Load Frequency Control in Two Area Power System Using Sliding Mode Control

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ABSTRACT

In this article, the sliding mode control of frequency load control of power systems is studied. The study area consists of a system of water and heat. First, a mathematical model of the proposed system disturbances is made and then sliding control mode for frequency load control is provided. By the system simulation and sliding mode control, it can be shown that the damping of oscillations is well led.

KEYWORDS: frequency Load control, sliding mode control, dual zone system;

1. INTRODUCTION

Frequency regulation in power systems which is named frequency load control is one of the most important controlling issues in the design and operation of power systems. Constant frequency deviation from the nominal value directly affects the exploitation and the reliability of the power system. Excessive frequency deviation can damage the equipment, degrade the performance of network loads, establish lines of communication and stimulation overload protection devices on the network and network collapse may result in adverse conditions. Therefore, it is important to keep the frequency at nominal value.

Today, in many parts of the controlling areas, integral-proportional controllers with fixed parameters are used to control the frequency of the charge-up. However, the proportional-integral controlling systems have along settling time and relatively large mutation in frequency transient response.[1] In addition, the proportional-integral controlling algorithm meet the required behavior in the neighborhood of the nominal system, where is fitted for However, the optimum operating point of a power system typically changes many times. This is due to the size and power consumption characteristics, characteristics of power plants and the counts of existing power plants in the frequency load control in the controlling area .In the future, power systems will have to rely on large amounts of distributed power systems with a high percentage of renewable energy sources this will increase the uncertainties in the system, where by the new requirements will result in frequency load control system. Therefore, there is a sense of need to a developed controller instead of the proportional-integral controllers to: (1) To guarantee the better turbulence remove;(2) To maintain the required quality of control in a broader scope;(3) To shorten the frequency transient response by avoiding Transmutations; And (4) to be resistant against the un certainties in the system. In addition, a new controlling algorithm for a control is should be able to control the decentralized time-frequency load control in the contiguous, areas. I.e. that It the structure and parameters should not depend on the controllers used in the neighboring controlling areas. Finally, it should be relatively simple in implementation, to be accepted as an appropriate alternate controlling Proportional-Integral algorithm

In recent years, many different control algorithms have been proposed. To control the frequency load controller in order to overcome the limitations of the proportional - integral controller. Among them, the most important are based on, robust control algorithms [5-3], fuzzy logic [6], neural networks [7], predictive controlling model [8], the optimal control [9], adaptive control [10 and sliding mode control [11]. In general, approaches to design LFC controller scan be divided into several categories: Classical techniques, adaptive methods and variable structure, robust controlling methods and methods based on artificial intelligence. In [12] a comprehensive overview of LFC methods proposed in previous research is provided.

The purpose of this paper is to design a control system based on sliding mode control (SMC) for frequency load control sets Sliding mode control is a kind of nonlinear controllers that can control the system in the presence of structural or non-structural uncertainties in a desired way. This type of controller by means of a control rule with high speed switch between two control structures will put the system state variables at a certain level, called the sliding surface. This level is defined to ensure that always by pushing the system states to it, the desired control objective scan be met. In this type the control law is usually composed of two distinct parts. The first part push the system states to the sliding surface and the other's task is to keep the state on the sliding surface. Sliding mode controller, in addition to resist uncertainty, it has other advantages such as insensitivity to external disturbances, fast transient response and simplicity of design and implementation as well.

A brief outline of this paper is as follows: In Section 2, we provide a mathematical model of the power system. In section 3 frequency Load control based on sliding mode control is introduced. Finally, in Section 4, the result of the simulation is evaluated. The paper is presented in Section 5.

2. THE MATHEMATICAL MODEL OF THE POWER SYSTEM

Power system used in this study consists of two interconnected control areas, which each represents a thermal or water power plant. Each control area has frequency load control of its own. The power system is modeled as a continuous, while the control signals are sent to equipment in discrete-time mode.

It is assumed that the power of the control area number1 is a water plant, while the 2nd control is a thermal power plant. Load frequency control based on sliding mode, used in CA1, while the other controlling area is based on the common algorithm proportional relation integral controller.

$$\dot{\mathbf{x}}_i(t) = \mathbf{A}_i\mathbf{x}_i(t) + \sum_j \mathbf{A}_{ij}\mathbf{x}_j(t) + \mathbf{B}_i\mathbf{u}_i(t) + \mathbf{F}_i\mathbf{d}_i(t),$$
$$\mathbf{y}_i(t) = \mathbf{C}_i\mathbf{x}_i(t) \qquad (1)$$

$\mathbf{x}_i \in \mathbb{R}^n$ System State Vector

$\mathbf{x}_j \in \mathbb{R}^p$ Neighboring System State Vector

$\mathbf{u}_i \in \mathbb{R}^m$ Controlling Signal Vector

$\mathbf{d}_i \in \mathbb{R}^k$ Perturbation Vector

$\mathbf{y} \in \mathbb{R}^l$ Output Vector

Top matrices have the following dimensions:

$\mathbf{A}_i \in \mathbb{R}^{n\times n}$

$\mathbf{A}_{ij} \in \mathbb{R}^{n\times p}$

$\mathbf{B}_i \in \mathbb{R}^{n\times m}$

$\mathbf{F}_i \in \mathbb{R}^{n\times k}$

$\mathbf{C}_i \in \mathbb{R}^{l\times n}$.

CA model is more linear rather than nonlinear; since the sliding mode control is proposed based on linear models, linear error is included in terms of uncertainties. Linear continuous-time models in areas of hydro and thermal control equipment, respectively, have been shown in Figures 1 and 2.

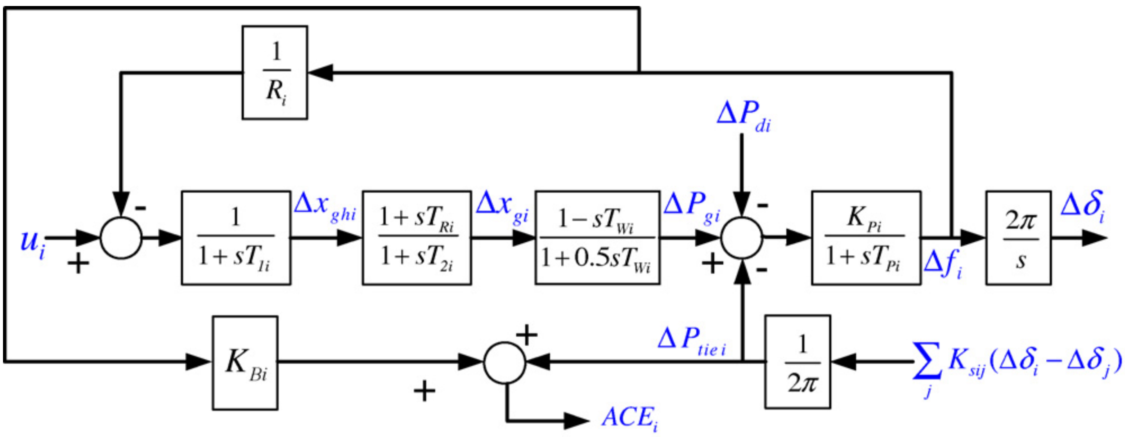

Fig.1. District 1 hydropower plant model system[13]

For the model shown in Figure 1, the state vector and confusion as follows:

$$\mathbf{x}_i(t) = \begin{bmatrix} \Delta f_i(t) \\ \Delta P_{tiei}(t) \\ \Delta P_{gi}(t) \\ \Delta x_{gi}(t) \\ \Delta x_{ghi}(t) \end{bmatrix}, \quad \mathbf{d}_i(t) = \Delta P_{di}(t) \qquad (2)$$

Matrices in equation (1) are as follows:

$$\mathbf{A}_i = \begin{bmatrix} -\frac{1}{T_{Pi}} & -\frac{K_{Pi}}{T_{Pi}} & \frac{K_{Pi}}{T_{Pi}} & 0 & 0 \\ \sum_j K_{Sij} & 0 & 0 & 0 & 0 \\ 2\alpha & 0 & -\frac{2}{T_{Wi}} & 2\gamma & 2\beta \\ -\alpha & 0 & 0 & -\frac{1}{T_{2i}} & -\beta \\ -\frac{1}{T_{1i}R_i} & 0 & 0 & 0 & -\frac{1}{T_{1i}} \end{bmatrix} \quad (3)$$

$$\mathbf{B}_i = \begin{bmatrix} 0 \\ 0 \\ -2R_i\alpha \\ R_i\alpha \\ \frac{1}{T_{1i}} \end{bmatrix}, \quad \mathbf{F}_i = \begin{bmatrix} -\frac{K_{Pi}}{T_{Pi}} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

With coefficients:

$$\alpha = \frac{T_{Ri}}{T_{1i}T_{2i}R_i}, \quad \beta = \frac{T_{Ri} - T_{1i}}{T_{1i}T_{2i}}, \quad \gamma = \frac{T_{2i} + T_{Wi}}{T_{2i}T_{Wi}} \qquad (4)$$

$\mathbf{A}_{ij}$ Matrices in Eq.(1) to describe the relationship depending on the water - heating or water –water have 5×4 or 5×5 dimensions. All elements are zero, except the elements in (1.2) which is equal.to $-K_{Sij}$

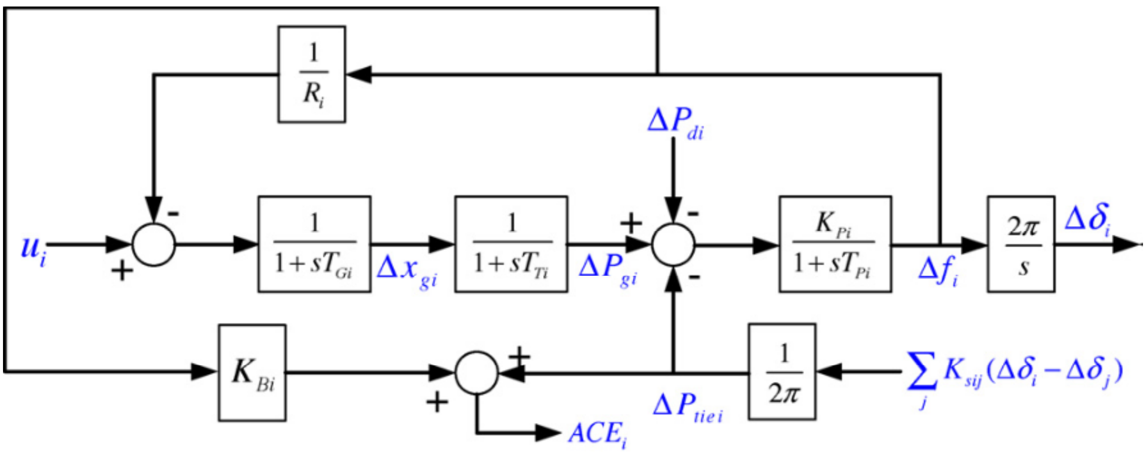

Fig.2. Thermal power plant model in district 2 system [۱۳]

For the thermal model shown in Figure 3 state and confusion vector as follows:

$$\mathbf{x}_i(t) = \begin{bmatrix} \Delta f_i(t) \\ \Delta P_{tiei}(t) \\ \Delta P_{gi}(t) \\ \Delta x_{gi}(t) \end{bmatrix}, \quad \mathbf{d}_i(t) = \Delta P_{di}(t) \qquad (5)$$

And the matrix is as follows:

$$\mathbf{A}_i = \begin{bmatrix} -\frac{1}{T_{Pi}} & -\frac{K_{Pi}}{T_{Pi}} & \frac{K_{Pi}}{T_{Pi}} & 0 \\ \sum_j K_{Sij} & 0 & 0 & 0 \\ 0 & 0 & -\frac{1}{T_{Ti}} & \frac{1}{T_{Ti}} \\ -\frac{1}{T_{Gi}R_i} & 0 & 0 & -\frac{1}{T_{Gi}} \end{bmatrix} \qquad (6)$$

$$\mathbf{B}_i = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{1}{T_{Gi}} \end{bmatrix}, \quad \mathbf{F}_i = \begin{bmatrix} -\frac{K_{Pi}}{T_{Pi}} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Here, too, depending on whether the matrix $\mathbf{A}_{ij}$ represents the relationship between thermal- thermal or thermal- water, the dimensions are 4×4 or 4×5. All elements are equal to zero, except for the element in position (1, 2) which is equal to $-K_{Sij}$.

Signals and parameters in Figures 1 and 2 are shown in Table 1.

An area control error signal as a measure of the deviation of the control of its proposed treatment have been introduced.ACE is defined as a combination of frequency deviation in a CA and active power flow deviations in the lines defined by the CA and its neighboring areas. ACE is to compensate for distortions in each area. Thus, the output of the system is defined as follows:

$$\mathbf{y}_i(t)=\mathbf{C}_i\mathbf{x}_i(t)=ACE_i(t)=K_{Bi}\Delta f_i(t)+\Delta P_{tiei}(t), \qquad (7)$$

On which K_B parameter can be set to ensure that the ACE is zero only when a disturbance occurs in CA.ACE signal values of all other CAs are specifically not affected by the disturbance

$\mathbf{C}_i$ Matrix in (7) for a CA with equipment of hydro is $\mathbf{C}_i=[K_{Bi} \quad 1 \quad 0 \quad 0 \quad 0]$ and for a thermal power plant is $\mathbf{C}_i=[K_{Bi} \quad 1 \quad 0 \quad 0]$.

3. LOAD FREQUENCY CONTROL BASED ON SLIDING MODE

Sliding mode control, a control method for time-varying control systems in the presence of external disturbances SMC which is only based on the output signal cannot be used in systems with non-minimum - phase because it may result in instability.

So in these cases SMC should be used based on complete system state.In order to improve the overall system behavior, confusion has been entered in the controller design.This article assumes that all the states of the system and turbulence can be measured.

Table 1 signals and parameters of the power system

Parameter / variable	***Description***	***Unit***
$\Delta f(t)$	Frequency deviation	Hz
$\Delta P_g(t)$	Deviation of power generator output	p.u. MW
$\Delta x_g(t)$	Diversion valve position of generator	p.u.
$\Delta x_{gh}(t)$	The head valve engine deviation of generator	p.u.
$\Delta P_{tie}(t)$	Deviation of active power communication line	p.u. MW
$\Delta P_d(t)$	Turbulent times	p.u. MW
$\Delta\delta(t)$	The tilt-rotor	Rad
K_P	Operation of the power system	Hz/ p.u. MW
T_P	Time constant of the power system	S
T_W	Since the beginning of the water	S
T_1, T_2, T_R	Water governor time constant	S
T_G	Governor time constant of water	S
T_T	Turbine time constant	S
K_S	The interest connection between the control areas	p.u. MW
K_B	Frequency bias factor	p.u. MW/Hz
R	Droop speed because of the governor act	Hz/ p.u. MW
ACE	Control area error	p.u MW

Equation (1) is an unchanging linear system model with time in the presence of external disturbances.But in real systems due to system dynamics which aren't modeled, or system parameters deviation there are many uncertainties that can severely affect system behavior. A continuous LTI system in (1) with uncertainties are described in the following result:

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t) + \mathbf{F}\mathbf{d}(t) + \xi(\mathbf{x},\mathbf{u},t) \qquad (8)$$

One way to classify the uncertainties in the system, is to dividing them to matched or non-matched uncertainties [14].

A condition which defines the similar uncertainties is as following:

$$\xi_m(\mathbf{x},\mathbf{u},t) \in \Re(\mathbf{B}) \qquad (9)$$

While all the other uncertainties are non-matched. Because of the comparative condition (4.9), matched uncertainties can be written as follows:

$$\xi_m(\mathbf{x},\mathbf{u},t) = \mathbf{B}\gamma \qquad (10)$$

In which:

$$\gamma \in \mathbb{R}^m$$

To better understand the dynamics of the system based on SMC and easier to synthesis the control, it is better if the system (8) be ordered in Canonical form [13]:

$$\begin{bmatrix}\dot{\mathbf{x}}_{c1}(t)\\ \dot{\mathbf{x}}_{c2}(t)\end{bmatrix} = \begin{bmatrix}\mathbf{A}_{11} & \mathbf{A}_{12}\\ \mathbf{A}_{21} & \mathbf{A}_{22}\end{bmatrix}\begin{bmatrix}\mathbf{x}_{c1}(t)\\ \mathbf{x}_{c2}(t)\end{bmatrix} + \begin{bmatrix}\mathbf{0}\\ \mathbf{B}_2\end{bmatrix}\mathbf{u}(t) + \begin{bmatrix}\mathbf{F}_1\\ \mathbf{F}_2\end{bmatrix}\mathbf{d}(t) + \begin{bmatrix}\xi_u(\mathbf{x},t)\\ \xi_m(\mathbf{x},\mathbf{u},t)\end{bmatrix} \qquad (11)$$

In which $\mathbf{x}_{c1}$ & $\mathbf{x}_{c2}$ represents the vector of state variables of the system which are separated subsystems of (8) system. In ordered form, uncertainties of the system are enumerated.to matched and non-matched. As of (11) can be seen, in Contiguous SMC o matched uncertainties can be fully compensated with an appropriate controlling signal, while is not correct about non-matched uncertainties.

Transforming of a system to an arranged form is performed by a non-singular conversion matrix .Matrix of the transformed system of the original system is obtained as follows:

$$\mathbf{x}_{cr}(t) = \begin{bmatrix}\mathbf{x}_{cr1}(t)\\ \mathbf{x}_{cr2}(t)\end{bmatrix} = \mathbf{T}_{cr}\mathbf{x}(t) = \begin{bmatrix} ACE_i(t)\\ \Delta P_{tiei}(t)\\ \Delta P_{gi}(t) + 2\Delta x_{gi}(t)\\ \Delta x_{gi}(t) - \frac{T_R}{T_2}\Delta x_{ghi}(t)\\ \Delta x_{ghi}(t)\end{bmatrix}, \qquad (11)$$

$$\mathbf{A}_r = \begin{bmatrix}\mathbf{A}_{11} & \mathbf{A}_{12}\\ \mathbf{A}_{21} & \mathbf{A}_{22}\end{bmatrix} = \mathbf{T}_{cr}\mathbf{A}\mathbf{T}_{cr}^{-1},$$

$$\mathbf{B}_r = \begin{bmatrix}\mathbf{0}\\ \mathbf{B}_2\end{bmatrix} = \mathbf{T}_{cr}\mathbf{B}, \qquad \mathbf{F}_r = \begin{bmatrix}\mathbf{F}_1\\ \mathbf{F}_2\end{bmatrix} = \mathbf{T}_{cr}\mathbf{F}.$$

3.1 Sliding Surface

The first step in the synthesis of the SMC controller is to select a sliding surface, which defines the desirable dynamics of the system:

$$\sigma(\mathbf{x}) = \mathbf{Sx} = \mathbf{0} \tag{13}$$

In which

$\mathbf{S} \in \mathbb{R}^{m \times n}$

is a switching matrix.

The aim of the SMC, is to deliver the system state to a sliding surface and then to keep it at this level. According to the statement, the system trajectory of SMC consists of two phases: One phase to achieve and the other slip phase. SMC to switch between different controlling structures (depending on the sign of the switching function) force the system trajectory to go to the sliding surface.The switching function is defined as follows:

$$\sigma(t) = \mathbf{Sx}(t) \tag{14}$$

It is important to distinguish between the sliding surface $\sigma(\mathbf{x}) = \mathbf{0}$, which is independent of time Many fold in the state space, and a switching function $\sigma(t)$, as a function of time dependent on the state of the system to the sliding surface.

For the system to be arranged in the form (11), the switching function will be as follows:

$$\sigma(t) = \mathbf{S}_{c1}\mathbf{x}_{c1}(t) + \mathbf{S}_{c2}\mathbf{x}_{c2}(t) \tag{15}$$

Where:

$$\mathbf{S}_{cr} = [\mathbf{S}_{c1} \quad \mathbf{S}_{c2}] = \mathbf{ST}_{cr}^{-1} \tag{16}$$

Sliding mode dynamics of the system is obtained from (11) and (15):

$$\begin{bmatrix} \dot{\mathbf{x}}_{c1}(t) \\ \dot{\sigma}(t) \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{A}}_{11} & \hat{\mathbf{A}}_{12} \\ \hat{\mathbf{A}}_{21} & \hat{\mathbf{A}}_{22} \end{bmatrix} \begin{bmatrix} \mathbf{x}_{c1}(t) \\ \sigma(t) \end{bmatrix} + \begin{bmatrix} \mathbf{0} \\ \hat{\mathbf{B}}_2 \end{bmatrix} \mathbf{u}(t) + \begin{bmatrix} \mathbf{F}_1 \\ \hat{\mathbf{F}}_2 \end{bmatrix} \mathbf{d}(t) + \begin{bmatrix} \xi_u(\mathbf{x},t) \\ \xi_s(\mathbf{x},\mathbf{u},t) \end{bmatrix} \tag{17}$$

In which

$$\begin{aligned} &\hat{\mathbf{A}}_{11} = \mathbf{A}_{11} - \mathbf{A}_{12}\mathbf{S}_c^*, \\ &\hat{\mathbf{A}}_{12} = \mathbf{A}_{12}\mathbf{S}_{c2}^{-1}, \\ &\hat{\mathbf{A}}_{21} = \mathbf{S}_{c1}\mathbf{A}_{11} - \mathbf{S}_{c1}\mathbf{A}_{12}\mathbf{S}_c^* + \mathbf{S}_{c2}\mathbf{A}_{21} - \mathbf{S}_{c2}\mathbf{A}_{22}\mathbf{S}_c^*, \\ &\hat{\mathbf{A}}_{22} = \mathbf{S}_{c1}\mathbf{A}_{12}\mathbf{S}_{c2}^{-1} + \mathbf{S}_{c2}\mathbf{A}_{22}\mathbf{S}_{c2}^{-1}, \\ &\hat{\mathbf{B}}_2 = \mathbf{S}_{c2}\mathbf{B}_2, \\ &\hat{\mathbf{F}}_2 = \mathbf{S}_{c1}\mathbf{F}_1 + \mathbf{S}_{c2}\mathbf{F}_2, \\ &\xi_s(\mathbf{x},\mathbf{u},t) = \mathbf{S}_{c1}\xi_u(\mathbf{x},t) + \mathbf{S}_{c2}\xi_m(\mathbf{x},\mathbf{u},t), \\ &\mathbf{S}_c^* = \mathbf{S}_{c2}^{-1}\mathbf{S}_{c1}. \end{aligned} \tag{18}$$

$\xi_s(\mathbf{x},\mathbf{u},t)$ phrase in (17) and (18) represents the sliding uncertainties that can be defined as general result of uncertainties in the dynamics of the sliding surface.

Entering the condition of sliding mode ($\sigma(t) = 0$) in the system (17), the sliding mode dynamics of the system will be as follows:

$$\dot{\mathbf{x}}_{c1}(t) = \hat{\mathbf{A}}_{11}\mathbf{x}_1(t) + \mathbf{F}_1\mathbf{d}(t) + \xi_u(\mathbf{x},t) \tag{19}$$

The improvement in the behavior of the system (19) is visible.One is that the level of system dynamics is reduced than the original system (11).Reduction factor is m , which is following the control signal of $\mathbf{u}(t)$ .Another improvement is system immutable than adapted uncertainties, whereas the other (19) are not present.

Note 1: For discrete-time systems, the improvement is not entirely correct. Because by the discrete control signal, system trajectory cannot be kept just on the surface and Matched uncertainties can affect the dynamics of the system.However, if bounded uncertainties are covered, system trajectory will remain within a narrow band in the vicinity of the sliding surface.

Switching matrix in (13) must be chosen in such a way that the system be stable in sliding mode. This means that all the eigenvalues of a matrix $\hat{\mathbf{A}}_{11}$ should be in the left half plane.

For LFC it is required that the output signal of the ACE system equal to zero at steady state.The output of the system at steady state of the sliding mode depends on the parameters of the $\mathbf{S}$ switching matrix [15].Thus, in addition to ensuring the stability of the sliding mode, the $\mathbf{S}$ matrix must be chosen such that the steady-state error of the system is minimized.

3.2 Control Act

A control law for approximation of discrete time ZOH will be calculate of joined-time LTI system with uncertainties (8)

$$\mathbf{x}((k+1)\tau) = \mathbf{G}\mathbf{x}(k\tau) + \mathbf{H}\mathbf{u}(k\tau) + \mathbf{W}\mathbf{d}(k\tau) + \xi_u(\mathbf{x},\mathbf{u},k\tau) \tag{20}$$

In which $\mathbf{G}$, $\mathbf{H}$ & $\mathbf{W}$ matrices, is obtained by the following equation.

$$\mathbf{G} = e^{\mathbf{A}_r\tau}, \quad \mathbf{H} = \int_0^\tau e^{\mathbf{A}_r t}\mathbf{B}_r dt, \quad \mathbf{W} = \int_0^\tau e^{\mathbf{A}_r t}\mathbf{F}_r dt \tag{21}$$

To calculate the control act, the discrete-time system (20) should be converted to a regular form by using a non-singular matrix $\mathbf{T}_{dr}$ .Conversion process is similar to that in the time continuous, arranged form of a discrete-time system will be as follows:

$$\begin{bmatrix}\mathbf{x}_1((k+1)\tau)\\ \mathbf{x}_2((k+1)\tau)\end{bmatrix} = \begin{bmatrix}\mathbf{G}_{11} & \mathbf{G}_{12}\\ \mathbf{G}_{21} & \mathbf{G}_{22}\end{bmatrix}\begin{bmatrix}\mathbf{x}_1(k\tau)\\ \mathbf{x}_2(k\tau)\end{bmatrix} + \begin{bmatrix}\mathbf{0}\\ \mathbf{H}_2\end{bmatrix}\mathbf{u}(k\tau) + \begin{bmatrix}\mathbf{W}_1\\ \mathbf{W}_2\end{bmatrix}\mathbf{d}(k\tau) \tag{22}$$

The above Sub block matrices are calculated as follows:

$$\mathbf{T}_{dr}\mathbf{G}\mathbf{T}_{dr}^{-1} = \mathbf{G}_r = \begin{bmatrix}\mathbf{G}_{11} & \mathbf{G}_{12}\\ \mathbf{G}_{21} & \mathbf{G}_{22}\end{bmatrix}, \quad \mathbf{T}_{dr}\mathbf{H} = \mathbf{H}_r = \begin{bmatrix}\mathbf{0}\\ \mathbf{H}_2\end{bmatrix}, \ \mathbf{T}_{dr}\mathbf{W} = \mathbf{W}_r = \begin{bmatrix}\mathbf{W}_1\\ \mathbf{W}_2\end{bmatrix} \tag{23}$$

For an Arranged form of a system, switching function defined as follows:

$$\sigma(k\tau) = \mathbf{S}_1\mathbf{x}_1(k\tau) + \mathbf{S}_2\mathbf{x}_2(k\tau) \tag{24}$$

In which

$$\mathbf{S}_r = [\mathbf{S}_1 \quad \mathbf{S}_2] = \mathbf{S}\mathbf{T}_{dr}^{-1} \tag{25}$$

By combining a discrete-time system in ordered form and the equation (25) system dynamics in the sliding mode comes in the form following

$$\begin{bmatrix}\mathbf{x}_1((k+1)\tau)\\ \sigma((k+1)\tau)\end{bmatrix} = \begin{bmatrix}\hat{\mathbf{G}}_{11} & \hat{\mathbf{G}}_{12}\\ \hat{\mathbf{G}}_{21} & \hat{\mathbf{G}}_{22}\end{bmatrix}\begin{bmatrix}\mathbf{x}_1(k\tau)\\ \sigma(k\tau)\end{bmatrix} + \begin{bmatrix}\mathbf{0}\\ \hat{\mathbf{H}}_2\end{bmatrix}\mathbf{u}(k\tau) + \begin{bmatrix}\mathbf{W}_1\\ \hat{\mathbf{W}}_2\end{bmatrix}\mathbf{d}(k\tau) + \begin{bmatrix}\xi_u(\mathbf{x},k\tau)\\ \xi_s(\mathbf{x},\mathbf{u},k\tau)\end{bmatrix} \tag{26}$$

That

$$
\begin{aligned}
&\hat{\mathbf{G}}_{11} = \mathbf{G}_{11} - \mathbf{G}_{12}\mathbf{S}^{*},\\
&\hat{\mathbf{G}}_{12} = \mathbf{G}_{12}\mathbf{S}_{2}^{-1},\\
&\hat{\mathbf{G}}_{21} = \mathbf{S}_{1}\mathbf{G}_{11} - \mathbf{S}_{1}\mathbf{G}_{12}\mathbf{S}^{*} + \mathbf{S}_{2}\mathbf{G}_{21} - \mathbf{S}_{2}\mathbf{G}_{22}\mathbf{S}^{*},\\
&\hat{\mathbf{G}}_{22} = \mathbf{S}_{1}\mathbf{G}_{12}\mathbf{S}_{2}^{-1} + \mathbf{S}_{2}\mathbf{G}_{22}\mathbf{S}_{2}^{-1},\\
&\hat{\mathbf{H}}_{2} = \mathbf{S}_{2}\mathbf{H}_{2},\\
&\hat{\mathbf{W}}_{2} = \mathbf{S}_{1}\mathbf{W}_{1} + \mathbf{S}_{2}\mathbf{W}_{2},\\
&\xi_{s}\left(\mathbf{x},\mathbf{u},k\tau\right) = \mathbf{S}_{1}\xi_{u}\left(\mathbf{x},k\tau\right) + \mathbf{S}_{2}\xi_{m}\left(\mathbf{x},\mathbf{u},k\tau\right),\\
&\mathbf{S}^{*} = \mathbf{S}_{2}^{-1}\mathbf{S}_{1}.
\end{aligned} \tag{27}
$$

The control law (26), will be calculated with a choice of law to be determined.Reaching law, is responsible for driving the system trajectory to the sliding surface. Among several of reaching laws, a linear reaching law of [16] for LFC is selected, defined as follows:

$$\sigma(k+1) = \Lambda\sigma(k) \tag{28}$$

Where $\Lambda$is a diagonal matrix whose elements are bound to $0 \le \lambda_i < 1$.

When this law in the system (26) is used and the uncertainties are negligible, reaching law (28) leads to following control law:

$$\mathbf{u}(k\tau) = \hat{\mathbf{H}}_{2}^{-1}\left[\left(\Lambda - \hat{\mathbf{G}}_{22}\right)\sigma(k\tau) - \hat{\mathbf{G}}_{21}\mathbf{x}_{1}(k\tau) - \hat{\mathbf{W}}_{2}\mathbf{d}(k\tau)\right] \tag{29}$$

Ignore the uncertainties, the control law (29) does not guarantee an ideal sliding mode.Instead, system trajectory in a quasi-sliding mode will remain in w_b band width. The bandwidth is dependent on the uncertainties slip vector component $\xi_s\left(\mathbf{x},\mathbf{u},k\tau\right)$, and matrix parameters [13]:

$$w_b = \sqrt{\sum_{i=1}^{m}\left(\frac{1}{1-\lambda_i}\max\left(\xi_{si}\left(\mathbf{x},k\tau\right)\right)\right)} \tag{30}$$

3-3: Application of SMC at LFC

Note 2. Since the control signal at LFC has a Dimension $1\; m = 1$ ،$\mathbf{u} \equiv u$ ،There is only one sliding surface.Therefore, the switching matrix can result into a switching vector And the arrival act matrix will be a scalar $\Lambda = \lambda$

$$\mathbf{S} = \begin{bmatrix} s_{ace} & s_{Ptie} & s_{Pg} & s_{xg} & s_{xgh} \end{bmatrix} \tag{31}$$

According to (12) vector switching to a CA in a hydropower plant is as follows:

$$\mathbf{S} = \begin{bmatrix} s_{ace} & s_{Ptie} & s_{Pg} & s_{xg} \end{bmatrix} \tag{32}$$

Parameters of switching vector Selection at (31) and (32)should ensure the stability of system in the sliding mode. And also to minimize the deviation of ACE in the steady state, which is the main goal of LFC.

4- Power system simulation of the control area

To test the proposed sliding mode algorithm, interconnected power system simulation includes two controlling area. A control area (CA1) is of the hydro power plant that would use the SMC controllers and other control area (CA2)is of the thermal power plant that controls the frequency load by using a PI controller Simulation system parameters can be seen in Table 2.$\tau = 1s$ Is the sampling time and duration of the simulation is. $T_{stop} = 120s$.

During the simulation, we entered two turbulence step into the system.A control area CA1 in the time $t = 1s$ and the amount of $P_{d1} = 1\%$ p.u.MW , and the other in the control area CA2 in the amount of $P_{d2} = -5\%$ p.u.MW . And the time $t = 30s$

Switching function in the control area CA1 is shown.in Figure 3 Can be seen that the system after a disturbance occurs, tends to slip back into sliding mode.

In Figure 4 the signal control error of area1 by using sliding mode control has been shown to lead to damping.Also in Figure 5 error signal for the second is displayed.

4. CONCLUSION

In this article by using sliding mode control system Load frequency controlled in two units consists of, t water and heat.By using the switching, path in the system mode can be directed towards the desired state

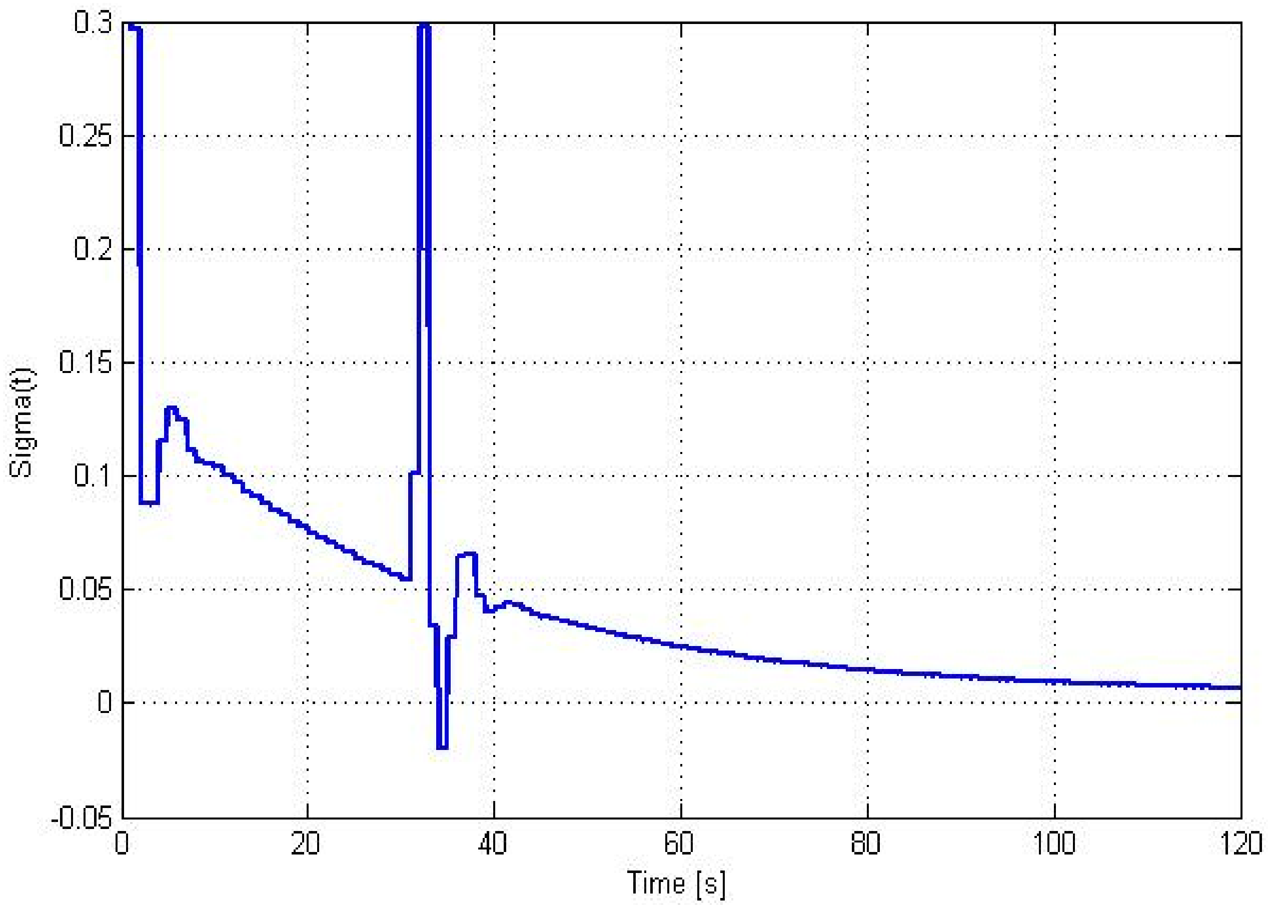

Fig.3.switching function based on the sliding mode control (CA1)

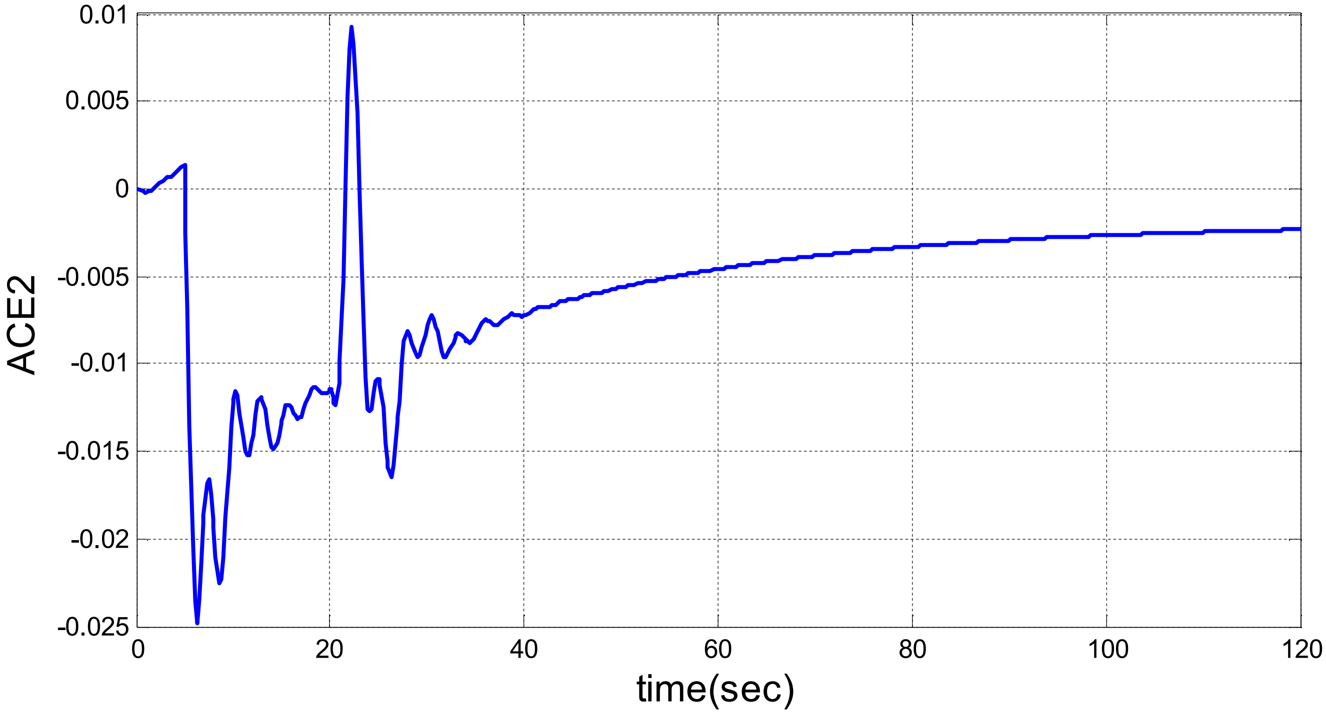

Fig.4. control error signal of area 1

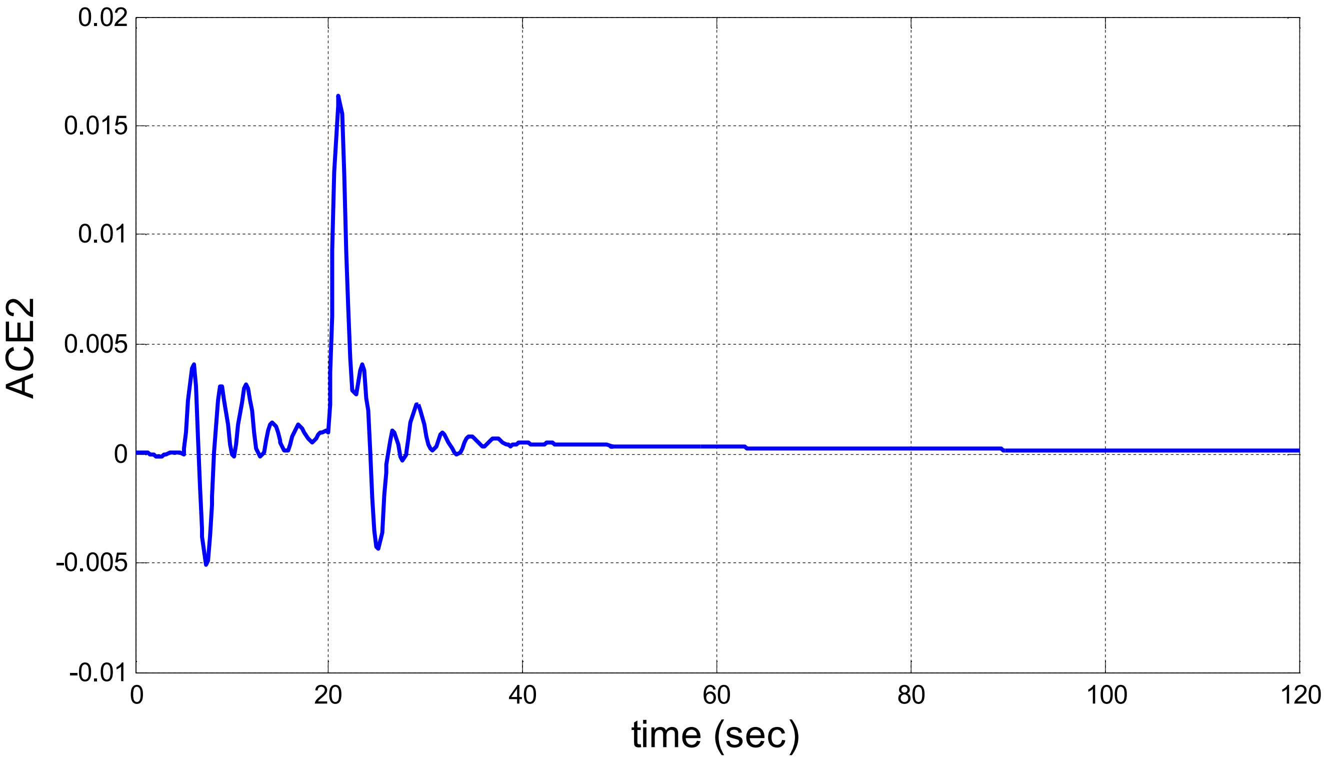

Fig.5.control error signal for area 2

Table.2 summarizes the parameters of power system simulation

Parameter	Unit	CA1	**CA2**
K_P	[Hz/p.u.MW]	80	120
T_P	[s]	13	25
R	[Hz/p.u.MW]	2.4	2.7
K_B	[p.u.MW/Hz]	0.43	0.38
T_R	[s]	6	_
T_1	[s]	5	_
T_2	[s]	48.7	_
T_W	[s]	1	_
T_G	[s]	_	0.072
T_T	[s]	_	0.33
K_{S12}	[p.u.MW]	0.5	0.5

which is diverted from the optimal path because of turbulence. By system simulation and the sliding mode control we show that this approach can be used to control the frequency load and disturbance damping as well enjoyed.

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