omega\,\Psi_{\mathrm{q}} \tag{2}$$

$$p\Psi_q = \omega_o \left(V_q + \mathrm{i_q}\,\mathrm{R_a} - \Psi_{\mathrm{d}} \right) - \omega\,\Psi_{\mathrm{d}} \tag{3}$$

$$p\Psi_{D1} = -\omega_o\,\mathrm{i_{D1}}\,\mathrm{R_{D1}} \tag{4}$$

$$p\Psi_{Q1} = -\omega_o\,\mathrm{i_{Q1}}\,\mathrm{R_{Q1}} \tag{5}$$

$$p\Psi_{D2} = -\omega_o\,\mathrm{i_{D2}}\,\mathrm{R_{D2}} \tag{6}$$

$$p\Psi_{Q2} = -\omega_o\,\mathrm{i_{Q2}}\,\mathrm{R_{Q2}} \tag{7}$$

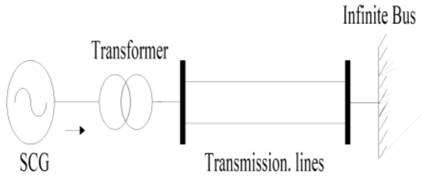

Fig. 1. Schematic diagram of the studied system

Mechanical Equations:

$$p\delta = \omega \tag{8}$$

$$p\omega = \frac{\omega_{\mathrm{o}}}{2H} (\mathrm{T_m} - \mathrm{T_e}) \tag{9}$$

$$\mathrm{T_e} = \Psi_{\mathrm{d}}\,\mathrm{i_q} - \Psi_{\mathrm{q}}\,\mathrm{i_d} \tag{10}$$

Transformer and transmission line

The transmission system can be approximated by a series lumped resistance and reactance. The d-q equations relating the machine terminals to the grid are:

$$V_d = V_b \sin\delta + r_e\, \mathrm{i_d} - \mathrm{X_e}\, \mathrm{i_q} \tag{11}$$

$$V_q = V_b \cos\delta + r_e\, \mathrm{i_q} - \mathrm{X_e}\, \mathrm{i_d} \tag{12}$$

Where $X_e=X_T+X_L$ and $R_e= R_T +R_L$

Turbine and governor system:

Various models that represent the turbine dynamics are given in the IEEE technical committee report[20]. The turbine system that drives SCGs should have fast response with fast valving routine, this is due to maintain and improve the stability of these low inertia units. The turbine-governor model represents a three-stage steam turbine with reheat. The state equations represent this model are :

$$PY_{HP} = \left(G_M\, P_\mathrm{O} - \mathrm{Y_{HP}} \right) / T_{HP} \tag{13}$$

$$PY_{RH} = \left(\mathrm{Y_{HP}} - \mathrm{Y_{RH}} \right) / T_{RH} \tag{14}$$

$$PY_{LP} = \left(G_I\, Y_\mathrm{RH} - \mathrm{Y_{LP}} \right) / T_{LP} \tag{15}$$

$$PY_{LP} = \left(\mathrm{Y_{IP}} - \mathrm{Y_{LP}} \right) / T_{LP} \tag{16}$$

$$T_\mathrm{m} = F_\mathrm{HP} Y_\mathrm{HP} + F_\mathrm{IP} Y_\mathrm{IP} + F_\mathrm{LP} Y_\mathrm{LP} \tag{17}$$

$$G_M = \left(\mathrm{U_{GM}} - \mathrm{G_M} \right) / T_{GM} \tag{18}$$

$$PG_I = \left(\mathrm{U_{GI}} - \mathrm{G_I} \right) / T_{GI} \tag{19}$$

Where the position and rate limits are,
$0 < G_M, G_I < 1.0$ and

$$-6.7 < PG_M, PG_I < 6.7 \;\; p.u/sec$$

The parameters of the studied system are given in the Appendix.

3. Phase advance

The phase advance circuit must be designed to ensure suitable behavior of the machine in both steady state and large disturbance. The phase advance controller is a lead-lag compensator as shown in Fig.(2)(without the dashed block). Many researchers have designed a phase advance in the governor control loop [1,5,7]. The designed phase advance controller has the following transfer function:

$$G_{ph.adv} = G\,\frac{1+sT1}{1+sT2}$$

where: T1 and T2 are the time constants of the controller and G is the gain. T1= 0.5 and T2= 0.01 sec. as the recommended time constant ratio for SCG is 50.

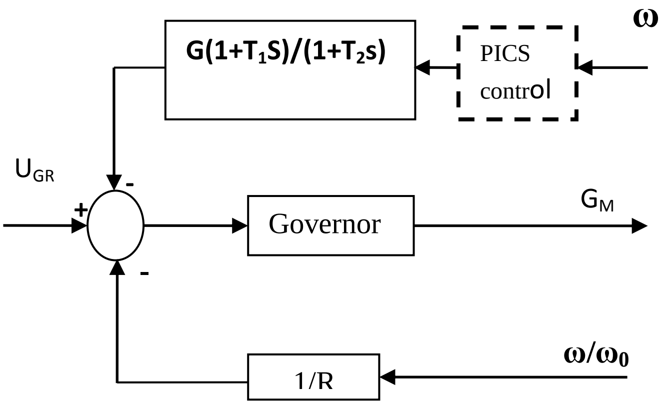

Fig.(2) The governor control loop with phase advance and PICS

4. Philosophy of PICS control:

This section presents the design concept and implementation of PICS control.

A) Design concept

Posicast control is a widely used method in reduction of damped oscillatory system especially in mechanical fields. The main concept of PICS method is to split the input signal U(t) into two parts as shown in Fig.(3-a). The first part is a scaled step that causes the first peak of the oscillatory response to precisely meet the desired final value. The second part of the reshaped input is scaled and time-delayed to precisely cancel the remaining oscillatory response, thus causing the system output to stay at the desired value[21]. The result of using the posicast is shown in Fig.(3-b). From Fig.(3-c), it is easy to derive the following transfer function between the input signal U(t) and the output signal $U_1(t)$

$$G_{PICS} = K_1 + (1 - K_1)e^{-STdp}$$

Where: K_1 represents the gain and T_{dp} is the time delay which are chosen so as to decrease the power system oscillations.

The overshoot in the response can be described by two parameters. First, the time to the first peak is one half the period of under damped response (T_d). Second, the peak value is described by 1+δ where δ is the normalized overshoot which ranges from zero to one. These PICS parameters can be calculated from the amplitude and time difference between the peaks as follows:

$$K_1 = \frac{1}{1+\delta} \quad , \quad T_{dp=\frac{Td}{2}}$$

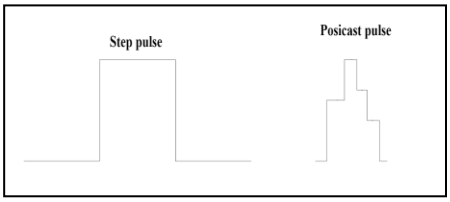

Fig.(3-a) Shaping step pulse to Posicast pulse

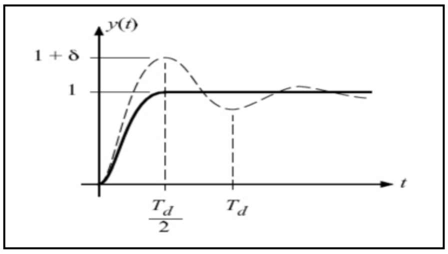

Fig.(3-b) A System output with Posicast (Dashed without Posicast)

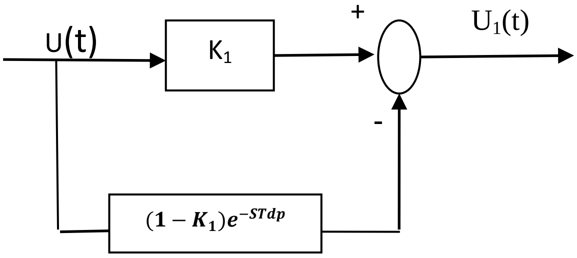

Fig.(3-c) PICS block diagram

B) Implementation of PICS control

The block digram of PICS for SCG equipped with phase advance is shown in Fig.(2)(with the dashed block) as proposed in this work. A simulation program using a non-linear system model has been carried out to investigate the effectiveness of the designed Posicast Input Command Shaping(PICS) for SCG which is equipped with phase advance controller in the governor control loop of SCG under different disturbances (3-phase short circuit at the transformer high voltage side for 120 ms and 10% step increase in mechanical input) under different operating conditions.

5. Simulation results

A Matlab Simulink program using a fairly detailed non-linear system model has been carried out to investigate the effectiveness of the proposed controller(combined PICS and phase advance)under 120ms three phase short circuit at the transformer high voltage side and 10% step increase in mechanical input at different operating conditions. Figs(4) and (5) show the simulation results in a comparative form when phase advance is applied with or without PICS for 0.8 lag and lead P.f. respectively. The simulation results illustrate that, PICS control produces significant improvement in the system behavior over phase advance network where the system returns to its initial operating conditions smoothly and quickly. A high damping to system oscillations and a fast recovery of system variables. Also, the designed PICS increases the stability reserve indicated by the reduction in the rotor angle first swing and a fast recovery of speed deviation and valve position. The simulation results verified the effectiveness of the proposed technique as it can increase damping of power system oscillations and provide better dynamic and transient performance. Also, highly improved system performance was obtained in all cases(three phase short circuit at the transformer high voltage side and 10% step increase in mechanical input over a wide range of operating conditions) with PICS in spite of its simple control structure. So in conclusion, it is clear that substantial improvements in both system damping and stability can be achieved by incorporating PICS in the governor control loop of the SCG.

6. Conclusions

This paper presents the design and implementation of combined PICS and phase advance controller in the governor control loop of the SCG. The performance of SCG with the designed controller is investigated using non linear time domain simulations. The simulation results verified that the proposed controller improves the power system performance in terms of minimizing the system overshoot, rise time , the settling time and system variables fast return to their nominal values . Also, that controller provides positive damping to the system oscillation and improves the steady state performance under different disturbances and over a wide range of operating conditions. So, the proposed technique is capable of guaranteeing the stability and performance of the studied power system. Finally, proposed technique may apply as an efficient method for practical systems.

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Appendix :

The following data in p.u. of a superconducting turbo-generator are chosen for digital simulation :

SCG parameters :

2000 MVA, 1700 MW, 3000 r.p.m

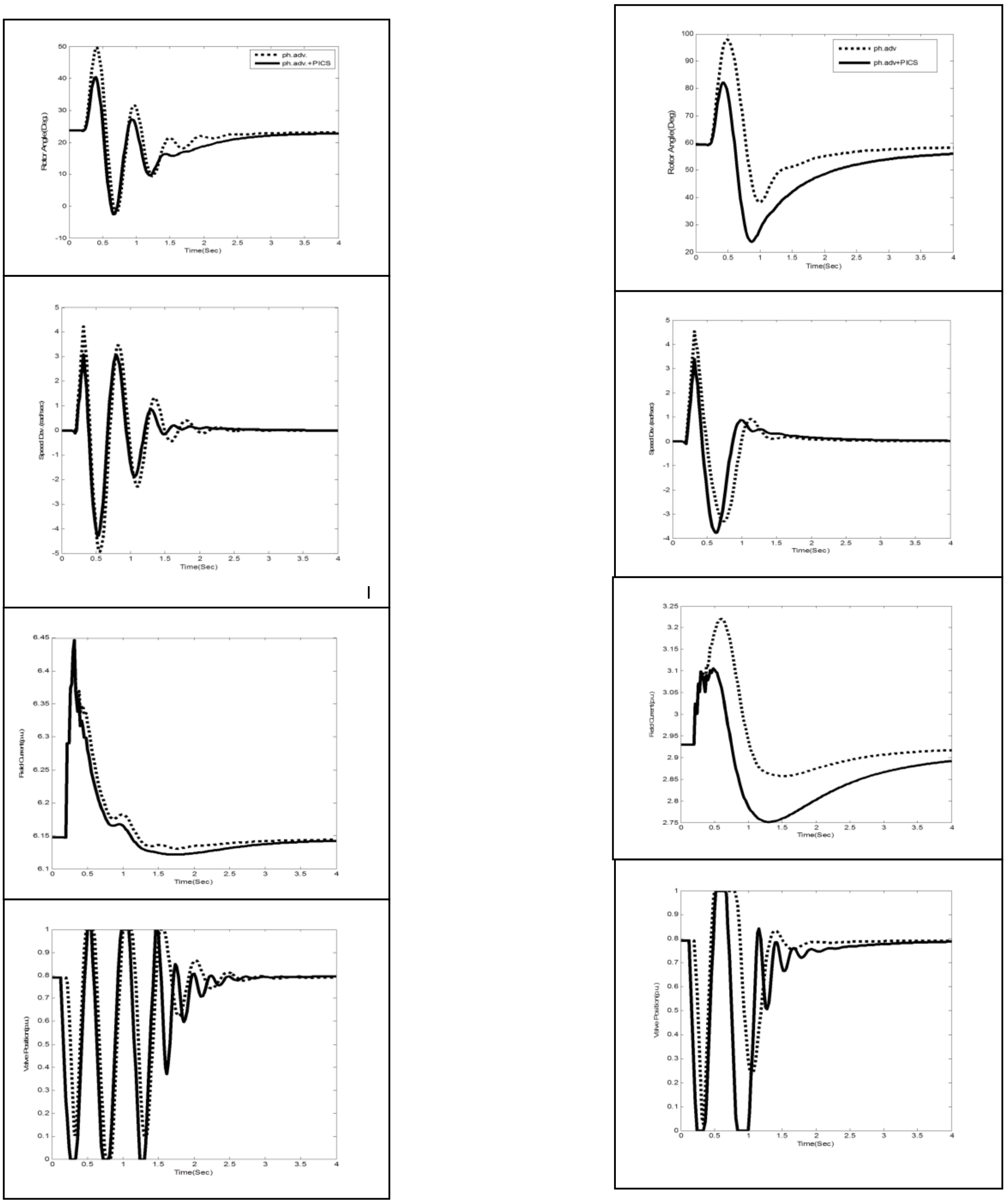
$X_d = X_q = 0.0453$ p.u., $X_f = 0.541$ p.u. , $X_{KD1} = X_{KQ1} = 0.2567$p.u., $X_{fKD2} = 0.3398$p.u.

$X_{af} = X_{fKD1} = X_{aD1} = X_{aD2} = X_{KD1KD2} = 0.237$p.u., $X_{aQ1} = X_{aQ2} = X_{KQ1KQ2} = 0.237$p.u.

$R_{KD1} = R_{KQ1} = 0.01008$p.u.,$R_a = 0.003$ p.u., $R_{KD2} = R_{KQ2} = 0.00134$p.u. ,H=3.0 KWS/KVA

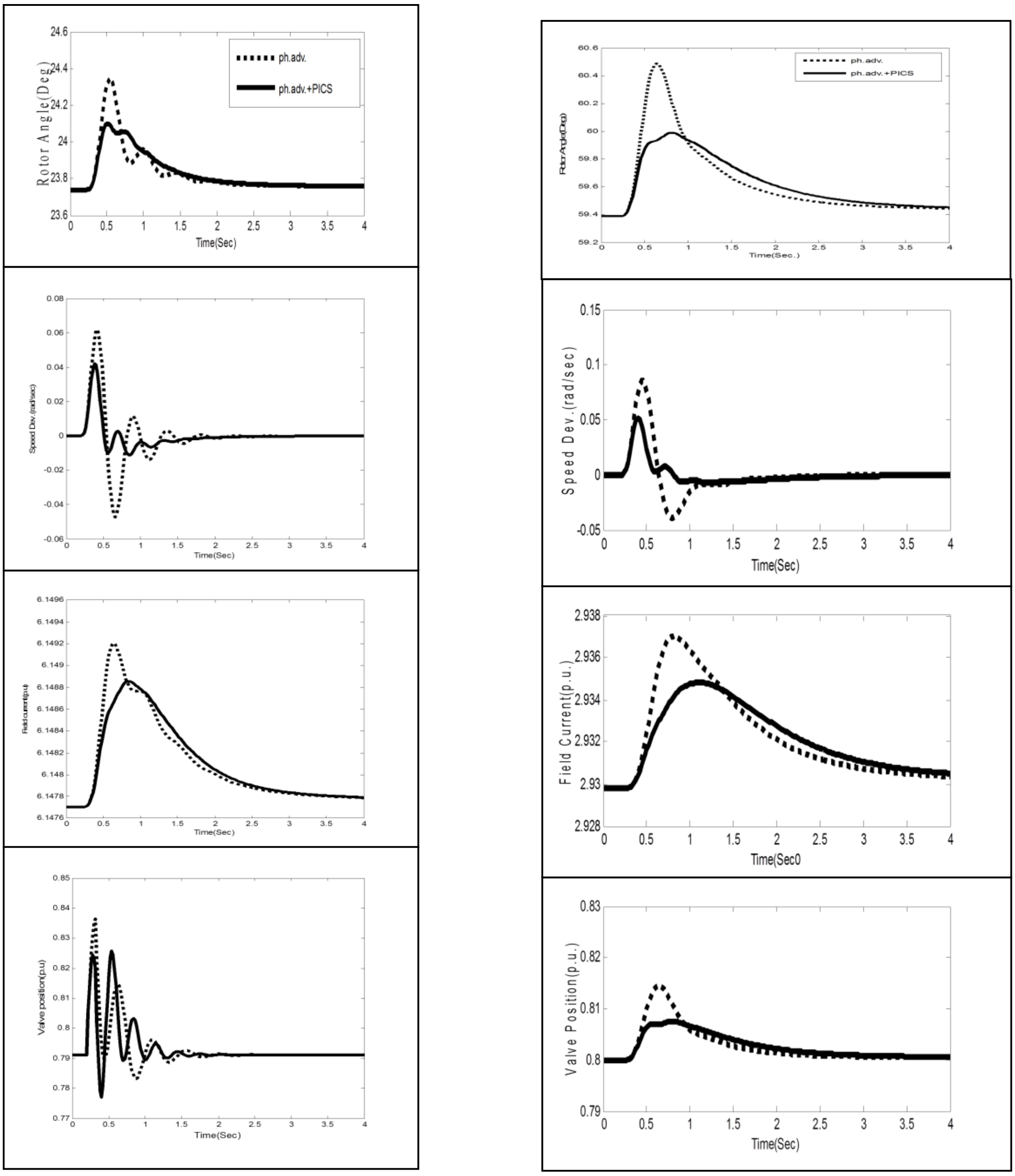
Transmission System Parameters :
X_T=0.15 p.u. , R_T=0.003p.u., X_L=0.05p.u.,
R_L=0.005p.u.

Parameters of Governor and Turbine :
T_{HP}=0.1 sec , F_{HP}=0.26 , T_{IP}=0.3 sec , F_{IP}=0.42 ,
T_{LP}=0.3sec ,F_{LP}=0.32 , T_{RH}=10 sec , T_{GM}=T_{GI}=0.1
sec , P_o=1.2 P.U



a) 0.8 lag p.f.　　　　b) 0.8 lead p.f.

Fig.(4) Response of the studied system to a 3-phase short circuit for 120-ms



(a) 0.8 lag p.f. (b) 0.8 lead p.f.

Fig.(5) Response of the studied power system to a 10% step increase in mechanical input