ERROR-TOLERANT COMMUNICATION PROTOCOL OF MULTI-AGENT SYSTEM FOR POWER SYSTEM ON-LINE VOLTAGE CONTROL

Zhong CHEN
Southeast University, CHINA
chenzhong_seu@163.com

Wenjuan DU
University of Bath, UK
ddwenjuan@tom.com

H F WANG
University of Bath, UK
eeshw@bath.ac.uk

ABSTRACT

In this paper, on-line collaboration of a multi-agent system is applied for the coordination of power system voltage control to maintain system voltage stability when the system is subject to severe faults. Through real-time information exchange and synthesis among various control agents based on predefined communication protocol, on-line collective actions can be taken to prevent the power system from losing voltage stability. In order to ensure correct information exchange among agents, this paper proposes an error-tolerant communication protocol based on a second round of group broadcasting among agents. The error-tolerant protocol grantees the maximum likelihood of correct information exchange among agents when communication errors caused by such as the lost of a communication channel and corruption of transmitted information. In the paper, application example of proposed scheme in the IEEE standard 10-machine 39-node New England power system is presented. Simulation results are given to demonstrate the effectiveness of the proposed scheme to maintain system voltage stability.

Ⅰ. INTRODUCTION

Information technology is playing more and more important role in the management and control of modern power systems. Successful IT applications in power systems have significantly enhanced the reliability and efficiency of power system operation. Such examples are the strategic power infrastructure defense systems [1], wide-area stability and voltage control system [2] and so on. In this field, recently a new concept of "Third Category Control (TCC)" [3] is proposed with one of its applications in "Post-Emergency Voltage Control (PEVC)" [4] of power systems. The PEVC is an on-line voltage control scheme to protect certain important area in a power system from the complete voltage collapse of the whole system via adding an extra defense line around the identified important area. Because the PEVC is based on multi-agents on-line information exchange technology, the errors in communication process are inevitable and will damage the effectiveness of the implementation of the PEVC. Hence the error-tolerant technique needs to be developed for the PEVC. In this aspect, there have been successful examples in power system applications, such as the grid failure diagnosis [5] and topology error identification [6]. In this paper, the multi-agents system and information theory are integrated to solve the error-tolerant problem in PEVC.

Ⅱ. ERROR-TOLERANT TECHNIQUE

A. Model of a multi-agent system

In order to apply information theory to the PEVC, a multi-agent system needs to be established as shown by figure 1 that includes the information sources, channel and receiver. The data-sending agent is called information source which sends out the real state information of local power control device the information channel. Similarly the data-receiving agent is called the information receiver which makes control strategy decision based on the received information and then sends out real control command to the connected local device.

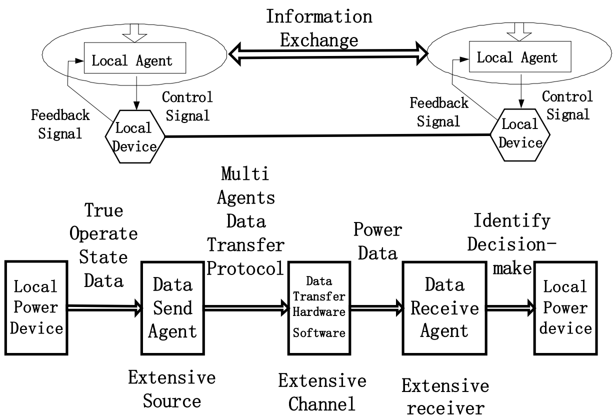

Fig. 1 model of multi-agent information system

B. Error-tolerant information exchange

In the model of Figure 1, we assume that for the information exchange system of multiple agents, the input variable x is the real state of help-seeking or help-offering agent, whose probability distribution is:

$$\begin{bmatrix} X \\ P(X) \end{bmatrix} = \begin{bmatrix} x_1 & x_2 & \cdots & x_N \\ p(x_1) & p(x_2)\cdots & p(x_N) \end{bmatrix} \quad (2\text{-}1)$$

The output variable y of the system is the data of each help-offering agent receives, whose probability distribution is:

$$\begin{bmatrix} Y \\ P(Y) \end{bmatrix} = \begin{bmatrix} y_1 & y_2 & \cdots & y_M \\ p(y_1) & p(y_2) & \cdots & p(y_M) \end{bmatrix} \quad (2\text{-}2)$$

How to make full use of the output y to identify the true state x of help-seeking agent is the process of information synthesis. The objective of an error-tolerant communication system is to identify the true input data from the polluted output via single channel model shown in Figure 2.

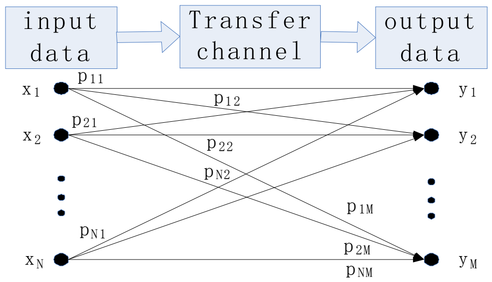

Fig. 2 Single-channel model of information exchange

According to the information theory, from $y = y_j$, the implied information of $x = x_i$ is:

$$I(x_i; y_j) = \log_2 \frac{p(x_i, y_j)}{p(x_i)p(y_j)} = \log_2 \frac{p_{ij}}{\sum_{i=1}^{N} p_{ij} p(x_i)} \quad (2\text{-}3)$$

From (2-3) we can see that $I(x_i; y_j)$ is associated with only $\{p(x_i)\}$ because transfer probability $\{p_{ij}\}$ is fixed when transfer channel is fixed. Hence the bigger $I(x_i; y_j)$ is, the higher the implied information of $x = x_i$ from $y = y_j$. And $x = x_i$ obtained from observed data $y = y_j$ with a higher $I(x_i; y_j)$ is more reliable.

If

$$I(x_M; y_j) = \max\{I(x_1; y_j), I(x_2; y_j), \cdots, I(x_N; y_j)\} \quad (2\text{-}4)$$

The lost information with $x = x_i$ from $y = y_j$ will be

$$I_{loss}^{i,j}(x_i; y_j) = I(x_M; y_j) - I(x_i; y_j) \quad (2\text{-}5)$$

Hence we have the objective function of single transferring channel to be

$$\min_i I_{loss}^{i,j} \quad (2\text{-}6)$$

In order to make full use of input data, we can have more output independent data. The objective function of the multi-channel information exchange is

$$\min \sum_{k=1}^{K} I_{loss,k} \quad (2\text{-}7)$$

The number of independent observed output data is K and $I_{loss,k}$ is the information loss of the k^{th} output.

C. Error-tolerant information exchange protocol

In the PEVC multi-agent system, the information exchange management centre decides the control strategy and sends out the relative information to various local agents at the steady-state operation (including identification of important loads, determination of agents in defense line, and so on). During the dynamic operation, such as in system contingency, communication exists among local agents via the information exchange to implement the on-line collaborative control without the interference from the information exchange management centre.

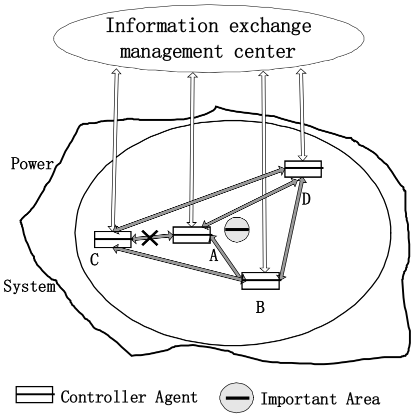

Fig. 3 The basic framework of error-tolerance

Figure 3 shows an example to illustrate error-tolerant protocol of communication. If in system contingent operation, the local agent A observes voltage problem that cannot be solved locally, immediately it sends out seeking-help information to other agent B, C and D. If without communication error, the agent B, C and D will receive the seeking-help information, and can react to support the need of agent A. That forms a collective action to cope with the observed voltage problem [4]. However, there are two types of errors in the communication. The first is caused by the broken down of transmission channel between various agents when the control agent can not receive information. The second is polluted information, namely, the local control agent receives wrong message. Taking agent C as an example, if the channel between agents A-C breaks down, agent C will not act. If agent C receives polluted message from C, agent C will not act either. These errors in communication can lead to the obsolete of the PEVC and the important area could not be protected by the PEVC from the loss of stability. Hence the error-tolerant communication protocol is essentially important in implementing the PEVC.

Hence, in the protocol of Figure 4, agent communication is conducted in two stages. Firstly, the help-seeking agent (for example agent A in Figure 3) broadcasts "direct help package" information that includes all direct help information from the agent. Secondly once each agent (for example agent B, C, D) receives and identifies the package information, it will re-broadcast the received information in the form of an "indirect help package". Hence in an n-agent system, for one action, a potential help-offering agent could receive the same help-seeking information as many as n-1 time through its n-1 links with other agents. Considering the fact that the probability of broken down of more than one link connected to and more than one polluted package of information sent to the agent at the same time is much lower, the proposed protocol of Figure 4 can effectively eliminate the damage caused by two types of communication errors mentioned in the above.

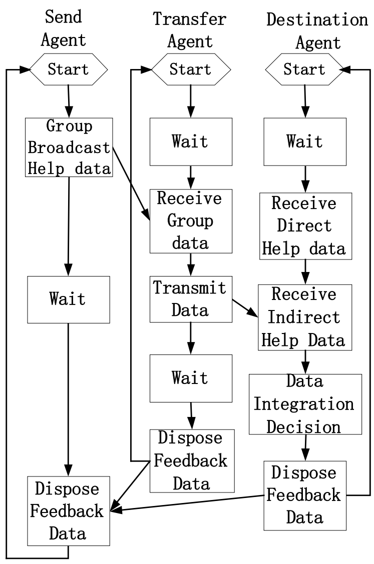

Fig. 4 Flow of information transfer and transmit

Ⅲ. SIMULATION

The feasibility and efficiency of the proposed error-tolerant communication protocol is tested in IEEE39 [7] shown by Figure 5. The multi-agents information system consists of L12 load (A agent), STATCOM (B agent), AVR2 (C agent), AVR3 (D agent), and each agent exchanges information via transfer channel.

A. Base Scenario

We assume that the contingent operation of the system starts due to the cascading faults of tripping off of line 7-8, line 3-4 and line 14-15 at 2.0s of simulation. The on-line control of the multi-agent system can maintain the stability of important isolated area shown in Figure 5 and the power supply is kept to the important load L12 when there is no error in the information exchange between agents.

B. Case of polluted information

In this case, we demonstrate the function of error-tolerant communication protocol by assuming that the STATCOM agent in the system receives polluted information. In the multi-agent system, L12 is the help-seeking agent and the STATCOM (agent B) is one of the help-offering agents in multi channels as shown in Figure 6.

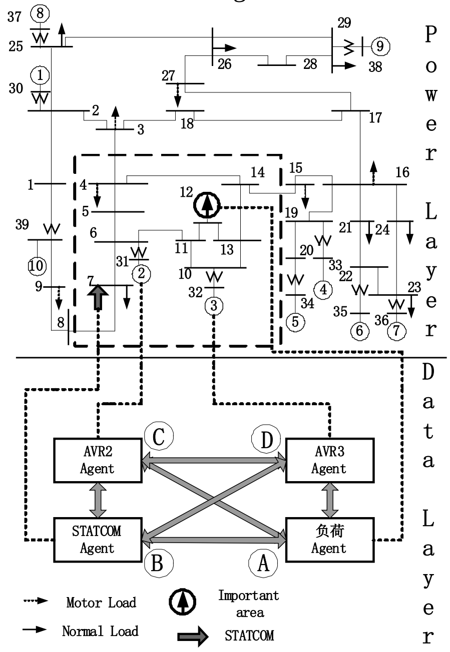

Fig. 5 Multi-agents information system of IEEE39

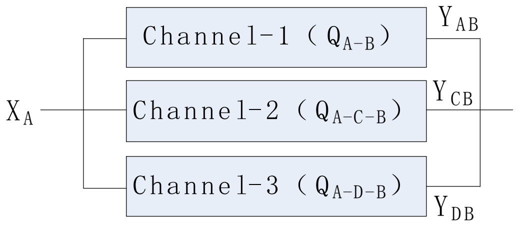

Fig. 6 Multi channels of agents information decision

Supposing that the probability of channel error between agents is α , the transfer probability matrix of transfer channel is:

$$Q_{A-B} = \begin{bmatrix} 1-\alpha & \alpha \\ \alpha & 1-\alpha \end{bmatrix}$$

$$Q_{A-C-B} = \begin{bmatrix} (1-\alpha)^2 & 1-(1-\alpha)^2 \\ 1-(1-\alpha)^2 & (1-\alpha)^2 \end{bmatrix}$$

$$Q_{A-D-B} = \begin{bmatrix} (1-\alpha)^2 & 1-(1-\alpha)^2 \\ 1-(1-\alpha)^2 & (1-\alpha)^2 \end{bmatrix}$$

The exchange of information can be described as follows.

Step 1: L12 agent observes the drop of voltage and predicts the possibility of loss of voltage stability; it immediately broadcasts the help-seeking information packet to AVR2、AVR3、STATCOM at 2.4s. The

format of the packet is:
[L12 ID {1 1 1} destination ID]
{1,1,1} indicate the content of the help-seeking information sent to AVR2, AVR3 and STATCOM agent respectively (0=no help needed, 1= help needed).

Step 2: Each agent receives direct information at 2.45s. of simulation. Supposing that STATCOM agent receives polluted information packet {1 1 0} which means no help is needed from STATCOM and hence $Y_{A-B} = 0$.

After receiving the data packet, AVR2 and AVR3 agent transmit indirect help information to STATCOM. This indirect help-seeking information packet is
【AVR2 agent ID 1 STATCOM agent ID】
【AVR3 agent ID 1 STATCOM agent ID】

Step3: STATCOM agent receives the indirect help-seeking information packet form AVR2, AVR3 agent at 2.5s:
$Y_{A-C-B} = 1$; $Y_{A-D-B} = 1$

Supposing that the prior probability is 0.5, and according to the loss-information calculating method [8], the loss-information of no help-needed state ($x = 0$) is:

$$2\log_2 \frac{(1-\alpha)^2}{1-(1-a)^2},$$

and that of help needed state ($x = 1$) is:

$$\log_2 \frac{1-a}{a}.$$

If probability of channel error $a < 0.1$, we have
$I_{loss}(x = 0) > I_{loss}(x = 1)$

Hence STATCOM can conclude the true state of L12 $x = 1$ with a smaller loss-information. The STATCOM agent decides to offer help to L12.

C. Case of error caused by broken down of communication channel

This is the scenario that we assume that the exchange channel between STATCOM agent and L12 agent is broken down. The action of information exchange can be described as follows.

Step 1: Same as that in the above case.

Step 2: STATCOM agent does not receive any information from L12 but the indirect help-seeking information form AVR2, AVR3 agent at 2.5s:
$Y_{A-C-B} = 1$; $Y_{A-D-B} = 1$

As STATCOM agent does not receive the direct help-seeking information with $Y_{A-B} = \Phi$ which means empty information.

Hence the loss-information of help-needed state ($x = 1$) is zero. And the loss-information of STATCOM agent of no help-needed state ($x = 0$) is:

$$2\log_2 \frac{(1-\alpha)^2}{1-(1-a)^2};$$

Therefore, STATCOM concludes that the true state is help-needed ($x = 1$) because loss information is smaller when help state is $x = 1$ and it decides to offer voltage support.

Ⅳ. CONCLUSION

This paper proposes a new error-tolerance information exchange protocol for the multi-agent system of voltage control in contingent operation. In the paper, test results of simulation in an example power system are given.

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