結合同步相量量測技術與彈性交流輸電裝置於電力系統穩定度改善研究 (2/3)

Research into Combination of Synchronized Phasor Measuring Technique and Flexible AC Transmission System Devices Applied to Improvement of Power System Stability (2/3)

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摘要：在本計劃中，提出一種適用於閘控串聯電容暫態穩定控制之具有自我修正能力的降階模型。本降階模型的建立僅需利用由同步向量量測單元所量測得到的即時資料即可。而降階模型與實際模型之間的誤差量亦可以利用即時的線上量測資料加以修正。另一方面，由於在降階模型推導時並沒有任何的線性化的假設。所以本降階模型很適合應用於多機系統之暫態穩定度控制。為了展示本計劃所提出之降階模型之適用性，本計劃亦發出一種以降階模型為基礎之迴授線性控制法則。最後，本計劃將所提出之控制器架構應用於一句含兩組閘控制串聯電容控制的六機十四匯流排之多機電力系統。由模擬的結果可以很知，本計劃所提出的控制器在系統加入嚴重的三相短路故障之後仍有相當良好的響應特性，而響應的結果也與原先的設計相符。另一方面，在經過系統參數變化的測試之後，本計劃所提出之降階模型亦具有相當優良的強健特性。

關鍵字：具自我修正能力之降階模型、迴授線性、同步向量量測單元、閘控串聯電容

Abstract: In this project, a self-correction reduced order model for thyristor controlled series capacitor transient stability control is proposed. The construction of the reduced order model needs only the real-time measurements by the Synchronized Phasor Measurement Units (PMUs), and the mismatch terms can be self corrected to match the real system performance. In addition, linearity approximation is not necessary in developing the model. Thus, the reduced order model is suitable for multimachine transient stability control. Feedback linearization control low based on the reduced order model is proposed to demonstrate the effectiveness of the reduced order model and good system performance can be easily achieved. This approach is used to design two thyristor controlled series capacitor (TCSC) controllers for a three-areas six-machine test system after a severe fault. All the feedback signals for the controller can be real-time measured from PMUs. The simulation results show the self-correction reduced order model is effective and robustive for stabilizing transient stability swings of interconnected systems under various conditions including various system uncertainty and post-fault change of network configuration.

Keyword : Self-correction reduced order model, feedback linearization, Synchronized PMUs, TCSC

I、計畫緣由及目的

近年來由於大容量電力電子元件逐漸開發完成，以及微處理機及通訊技術漸趨成熟，使得快速(high-speed)、即時(real-time)監測及控制電力輸電線路參數(電壓大小、相角及阻抗)成為在既有網路架構下，解決供電瓶頸、提高設備利用率的有效方法之一。彈性交流輸電系統(Flexible AC Transmission Systems, FACTS)的定義為以電力電子為基礎可增進輸電系統輸電量的裝置，例如：靜態虛功補償器(Static Var Compensator, SVC)、閘控串聯電容器(Thyristor Controlled Series Capacitor, TCSC)、相角控制器(Phase-Shifting Controller)、整合電力潮流控制器(Unified Power Flow Controller, UPFC)等。因此，FACTS裝置是在現有發電、輸電設備下改善系統穩定運轉之方法之一。FACTS裝置利用電力電子快速控制速度，達成系統理想運轉(指穩態、動態及暫態運轉情況下)：即對電網的電壓大小、相角及阻抗實行即時(real-time)的閉迴路控制(closed loop control)。故電力系統狀態即時量測對FACTS控制而言是非常重要。晚近發展的同步相量量測單元(synchronized phasor measurement unit, PMU)，以接收全球定位系統(Global Positioning System, GPS)所發出1Hz的觸發信號當做各量測單元時間共同參考軸。如此，可精確獲得相隔遙遠各匯流排相角差，其誤差為0.0216(徑度)(對60Hz系統而言)。PMU所即時量測到系統匯流排之相量可當做監測穩定度及FACTS迴饋信號之用。本期計畫目的則僅探討結合PMU及TCSC改善電力系統暫態穩定度。

II、 研究方法

A、Self-Correction Reduced Order Model

A.1 Reduced Order Model

Considering the interconnected power system transient stability regulation control, there need the information of COI state variables and their derivatives [1]. In addition, for the multimachine applications, there also need the reduced order model to reduce the computation burden in controller. In considering the multimachine power system including n generator bus and n + m bus, 3rd order generator model [7] is used to develop the reduced order model and the model including transmission line and load are written follows,

$$\dot{\delta}_i = \omega_i \quad i=1,..,n$$

$$M_i\dot{\omega}_i = P_{mi} - D_i\omega_i - E'_{qi}V_j\sin(\delta_i - \theta_j)/x'_{dsi},\ i=1,..,n$$

$$\dot{E}'_{qi} = (E_f(t) - E'_{qi} + I_{di}(x_{di} - x'_{di}))/T'_{do},\ i=1,\dots,n$$

$$I_{di} = (E'_{qi} - V_j\cos(\delta_i - \theta_j))/x'_{dsi},\ i=1,\dots,n$$

$$P_i^0 = \sum_{j=1}^{n} V_iV_j(g_{ij}\cos(\theta_i - \theta_j) + b_{ij}\sin(\theta_i - \theta_j)),\ i=1,..,m$$

$$Q_i^0 = \sum_{j=1}^{n} V_iV_j(g_{ij}\sin(\theta_i - \theta_j) - b_{ij}\cos(\theta_i - \theta_j)),\ i=1,..,m \quad (1)$$

where

M_i - inertia of each generator i,

P_{mi}, D_i- the desired mechanical power input and damping of generator i,

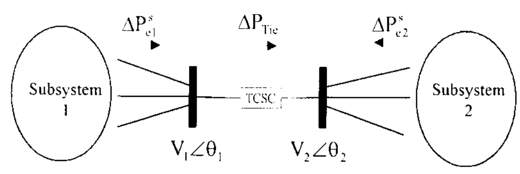


Figure 1 、Two-area interconnected system with a weak tie-line

P_i^0 – the constant real power injection of bus i.

Q_i^0 – the constant image power injection of bus i..

E'_{qi} - the transient EMF in the q-axis of the generator i

T'_{do} - d-axis transient short circuit time constant of the generator i

x'_{di}, x_{di} - synchronous and transient d-axis reactance of the generator i,

δ_i, ω_i - the power angle and angle speed of the generator i,

V_i, θ_i – the voltage magnitude and angle of bus i.

g_{ij} , b_{ij} – the conductance and susceptance of transmission line between bus i and bus j.

the network algebraic equations are denoted at the nodes 1,..,m, and the generator internal nodes are denoted at the nodes m+1,..,m+n.

Considering the inter-area dynamics of the interconnected system, the interconnected system can be divided into two areas interconnected by a relatively weak tie such as Fig.1, and a TCSC has been placed in series with the transmission line to increase the power transfer capability, and to provide additional damping to the inter-area mode oscillation in this system.. In [1], one reduced model has been proposed for the multimachine inter-area mode oscillation. However, the parameters of the internal voltages of this model corresponding to the COI are not measurable variables. Therefore, there needs another reduced order model suitable for real-time application. In developing the reduced order model, the following central of inertia (COI) variables should be defined first

$$
\begin{aligned}
M_1^s &= \sum_{i=1}^{k} M_i & M_2^s &= \sum_{i=k+1}^{n} M_i \\
\delta_1^s &= \sum_{i=1}^{k} M_i\delta_i / M_1^s & \delta_2^s &= \sum_{i=k+1}^{n} M_i\delta_i / M_2^s \\
\omega_1^s &= \sum_{i=1}^{k} M_i\omega_i / M_1^s & \omega_2^s &= \sum_{i=k+1}^{n} M_i\omega_i / M_2^s \qquad (2)
\end{aligned}
$$

, where indices i=1..k refer to the generators in subsystem 1, and indices i=k+1..n denotes generators in subsystem2. Therefore, two-machine equivalent of the inter-area dynamics is given by

$$
\begin{aligned}
\dot{\delta}_i^s &= \omega_i^s & &, i=1,2 \\
\dot{\omega}_i^s &= \frac{1}{M_i^s}\Delta P_{ei}^s & &, i=1,2 \qquad (3)
\end{aligned}
$$

where $\Delta P_{ei}^s = \sum_j (P_{mj} - P_{ej})$, $\begin{cases} j = 1..k & \text{for } i = 1 \\ j = k+1..n & \text{for } i = 2 \end{cases}$ (4)

P_{ej} : the real power output of generator j .

Due to the highly inductive nature in transmission lines, the interconnected transmission line can be approximated as lossless network. Then the model of (3) of subsystem 1 can be reduced as

$$
\begin{aligned}
\dot{\delta}_1^s &= \omega_1^s \\
\dot{\omega}_1^s &= \frac{1}{M_1^s}\Delta P_{Tie} \qquad (5)
\end{aligned}
$$

$$\Delta P_{Tie} = P_{spec} - \frac{V_1 V_2}{x_L}\sin(\theta_1 - \theta_2) \qquad (6)$$

, where θ_1 and θ_2 are the phase angles of the tie-line terminal bus voltages, V_1 and V_2 are the magnitudes of the tie-line terminal bus voltage, x_L is the transmission line equivalent impedance between two tie-line terminal bus, and P_{spec} is the desired real-power transmission between the interconnected system in steady state. Thus, the dynamic behavior of subsystem 1 can be represented with the real-time measurements of the tie-line terminal voltage phasors.

Now, the dynamic behavior between two subsystems can be further reduced as the following reduced order model:

$$
\begin{aligned}
\dot{\delta}_{COI}^s &= \omega_{COI}^s \\
\dot{\omega}_{COI}^s &= \frac{1}{M_1^s}\Delta P_{Tie} + \frac{1}{M_2^s}\Delta P_{Tie} \qquad (7)
\end{aligned}
$$

where

$$\delta_{COI}^s = \delta_1^s - \delta_2^s \qquad \omega_{COI}^s = \omega_1^s - \omega_2^s \qquad (8)$$

and can be further simplify as

$$
\begin{aligned}
\dot{\delta}_{COI}^s &= \omega_{COI}^s \\
\dot{\omega}_{COI}^s &= \frac{1}{M_T^s}\Delta P_{Tie} \qquad (9)
\end{aligned}
$$

where

$$\frac{1}{M_T^s} = \frac{1}{M_1^s} + \frac{1}{M_2^s}$$

Thus, one can note that the dynamic performance between two subsystems can be controlled by suitable tuning ΔP_{Tie}. In addition, the can be ΔP_{Tie} further controlled by suitable tuning transmission line impedance (TCSC) or terminal voltage (SVC) ... etc. In this project, the series compensator device of TCSC is preferred and the transmission line impedance x_L can be replaced as $x_L + x_{eq}$, where x_{eq} is the equivalent impedance of the variable impedance model of TCSC device. In addition, if the terminal voltage phasor is measured just beside the TCSC device terminal, the x_L will equal to x_{eq} The reduced order model proposed in this project can be applied to any control strategy such as optima aim strategy, time optimal bang-bang control...etc. Moreover, the reduced order model proposed in this project is only used for the controller design. In time-domain simulation, the Eq.(1) model or more higher order model in [6] of interconnected multimachine system is needed. In section IV the 6-order model is used on test system to demonstrate the robustness of the proposed model.

A.2 Self-Correction Reduced Order Model

In developing the proposed reduced order model, we need the following assumptions:

- Transmission line is lossless.
- Load model is assumed as constant power load.
- Local mode oscillation in each subsystem well damped and could be ignored in reduced order model.

In the normal systems, the above assumptions might be reasonable, and the errors between the reduced-order system and the real system can be neglected. While the systems are different from the above assumptions, the errors between the reduced order system and the real system can't be neglected no more and will take the majority effect in transient period. Thus, the response of the real system would not follow the desired response and remains some uncontrolled transient.

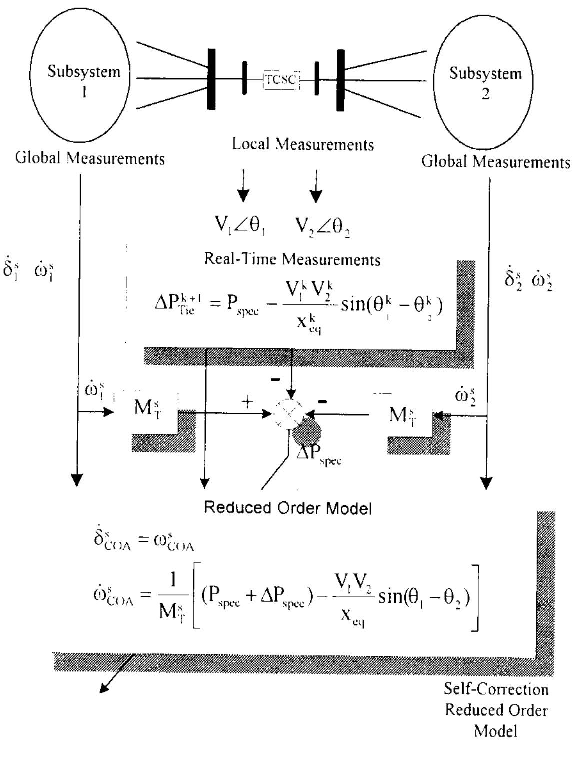


Figure 2 、Self-Correction reduced order model block diagram

Therefore, there must find some strategies to quantified the above errors and tuning the reduced order model to follow the real system.

To quantified the above errors caused by the above assumptions, we can replace the Eq.(6) as

$$\Delta P_{Tie} = (P_{spec} + \Delta P_{spec}) - \frac{V_1 V_2}{X_{eq}} \sin(\theta_1 - \theta_2) \quad (10)$$

where the mismatch term ΔP_{spec} represents the un-modeled real power oscillation between the generator side and the tie-line side generated by the transmission line resistance, local mode oscillation power and load bus, and the un-modeled oscillation term will become zero while the system states all reach their equilibrium point. While the system be perturbed by sever fault and their states does not reach their equilibrium point, the un-modeled mismatch term ΔP_{spec} will cause the COI accelerate signal $\dot{\omega}^s_{COI}$ of the reduced order model contains some errors and will not equal to the COI accelerate signal $\dot{\omega}_{COI}$ of the real system. Thus, one can use the errors of the $\dot{\omega}^s_{COI}$ to adaptive correct the un-modeled mismatch term ΔP_{spec} as follows

$$\Delta P^{k+1}_{spec} = M^s_T \dot{\omega}^k_{COI} - \Delta P^k_{Tie} \quad (11)$$

, where $\dot{\omega}_{COA}$ represents the COI speed deviation calculated from the phasor signals measured from PMUs ($\dot{\omega}_{COI} = d^2\delta^s_{COI}/dt^2$), and the superscript k+1 and k represent the variables at time instant k+1 and k. The result self-correction reduced order model is illustrated in Fig.2. Therefore, the parameter ΔP_{spec} of the proposed reduced order model can be self-correction to follow the real system, and the un-modeled errors caused by the above two assumptions can be almost eliminated.

B 、Feedback Signal Synthesis

In considering the proposed reduced order model, the state variables of the reduced order model are the COI power angles and speed signals in each subsystem. Instead of measuring COI power angles, which are difficult to measure, we try to find the buses whose voltage angles are most sensitive to the COI power angle of the reduced order model to achieve the output feedback control.

In previous work of [2], optimal placement of PMUs has been developed based on coherency variables analysis. In considering the reduced order model application, PMUs placement strategy based on COI variables is necessary. Therefore, the relationship between COI aggregate state variables and output variables is needed. We may first linearize the power system model around the normal operating point and one can get the linearized state equations as follows

$$\dot{x} = Ax + Bu \quad (12)$$

$$y = Cx \quad (13)$$

where x is the state vector of the system, y and u are the system output vector and command vector respectively. In this study, x is the generator power angle, y is the bus voltage angle measured by PMUs, u is the command generated from the TCSC controller. Matrices A 、B and C are the constant matrices evaluated at the normal operating point, respectively. In considering the slow coherency decomposition proposed in [3], the dynamic behavior of the system could be approximated using the slow coherency aggregate variables, and the inertia weighted aggregate slow coherency variables are defined as follow.

$$x_{COI} = Gx \quad (14).$$

, where the non-zero entries of G are ratios of inertias. We could thus define a $m \times r$ selective matrix as H, where $H_{ij} = \langle C_i, G_j \rangle$, r is the number of coherency areas, n is the number of output variables, C_i is the ith row of matrix C, and G_j is the jth row of matrix G. For selecting the PMUs bus, one could further normalize each column of matrix H to get the normalized selective matrix R.

For each COI aggregate variable x^i_{COI}, the preferred bus to install PMU will contains the largest dynamic information of the considered COI aggregate variable and the least dynamic information of the other COI aggregate variables. Thus, the procedures of selection the PMU bus are as follows

1. Define a vector $S \in R^m$ for x^i_{COI} as follow

$$\begin{cases} S_j = R_{ji}, & \text{when } R_{ji} = \max_{1 \le k \le r} R_{jk} \\ S_j = 0, & \text{otherwise} \end{cases}$$

2. The PMU is installed at bus j, when $S_j = \max_{1 \le k \le m} S_k$.

Once the bus has been selected to install PMUs, the δ^s_i dynamic behavior of subsystems i could be approximated by the dynamic behavior of the selected bus voltage angle θ^i_k (where bus $k \in$ subsystem i). To simplify the representation of bus voltage angle, one could define variable $\theta^*_i \equiv \theta^i_k$ to represent the bus voltage angle. In considering the inter-area mode between subsystems 1 and 2, δ^s_{12} could be approximated by $\theta_{12} = \theta^*_1 - \theta^*_2$, and the relationship could be thought as $\dot{\theta}_{12} = \dot{\delta}^s_{12} + \varepsilon$, where ε is a small random variable. If the PMUs bus have been selected properly, one could have the following relationship $\varepsilon << \dot{\delta}_{12}^{s}$, and ε will decay to zero while system state reach its equilibrium point. Thus, the dynamic behavior of the COI power angle between two subsystems could be approximated with the bus voltage phasors measurements.

C、Reduced Order Model Based Controller Design

Up to now, the self-correction reduced order model has been proposed. In this section, the nonlinear control strategy is discussed to demonstrate the effectness of the proposed reduced order model. Due to the direct feedback linearization (DFL) control law [4,5] has been proven as a powerful technique for transient stability control in single machine infinite bus system, the DFL is also used in this project for reduced order model based multimachine controller design. By using the proposed reduced order model, DFL control law can be easily applied to multimachine system.

From the proposed reduced order model, the multimachine power system can be reduced to a nonlinear two orders system. Then, the problem is to find a nonlinear feedback such that the closed-loop system is equivalent to a system whose input-output map is linear and decoupled. In this section, the design principles using a direct feedback linearization (DFL) technique to design a nonlinear controller for the multimachine power system.

Considering the reduced order model of Eq.(5,10), the nonlinear terms of this equation can be replace with command v(t) and rewritten as follows:

$$\dot{\delta}_{COI}^{s} = \omega_{COI}^{s} \qquad \dot{\omega}_{COI}^{s} = v(t) \tag{15}$$

$$v(t) = \frac{1}{M_T^s}\Delta P_{Tie} = \frac{1}{M_T^s}\left[(P_{spec} + \Delta P_{spec}) - \frac{V_1V_2}{x_{eq}}\sin(\theta_1 - \theta_2)\right] \tag{16}$$

. Then, the linear control technique is used to design the command v(t) as follows:

$$v(t) = -K\omega_{COI}^{s} \tag{17}$$

and the resulting system can be written as

$$\begin{bmatrix}\dot{\delta}_{COI}^{s}\\ \dot{\omega}_{COI}^{s}\end{bmatrix} = \begin{bmatrix}0 & 1\\ 0 & -K\end{bmatrix}\begin{bmatrix}\delta_{COI}^{s}\\ \omega_{COI}^{s}\end{bmatrix} \tag{18}$$

Then, substitute Eq.(17) into Eq.(16), the TCSC equivalent impedance can be designed as follows:

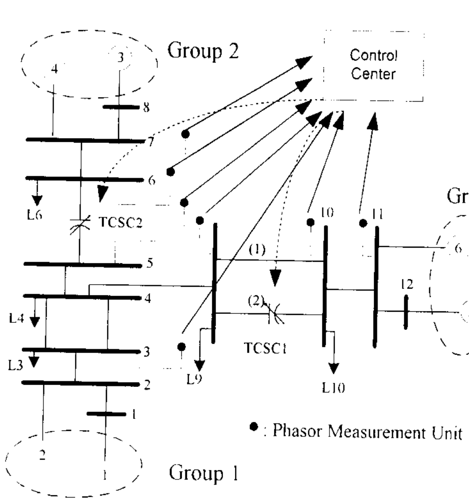


Figure 3、6-machines, 14-bus test system

$$\bar{u} = x_{eq} = r\left\{(V_1V_2\sin\theta_{12})\Big/\left[(P_{spec} + \Delta P_{spec}) + M_T^s K\omega_{COI}^s\right]\right\} \tag{19}$$

It is observed that Eq.(17) is a pure linear state equation. If K is chosen, all the parameters of the linear state equation are known. The behavior of the nonlinear system is just equivalent to a linear one by adding the DFL based TCSC controller. Therefore, one can use the linear control technique to design parameters K, and the relationship between the settling time t_s and parameter K can easily be described as t_s=4/K (steady state error =2%). In addition, the selection of parameter K is independent on system operating point, and the controlled system can be thought as a global stable system. Moreover, all signals involved in Eq.(19) are available from PMUs, and the real-time application can be easily achieved.

The design process of the reduced order model based DFL TCSC controller is very easily and straightforward by properly choosing parameter K. In addition, due to the linearity of the closed-loop system, the linear control theory can be easily applied in the selection of parameter K.

D、Robustness Discussion

The most important issues of DFL controller are eliminated the nonlinear terms in the model and tuning the performance of the system as specified linear system by using the controller command. Therefore, the most important issue in the controller designing is the validity of the system model. If there exists some un-modeled mismatch terms between the system model and the real system, the DFL technique can no longer be used and. Furthermore, while the mismatch terms can not be ignored, the un-modeled terms will cause some un-controlled oscillation and the system response will become un-controlled.

In considering the robustness of the reduced order model based controller, the above three assumptions of the reduced order model can be all considered as the mismatch terms of Eq.(11). Thus, the reduced order model will be thought as validity and the robustness of the reduced order model based DFL controller can be easily achieved, and some simulation in next section will be shown.

III、 結論與成果

A.、Simulation Results

In this section, the reduced order model based DFL controller is applied to a three-areas, six-machine multimachine power system with two TCSC devices shown in Fig.3. The transmission system data, the data of generation and load are the same as [6] and no power system stabilizers (PSS) are installed for subsystem local mode oscillation. For demonstrate the robustness of the reduced order model, all generators are identical and modeled with 3 state variables [7] instead of classical model, and the exciter model block diagram and the machine and exciter data are the same as [6]. Constant impedance load model are also used instead of the constant PQ load model. Compensation range of TCSC1 and TCSC2 are x^{max}=0.2pu (25% compensation), x^{min}=-0.5p.u. (62.5% compensation) and equilibrium operating point $\bar{x}$ =-0.4pu (50% compensation). The three areas of machines in the system are circled in Fig.3.

Many simulation studies have been carried out on the test system. Due to the space constraints, only one example has been presented. A three phase fault occurs at the tie line between Bus9 and Bus10 near Bus9 without TCSC at the instant t=0.167sec. Fault cleared after six cycles, and transmission line is disconnected. The COI speed of all three areas are defined as

COI speed of area 1 = $(\omega_1+\omega_2)/2$

COI speed of area 2 = $(\omega_3+\omega_4)/2$

COI speed of area 3 = $(\omega_5+\omega_6)/2$

, where ω_i is defined as the power angle speed of generator i.

In order to analysis the three areas system, two COI subsystems speed signals of $Speed_1$ and $Speed_2$ are defined for applying the proposed controller

$Speed_1$ = (COI speed of area 1 + COI speed of area 2)/2 – COI speed of area 3,

$Speed_2$ = (COI speed of area 2 + COI speed of area 3)/2 – COI speed of area 1.

Thus, the three-areas two TCSCs controller system can be divided into two independent subsystems by using the proposed reduced order model. In addition, if three TCSCs are considered in the system, the original system can be further divided into three subsystems by using the same strategies. According to the proposed reduced order model based DFL design procedures, the controller parameters K of two TCSC all setting as 5 while the settling time of two COI variables are all settling as 0.8sec ($K=4/t_s=4/0.8$). The simulation results of the $Speed_1$ and $Speed_2$ speed signal are shown in Fig.4(a) and Fig.4(b), respectively. In Fig.4, the solid line show the controlled case and the uncontrolled case are shown as dashed line for comparison. One can see that the system have good performance under severe fault by using the proposed reduced order model based controller, and the response of the system can follow the specified setting.

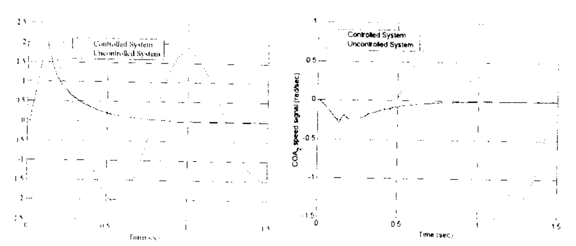
In the following simulations, the robustness and accuracy of the reduced order model based DFL controller is discussed. Considering the robustness of the reduced order model based controller, system uncertainty will be thought as represented by using two parameters as k_r and cPQ, and the definition of two parameters written as follows

- k_r = R/X, the transmission line resistance and inductance ratio (in the normal case, k_r=0.1).
- cPQ = 1, Load bus modeled as constant PQ model
  cPQ = 0, Load bus modeled as constant impedance model

One can note that the un-modeled mismatch term between the proposed reduced order model and the real system would be vanished while k_r=0 and cPQ=1. The robustness discussion of the reduced order model will include k_r=0, 0.05, 0.1, 0.15, 0.2 and cPQ=0, 1. The simulation results with and without self-correction are shown in Fig.5(a) and Fig.5(b) respectively. In Fig.5(a), the simulation results are not depend on the system uncertainty, and the system response will always follow the specified performance. In Fig.5(b), the simulation results are depend on the variation of system uncertainty, due to the un-modeled mismatch terms will take the majority effects while the major transient response has been nearly damped out. One can note that the special case of cPQ=1 and k_r=0 in Fig.5(b) may follow the specified setting. Considering the accuracy of the reduced order model based DFL controller, different settling time (t_s=0.2, 0.4, 0.8, 1.4 sec) is used. Fig.6 shows the system response of different settling time of DFL, and Fig.6(a) and Fig.6(b) show the reduced order model with and without self-correction respectively. In Fig.6(a), system response of different settling time are all follow its specified setting and accuracy. Otherwise, In Fig.6(b), system response are effect by the system uncertainty (k_r=1, cPQ=0) and will become un-controlled. In addition, the errors will become larger while the settling time becomes larger (K becomes smaller), due to the un-modeled mismatch terms will take majority effects while K becomes smaller. In addition, while the setting time becomes very small (K becomes very larger), the system response is almost follows the specified setting, due to the system transient can almost take the majority effect.

B 、Conclusions

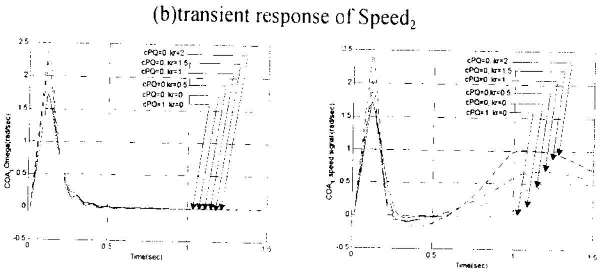
The self-correction reduced order model has been proposed for transient stability controller design. The shaping of the proposed model needs only the real-time measurements from PMUs and needs no linearize approximation. Thus, the proposed model can be easily applied to the nonlinear adaptive controller. For demonstration of the proposed model, the reduced order model based DFL controller also has been proposed. By using the proposed controller, the response of the system can be easily specified. In considering the robustness of the proposed controller, the un-modeled mismatch terms between the proposed reduced order model and the original system also can be easily corrected by using the real-time measurements. The simulation results also show that the reduced order model based DFL TCSC controller are effective and robustive for transient stability control of interconnected systems under various mismatch conditions or post-fault change of network configuration. In addition, due to the reduced order system always remains as a two order system, reduced order model based controller design can easily be applied to other larger interconnected systems. In the future, the proposed reduced order model based controller will be tried to apply on actual interconnected power systems, such as Taiwan power system (which is a longitudinal interconnected power system).



(a) (b)

Figure 4 、(a) transient response of $Speed_1$

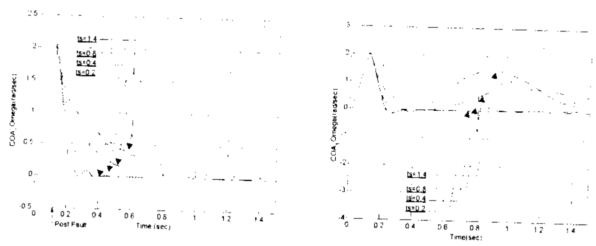
(b)transient response of $Speed_2$



(a) (b)

Figure 5 、(a) robustness analysis with self-correction

(b)robustness analysis without self-correction



(a) (b)

Figure 6、(a) different settling with self correction

(b) different settling without self correction

計劃成果：

本計劃部分成果已發表於下列國際會議及期刊上：

- Chi-Shan Yu and Chih-Wen Liu, "A Practical Design of TCSC Controllers for the Inter-area Transient Stability Control Using Real-Time Measurement", presented in the IEEE 1999 Winter Power Meeting.
- Jun-Zhe Yang and Chih-Wen Liu, "A Precise Calculation of Power System Frequency and Phasor", accepted by IEEE Transactions on Power Delivery.

IV、參考文獻

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