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Fuzzy and Grey Fuzzy Controller : Applications and Usage in Power System

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Abstract - In this paper, we proposed an effective method to design the power system stabilizers (PSS). The design of a PSS based on Grey Fuzzy PID Control (PSS+GFPIDC) can be formulated as an optimal linear regulator control problem; however, implementing this technique requires the design of estimators.A grey predictor with a small fixed forecasting step-size will make the system respond faster but cause larger overshoots. Conversely, the bigger step-size of the grey predictor will cause over compensation, resulting in a slow system response. In order to obtain a fast system respond with a little overshoot, the step-size of the grey predictor can be changed adaptively. In the literature of the grey system theory, there are some methods that tune the step-size of the grey predictor according to the input state of the system. In order to determine the appropriate forecasting step-size, some online rule tuning algorithms using a fuzzy inference system have been proposed for the control of an inverted pendulum, fuzzy tracking method for a mobile robot and non-minimum phase systems. The power system stabilizers are added to the power system to enhance the damping of the electric power system. The design of PSSs can be formulated as an optimal linear regulator control problem whose solution is a complete state control scheme**.** But, the implementation requires the design of state estimators. These are the reasons that a control scheme uses only some desired state variables such torque angle and speed. Upon this, a scheme referred to as optimal reduced order model whose state variables are the deviation of torque angles and speeds will be used. The approach retains the modes that mostly affect these variables. In this paper, we adopt a grey model to predict the output states value. The PID controller is the master controller and the fuzzy control is the slave control to enhance the master one. Furthermore, we cannot make sure that the forecasting step size and PID parameters.

Key Words**:** PID Controller, Power System Stabilizer (PSS), On-line rule tuning, Grey Prediction, Grey Fuzzy PID Control

1.INTRODUCTION

The essential concept is that the forecasting step size in the grey predictor can be tuned according to the input state of the system during different periods of the system response. To approach this object, an on-line rule tuning mechanism was proposed so that it can quickly regulate an appropriate negative or positive forecasting step size. An on-line rule tuning algorithm using the concept of reinforcement learning and supervised learning is proposed to tune the consequent parameters in the fuzzy inference system such that the controlled system has a desired output.

Power system oscillations occur due to the lack of damping torque at the generators rotors. The oscillation of the generators rotors cause the oscillation of other power system variables (bus voltage, bus frequency, transmission lines active and reactive powers). Power system oscillations are usually in the range between 0.1 and 2 Hz depending on the number of generators involved. Local oscillations lie in the upper part of that range and consist of the oscillation of a single generator or a group of generators against the rest of the system. In contrast, inter-area oscillations are in the lower part of the frequency range and comprise the oscillations among groups of generators.

To improve the damping of oscillations in power system, a Power System Stabilizers (PSSs) applied on selected generators can effectively damp local oscillation modes while for inter-area oscillations a supplementary controller can be applied. Most of these controllers are designed based on conventional approach that is designed based on a Linearized model which cannot provide satisfactory performance over a wide range of operation points and under large disturbances. Neural networks, enjoy a variety of advantages (e.g., high speed, generalization capability and learning ability), are a viable choice for non-linear control design.

It has been successfully applied to the identification and control of dynamical systems especially in the field of adaptive control by making use of on-line training. Direct and indirect adaptive control with MLP and RBF neural networks has been discussed for such systems which rely on continuous online training of the identifier and controller network. It presents single-neuron and multi-neuron Radial Basis Function Controller (RBFNN) for the UPFC control in single machine-infinite-bus and three-machine power systems and claimed to provide the best transient stability performance of the power system. This is because output layer of RBF can be optimized fully using traditional linear modeling techniques but, before linear optimization can be applied to the output layer of an RBF network, the number of radial units must be decided and then their centers and deviations must be set. The use of Neuro-fuzzy to aid in controlling power oscillation damping in large power system has been studied for some years by several researchers. In this thesis, the implementation of GrANFIS-PSS for Multi-machine power system has been described. Initial values of membership functions and rule base of the ANFIS have been obtained using the knowledge of dynamic behavior of the power devices in multi-machine power system, and then membership functions' values have been optimized by the ANFIS. The performance of the GrANFIS-PSS with the conventional controller for a number of operating conditions has been compared.

GM (n, m) Model

In grey systems theory, GM (n, m) denotes a grey model, where n is the order of the difference equation and m is the number of variables. Although various types of grey models can be mentioned, most of the previous researchers have focused their attention on GM (1, 1) model in their predictions because of its computational efficiency. It should be noted that in real time applications, the comutational burden is the most important parameter after the performance.

2. The Structure of Power System Stabilizer

The structure of the grey prediction fuzzy PID control (GFPIDC) power system stabilizer is composed of five units:

Grey predictor unit: The grey predictor is used to predict the forecasting values Δ8 and Δ ω, these values provide the PID and Fuzzy controller.

Fuzzy controller unit: The fuzzy system is constructed from a set of Fuzzy IF-THEN rules that describe how to choose the input of PID under certain operation conditions.

The PID controller unit: The PID controller is using the simple structure inthe general processes. The control signal of power system is generated from this unit.

The global gain unit: The global gain is obtained from the optimal reduced order model of the whole system by using only output feedback.

Online-Tuning unit: An on-line rule tuning algorithm using the concept of reinforcement learning and supervised learning is proposed to tune the consequent parameters in the fuzzy inference system from this unit.

Generations of Grey Sequences

The main task of grey system theory is to extract realistic governing laws of the system using available data. This process is known as the generation of the grey sequence. It is argued that even though the available data of the system, which are generally white numbers, is too complex or chaotic, they always contain some governing laws. If the randomness of the data obtained from a grey system is somehow smoothed, it is easier to derive the any special characteristics of that system. For instance, the following sequence that represents the speed values of a motor might be given:

X(0) = (200, 300, 400, 500, 600)

It is obvious that the sequence does not have a clear regularity. If accumulating generation is applied to original sequence, X(1) is obtained which has a clear growing tendency.

X(1) = (200, 500, 900, 1400, 2000)

GM (n, m) Model

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GM (1, 1) Model

GM (1, 1) type of grey model is most widely used in the literature, pronounced as "Grey Model First Order One Variable". This model is a time series forecasting model. The differential equations of the GM (1,1) model have time-varying coefficients. In other words, the model is renewed as the new data become available to the prediction model. The GM (1,1) model can only be used in positive data sequences. In this paper, a non-linear liquid level tank is considered. It is obvious that the liquid level in a tank is always positive, so that GM (1, 1) model can be used to forecast the liquid level. In order to smooth the randomness, the primitive data obtained from the system to form the GM (1, 1) is subjected to an operator, named Accumulating Generation Operation (AGO), described above. The differential equation (i.e. GM (1, 1)) thus evolved is solved to obtain the n-step ahead predicted value of the system. Finally, using the predicted value, the inverse accumulating operation (IAGO) is applied to find the predicted values of original data. Consider a single input and single output system. Assume that the time sequence $X^{(0)}$ represents the outputs of the system) x.

$$X^{(0)} = \left(x^{(0)}(1), x^{(0)}(2), \ldots\ldots x^{(0)}(n)\right), n \geq 4 \quad (1)$$

Where X(0) is a non-negative sequence and n is the sample size of the data. When this sequence is subjected to the Accumulating Generation Operation (AGO), the following sequence X(1) is obtained. It is obvious that X(1) is monotone i0)(n)) , n ≥ 4

$$X^{(1)} = \left(\left(x^{(1)}(1), x^{(1)}(2), \ldots\ldots x^{(1)}n\right)\right), n \geq 4 \quad (2)$$

Where

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$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i), k = 1,2,3, \ldots . n$

(3)

The generated mean sequence Z(1) of X(1) is defined

- $z^{(1)} = \left(z^{(1)}(1), z^{(1)}(2), \ldots \ldots z^{(1)}(n)\right)$

(4)

Where z(1)(k) is the mean value of adjacent data, i.e.

$z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k-1), k = 2,3, \ldots . . n$

(5)

The least square estimate sequence of the grey difference equation of GM (1,1) is defined as follows:

$x^{(0)}(k) + az^{(1)}(k) = b$

(6)

The whitening equation is therefore as follows:

$\frac{dx^1(t)}{dt} + ax^1(t) = b$

(7)

In above, $[a, b]^T$ is a sequence of parameters that can be found as follows:

$[a, b]^T = (B^T B)^{-1} B^T Y$

(8)

Where

$Y = \left[x^{(0)}(2), x^{(0)}(3), \cdots \cdots \cdots, x^{(0)}(n)\right]^T$

(9)

$$B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(2) & 1 \\ . & \\ . & \\ . & \\ -z^{(1)}(n) & 1 \end{bmatrix}$$

(10)

According to equation (8), the solution of x(1)(t) at time k:

$x_p{}^{(1)}(k+1) = \left[x^{(0)}(1) - \frac{b}{a}\right] e^{-ak} + \frac{b}{a}$ (11)

To obtain the predicted value of the primitive data at time (k+1), the IAGO is used to establish the following grey model.

$x_p{}^{(0)}(k+1) = \left[x^{(0)}(1) - \frac{b}{a}\right] e^{-ak}(1 - e^{a})$

(12)

And the predicted value of the primitive data at time (k+H):

$x_p{}^{(0)}(k+H) = \left[x^{(0)}(1) - \frac{b}{a}\right] e^{-a(k+H-1)}(1 - e^{a})$

(13)

The parameter (a) in the GM (1,1) model is called "development coefficient" which reflects the development states of X(1)p and X(0)p . The parameter b is called "grey action quantity" which reflects changes contained in the data because of being derived from the background values.

3. Combining Fuzzy and PID Type Control

Analysis of a Fuzzy Controller

Consider a product-sum type fuzzy controller with two inputs and one crisp output (MISO). Let the inputs to the fuzzy controller be the error e and the rate of change of the error e˙, and the output of the fuzzy controller (that is the input to the controlled process) be u. If an analysis of this controller is made, it can be seen that it behaves approximately like a PD controller. We can therefore consider it as a time-varying parameter PD controller. Such a controller is named as a PD type fuzzy controller (PDFC) in the literature. It is well known that if the controlled system is type "0", a P or PD type controller cannot eliminate the steady-state error. Although the use of an integral term in the controller (such as PI controller) can take care of the steady-state error, it can deteriorate the transient characteristics by slowing the response. However, with a PID-type fuzzy controller fast rise times and small overshoots as well as short settling times can be achieved with no steady-state error.

PID Type Fuzzy Control

In order to design a PID type fuzzy controller (PIDFC), one can design a fuzzy controller with three inputs, error, the change rate of error and the integration of the error. Handling the three variables is however, in practice, quite difficult. Besides, adding another input to the controller will increase the number of rules exponentially. This requires more computational effort, leading to larger execution time. Because of the drawbacks mentioned above, a PID type fuzzy controller consisting of only the error and the rate of change of error is used in the proposed method. This allows PD and PI type fuzzy controllers to work in parallel. An equivalent structure is shown in Fig. 3, where β and α are the weights of PI and PD type controllers, respectively. Similarly, K and Kd are the scaling factors for e and e˙, respectively. As the α/β ratio becomes larger, the effect of the derivative control increases with respect to the integral control.

The output of the controller can be expressed as,

$$u_c = \propto u + \beta \int u dt \quad (14)$$

This controller is called as PID type fuzzy controller (PIDFC).

The PID Controller

Due to their simple structure and robust performance, proportional-integral-derivative (PID) controllers are the most commonly used controllers in industrial process control. The transfer function of **a** PID controller has following form:

$$G(s) = K_p + \frac{K_i}{s} + K_d s \quad (15)$$

Where *K,* and K_d are called the prepositional, integral, and derivative gains, respectively.

Grey Fuzzy PID Type Controller (GFPIDC)

In a conventional fuzzy inference system, an expert, who is familiar with the system to be modeled, decides on the number of rules.

A novel fuzzy PID control structure has been developed in this paper for power oscillation damping of two area four machine system.

4.Simulation Result

The Power system in Fig.2 is simulated in Fig.3 considering three phase short circuit between two areas. For having a complete modeling of the system, the surface internal modeling of each area, machine and turbine are shown in Fig.1, 2 and 3. The PID controllers of PSS+GFPIDC stabilizer for Kunder test generators are given in Table 1. Each generator parameters are based on data in Table 2.

Table -1: Sample Table format

Parameter	K_p	K_I	K_d
G1	10.50	0.67	0.45
G2	9.67	0.60	0.40
G3	9.00	0.50	0.30
G4	8.33	0.67	0.53

Parameter	Generator
X_d	1.80
X_d'	0.30
X_d''	0.25
X_q	1.70
X_q'	0.55
X_q''	0.25
X_t	0.20
T_{do}	8
T_{do}'	0.03
T_q	0.40
T_q'	0.05

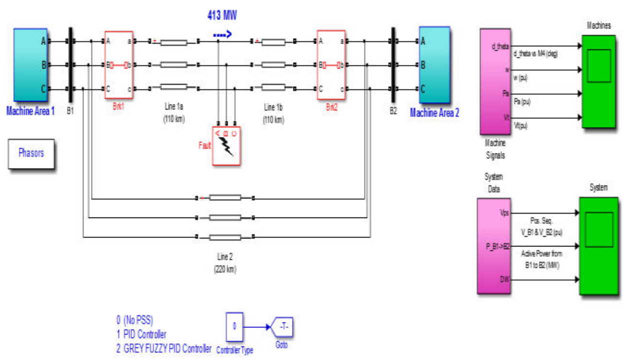

Fig.2 Simulation of Power system

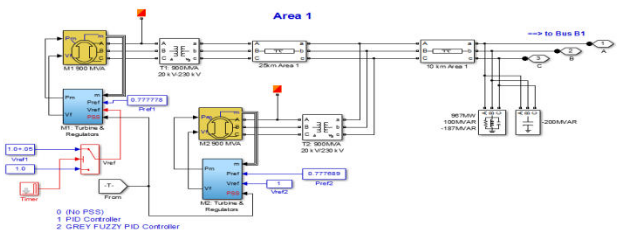

Fig.3 Internal configuration of area 1(subsystem)

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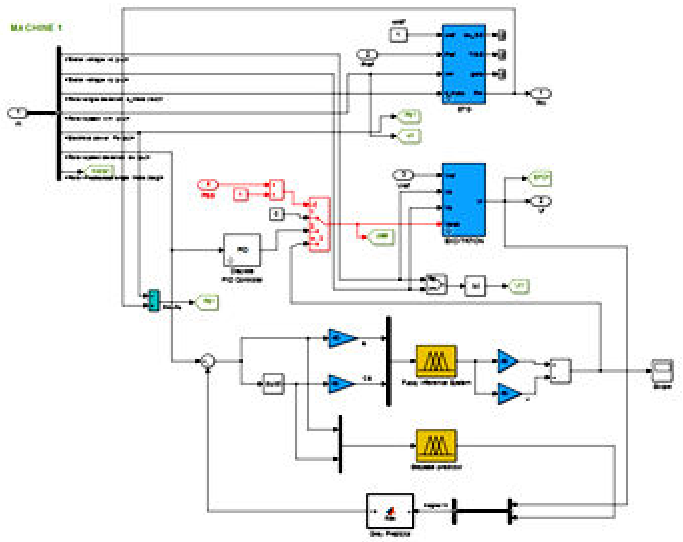

Fig.4 Internal configuration of Turbine and regulator (subsystem)

(5) Single Phase Fault

Figure (5) (a) and (b). Shows the system performance of without PSS for single phase to ground fault occurs on the line 1 at 110 km. A single-phase fault were applied at 1.0 sec and cleared at 1.2 sec. Figure (6).shows the various system responses under PID Controller. Figure (7) shows the various system responses of the grey fuzzy PID controlled power system stabilizer. It should be noted that the oscillation under system with grey fuzzy PID PSS decays faster than under system with PID. Fuzzy logic power system stabilizer achieves a significantly fast damping for power flow from bus 1 to bus 2.

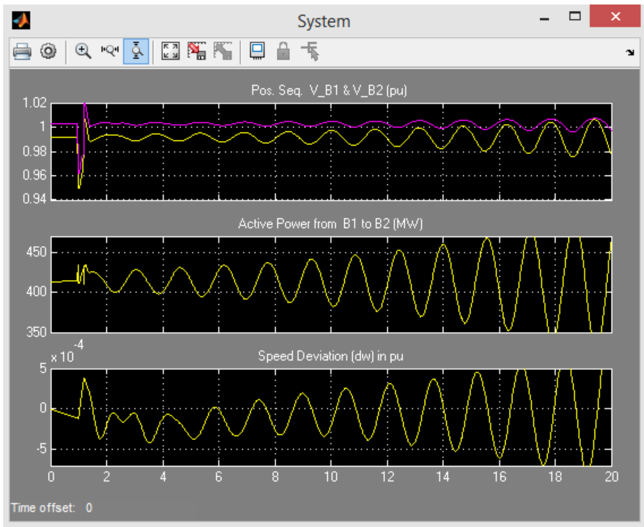

Figure (5) (a) System Response for Single Phase fault condition without PSS

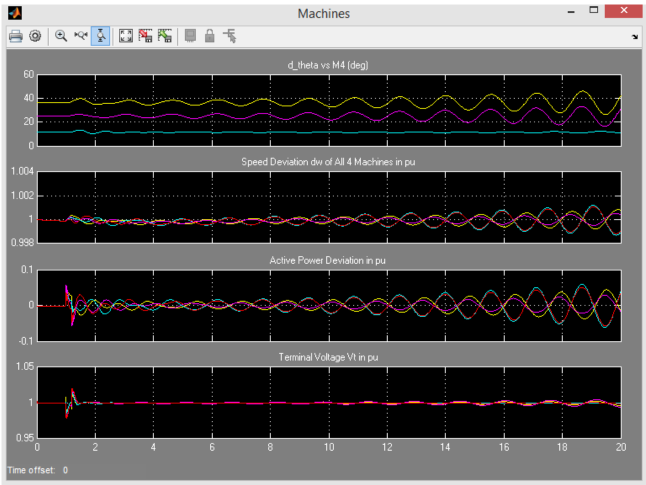

Figure (5) (b) System Response for Single Phase fault condition without PSS

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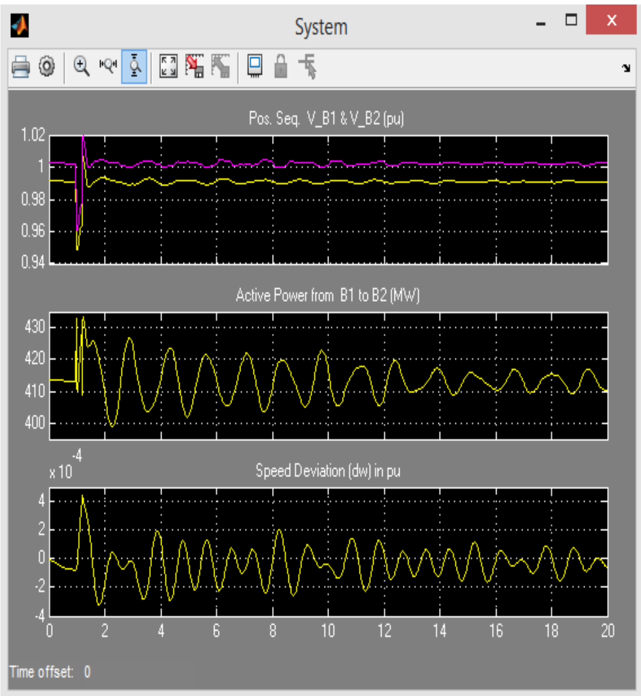

Figure (6) (a) System Response for Single Phase fault condition with PID Controller

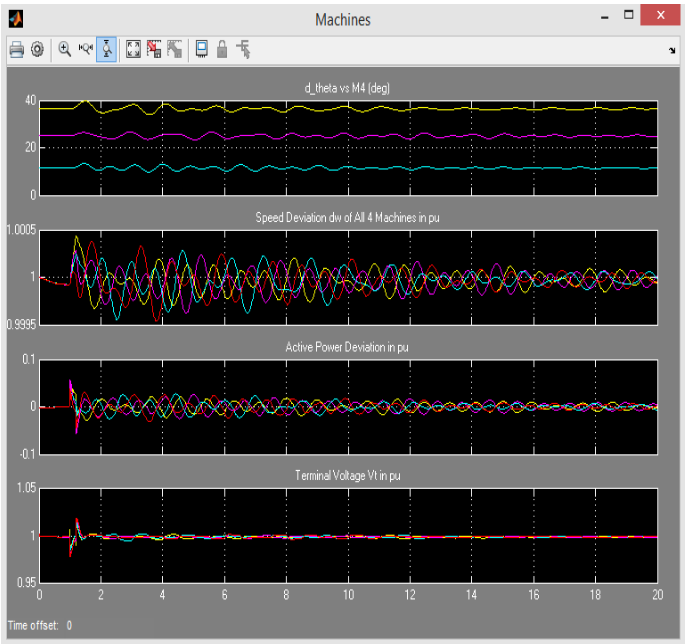

Figure (6) (b) System Response for Single Phase fault condition with PID Controller

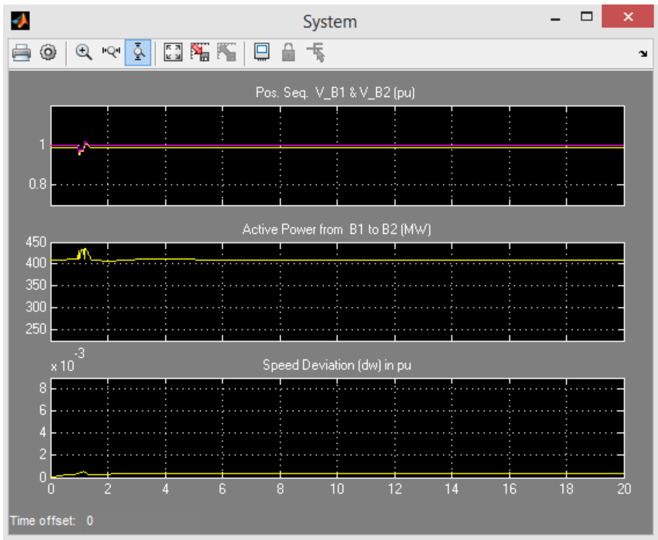

Figure (7) (a) System Response for Single Phase fault condition with Grey Fuzzy PID Controller

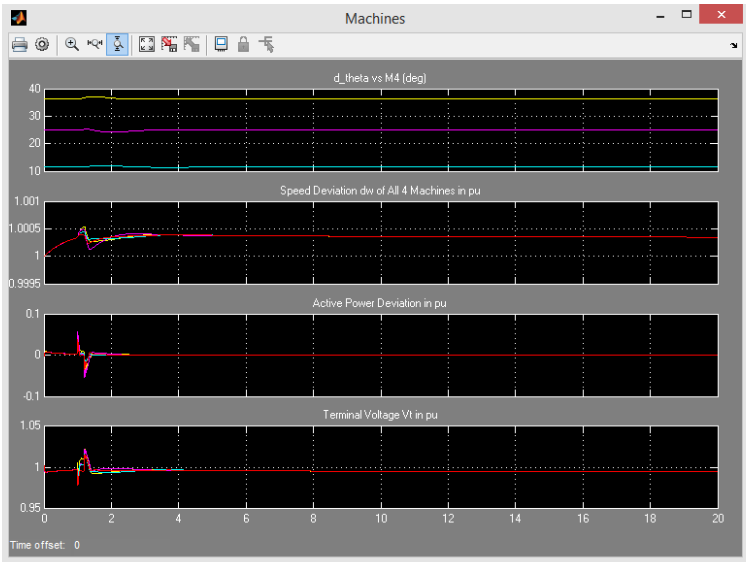

Figure (7) (b) System Response for Single Phase fault condition with Grey Fuzzy PID Controller

6. CONCLUSIONS

This piece of research work proposes a grey Fuzzy PID Controller(GFPIDC) with a variable prediction horizon for power system stability control. The simulationresults show that the proposed method not only reducesthe overshoot and the rise time but also maintain a betterdisturbance rejection. In real life, there are always some uncertainties because an accurate mathematical model of a physical system cannot generally be defined.

it is obvious that the GFPIDC controller based PSS stabilizer (PSS-GFPIDC) can stabilize the mentioned synchronous generator. It is also observed that the system turned back to its stabilizer mode after disturbance, due to the three phase short circuit, to compensate the bad impact of disturbance.

In this work we suggest a new design procedure for the power system stabilizer. The proposed method combines the grey system theorem, the fuzzy theorem and the PID control to replace the traditional full order optimal control method. The effectiveness of the grey prediction PID control power system stabilizer in enhancing the dynamic performance testability is verified through the simulation results.

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