Optimal Guaranteed Cost Event-triggered Control of Smart Grid Against Time Delay Switch Attack

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Abstract: This paper mainly studies the optimal robust guaranteed cost load frequency control (LFC) problem for a class of uncertain power system under time delay switch (TDS) attack. The closed-loop power system is modelled as time delay system when an event-triggered communication scheme is adopted to reduce bandwidth consumption. In order to obtain less conservative stability criteria of the system with additive time delays, a novel Lyapunov-Krasovskii (L-K) functional is proposed and some latest integral inequalities are applied as well. Consequently, it is necessary to study the secure control problem of cyber attacked power system and an augmented controller with a time delay estimator is offered in Yue D (2013), Hu S (2012). Many scholars pay special attention to discrete event triggered scheme based on sampled data, and the modelling approach based on delay system is proposed in Yue D (2013), which facilitated the study of network induced constraints such as communication delay.

Motivated by existing weaknesses and strengths, we focus attention on the optimal guaranteed cost controller design of power system which takes the event triggered scheme and TDS attack into account. The main contributions can be listed as

i) The closed-loop power system is modeled as an additive time delay system when both event triggered scheme and TDS attack are considered, and the communication bandwidth consumption is drastically reduced.

ii) The optimal guaranteed cost controller designed can not only ensure the system asymptotically stable but also have certain robustness, and the triggering matrix and controller gain can be obtained simultaneously by solving a convex optimization problem with LMI constraints.

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Keywords: time delay switch attack, additive time delay, event-triggered scheme, optimal guaranteed cost control.
2. PROBLEM FORMULATION

2.1 Power System Model

In fact, some parameters in actual power system may be different from their nominal values, which means there exists system uncertainties. (Assuming that the time constants of governor and turbine deviate from the nominal value.) Then, combined with Fig. 1, the system dynamic model can be written like Yang F (2019):

\[
\begin{align*}
\dot{x}(t) &= (A + \Delta A)x(t) + (B + \Delta B)u(t) + Fw(t) \\
y(t) &= Cx(t)
\end{align*}
\]  
(1)

with:

\[
A_{ii} = \begin{bmatrix}
-\frac{\beta_i}{\tau_i} & \frac{1}{\tau_i} & 0 & 0 \\
0 & -\frac{\beta_i}{\tau_i} & 0 & 0 \\
0 & 0 & -\frac{\beta_i}{\tau_i} & 0 \\
2\pi \sum_{j \neq i} T_{ij} & 0 & 0 & 0
\end{bmatrix}, \\
B_{ii} = \begin{bmatrix} 0 & 0 & 0 & 0 \end{bmatrix}^T
\]

The time-varying uncertainties are defined as below

\[
[\Delta A \Delta B] = DG(t)[E \bar{E}]
\]

where \(D, E, \bar{E}\) are known constant matrices and uncertain time varying matrix \(G(t)\) satisfies \(G(t)^T G(t) \leq I\).

2.2 Event-triggered Communication Scheme

The triggered scheme can be obtained by substituting the output into the triggered condition given in Yue D (2013).

\[
e(i_k h)^T C^T \Lambda C e(i_k h) < \rho x^T (i_k h) C^T \Lambda C x(i_k h)
\]  
(2)

where \(\Lambda\) is the triggered matrix, and \(\rho \in (0,1)\) is pre-set triggered threshold, \(i_k h\) stands for the latest instant which the sampled data is triggered successfully. \(i_k h = t_k h + \tau h\), \(r = 1, \cdots, m_k\) is the unsuccessfully triggered sampled packet in interval \([t_k h, t_{k+1} h]\). \(m_k\) stands for the total sampled number which dissatisfies the triggered condition, and \(e(i_k h) = x(i_k h) - x(t_k h)\).

Remark 1: It is obvious that the sampling data will be transmitted only when the triggered scheme (2) is violated, thus, the communication bandwidth can be saved.

The delay \(d(t)\) is introduced and defined as:

\[
d(t) = t - \tau h - t_k h, \quad t \in [t_k h + \tau h, t_k h + (r + 1)h)
\]

where \(r = 0, 1, \cdots, m_k\). Then, \(\forall t \in [t_k h, t_{k+1} h)\) define

\[
e_k(t) = x(t_k h) - x(t_k h + \tau h) = x(t_k h) - x(t - d(t))
\]

Then (1) is transformed into the following form:

\[
\begin{align*}
\dot{x}(t) &= (A + \Delta A)x(t) - (B + \Delta B)KCx(t - d(t) + e_k(t)) + \bar{F}w(t) \\
y(t) &= Cx(t)
\end{align*}
\]  
(3)

2.3 Time Delay Switch Attack

As stated in Sargolzaei A (2018), TDS attack is a switch behavior where the delay \(\tau(t)\) exists or not, and we study the case that TDS attack exists all the time. Here we emphasize that stability is a boundary of security.

Combined with the analysis in Shafiqu M (2015), then the system dynamic model (3) can be rewritten as follows.

\[
\begin{align*}
\dot{x}(t) &= (A + \Delta A)x(t) - (B + \Delta B)KCx(t - \tau(t)) - (B + \Delta B)KC\bar{e}_k(t) + \bar{F}w(t) \\
y(t) &= Cx(t)
\end{align*}
\]  
(4)

The delay functions are assumed to be continuous, differentiable, and satisfy the following constraints

\[
\begin{align*}
0 < \mu(t) &\leq d, & d(t) &= k_1 \quad = 1 \\
0 \leq \tau(t) &\leq \bar{\tau}, & \bar{\tau}(t) &\leq k_2 < 1 \\
0 \leq \mu(t) &\leq d + \bar{\tau}, & \bar{\mu}(t) &\leq 1 + k_2 = k
\end{align*}
\]  
(5)

The performance index is given as follows.

\[
J = \int_0^\infty [x^T(t)M_1 x(t) + u^T(t)M_2 u(t)] dt
\]  
(6)

where \(M_1, M_2\) are given symmetric positive definite matrices.
The main purpose of this paper is to study the attacked system stability under the premise of saving the limited network bandwidth while ensuring

1) The system (4) is asymptotically stable when \( w(t) = 0 \).

2) Under zero initial condition, for any nonzero \( w(t) \in \mathbb{Z}_2 \{0; +\infty \} \) and a prescribed \( \gamma > 0 \) is \( H_\infty \) performance index, the inequality \( \|y(t)\|_2 \leq \gamma \|w(t)\|_2 \) holds;

3) There exists a controller \( u^* \) which is the optimal guaranteed cost controller and a positive scalar \( J^* \), which is the minimum upper bound of \( J \) such that for all admissible uncertainties, system (4) is asymptotic stable.

### 3. MAIN RESULTS

#### 3.1 Stability Analysis

**Theorem 1**: For given scalars \( \bar{d}, \bar{\tau}, \bar{\mu}, k_2, k \) and \( \rho \), the system (4) is asymptotically stable if there exist positive define symmetric matrices \( 0 < P = P^T \in \mathbb{R}^{n \times n}, 0 < Q_i \in \mathbb{R}^{n \times n}, i = 1 \ldots 5, 0 < R_j \in \mathbb{R}^{n \times n}, j = 1, 2, 0 < Z_i \in \mathbb{R}^{n \times n}, l = 1, 2, 3 \), and arbitrary matrices \( S \in \mathbb{R}^{3n \times 3n} \) such that (7) holds.

\[
\begin{bmatrix}
\Phi^T \Phi & -\gamma I & * & * & * & * & * & * & * & * & * & * & * & * & * & * \\
\rho R_1 \Phi & -\gamma I & -R_1 & * & * & * & * & * & * & * & * & * & * & * & * & * \\
\frac{d_{12}}{d_{12}} R_2 \Phi & \frac{d_{12}}{d_{12}} R_2 \Phi & 0 & -R_2 & * & * & * & * & * & * & * & * & * & * & * & * \\
\frac{\tau_{12}}{\tau_{12}} Z_1 \Phi & \frac{\tau_{12}}{\tau_{12}} Z_1 \Phi & 0 & 0 & -Z_1 & * & * & * & * & * & * & * & * & * & * & * \\
\frac{\tau_{12}}{\tau_{12}} Z_2 \Phi & \frac{\tau_{12}}{\tau_{12}} Z_2 \Phi & 0 & 0 & 0 & -Z_2 & * & * & * & * & * & * & * & * & * & * \\
\frac{\tau_{12}}{\tau_{12}} Z_3 \Phi & \frac{\tau_{12}}{\tau_{12}} Z_3 \Phi & 0 & 0 & 0 & 0 & -Z_3 & * & * & * & * & * & * & * & * & * \\
\frac{\tau_{12}}{\tau_{12}} Z_4 \Phi & \frac{\tau_{12}}{\tau_{12}} Z_4 \Phi & 0 & 0 & 0 & 0 & 0 & -I & * & * & * & * & * & * & * & * \\
\end{bmatrix} < 0 \tag{7}
\]

where:

\[
\begin{align*}
\Phi &= S \sum \{ e^T_i \Phi (e_i + Q_1 + Q_2 + Q_3 + Q_4) e_i - e^T_i Q_4 e_5 \\
&+ d_{12} e^T_i Q_5 e_6 - d_{12} e^T_i Q_7 e_2 - (1 - k_2) e^T_i Q_3 e_4 \\
&- \Pi \sum \{ \Pi_1 - \Omega^T \Pi_2 \Omega - \Xi^T \Pi_3 \Xi_1 - \Xi^T \Pi_4 \Xi_2 - \Xi^T \Pi_5 \Xi_3 \\
&- e^T_{23} C^T \Lambda_1 e_23 + \rho (e_2 + e_{23}) C^T \Lambda_1 C(e_2 + e_{23}) \}
\end{align*}
\]

\[
H_1 = \frac{A e_1 - B K e_2 - B K e_{23}}{1 - \bar{\nu}}
\]

\[
H_2 = D G(t) E \Pi_1 - D G(t) \tilde{E} K e_{23}
\]

\[
\tilde{R}_i = \Pi \{ R_i, 3 R_i, 5 R_i \}, i = 1, 2, 3
\]

\[
Z_{di} = \Pi \{ Z_{2i}, 2 Z_{2i}, 6 Z_{2i} \}, i = 1, 2, 3
\]

\[
\Psi_1 = \left[ \begin{array}{cccc}
(2 - \alpha) \tilde{R}_1 + (1 - \alpha) T_1 \\
& S \\
& (1 + \alpha) \tilde{R}_1 + \alpha T_2
\end{array} \right]
\]

\[
\alpha = \frac{\mu(t)}{\bar{\mu}}
\]

\[
\Pi_1 = \left[ \begin{array}{cccc}
e_1 + e_2 - 2 e_10 & 0 & 0 & 0 \\
0 & e_1 + e_2 - 2 e_11 & 0 & 0 \\
0 & 0 & e_1 + e_2 - 2 e_12 & 0 \\
& & & e_1 + e_2 - 2 e_13
\end{array} \right], \Xi_1 = \left[ \begin{array}{cccc}
0 & e_1 + e_14 & 0 & 0 \\
e_1 + e_14 & e_1 - e_14 - 3 e_15 & 0 & 0 \\
0 & 0 & e_1 - e_14 - 3 e_15 & 0 \\
& & & e_1 - e_14 - 3 e_15 - 30 e_16
\end{array} \right]
\]

\[
\Xi_2 = \left[ \begin{array}{cccc}
e_1 & e_17 & 0 & 0 \\
0 & e_1 - e_17 & 0 & 0 \\
0 & 0 & e_1 - e_17 - 3 e_18 & 0 \\
& & & e_1 - e_17 - 3 e_18 - 30 e_19
\end{array} \right], \Omega = \left[ \begin{array}{cccc}
e_6 + e_7 & 0 & 0 & 0 \\
ek_2 e_6 + e_7 & e_6 + e_7 & 0 & 0 \\
0 & 0 & e_6 + e_7 & 0 \\
& & & e_6 + e_7 - 6 e_9
\end{array} \right]
\]

The upper bound of the quadratic performance index is given

\[
J = \gamma^2 \|w(t)\|_2^2 + x^T(0) P x(0) + \int_0^\tau x^T(s) Q_4 x(s) ds
\]

\[
+ d_1 \int_{-\tau}^0 x^T(s) Q_5 x(s) ds + \mu \int_0^\tau \int_0^\tau \hat{x}^T(t) R_1 \hat{x}(s) dsd\beta
\]

\[
+ d_2 \int_{-\bar{\tau}}^\tau \int_0^\tau \hat{x}^T(s) R_2 \hat{x}(s) dsd\beta
\]

\[
+ \int_0^\tau \int_0^\tau \hat{x}^T(t) Z_1 \hat{x}(s) dsd\beta \tag{8}
\]

\[
+ \int_0^\tau \int_0^\tau \hat{x}^T(t) Z_2 \hat{x}(s) dsd\beta
\]

\[
+ \int_0^\tau \int_0^\tau \hat{x}^T(t) Z_3 \hat{x}(s) dsd\beta
\]

**Proof:** Firstly, the L-K functional candidate is given as:

\[
V(t) = \sum_{i=1}^4 V_i(t) \quad V_i(t) = x^T(t) P x(t)
\]

\[
V_2(t) = \int_{-\tau}^t x^T(s) Q_1 x(s) ds + \int_{-\tau}^t x^T(s) Q_2 x(s) ds
\]

\[
+ \int_{-\tau}^t x^T(s) Q_3 x(s) ds + \int_{-\tau}^t x^T(s) Q_4 x(s) ds
\]

\[
+ (\tau - \bar{\tau}) \int_{-\bar{\tau}}^0 x^T(s) Q_5 x(s) ds\]

\[
V_3(t) = \bar{\mu} \int_{-\tau}^\tau \int_{-\tau}^\tau \hat{x}^T(t) R_1 \hat{x}(s) dsd\beta
\]

\[
+ (\tau - \bar{\tau}) \int_{-\bar{\tau}}^\tau \int_{-\bar{\tau}}^\tau \hat{x}^T(s) R_2 \hat{x}(s) dsd\beta
\]

\[
V_4(t) = \int_{-\bar{\tau}}^\tau \int_{-\bar{\tau}}^\tau \hat{x}^T(t) Z_1 \hat{x}(s) dsd\beta
\]

\[
+ \int_{-\bar{\tau}}^\tau \int_{-\bar{\tau}}^\tau \hat{x}^T(s) Z_2 \hat{x}(s) dsd\beta
\]

\[
+ \int_{-\bar{\tau}}^\tau \int_{-\bar{\tau}}^\tau \hat{x}^T(t) Z_3 \hat{x}(s) dsd\beta
\]

where \( P, Q_i, (i = 1 \ldots 5), R_j, (j = 1, 2), Z_l, (l = 1, 2, 3) \) are matrices to be determined. For simplicity of vector and matrix representations, we define a column vector \( \varsigma(t) \) as

\[
\varsigma(t) = \text{col} \{ x(t), x(t - \mu(t)), x(t - d(t)), x(t - \tau(t)) \},
\]

\[
x(t - \mu), x(t - d), x(t - \tau), \frac{1}{\tau - d} \int_{t - \tau}^t x(s) ds
\]

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\[
\begin{split}
\frac{1}{\tau} \int_{t-\tau}^{t} \delta_{t-(t-\tau)} x(s) \, ds, \\
\frac{1}{\mu(t)} \int_{t-\mu(t)}^{t} x(s) \, ds, \\
\frac{1}{\mu(t)} \int_{t-\mu(t)}^{t} \delta_{t-(t-\mu(t))} x(s) \, ds.
\end{split}
\]

\[
\begin{split}
\frac{1}{\tau} \int_{t-\tau}^{t} \delta_{\frac{\mu(t)}{t} x(t) + \sigma(t)} x(s) \, ds, \\
\frac{1}{\mu(t)} \int_{t-\mu(t)}^{t} \delta_{\frac{\mu(t)}{t} x(t) + \sigma(t)} x(s) \, ds, \\
\frac{1}{\mu(t)} \int_{t-\mu(t)}^{t} \delta_{\frac{\mu(t)}{t} x(t) + \sigma(t)} x(s) \, ds.
\end{split}
\]

Some transformation should be made for solving the uncertain term in (10) according to the existing Lemma 2.4 in Xie L (1992). Then, combined with (7), we have

\[
\dot{V}(t) \leq -y^T(t)y(t) + \gamma^2 w(T)w(t) - x^2(t)M_1 x(t)
\]

Since \( x(t) \) and \( \dot{V}(t) \) are both continuous in \( t \), and taking integral from \( 0 \) to \( \infty \) on both sides of (11), we can get

\[
V(\infty) - V(0) \leq \int_{0}^{\infty} \{ -y^T(t)y(t) - x^2(t)M_1 x(t)
\]

Hence under zero initial conditions, the following holds

\[
\int_{0}^{\infty} \left[ -y^T(t)y(t) + \gamma^2 w(T)w(t) \right] dt \geq 0
\]

The upper bound of the performance index can be obtained that

\[
J = \int_{0}^{\infty} \{ x^T(t)M_1 x(t) + |x(t - \mu(t)) + e_k(t)|EKCx \} \]  

\[
\leq V(0) + \int_{0}^{\infty} \left[ -y^T(t)y(t) + \gamma^2 w(T)w(t) \right] dt
\]

This completes the proof.

3.2 Optimal Guaranteed Cost Load Frequency Control

**Theorem 2:** For given positive scalars \( \rho, d, \tau, \mu, \) and \( k_2 \), if there are positive definite matrices \( X, R_j, j = (1, 2), Q_i, i = (1, \cdots, 5), Z_i, i = (1, 2, 3) \) such that the following LMI holds, we can conclude that the system with feedback gain \( K \) and weighted cost performance index (6) is asymptotically stable.
sides of (8), and using Schur complement and Lemma 3.1
in Xie L (1992), (12) is derived.
Firstly, define matrices as ... and hold on about 5 s.
It is obvious that the three area system with controller K
achieves robust asymptotic stability.

\[
\Theta_1 = \int_{-\tau}^0 x(s)x^T(s)ds \\
\Theta_2 = d_1\int_{-\tau}^0 x(s)x^T(s)ds \\
\Theta_3 = d_2\int_{-\tau}^0 x(s)x^T(s)ds \\
\Theta_4 = d_3\int_{-\tau}^0 x(s)x^T(s)ds \\
\Theta_5 = \int_{-\tau}^0 \int_0^\beta x(s)x^T(s)dsd\beta \\
\Theta_6 = \int_{-\tau}^0 \int_0^\beta x(s)x^T(s)dsd\beta \\
\Theta_7 = \int_{-\tau}^0 \int_0^\beta x(s)x^T(s)dsd\beta \\
\Theta_8 = \int_{-\tau}^0 \int_0^\beta x(s)x^T(s)dsd\beta \\
\psi \Theta_1^2 X^2 - \Theta_5 > 0
\]

Assume that there exists positive scalar $\psi$ satisfying
\[
x^T(0)X^{-1}x(0) < \psi,
\]
and we can obtain:
\[
\psi = \left\lbrack \begin{array}{cc}
-\psi_1 & \Theta_5^2 \\
* & -XQ_4^{-1}X
\end{array} \right\rbrack < 0
\]

and
\[
\int_0^\mu x^T(s)X^{-1}Q_4X^{-1}x(s)ds \leq tr(\psi_1)
\]

Similarly, the following inequalities are derived:
\[
d_2\int_{-\tau}^0 x^T(s)X^{-1}Q_5X^{-1}x(s)ds \leq tr(\psi_2)
\]

\[
\bar{\mu}\int_{-\tau}^0 \bar{x}^T(s)X^{-1}\bar{\bar{R}}_1X^{-1}\bar{x}(s)dsd\beta \leq tr(\psi_3)
\]

\[
d_3\int_{-\tau}^0 \int_0^\beta \bar{x}^T(s)X^{-1}\bar{\bar{R}}_2X^{-1}\bar{x}(s)dsd\beta \leq tr(\psi_4)
\]

\[
\int_{-\tau}^0 \int_0^\beta \bar{x}^T(s)X^{-1}\bar{\bar{Z}}_1\bar{x}(s)dsd\beta \leq tr(\psi_5)
\]

\[
\int_{-\tau}^0 \int_0^\beta \bar{x}^T(s)X^{-1}\bar{\bar{Z}}_2\bar{x}(s)dsd\beta \leq tr(\psi_6)
\]

\[
\int_{-\tau}^0 \int_0^\beta \bar{x}^T(s)X^{-1}\bar{\bar{Z}}_3\bar{x}(s)dsd\beta \leq tr(\psi_7)
\]

To sum up above,
\[
\begin{align*}
\dot{J} & \leq \dot{\bar{J}} + tr(\psi_1) + tr(\psi_3) + tr(\psi_4) + tr(\psi_5) \\
& \quad + tr(\psi_6) + tr(\psi_7) + \gamma^2||w(t)||^2_2 = J^*
\end{align*}
\]

Hence, the minimization problem can be shown as follows.
\[
\min_{\Xi} J^* \quad \text{s.t. (1) (12), (2) \left\lbrack \begin{array}{cc}
-\psi_1 & \Theta_5^2 \\
* & XQ_4 - 2X
\end{array} \right\rbrack < 0
\]

\[
\left\lbrack \begin{array}{cc}
-\psi_2 & \Theta_5^2 \\
* & XQ_5 - 2X
\end{array} \right\rbrack < 0
\]

where $\Xi$ indicates the constraints that for given positive
scalars $\rho$, $\gamma$, $\bar{d}$, $\bar{\bar{\tau}}$, $\bar{\mu}$, $k_2$, there exist positive definite
matrices $X, \bar{R}_1, \bar{Q}_1, \bar{Z}_1, \psi_1$, and positive scalar $\rho$ such that
the minimization problem is solvable.

Then the minimum upper bound of the performance index,
the optimal guaranteed cost controller $u^*$, and the triggered
matrix can be obtained simultaneously. The control gain
can be expressed as: $K = X_1(CX)^+$.

Remark 3: It should be noted that only conservative suffi-
cient conditions can be obtained in this paper, thus, the
value of the calculated robust performance index is greater
than its real value.

4. CASE STUDY

In this section, we aim to verify the controller designed
by Theorem 2 has certain robustness for external
disturbances. For the single area system, the nominal sys-

tem parameters are given as follows: $T_i = 0.3; T_q = 0.1; R = 0.05; D_1 = 1; M_1 = 6; \beta = 21; \lambda = \rho = 0.1; D = 0.5I_2; G(t) = diag[0, \sin(t), \sin(t), 0, 0], M_1 = I_2, M_2 = 1,
and for $\forall t \in [-\bar{\mu}, 0]$, $x(t) = [0 e^0 e^{0.5t} 0]$. Choose $\bar{\tau}(t) = 0.25\sin(t)$, $\bar{d} = 0.15$, $\bar{\bar{\tau}} = 0.25$, $\rho = 0.01, \gamma = 10; \sigma = 0.06$. Supposed that an external disturbance
occurs at $t = 2s$ and hold on about $2s$, the system state
response is shown as Fig 2(a), we can easily conclude that
the system is robust asymptotic stability. Then the con-
troller gain matrix $K$ and triggered matrix $\Lambda$ are obtained as follows:
\[
\Lambda = \begin{bmatrix}
0.3202 & -0.4619 \\
-0.4619 & 85.2596
\end{bmatrix}, K = [-0.4737 0.0018]
\]

The minimum upper bound of the performance index
$J^* = 1.9368$.

As to the three-area LFC power system, parameters in
different regions are various. Choose $\gamma = 15; \sigma = 0.01, and
system initial value $x(t) = [0 1 0 1 0, t \in [-\bar{\mu}, 0]$. Then, the system gain matrix $K$ and triggered matrix $\Lambda$ are computed as follows:
\[
\Lambda = diag\{A_1, A_2, A_3\}, A_1 = \begin{bmatrix}
0.1242 & -0.0034 \\
-0.0034 & 0.3309
\end{bmatrix}, A_2 = \begin{bmatrix}
0.1242 & -0.0038 \\
-0.0038 & 0.3121
\end{bmatrix}, A_3 = \begin{bmatrix}
0.1181 & -0.0031 \\
-0.0031 & 0.3386
\end{bmatrix}
\]

\[
K = \begin{bmatrix}
-0.2278 & 0.0002 \\
-0.0983 & 0.0022
\end{bmatrix}
\]

And the minimum upper bound for this three area LFC
power system is $J^* = 2.2362$. Fig 2(b) shows the system
state response when the external disturbance are injected
into the power system at $t = 5s$, and hold on about $5s$.
It is obvious that the three area system with controller $K$
achieves robust asymptotic stability.
Fig. 2. (a) System frequency deviation response for single area power system. (b) System frequency deviation response for multi area power system.

Fig. 3. (a) Release instants and intervals with $\rho = 0.01$. (b) Release instants and intervals with $\rho = 0.1$

Fig 3(a) and Fig 3(b) show the release instants and intervals by different event-triggered parameter $\rho$.

5. CONCLUSION

This paper mainly studies the optimal guaranteed cost control of power system with system uncertainties. Firstly, an additive time delay closed-loop system model is given when event-triggered communication scheme and TDS attack are taken into account. Then, less conservative stability criteria are derived based on an improved L-K functional and some latest inequalities such as truncated Bessel-Legendre inequality and improved extended reciprocal convex approach. Finally, the optimal robust guaranteed cost controller, triggered matrix and minimum upper bound of performance index are obtained simultaneously by solving a convex optimization problem.

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