論 文
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최적선형 추적법에 의한 부하-주파수제어

Load Frequency Control by Optimal Linear Tracking

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요 약

본 논문은 실재전력 계통에서 계속적인 부하변화시 즉각적인 주파수 제어가 가능하도록 하기 위하여 LFC에 최적선형 추적법을 도입하였다. 기존의 부하주파수제어는 부하의 변화에 의하여 발생하는 계통상태 오차의 폐루프제어에 의하여 이루어진다. 따라서 계속적인 부하변화에 따라 주파수제어를 하기 위해서는 부하가 변화할때 마다 계통의 기준상태를 변화시켜야 한다. 본 연구에서는 LFC에 최적선형 추적법을 도입함으로써, 고정된 기준상태에서 폐루프 제어가 이루어질수 있도록 하였다. 제시한 LFC는 계통기준상태의 변화없이, 리크로져나 피터 스위치의 개폐에 따른 부하 변화에 의한 계통의 계속적인 교란시에 효과적으로 적용할 수 있다. 또한 이 부하주파수 제어시, 상태와 제어입력의 변화량을 최소로 유지시키면서 원하는 제어를 만족시키는 최적정상 상태를 구하는 기법을 제시하였다. 제시한 부하주파수 제어를 연계된 전력계통에 적용한 결과 계속적인 부하변화에 대하여 효과적으로 적용될 수 있음을 보였다.

Abstract-This paper presents a load frequency control by optimal linear tracking, which can be well adapted to practical power systems with successive load disturbances. Conventional Load Frequency Controls (LFC's) have a feedback control scheme of the state error deviated from the post-disturbance steady state. This requires the modification of reference everytime the system encounters load changes. In this study, a new feedback scheme of LFC is developed by using the optimal linear tracking method with a fixed reference. As a result, the proposed LFC, which requires no reference modification, can be efficiently applied to power systems with successive disturbances such as load changes due to the on-off operations of reclosers or feeder switches. Another feature of the proposed LFC is that it adopts an algorithm to calculate an optimal post-fault steady state with the consideration of control input changes. The proposed LFC has been tested for a 2-area power system, which shows that it can be well adapted to successive load disturbances with good frequency response.

1. Introduction

Power system should be operated to provide with good quality of electricity. Recently, the fast growth in the precision machinary industry req-uires the exactness in the voltage and frequency of supplied electricity. The frequency control has been one of the major topics in the power system operation. Theories of optimal frequency control

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are well-established with the use of the optimal control theory. However, most of power systems still experience difficulties in suppressing frequency fluctuation. Since Elgerd and Fosha 1)proposed an optimal frequency control technique based on the linear regulator theory, many papers have been presented. However, most of the conventional LFC (Load-Frequency Control)techniques adopted a feedback control scheme by taking the state error deviated from the post disturbance steady state. This requires the successive reference modification in the LFC whenever the system encounters a disturbances such as load changes and generator outages. On the other hand, Kwatny et al. 2)attempted to apply an optimal tracking theory. They presented the basic idea of the optimal tracking approach to the load frequency control without the detailed discussion of the determination of target trajectory.

In this study, a new feedback scheme of LFC is developed by using the optimal linear tracking method with a fixed reference. The proposed LFC technique presents a precise method of the determination of target trajectory after system disturbance. As a result, the proposed LFC, which is of no need of reference modification, can be efficiently applied to practical power systems with successive a disturbances such as load changes due to the on-off operations of reclosers or feeder switches. Another feature of the proposed LFC is that it adopts an algorithm to calculate an optimal post fault steady state with the consideration of control input changes.

The proposed LFC technique is tested for a two-area power system, which shows that it can be well adapted to successive load disturbances with good frequency response.

2. System Modeling

The generator control system has two control loops : megawatt-frequency control loop and voltage excitation loop. Since the latter has very fast response compared with the former, the excitation control loop is usually regarded to be independent of the megawatt-frequency control loop. On the other hand, the voltage variation should be reflected to the frequency control loop due to the voltage dependency of loads.

This study deals with the load frequency control of a 2-area system, and adopts a LFC model which was established by Aggarwal 3)under the above considerations. The control block diagram is shown

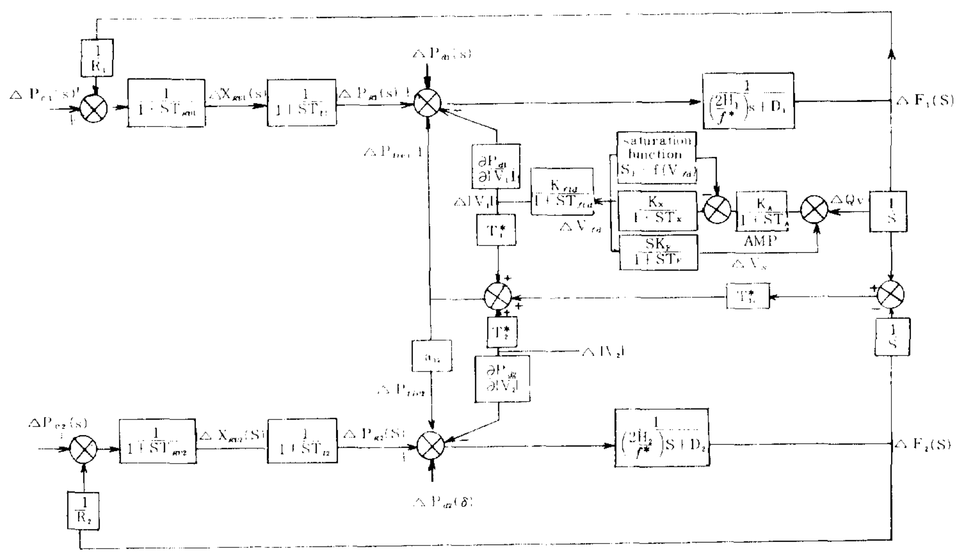


Fig. 1 Frequency control model of 2-area system.

in Fig. I. However, this study considers the excitation system in more detail in area I in order to take account of the load changes due to voltage variations. In area II, it is assumed that the voltage is controlled optimally with fast response by the practical approximation as mentioned above. This assumption allows us to consider the generator terminal voltage as a control variable.

For the control system in Fig. I, the state variables $\underline{x}$, input signals $\underline{u}$, and disturbance variables $\triangle \underline{P}_d$ are selected as follows :

State variable vector :

$$\underline{x}=[x_1, x_2, x_3, x_4, x_5, x_7, x_8, x_9, x_{10}, x_{11}]^T$$

$$\begin{array}{lll} x_1=\int \Delta f_1(t)\,dt & x_2=\Delta f_1(t) & x_3=\Delta P_{G1} \\ x_4=\Delta x_{gv1} & x_5=\int \Delta f_2(t)\,dt & x_6=\Delta f_2(t) \\ x_7=\Delta P_{G2} & x_8=\Delta x_{gv2} & x_9=\Delta |V_1| \\ x_{10}=\Delta V_{fd} & x_{11}=\Delta V_s & \end{array} \tag{1}$$

Input signal :

$$\underline{u}=[\Delta P_{C1}, \Delta P_{C2}, \Delta Q_V, \Delta |V_2|] \tag{2}$$

Where $\triangle P_{c1}$, P_{c2} : positions of speed changers of Generator I and Generator II respectively

$\triangle Q_V$: control variable for excitation system

$\triangle |V_2|$: voltage perturbation in area II (used as a control variable)

Disturbances :

$\triangle \underline{P}_d=[\triangle P_{d1}, \triangle P_{d2}]$

where $\triangle P_{d1}$, $\triangle P_{d2}$: load disturbances in Areas I and II

The state equation for the system model can now be giyen as follows :

$$\dot{\underline{x}}\ (t)=A\underline{x}(t)+B\underline{u}(t)+\Gamma\Delta\,\underline{P}_d \tag{3}$$

The system matrices are as follows :

3. Load Frequency Control by Optimal Linear Traking

3.1 Introduction

$$A=\begin{bmatrix}
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\frac{-f^*T_{12}^*}{2H_1} & \frac{-f^*D_1}{2H_1} & \frac{f^*}{2H_1} & 0 & \frac{f^*T_{12}^*}{2H_1} & 0 & 0 & 0 & \frac{-f^*\left(T_1^*+\frac{\partial P_{d1}}{\partial |V_1|}\right)}{2H_1} & 0 & 0 \\
0 & 0 & \frac{-1}{T_{t1}} & \frac{1}{T_{t1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{-1}{T_{gv2}R_1} & 0 & \frac{-1}{T_{gv1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
\frac{-a_{12}f^*T_{12}^*}{2H_2} & 0 & 0 & 0 & \frac{a_{12}f^*T_{12}^*}{2H_2} & \frac{-f^*D_2}{2H_2} & \frac{f^*}{2H_2} & 0 & \frac{a_{12}T_{12}^*f^*}{2H_2} & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{t2}} & \frac{1}{T_{t2}} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{gv2}R_2} & 0 & \frac{-1}{T_{gv2}} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{fld}} & \frac{K_{fld}}{T_{fld}} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-(1+K_XS_E)}{T_X} & \frac{-K_XK_A}{T_X} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-K_F(1+K_XS_E)}{T_FT_X} & \left(\frac{1}{T_F}+\frac{K_AK_XK_F}{T_FT_X}\right)
\end{bmatrix} \tag{4a}$$

$$B=\begin{bmatrix}
0 & 0 & 0 & \frac{1}{T_{gv1}} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{T_{gv2}} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{K_AK_X}{T_X} & \frac{K_AK_F}{T_F}\ \frac{K_X}{T_X} \\
0 & -\frac{f^*T_2^*}{2H_1} & 0 & 0 & 0 & -\frac{\left(a_{12}T_1^*+\frac{\partial P_{d2}}{\partial |V_1|}\right)f^*}{2H_1} & 0 & 0 & 0 & 0 & 0
\end{bmatrix}^T \tag{4b}$$

$$\Gamma=\begin{bmatrix}
0 & -\frac{f^*}{2H_1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{f^*}{2H_2} & 0 & 0 & 0 & 0 & 0
\end{bmatrix}^T \tag{4c}$$

A disturbances such as load changes, generator outages cause the fluctuation of system frequency. The load frequency controller should be designed to suppress these frequency fluctuations efficiently. Most of conventional LFCs are based on the linear regulation technique, which are unsuitable to the practical application as mentioned earlier. In this study, an optimal linear tracking technique is adopted to develop an efficient LFC which can be well-adapted to the practical power systems with incessant load changes.

If the system encounters a disturbance, the system state is fluctuated in accordance with the dynamic behaviours of the system and will finally transfer to a steady state via transient states. It is noted here that the final steady state can be controlled by changing references of input signals. With the use of the conventional approach, the LFC problem can be formulated as follows :

Minimize

$$\frac{1}{2}\int_{t_0}^{\infty}[(\underline{x}(t)-\underline{x}_{ss})^T Q(\underline{x}(t)-\underline{x}_{ss})+(\underline{u}(t)-\underline{u}_R)^T R(\underline{u}(t)-\underline{u}_R)]dt \quad (5)$$

subject to $\dot{\underline{x}}=A\underline{x}+B\underline{u}+\Gamma\Delta\underline{P}_d$

where t_0 : time when the disturbance occurs.

$\underline{x}_{ss}$: steady state after disturbance.

u_R : reference input after disturbance.

Therefore, the frequency control should be performed by the following procedures :

(i) If the system encounters a distur ance, determine optimal steady state x^*_{ss} and optimal reference inputs $\underline{u}^*_R$ after disturbance.

(ii) Perform an optimal control which can make the system state approach to the optimal post disturbance steady state with the fastest speed.

(iii) If any other disturbance is encountered, repeat the above procedures.

On the other hand, any disturbance which may occur in the near future is not considered in the determination of the input control at the present moment. This is because the disturbance occurs at random in time and magnitude.

In the above procedures, the LFC can be formulated as an optimal linear tracking problem if we consider the trajectory of the post-disturbance steady state as the target trajectory to track. Consequently, this study is aimed to apply the linear tracking technique to the LFC. In this section, an efficient method to determine the optimal target trajectory after disturbance is presented, and next the optimal LFC algorithm will be developed.

3.2 Calculation of Optiml Target Trajectory and Reference Input after Disturbance

An occurrence of disturbance transfers the system state to a post-disturbance steady state via the transient fluctuation, where the final steady state is determined by the disturbance and the post-disturbance reference inputs. For example, the system frequency and the generator terminal voltage can be controlled arbitrarily by changing the reference position of the speed changer and the reference voltage in the exciter system respectively. This means that the post-disturbance steady state should be determined by taking into account its relation with the refernce input for a disturbance. The post-disturbance steady states will be regarded as the target trajectory denoted by x_d Then, the following steady state equation must hold.

$$A\underline{x}_d+B\underline{u}_d+\Gamma\Delta\underline{P}_d=0 \quad (6)$$

Where $\underline{u}_d$: reference input after disturbance

Here it is noted that any x_d and $\underline{u}_d$ which satisfy the above equation can be the target trajectory and reference input for the system disturbance $\triangle P_d$. On the other hand, the system operation has the restrictions that the final steady state of the frequency deviation and the integrated frequency deviation must be zero. That is

$$\Delta f(t)\rightarrow 0 \quad \text{as} \quad t\rightarrow 0 \quad (7a)$$

$$\int_0^t f(t)\,dt\rightarrow 0 \quad \text{as} \quad t\rightarrow 0 \quad (7b)$$

In order to simplify the optimization procedure, we assume that the system has been operated at an optimal state before the system disturbance occurs, and that the least changes of states and inputs can roughly guarantee the optimality of the post-disturbance target trajectory. This assumption for the optimization procedure enables us to get an approximated optimal solution with simple calculation procedures. It is not impossible to analyze the optimality of the system operation condition rigorously. However, that requires excessively long computation time to apply to the on-line control. Thus, the above assumption is considered to be reasonable in the practical point of view.

With the consideration of the above discussions, the determination of the optimal target trajectory can be formulated as the following optimization problem.

$$\underset{\underline{x}_d,\underline{u}_d}{\text{Minimize}} \quad \frac{1}{2}[\underline{x}_d^T \underline{x}_d + \underline{u}_d^T \underline{u}_d] \tag{8a}$$

Subject to

$$A\underline{x}_d + B\underline{u}_d + \Gamma\Delta\underline{P}_d = 0 \tag{8b}$$

$$x_{d1} = x_{d2} = x_{d5} = x_{d6} = 0 \tag{8c}$$

The last constraints (Eq. 8c) are given by Eq.s (7a) and (7b).

In this study, an efficient method is developed rather than solving the above minimization problem directly.

Let a new variable vector $\underline{y}$ and a matrix G defined by :

$$\underline{y} = [x_{d3},\ x_{d4},\ x_{d7},\ x_{d8},\ x_{d9},\ x_{d10},\ u_{d1},\ u_{d2},\ u_{d3},\ u_{d4}]^T \tag{9a}$$

$$H = [A_R \vdots B_R] \tag{9b}$$

where matrix A_R is a reduced matrix of matrix A by eliminating the 1, 2, 5, 6th columns and the 1st ant and 5th rows. The two rows are eliminated since the equation are trivial. The matrix B_R is also a reduced matrix by eliminating the 1st and 5th rows in matrix B. In the above definition, state variables x_{d1}, x_{d2}, x_{d5}, x_{d6} are not included in the new variable vector $\underline{y}$ Eq.(8c) directly.

The optimization problem (8) can now be reformulated as follows :

$$\text{Minimize} \quad h(\underline{y}) = 1/2\ \underline{y}^T\underline{y} \tag{10a}$$

$$\text{subject to} \quad H\underline{y} + \Gamma_R\Delta\underline{P}_d = 0 \tag{10b}$$

Where Γ_R is a reduced matrix by eliminating the 1st and 5th rows in matrix Γ.

With the use of the Lagrangean multiplier method, the optinal solution $\underline{y}^*$ can be easily calculated as follows :

$$\underline{y}^* = -H^T[HH]^{-1}\Gamma_R\Delta\underline{P}_d \tag{11}$$

Once the optimal solution $\underline{y}^*$ is calculated, the optimal target $\underline{x}^*_d$ and optimal reference input $\underline{u}^*_d$ are directly determined by the definition of $\underline{y}$ in Eq.(9a).

3.3 Optimal Control Input

The previous section gives the optimal target trajectory and optimal reference input after disturbance. The next task is to determine the optimal control input to track the given target trajectory.

For the given optimal target trajectory and optimal reference input, the LFC problem can be formulated as follows :

System dynamic equation :

$$\dot{\underline{x}} = A\underline{x} + B\underline{u} + \Gamma\Delta\underline{P}_d \tag{12a}$$

Performance index to be minimized :

$$J = 1/2\int_0^{\infty}\{[\underline{x}(t) - \underline{x}^*_d(t)]^T Q[\underline{x}(t) - \underline{x}^*_d(t)] + [\underline{u}(t) - \underline{u}^*_d(t)]^T R[\underline{u}(t) - \underline{u}^*_d(t)]\}dt \tag{12b}$$

where

$\underline{x}^*_d(t)$, $\underline{u}^*_d(t)$: optimal target trajectory and optimal reference input for the successive load changes respectively.

The above linear tracking problem can be solved with the use of the optimal linear tracking theory [6], and the optimal control input can be calculated as follows :

$$\underline{u}^*(t) = -R^{-1}B^TK\underline{x}(t) - R^{-1}B^T\underline{s}(t) + \underline{u}_d^*(t), \tag{13}$$

Where the matrix K and vector s(t) are determined by the following equations

$$0 = -KA - A^TK - Q + KBR^{-1}B^TK \tag{14}$$

$$\dot{\underline{s}}(t) = -A^T\underline{s}(t) + KBR^{-1}B^T\underline{s}(t) + Q\underline{x}_d^*(t) - KB\underline{u}_d^*(t) - K\Gamma\Delta\underline{P}_d \tag{15}$$

Of these equations, the former is the algebraic Riccati equation, and the latter is a differential equation to determine the command signal to track the target trajectory. The solution methods are briefly described.

3.3.1 Solution of Algebraic Riccati Equation

There are many methods presented to solve the algebraic Riccati equation. However, the computation time rapidly increases with the dimensionality of matrix K. This study adopts the matrix quadratic solution algorithm presented by Potter [8] since the algorithm is suitable to a large-dimensionality Riccati equation with good convergence and comparatively short computation time.

The algorithm can be briefly described as follows:

(1) Compose a (2n×2n) matrix M as follows:

$$M = \begin{bmatrix} A^T & Q \\ BR^{-1}B^T & -A \end{bmatrix} \tag{16}$$

(2) Calculate all the eigenvalues of matrix M, and calculate the eigenvectors associated with the positive-real eigenvalues only. Here it is noted that matrix M has n positive-real eigenvalues.

(3) Compose a (2n×n) matrix T by using the n eigenvectors obtained in step (2). Each column of matrix T is set up by taking one of the selected eigenvectors. By partitioning the matrix T into two parts : upper and lower parts, we get two matrices B and C as follows :

$$T = [\underline{a}_1, \underline{a}_2, \cdots\cdots, \underline{a}_n] = \begin{bmatrix} B \\ \cdots \\ C \end{bmatrix} \tag{17}$$

where $\underline{a}_k$: eigenvector of matrix M associated with positive-real eigenvalue λ_k

(4) The solution of the algebraic Riccati equation is given by

$$K = BC^{-1} \tag{18}$$

In the above algorithm, the eigenvalues and eigenvectors are calculated by using the IMSL program package.

3.3.2 Optimal Solution of Tracking Command Signal

The second term in Eq. (13) is called the command signal for the linear tracking. The optimal command signal can be calculated by solving Eq. (15). Since the final time is infinite, the optimal command signal $s^*(t)$ can be calculated with an approximation as follows.

For the approximated approach, we choose arbitrary large time T_1 and T_2 which satisfy the following relations.

$$0 < T_1 \ll T_2 < \infty \tag{19}$$

The equation (11) can be rewritten in a simple froms :

$$\dot{\underline{s}}(t) = G\underline{s}(t) + \underline{w}(t) \tag{20}$$

where

$$G = KBR^{-1}A \tag{21a}$$

$$\underline{w}(t) = Q\underline{x}_d^*(t) - K[B\underline{u}_d^*(t) + \Gamma\Delta\underline{P}_d] \tag{22b}$$

In the above equation, it is noted that $\underline{w}(t)$ is a piecewise constant vector.

The command signal at time $t=T_2$, that is, $\underline{s}(T_2)$, has the following relation with the signal $\underline{s}(t)$ at an arbitrary moment $t \in [O, T_2]$.

$$\underline{s}(T_2)=\exp[G(T_2-t)]\underline{s}(t)+\int_0^{T_2}\exp[G(T_2-\tau)]\underline{w}(t)\,d\tau \qquad (22)$$

This equation can be solved for the command signal $\underline{s}(t)$, which gives

$$\underline{s}(t)=\exp[-G(T_2-t)]\{\underline{s}(T_2)-\int_t^{T_2}\exp[G(T_2-\tau)]\underline{w}(t)\,d\tau\} \qquad (23)$$

Since $\underline{w}(t)$ is a piecewise constant vector, the evaluation of integration of Eq.(23) gives

$$\underline{s}(t)=\exp[-G(T_2-t)][\underline{s}(T_2)+G\underline{w}(t)]-G^{-1}\underline{w}(t) \qquad (24)$$

If we assume that the system control is performed in the time interval $[0,T_1]$, then matrix $\exp[-G(T_2-t)]$ is a nearly zero matrix due to the fact that all eigenvalues of matrix G are negative-real. This allows the following approximation with respect to $\underline{s}(t)$

$$\underline{s}(t)\fallingdotseq -G^{-1}\underline{w}(t) = -[KBR^{-1}B^T\{Q\underline{x}_d^*-K[B\underline{u}_d^*(t)+\Gamma\Delta\underline{P}_d(t)]\} \quad \text{for all } t\in[0,\ T_1] \qquad (25)$$

Control gain matrix K and input command signal $\underline{s}(t)$, which can be calculated from Eq.(18) and (25), determine the optimal control input $\underline{u}^*(t)$ by Eq(13). This optimal input controls the system state to track the target trajectory after disturbance.

4. System Simulation

The LFC for the two-area system given in Fig. 1 is simulated by computer programming in order to test the proposed LFC control algorithm. The effect of load changes due to the voltage variation is reflected to the LFC simulation in area I by including the whole excitation system in the generator model. However, the generator terminal voltage in area II is regarded as an control input as mentioned earlier. The system constants are given in Table I.

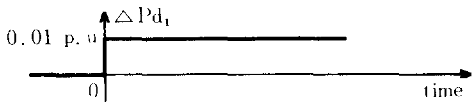
The proposed LFC technique has been tested for various load disturbances such as load outage, load increase, and sudden load changes due to on-off operation of feeder switches and reclosers. In the computer simulation, it is assumed that the LFC system has a perfect disturbance observer. The design of disturbance observer is remained for further study. The simulation results are listed for the two typical patterns of load changes.

Table 1 System constants for the model system.

$f^*=60Hz$
$D_1=D_2=8.33\times10^{-3}p.u.\ MW/Hz$
$T_{gv1}=T_{gv2}=0.08s$
$T_{12}^*=0.545p.u.\ MW/H_z$
$\Delta P_{d1}=0.01p.u.\ MW$
$\delta_1-\delta_2=30°$
$T_1^*=\partial \text{Ptiel}/\partial\|V_1\|=0.05$
$\partial P_{d1}/\partial\|V_1\|=\partial P_{d2}/\partial\|V_2\|=1.0$
Saturation factor $S_E=1.25$
$T_{fld}=6.17s$
$T_X=T_E/K_E=-10.0s$
$T_A=0.0s$
$T_f=1.0s$
$H_1=H_2=5.0s$
$T_{t1}=T_{t2}=0.3s$
$R_1=R_2=2.4Hz/p.u.\ MW$
$P_{r1}=P_{r2}=2000MW$
$\Delta P_{d2}=0.0p.u.\ MW$
$a_{12}=-P_{r1}/P_{r2}=-1.0$
$T\ T_2^*=-\partial \text{Ptiel}/\partial\|V_2\|=0.05$
$\|V_1^*\|=\|V_2^*\|=1.0$
$K_{fld}=0.57$
$K_X=1/K_E=1/-0.05=-20.0$
$K_A=25.0$
$K_f=0.04$

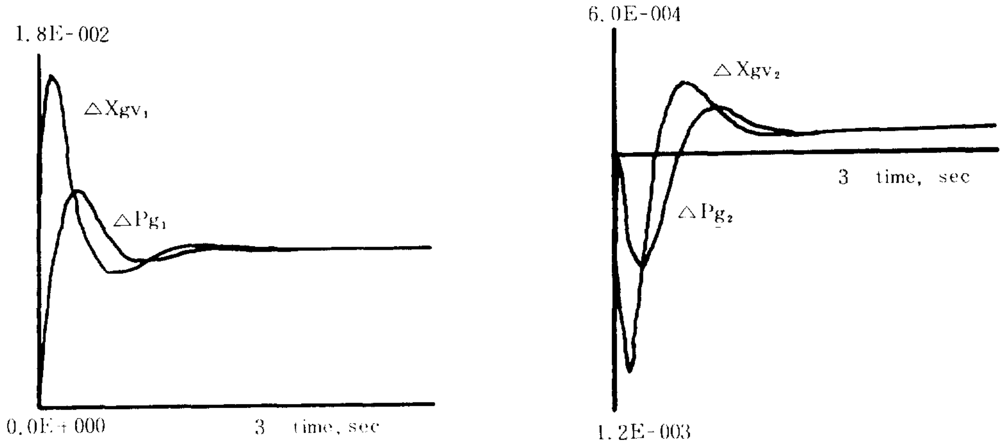
4.1 Simulation Results for Step Load Disturbance

This is the case where the load is suddenly increased and lasted for a long time. The simulation results is as given in Fig. 2. The graphs are plotted only for the steam valve position, generation output and frequency deviation among the 9 state variables. In this case, it is assumed that the duration of the load disturbance is sufficiently long so that no other disturbance occurs until the transition of system state is completed. These simulation results show that the proposed LFC technique has better performance than the conventional techniques. It is noted that there is no steady state frequency error in the proposed LFC simulation.

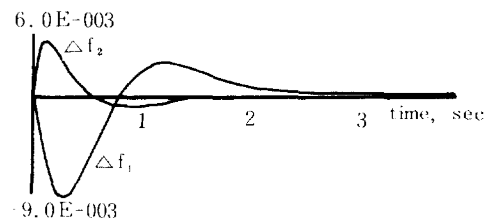


(a) Load disturbance curve

according to the clearance of the fault. In this case, the load disturbance is as shown in Fig. 3 (a). The response of the power generation and frequency fluctuation are shown in Fig. 3(b) and (c). This results shows that the proposed LFC tracks the target trajectory with the high speed, and it can be well-adapted to the practical power system which is subjected to successive disturbances.



(b) Response of power generation output and steam valve position



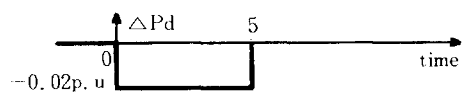
(c) Frequency response

Fig 2 Frequency response for step load disturbance.

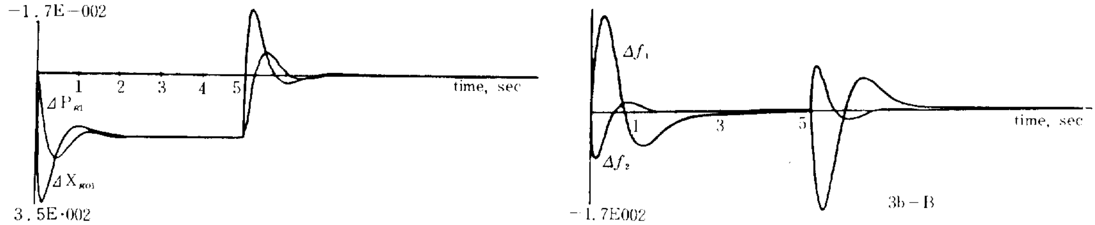
4.2 Simulation Results for the Load Disturbance by Recloser on-off Operation

This case deals with the LFC for the disturbance by the recloser on-off operation, where a temporary fault triggers the feeder switch open and next the circuit is reclosed by the recloser operarion

The above simulations are based on the assumption that the load disturbance can be exactly observed. However, the LFC system requires a disturbance observer, and a practical disturbance observer yields a smooth disturbance curve even for a step load disturbance. A feature of te proposed technique is that it can be applicable for the smoothly varying load disturbances, which can be considered as an improved LFC technique.



(a) Load disturbance curve.



(b) Response of generator power and steam valve position

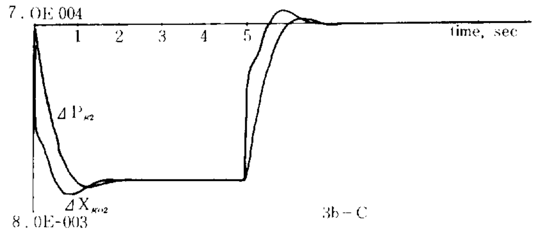


Fig. 3 LFC Simulation for the Load disturbances due to the recloser on-off operation.

5. Conclusion

A load frequency control technique is developed on the basis of the application of optimal linear tracking, which is applicable to the real power systems with successive disturbances. The results can be summarized as follows :

(1) The proposed LFC technique, which is of no need of reference modification, is applicable to the practical power systems with successive disturbances, and it can realize the optimal LFC system with a disturbance observer.

(2) A precise method has been presented to determine the optimal target trajectory. This makes it possible to achieve the steady state optimization after disturbances.

(3) The system simulation shows that the proposed LFC technique yields convenient performance for load disturbance due to the recloser on-off operation.

(4) The proposed LFC technique is applicable to the power system with a practical disturbance observer which yields a smoothly varying load disturbance curve.

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