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Self-Tuning Power System Stabilizer Design Based on Pole-Assignment and Pole-Shifting Techniques

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Abstract: In order to improve dynamic stability of the power systems, the use of Power System Stabilizer (PSS) has been recently increased. For this purpose, there are varieties of methods for determining the controller coefficients of the system stabilizers. If these coefficients are tuned in each operational point by an adaptive mechanism, the robust performance of the system is improved. In this study, a new method for determining the coefficients of a self-tuning PSS with lead-lag controller based on pole-assignment and pole-shifting techniques is presented. In the design procedure, the required identification in self-tuning regulator is performed by using active and reactive power values. Moreover, the properties of the proposed methodology are compared with self-tuning PID stabilizer whose coefficients are determined by using pole assignment technique. Then, the advantages of the proposed stabilizer in which parameter adaptation is accomplished based on the proposed self-tuning method by combining the pole-assignment and pole-shifting techniques, is expressed with respect to other stabilizers. Finally, in order to show the effectiveness of the proposed methodology, some simulation results on a power system with definite parameters and different operational points are provided and compared by using ITAE performance index which denotes the integral of time multiplied by absolute error.

Key words: Self-tuning regulator (STR), power system stabilizer (PSS), PID stabilizer, pole-shifting, pole-assignment

INTRODUCTION

The excitation control of a synchronous generator has significant effect on the stability improvement and damping of the power system. Therefore, numerous studies have been accomplished on the generator excitation control and different stabilizing methods through excitation system (Yu, 1983; Kothari *et al*., 1996; Chaturvedi *et al*., 2004; Segal *et al*., 2000; Sharma and Kothari, 2003; Buamud and Shamekh, 2002; Murdoch *et al*., 1999; Astrom, 1980). The main goal of these researches is to find a stabilizer with desired performance.

Generally, the design procedure of power system stabilizers can be considered in two categories. One method is based on controller design for a power system and the other is based on determining the feedback gains for stabilizing the system (Yu, 1983). In the transfer function based method, the velocity feedback of the generator is used to obtain a supplementary excitation signal. In the conventional PSS design, the root locus of the system poles is not so important and the only issue that should be investigated is the stabilization of the feedback loop (Yu, 1983). In conventional controller with lead-lag phase transfer function $(K_c.\frac{1+s.T_1}{1+s.T_2})$, the control variables are K_c and T_1. These parameters are determined so that the desired ζ and ω_n are achieved. The disadvantage of this method is that by changing the system operational point, the values of ζ and ω_n do not remain close to the desired values and even the system response may be undesirable. Of course, by shifting the system eigenvalues to the left half plane, suitable stability can be achieved. For this purpose, the pole shifting method is used (Motoki *et al*., 2002).

In the above mentioned studies, the controller is an analog controller with non-adaptive mechanism. On the other hand, because of many developments in using digital systems, the digital control methods can be used for determination of controller parameters. Moreover, the controller can be designed by using an adaptive mechanism so that the control objectives in spite of changes in operational points can be achieved (Kothari *et al*., 1996; Astrom, 1980). For this purpose, the system identification may also be required.

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The other control approach that can be used is intelligent control methods (Abdelazim and Malik, 2003; Hassan and Malik, 1993; Gillard and Bollinger, 1996; Tavares *et al*., 2002). These methods can be used when the user has enough information about the system. Otherwise, it is possible that the system training is not accomplished well and control system is failed and stability is lost.

The other control method that can be used is a PID controller whose coefficients are tuned in an adaptive manner such that ζ and ω_n of the system response remain in a desired range (Buamud and Shamekh, 2002). Since the stability of the system is the main design objective, tuning mechanism of the PID coefficients can be accomplished based on the stability condition (Kothari *et al*., 1993). By this, the satisfactory response in all operational points is achieved. Of course, using of PID controller has some practical drawbacks that most of them are due to the derivative term in this controller. In other words, existence of the noise and high frequency oscillations in the system creates a large control signal that, may lead to the system instability. Therefore, instead of PID, a lead-lag transfer function is used as a controller. Moreover, in order to achieve desired performance in all operational points, it is required to determine the lead-lag parameters by an adaptive mechanism.

The usage of adaptive PSS as a controller for power system is a method to which has been recently paid attention (Ardanuy and Zufiria, 2005; Chaturvedi and Malik, 2007; Ardanuy and Zufiria, 2007). The considerable point about this PSS is that its coefficients are determined by using combined intelligent methods regarding different operational points. It should be noted that for using this PSS, a powerful initial data bank is required which should contain all statuses and probable changes in actual power system. Otherwise, the adaptive training mechanism of the power system coefficients determination is not accomplished properly and the system will not be necessarily stable in all operational points.

In this study, the design of a robust stabilizer for the power system by using lead-lag transfer function is considered. To achieve robustness against the changes in operational conditions, the controller coefficients are tuned by an adaptive mechanism. For this purpose, a new method for determining the coefficients of a self-tuning PSS is presented. In this way, the conventional solution method of the Diophantine equation in Self Tuning Regulator (STR) design encounter with problem and to overcome that, the combination of the pole shifting and pole assignment techniques is used. Moreover, the STR design is based on the system identification and in order to increase the speed of this identification, it is performed by using P and Q quantities in this study.

THE SYSTEM MODELLING

The under study system is a synchronous generator that is connected to a transmission line. This transmission line is connected to a huge power system that is equivalent to infinity bus. The schematic diagram of the system has been shown in Fig. 1.

Since the controller is designed on the basis of the linear model of the system, the system should be linearized around an operating point. In this purpose to achieve a linear model, the modified model of Heffron-Phillips-Demello-Coconda is used, that is shown in Fig. 2.

As it seen in this model, the system has five state variables and consequently has five eigenvalues. By examining the eigenvalues of the under study system, it is found that there are two eigenvalues which are unstable or near instability. Our objective is to stabilize the system in all operational points and to achieve a desired performance. For this purpose, the samples of $\Delta\omega$ signal are used to create the control signal U. Therefore, the following transfer function can be considered:

$$U(s) = H(s).\Delta\omega(s) \tag{1}$$

In this study, the transfer function H(s) is considered as the following formats when a lead-lag or PID controller is used respectively:

$$H_{PSS}(s) = \frac{K_C.s}{1+T_w.s}.\left(\frac{1+s.T_1}{1+s.T_2}\right) \tag{2}$$

$$H_{PID}(s) = \frac{T_w.s}{1+T_w.s}.\left(K_P + K_D.s + \frac{K_I}{s}\right) \tag{3}$$

And the main goal is to determine the parameters K_P, K_D and K_I or T_1, T_2 and K_c in an adaptive manner.

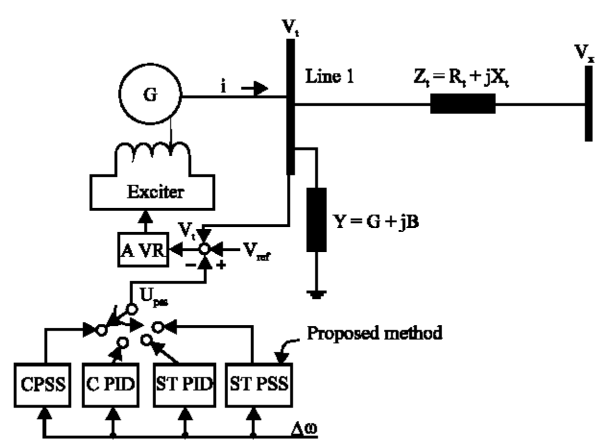

Fig. 1: Infinite bus generator

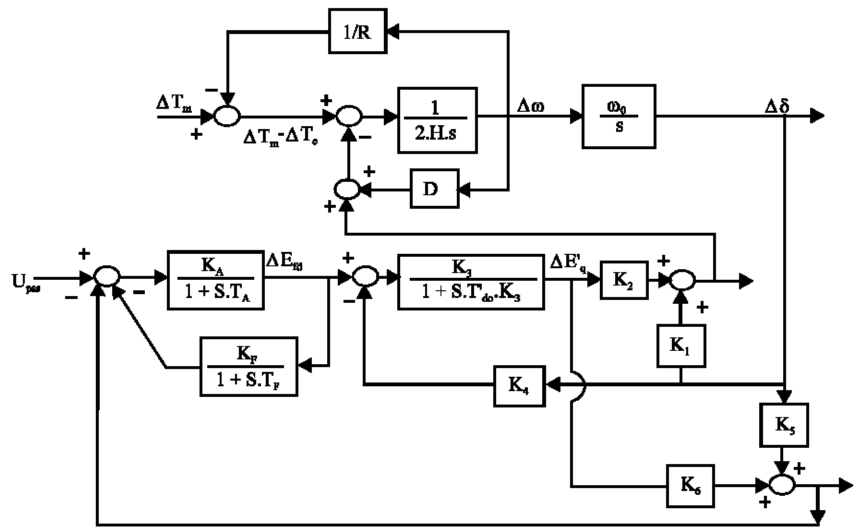

Fig. 2: The linearized model of the synchronous generator in operating point

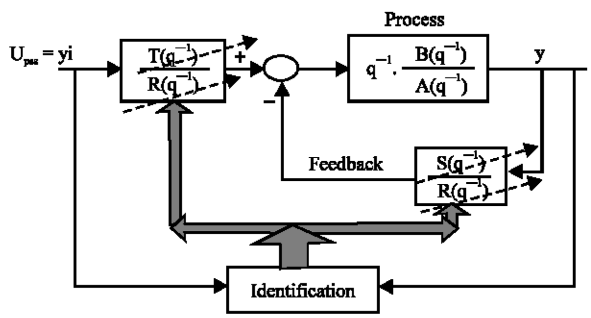

Fig. 3: The self tuning regulator

The review of STR design: Since the proposed stabilizer in this paper is based on STR approach, some background materials are provided in this section. The model of a self tuning controller is generally as shown in Fig. 3 (Astrom and Wittenmark, 2007) in which the process is the power system with variables y and U as the output and input variables respectively. The input-output relation is as follows:

$$A(q^{-1}).y(q^{-1}) = q^{-1}.B(q^{-1}).U(q^{-1}) \tag{4}$$

where q^{-1} is backward time shift operator. In this equation, the values of variable y are also sampled values of the output signal with sampling time $1/T_s$ and y_i denotes to the input variable in Fig. 3.

One step in STR design is the system identification by using the input and output data. In other words, the polynomials A and B in the Eq. 4 that are used in the later steps of the STR design should be identified. This can be accomplished conventionally by using Recursive Least Squares (RLS) method. However, in this paper, the sampled values of the active and reactive power are used.

After the identification step, the procedure of parameter tuning of the regulator is performed. In this regulator the control input is obtained as follows:

$$U(q^{-1}) = \frac{T(q^{-1})}{R(q^{-1})}.y_i(q^{-1}) - \frac{S(q^{-1})}{R(q^{-1})}.y(q^{-1}) \tag{5}$$

where, R, S and T are polynomials in terms of backward time shift operator.

Let the desired transfer function G_m as follows:

$$G_m(q^{-1}) = \frac{q^{-1}.B_m(q^{-1})}{A_m(q^{-1})} \tag{6}$$

By considering G equal to G_m we have:

$$G(q^{-1}) = \frac{y(q^{-1})}{y_i(q^{-1})} = \frac{q^{-1}.T(q^{-1}).B(q^{-1})}{A(q^{-1}).R(q^{-1}) + q^{-1}.B(q^{-1}).S(q^{-1})} = \frac{q^{-1}.B_m(q^{-1})}{A_m(q^{-1})} \tag{7}$$

So, the relation $A_m(q^{-1}) = P(q^{-1})$ specifies the desired pole locations. By balancing the denominators of rational functions in Eq. 7, the following equation entitled as Diophantine equation is achieved:

$$A(q^{-1}).R(q^{-1}) + q^{-1}.B(q^{-1}).S(q^{-1}) = A_m(q^{-1}) \tag{8}$$

The solution of this equation normally leads to determination of the R, S and T polynomials. However, in this study, regarding the selected lead-lag transfer function, the Diophantine equation can not be solved conventionally and to overcome this problem, the pole shifting idea is considered.

It should be noted that the desired characteristic polynomial of the closed loop system can be selected as $s^2 + 2\zeta.\omega.s + \omega^2$ that is equivalent to $P(q^-)^1 = 1 + p_1.q^{-1} + p_2.q^{-2}$ in discrete time domain (Astrom and Wittenmark, 1997) and the relations of the coefficients are as follow:

$$P_1 = -2.e^{(-\zeta.\omega.T_s)}.\cos(\omega T\sqrt{1-\zeta^2}) \quad (9)$$

$$P_2 = e^{(-2\zeta.\omega.T_s)} \quad (10)$$

Where:
T_s = Sampling period

THE DESIGN OF SELF-TUNING STABILIZER FOR POWER SYSTEM

Here, the proposed method for determining the coefficient of Self Tuning PSS (STPSS) in which a lead-lag compensator has been used is presented. Moreover, the stabilization method with PID compensator whose coefficients are computed via self tuning method is presented to compare with STPSS.

The design of STPSS: A PSS is constructed from a high pass filter and a lead-lag transfer function controller which can be considered as follows:

$$H_{PSS}(s) = \frac{K_c.s}{1+T_w.s}.(\frac{1+s.T_1}{1+s.T_2}) \quad (11)$$

Let the high pass term of this transfer function as

$$\frac{s}{1+T_w.s}$$

with T_w = 0.5, then the variant part of the PSS is in the form of

$$K_c(\frac{1+s.T_1}{1+s.T_2}).$$

The general objective of PSS design is to determine the coefficients T_1, T_2, K_c.

In conventional PSS design, T_2 is considered as a constant. Then, T_1 and K_c is calculated so that the desired stability of the system is achieved (Yu, 1983). For this purpose, the damping ratio of the system, ζ, is selected in the range of $0.1 \le \zeta \le 0.3$. In this case, the designed PSS leads to desired performance in an operational point. In order to have suitable performance in all operational conditions, the issue of STPSS is raised. Generally, the problem definition can be illustrated as follows: The transfer function of the PSS is assumed as

$$\frac{K_c.s}{1+0.5s}.(\frac{1+s.T_1}{1+s.T_2}).$$

An adaptive mechanism for determining the coefficients of T_1, T_2, K_c is required such that a desired response in all operational points is achieved.

In the following subsections the related steps of this design procedure are presented.

The system model identification: In this subsection, at first, the system in the continuous time domain is mapped to discrete time domain. The goal is to determine polynomials A and B in relation (4). Here, two first terms of the mapped transfer function numerator is considered as polynomial B.

Identification by using P and Q data: In power plants, the values of active power (P), reactive power (Q) and output voltage (E) are known. It is proved in that the values of currents, voltages, fluxes and other components of the generator can be calculated by using the values of P and Q. On the other hand, by knowing the values of P, Q, E and electrical characteristics of the generator, the linearized model of the power system and after that the coefficients K_1 to K_6 in the Heffron-Phillips model can be achieved.

This method of the system identification has been recently used in (Ardanuy and Zufiria, 2005, 2007). Of course, it should be noted that in these references, changes in the values of P and Q has been considered as a new operational point but the values of parameters K_1 to K_6 are not determined based on this new point. However, these parameters can be determined by using P and Q for identifying the system as is performed in our paper.

The advantages of identification by using P and Q data with respect to conventional RLS: In the case of using RLS in the power system identification, in the transient state i.e., when the power plant entered the grid or large fault has been occurred, the large control signals are obtained that may leads to the system instability. If there is unstable pole and zero in the system transfer function, using of the RLS doesn't lead to desired response. Especially, when the system identification is used for coefficient tuning of the STR, it is possible for eliminating the pole and zero, the polynomials R, S and T become unstable that cause instability in the power system. Contrary to this, if we calculate the parameters of the linearized model by using the values of P and Q, the unstable transient state will not obtained. Because, this method doesn't need so much time like RLS method and the values of K_1 to K_6 are updated with changes of the operational point.

The determination of the values K_1 to K_6 from P and Q is an issue related to special conditions of the synchronous machine. On the contrary, RLS method for any system with input and output will respond. On the other hand, the values of the P and Q are always available in the power plants, however, ΔT and $\Delta\omega$ that are required in identification mechanism can not be achieved easily.

The determination of the regulator coefficients: In this subsection, the main idea is that the regulator coefficients are determined for discrete system based on the pole assignment. Then, by using reverse map relations, the PSS parameters are determined. Regarding the mapping relation, the stabilizer equation in the discrete time domain becomes as follows:

$$G = \frac{S_1.z - S_2}{z - z_2} \quad (12)$$

where, z denotes to forward time shift operator. Then, the Diophantine equation will be as follows:

$$A(z).(z - z_2) + z.(S_1.z - S_2).(b_o.z + b_1) = z^3 + a_{m1}.z^2 + a_{m2}.z \quad (13)$$

This means that the polynomials R, S and T in the general form of the Diophantine equation are as follow:

$$R = (z - z_2) \quad (14)$$

$$S = (S_1.z - S_2) \quad (15)$$

$$T = S(1) = (S_1 - S_2) \quad (16)$$

The relation (13) leads to 4 equations with 3 unknown variables that do not have any solution. To overcome this problem, the pole shift technique is used in which the values of the desired poles are shifted by unknown parameter α (Kothari *et al*., 1993). By this method, α is added to unknown variables and relation Eq. 17 which includes 4 equations and 4 unknowns, is resulted as follows:

$$A(z).(z - z_2) + z.(S_1.z - S_2).(b_o.z + b_1) = (z.\alpha)^3 + a_{m1}.(z.\alpha)^2 + a_{m2}.(z.\alpha) \quad (17)$$

It should be noted that in this equation α and α^2 are appeared. By computing the parameters S_1, S_2, z_2, α the values of T_2, T_1, K_c can be achieved. For this purpose, the values of T_2, T_1, are calculated based on the reverse map relation as following relations:

$$T_1 = \frac{-T_s}{Ln(\frac{S_2}{S_1})} \quad (18)$$

$$T_2 = -\frac{1}{2}\frac{T_s}{Ln(z_2)} \quad (19)$$

Therefore, the design procedure of the STPSS can be summarized as follows:

Design procedure:

- Determination of the desired poles locations based on the desired ζ and ω_n and consequently obtaining the A_m polynomial.
- Considering the discrete time domain transfer function for the stabilizer as relation Eq. 12.
- Derivation of the Diophantine equation in discrete domain as relations Eq. 13-16.
- Using the idea of the combining the pole assignment and pole shifting technique to solve the Diophantine equation and computing the parameters S_1, S_2, z_2, α.
- Determining the original coefficients T_1, T_2, K_c by using the reverse map relations Eq. 18 and 19.

The design of Self Tuning PID (STPID): The transfer function of a power system stabilizer with PID compensator is as follows:

$$H_{PID}(s) = \frac{T_w.s}{1 + T_w.s}.(K_P + K_D.s + \frac{K_I}{s}) \quad (20)$$

The design objective in this case is to determine the PID coefficients: K_P, K_D, K_I.

By knowing the desired poles locations and creating a sufficient lead phase by a PID transfer function, a conventional stabilizer can be designed (Buamud and Shamekh, 2002) that obtains desired response for a definite operating point. However, as described earlier, in order to achieve desired performance in different operation conditions, the design of STPID is presented. In this case the design procedure is similar to procedure which described earlier, therefore only the distinct points are illustrated and the problem is again considered based on a STR design by pole placement method. For this purpose, in the Diophantine Eq. 13, polynomials R, S and T are considered with degree of two. On the other hand, since the transfer function is obtained in the integral form, the polynomial of R is contained the term $(1 - q^{-1})$. Also, in order to achieve the zero steady state error, it should be considered $T(q^{-1}) = S(1)$. Thus, in solving the Diophantine equation, the unknown parameters are S_2, S_1, S_o and r_1 that are appeared in polynomials R, S and T as follow:

$$R(q^{-1}) = (1 + r_1.q^{-1}).(1 - q^{-1}) \quad (21)$$

$$S(q^{-1}) = S_o + S_1.q^{-1} + S_2.q^{-2} \quad (22)$$

$$T(q^{-1}) = S_o + S_1 + S_2 \quad (23)$$

Thus by determining the unknown variables in the Diophantine equation, the STR design is completed. On the other hand, since the final goal is to tune the unknown parameters of the PID controller, these parameters should be calculated by using STR mechanism. For this purpose, by solving the Eq. 24, the coefficients K_p, K_D and K_I are calculated as the relations Eq. 25-27.

$$U(k) = \frac{S_o + S_1 + S_2}{(1 + r_1.q^{-1}).(1 - q^{-1})}.y_i(k) - \frac{S_o + S_1.q^{-1} + S_2.q^{-2}}{(1 + r_1.q^{-1}).(1 - q^{-1})}.y(k) \quad (24)$$

$$K_p = \frac{S_1 + 2S_2}{1 + r_1} \quad (25)$$

$$K_I = \frac{S_o + S_1 + S_2}{T_s} \quad (26)$$

$$K_D = \{[r_1.s_1 - (1 - r_1)s_2]/(1 + r_2)\} \quad (27)$$

Remark 1 - If the system zero is a stable zero i.e.,

$$-0.1 < -\frac{b_2}{b_1} < 0.9,$$

the polynomial Am in solving the Diophantine equation is replaced by following relation:

$$A_m = P(q^{-1}).(1 + \frac{b_2}{b_1}.q^{-1}) \quad (28)$$

Therefore, the design procedure of the STPID can be summarized as follows:

Design procedure:

- Determination of the desired poles locations based on the desired ξ and ω_n and consequently obtaining the A_m polynomial (Remark 1 should be considered in this regard)
- Considering two degree polynomials R, S and T as relations Eq. 21-23 in which the polynomial of R is contained the term $(1\text{-}q^{-1})$ and also $T(q^{-1}) = S(1)$
- Solving the Diophantine equation and computing the unknown parameters S_2, S_1, S_o and r_1.
- Calculating the unknown parameters K_P, K_D and K_I of the PID controller by solving the Eq. 24 and using the relations Eq. 25-27.

THE ITAE PERFORMANCE INDEX

For comparison of the above mentioned methods many criteria can be used, that one of them is minimum ITAE performance index. This index is based on the Integral of Time multiplied Absolute Error (ITAE) and has been used in (Ardanuy and Zufiria, 2005, 2007). This function is defined as follows:

$$f_1 = \int_{t_2}^{t_1} t.|\Delta\omega(t)|\,dt \quad (29)$$

where, t_1 and t_2 are the study time limits and $\Delta\omega(t)$ represents the speed deviation of the generator. The advantage of this selected performance index is that minimal dynamic plant information is needed.

THE SIMULATION RESULTS

The initial data of the case study: The parameters of the under study system are provided in the appendix (A). This system is examined in two different operational conditions. The features and parameters of the first operational point are as follow:

$$Q = 0.55 \quad P = 0.8 \quad X_e = 0.4$$
$$\Rightarrow \begin{Bmatrix} k_1 = 0.97 & k_2 = 0.97 & k_3 = 0.36 \\ k_4 = 1.24 & k_5 = -0.05 & k_6 = 0.46 \end{Bmatrix}$$

The second operational condition also has the following characteristics:

$$Q = 0.5 \quad P = 1 \quad X_e = 0.7$$
$$\Rightarrow \begin{Bmatrix} K_1 = 0.97 & K_2 = 0.96 & K_3 = 0{,}42 \\ K_4 = 1.228 & K_5 = -0.12 & K_6 = 0.536 \end{Bmatrix}$$

In order to show the abilities of the proposed stabilizer in different operational conditions, the responses of two above designed stabilizers are examined. Before that, the response of the system without using any stabilizer is given in the Fig. 4 and 5 that show the oscillations $\Delta\omega$ in two operational points. These oscillations indicate the dynamical instability of the system and show the necessity of using stabilizer.

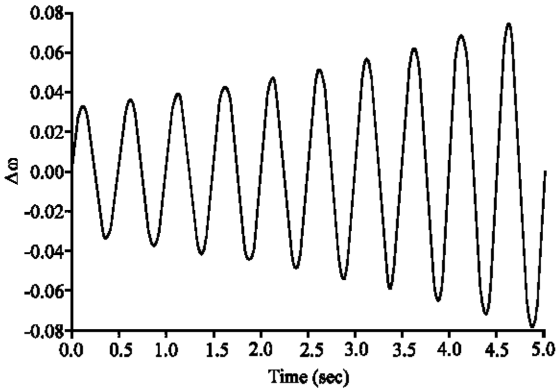

Fig. 4: The response of Δω(t) with respect to time in the first operating point without using stabilizer

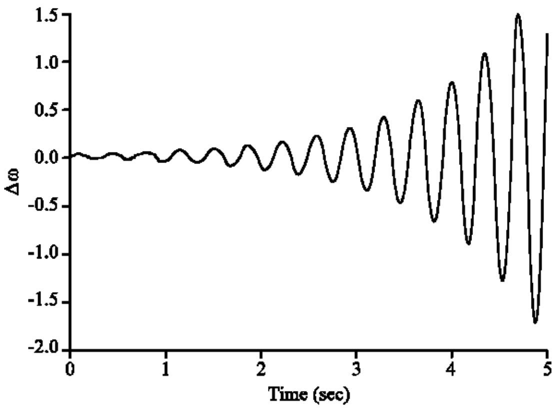

Fig. 5: The response of Δω(t) with respect to time in the second operating point without using stabilizer

The simulation results in the case of using PSS

The results related to conventional PSS: By considering ζ = 0.2, the PSS is designed for the second operating point and this PSS is used also for the first operating point. The method for computing the coefficients of the conventional PSS is given in (Yu, 1983). The simulation results of this part are shown in Fig. 6 and 7 with dashed lines graphs. Since this conventional PSS has been designed based on the second operating point characteristics, the results related to this point is more desirable than one related to the first point. This implies the lack of the robustness in the conventional PSS against the variations of the operational conditions.

The results related to proposed Self-Tuning PSS (STPSS): The PSS is designed and has been simulated in two operational points. These simulation results are also provided in Fig. 6, 7 with solid lines graphs. As it is seen, the proposed self tuning PSS has a desirable performance in both operational conditions.

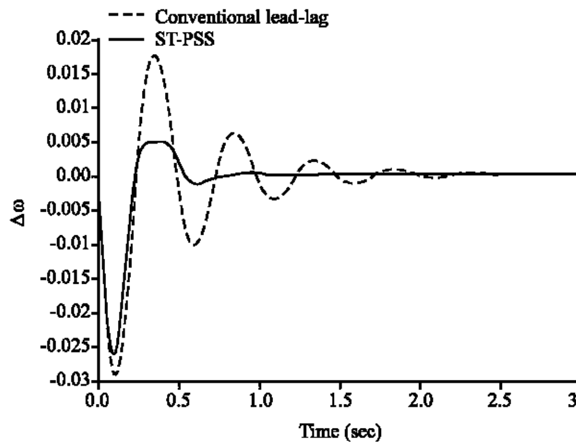

Fig. 6: The response of Δω(t) with respect to time in the first operating point by using Lead-Lag stabilizer

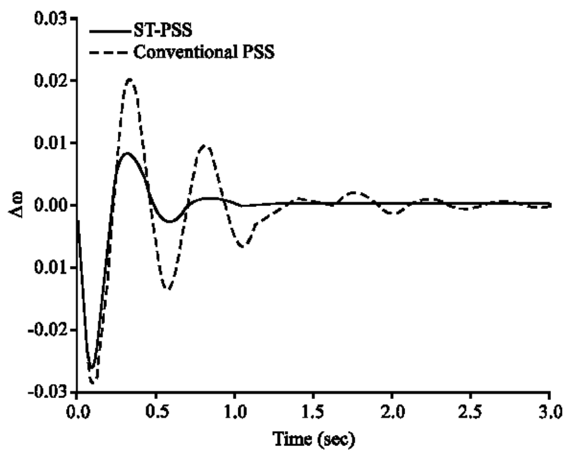

Fig. 7: The response of Δω(t) with respect to time in the second operating point by using Lead-Lag stabilizer

The simulation results in the case of using PID in system stabilizer

The results related to conventional PID: In this step, at first, the coefficients of PID compensator were designed by usual method that resulted values are as follow:

$$K_P = 29.2 \quad K_I = -100.29 \quad K_D = 5.5 \quad T_w = 0.5$$

The simulation results related to this design have been shown in Fig. 8 and 9 by dashed lines graphs.

The results related to Self Tuning PID (STPID): The coefficients of PID are designed. By implementing the control mechanism and simulating, the system responses for two operational conditions are also provided in Fig. 8, 9 by solid lines graphs.

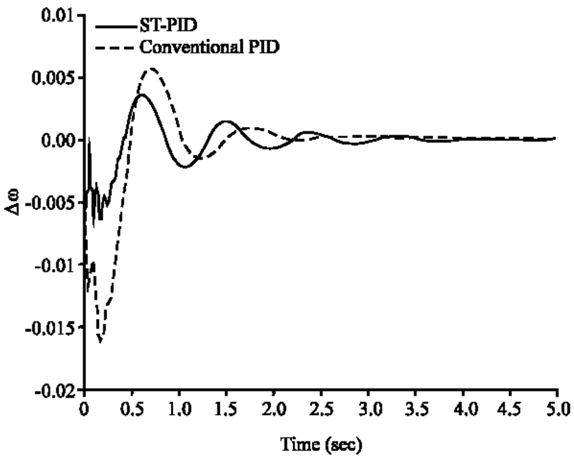

Fig. 8: The response of Δω(t) with respect to time in the first operating point by using PID stabilizer

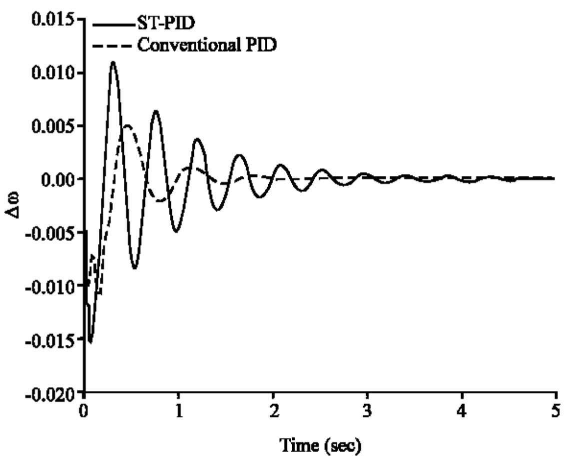

Fig. 9: The response of Δω(t) with respect to time in the second operating point by using PID stabilizer

By comparing the results of two methods, it is seen that the response characteristics such as rise time and overshoot of the response in the case of using Pole Placement STR (PP-STR) based approach are more desirable. Moreover, the sensitivity of the system to the operational point changes is less in this case.

The comparison between two stabilizing approaches: The stabilizer by using PID compensator is compared with lead-lag stabilizer in different points of view. It should be noted that for this comparison, the coefficients of PID controller are calculated based on PP-STR approach (which resulted in better responses with respect to conventional PID based stabilizers) and the unknown parameters of the lead-lag stabilizer are designed by using STPSS method (which resulted in relatively better

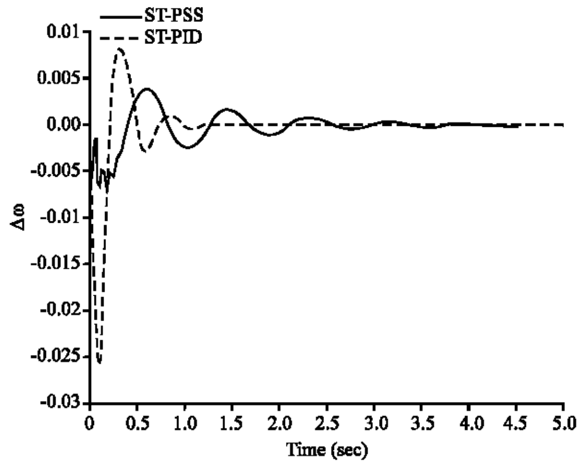

Fig. 10: The response of Δω(t) with respect to time in the first operating point-comparison of two methods

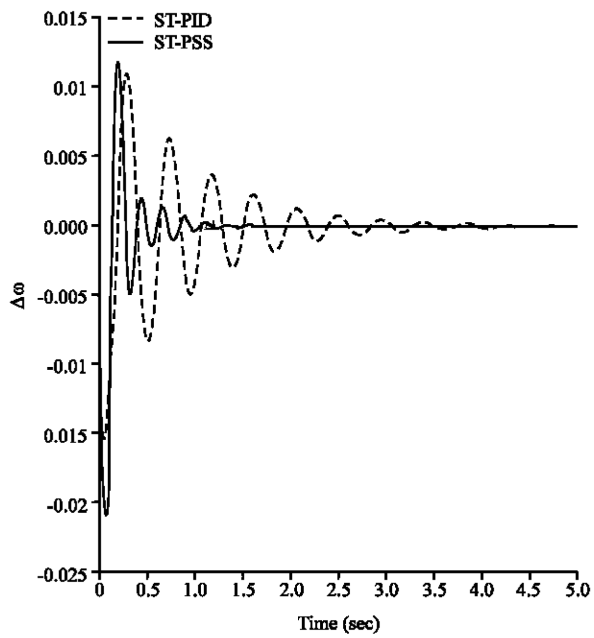

Fig. 11: The response of Δω(t) with respect to time in the second operating point-comparison of two methods

responses in lead-lag based stabilizers). The responses of two methods for two operational points are provided in Fig. 10 and 11. As it is seen, the lead-lag stabilizer response has less settling time and also there isn't any undesirable transient oscillation in the response. On the other hand, less overshoot is the only advantage of PID stabilizer. The main disadvantage of this method is the existence of the undesirable transient in the system response i.e., Δω, which is due to differential term in the compensator transfer function. If the amplitude of this

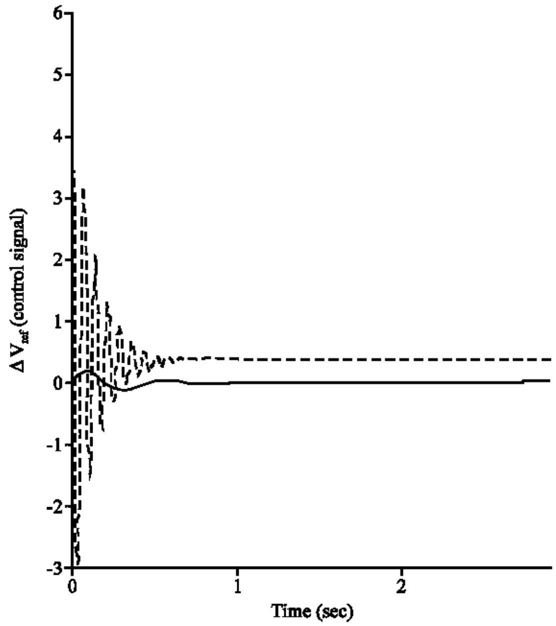

Fig. 12: The control signal in the first operating point (… for PID stabilizer, — for Lead-Lag stabilizer)

transient response increases, it may lead to dynamic instability in the system in some operational points or in the system identification process. This problem can also be seen in the control signal more clearly. To show this, the control signal $U = \Delta V_{ref}$ with respect to time for both methods is provided in Fig. 12. It is seen that PID stabilizer obtains the control signals with high amplitude and frequency that are not usable in practical case in which a limiter is used. The amplitude of the control signal of PID stabilizer is almost 25 times of the lead-lag stabilizer one and therefore it can not be used in practice. This problem doesn't occur in the lead-lag stabilizer because there is no differential term in its transfer function.

COMPARISON OF THE ITAE PERFORMANCE INDEX FOR ALL METHODS

All stabilizing methods which were described in the last sections are compared according to ITAE performance index. For this purpose, by using Eq. 29, the ITAE value of the output responses for different stabilizers including conventional PID, STPID, conventional PSS and proposed STPSS controllers are calculated that are summarized in the Table 1 for both operational points.

As it is shown in Table 1, the value of the ITAE index in the self tuning methods (STPID and STPSS) is less than conventional methods that implies more desirable

Table 1: ITAE performance Index for all stabilizing approaches

	ITAE index	
Methods	ITAE performance index for 1st Q point	ITAE performance index for 2nd Q point
ST PSS	0.001054	0.001349
ST PID	0.001592	0.004375
CPSS	0.005463	0.005310
CPID	0.004992	0.004810

dynamic responses. Moreover, the performance of both self tuning methods can be also compared in two operational points. As it is shown in Table 1, in the first operational point, the index performance ITAE is near to each other for both methods. Of course, the differential term in the PID controller leads to high amplitude and frequency control effort which encounter with some practical issues. But, in the second operational point, the ITAE value for STPSS is less than STPID which implies more desirable dynamic response. The other considerable point is that the difference of the ITAE index in two operational points in the case of using STPSS is smaller than STPID which indicates a uniform performance of the STPSS in different operational points. With the above explanation, it is concluded that the STPSS method has more acceptable results with respect to other methods that discussed in this study.

CONCLUSIONS

In this study, a new method for power system stabilizing by using lead-lag compensator in a self tuning manner was presented so that the unknown coefficients were designed based on pole-assignment and pole-shifting techniques. The required system identification procedure in the regulator design stage is accomplished by using active and reactive power data that causes the increment of the speed and accuracy of the identification. To examine the advantages of the proposed stabilizer, the simulation results of the implementation of this method were compared with the PID based stabilizer. For this comparison, the PID coefficients were tuned by using STR approach. By examining the system responses in two different operational points, it was seen that the proposed method decreases the transient oscillations and also decreases the settling time of the response. This improvement in transient response is a major criterion in the system design that does not exist in the PID based stabilizers because of its differential term. Moreover, because of the adaptive mechanism of the proposed methodology, the simulation results were acceptable for different operational conditions.

Appendix A: The Model Parameters of the Case Study
The parameters of the model and the synchronous

generator which is used in the example are given as follow. All values are in per unit (p.u.) except the H and T that are in second.

H = 5 sec, T'_{do} = 6 sec, X_c = 1.6 p.u, X_q = 1.55 p.u, X'_d = 0.32 p.u

Also, the system excitation parameters are given as follow:

$$K_A = 400,\ K_F = 0.025,\ T_A = 0.05 \text{ sec},\ T_F = 1 \text{ sec}$$

Moreover, the parameters which are used in the controller design are given as follows:

$P_{1\text{-self-tuning}}$ = -1.07
$\omega_{\text{conventional-PSS}}$ = 7.6
$T_{2\text{conventional-PSS}}$ = 0.2
$P_{2\text{-self-tuning}}$ = 0.6376
$\xi_{\text{conventional-PSS}}$ = 0.2

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