A Study on Transient Stability of Power System Based on Multi-Agent System

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Abstract - With the rapid development of power system, system stability problem has become more and more serious in the world. The unceasing progress of computer application level and artificial intelligence technology contribute greatly to the development of the smart grid. The paper, A hierarchical classification control structure is hired to finish coordinated control tasks based on multi-agent system (MAS), which help multi-machine system to finish coordinated control tasks. It conduct extensively test carried out on the New England bus system. The simulation results show that decentralized coordinated control scheme is better than a simple decentralized robust control, decentralized coordinated control programs, especially in the case of large interference effect. Thus, the proposed scheme(MAS) is effective to improve power systems transient stability and improves the robustness of the transient stability prediction system significantly.

Keywords - MAS, transient stability, power systems, Coordination Control simulation

I. INTRODUCTION

Power system stability refers to the ability of synchronous machines to move from one steady-state operating point following a disturbance to another steady-state operating point, without losing synchronism[1,2]. There are three types of power system stability: steady-state, transient, and dynamic. With the expending of power system and the complexity of system structure, operating stability, reliability and economy, it is faced with opportunities and new challenges. Transient stability analysis plays a crucial role in power systems, and is widely used in the planning, design, operation and control of power systems. As we all known, transient stability assessment of power systems has to deal with nonlinear differential equitation set with huge dimension[3]. With the development of system scales and the need for more accurate models of China power grid, the computational task has become more and more intensive. The requirement for real-time simulation and on-line dynamic security analysis motivates many researchers to pursue new simulation algorithms based on high-performance parallel computers. The unceasing progress of computer application level and artificial intelligence technology contribute greatly to the development of the smart grid[4,5]. A great deal of effort over the past decades has been devoted to the research. For the distribution structure and dynamic characteristics of power systems, this paper pays more attention to the research of system structures and control schemes for transient stability[6]. Multi-agent is an important branch of distributed artificial intelligence. It is developed to solve the large-scale complex problems intelligently[7,9]. Its basic idea is to separate large complex systems into many small autonomy systems(agents), which can communicate with each other and operate coordinately. With the development of modern industry, the increasing demand of electricity, the user of power supply safe, reliable and diversity. The requirements of more and more is also high. China's energy, resources distribution and regional economic development imbalance, makes our country modern Complex structure power system, distribution widespread, operation of electromagnetic loop network, the weak link in parallel, on the whole show the characteristics of loose coupling, results in the decrease of complex power system stability margin[10]. It deems that stabilization of different instability modes should be unified according to the essential factor of instability. For rotor angle stability, the energy deviation between the input mechanical energy and the output electrical one of each generator, which is defined as “unbalanced energy”, is the essential one. Stemmed from this point of view, a stabilization principle based on the elimination of the unbalanced power of the controlled systems is proposed and a relevant emergency control algorithm to dissipate the unbalanced energy is given[11].

II. TRANSIENT STABILITY SIMULATION MODEL

Transient stability, involves major disturbances such as loss of generation, line-switching operations, faults, and sudden load changes. Following a disturbance, synchronous machine frequencies undergo transient deviations from synchronous frequency, and machine power angles change[12,13]. The objective of a transient stability study is to determine whether or not the machines will return to synchronous frequency with new steady-state power angles. Changes in power flows and bus voltages are also of concern. The power system transient stability model is described by a group of differential equations and a group of algebraic equations as follow:

\[
\frac{dx}{dt} = f(x, V) \tag{1}
\]

\[
0 = Y_N V - I \tag{2}
\]

where x is the state variable vector of the dynamic units, V is the bus voltage vector, I is the current injection vector, and \(Y_N\) is the network admittance matrix. Equation (1) includes the differential equations for all dynamic units(such as the generation unit). Each unit is coupled to the other units only through the network, so (1) is a collection of separate, uncoupled subsets. Eq.(2)
includes the network equations for the whole power grid. Considering that each generation unit only interacts with the rest of the system through the bus it attaches to, the detailed structure of it can be formulated as a block bordered diagonal structure. The equivalent reactance between the machine internal voltage and the infinite bus.

Stemmed from this point of view, a stabilization principle based on the elimination of the unbalanced power of the controlled systems is proposed and a relevant emergency control algorithm to dissipate the unbalanced energy is given, which can help to select proper control location and control amount with the transition of CUEP[14].

Multi-Agent can be a physical entity, such as in the Cartesian task environment it operates objects work together cooperatively, which move them from one location to another location ,intelligent body can also be calculation code, such as optimizing agents, they could work together to examine certain values and can effectively narrow the search space to achieve a series of small space[12]. Regardless of the domain on agent , one thing is the same, namely, during the problem-solving processing, it conducts local physics or computing interactively in task space. In response to the different local constraints received from the task space, the agent can select and show different behavior patterns .Multi-agent is composed of multiple autonomous agents, which has problem-solving ability and interact with each other to achieve the overall goal[13-14]. due to the above characteristics of multi-agent body, so it can be applied to the power systems simulation and control .through the sensor to sense the environment, each agent have data processing and communication function, after processing the data can be linked with the corresponding agent communicate with each other to complete the interaction. The processing flow can be summarized as: perception environment, analysis and reasoning, decision, dispatch task, execution control. Power systems are interacted through different agents (Fig.1).

The model consists of power systems Decision Support System and multi-agent systems. The agents are divided into Knowledge Agent, Information Agent and Collaborative Agent. Information agents have such behaviors as observation, perception, comparison and evaluation, and can express the particular desires based on background and knowledge. These desires determine the observation content of Information agents in the spatial system. The observation result is called a fact. By perceiving and evaluating facts, Information agent will form the perception directly.

Fig. 1 The general scheduling process based on MAS
related to the state of power systems system. Each Information agent will compare its own perception with perception of other Information agents and evaluate all perceptions of other Information agents relative to its own perception. Comparison and evaluation information will be communicated with Collaborative agent[15].

Aim to guarantee the convergence of the model, improve the speed that agents achieve a consistent decision, and ensure that information agents can express the application requirements in time and receive feedback information, the model conforms to the following two assumed conditions.

(1) Each agent should follow a set of predefined desire rule, in which new desires can not be added and utility function cannot be dynamically changed.

(2) In order to enhance the comparability of different transient stability margins due to different dominant modes. All agents in the model can equally and fully utilize all information of decision-making system.

According to the framework of the model, with reference to related studies, Under ideal conditions, considering all the factor of power systems, Specifically interaction rules between agent and the surrounding environment are as follows:

Definition 1. MAS is a multi-agent system of power systems, MAS = <, Δ, E, G, S, R, x >- the task set of agents need to perform, Λ = {ai, i = [1, ..., m]} stand for the set of all kind of agents, and |Λ| = m, E - the status set of the system respond to different factors, G- the set of the target status, S - the observable status set of system, R - the collection of related resources.

Definition 2. Λ1 → Λ2, define task function task() is the map of Λ→(τ), and ∀aΛ, Then Task(a)= (τ)|τ|, Task(a) stand for the task of agent a needs to perform.

Definition 3. Λ1 → Λ2, define task function task() is the map of Λ→ (R), then performable Task (s,a) = task(a).

Definition 4. s ∈ S, a ∈ Λ, and g ∈ G, t ∈ τ, define task execution function(task) is the map of S*Λ→ (τ), then performable Task (s,a,g) = task(s,a).

Definition 5. i ∈ [1,...,|Λ|], j ∈ [1,...,|Λ|] , i not equal j, define task call function(call) is the map of τ → τ, true, false)

call(t, t, t') = true it means that the task t need to perform the task t'.

Definition 6. i ∈ [1,...,|Λ|], j ∈ [1,...,|Λ|] , i not equal j, define interaction function(interaction) is the map of Λ×Λ→ (true, false), then communication (a, a') = true = i Λ ∈ task(a), a' Λ task (a) | call(t)|true=

Definition 7. i ∈ [1,...,|Λ|], j ∈ [1,...,|Λ|] , i not equal j, define interaction function(interaction) is the map of Λ×Λ→(R), then interaction (a) = { a | Λ communication (a), a)|true=true.

Definition 8. a ∈ Λ, define function(resourceAccessibility) is the map of Λ→(R), then resource Accessibility (a) = (R)|true|task(a)|true|resources(R).

It is not considered realistic to further increase the penetration level. Generally, the methods for model identification can be classified into three categories. First, according to the information agent before the fault is cleared, the candidate models are selected. Then the stability margin of each model can be calculated and the least one can be chosen as the stability or instability mode. This method can furnish the algorithm, which could help to save time but with a low precision because less information is used. The method of cooperation control based on MAS insures the stable operation of the subsystem under the premise of the openness and flexibility of MAS. It facilitates the practicable application, increases the openness, reliability and economy and lays an important foundation for the practical application of the system.

III. TRANSIENT STABILITY ANALYSIS METHOD

It seems that Lyapunov’s first direct method has been thought as the first choice for assessing and identifying stability of systems, especially nonlinear complex systems, such as multi-machine power systems. Extended equal area method (EEAC) is an improved direct method, the energy function can be calculate by the rotor of the generator, then according to the energy function to calculate the fault during the transient and residual energy during system failure. through comparison the limit transient energy, then judge the performance of the system transient stability. In order to provides an effective means real-time massive power system transient stability calculation. It can combine artificial intelligence method and the EEAC method, using intelligent agent to rapid identification of homology fleet. In this paper, on the basis of physical observation for rotor movement, the power system stability criterion is established, through the equation transform of rotor motion, to calculate the acceleration area and deceleration area. and then using the EEAC method for judging system put more stability, can be make up for the inadequacy of traditional EEAC transient analysis method, greatly improving the efficiency of transient stability assessment. if ignore the damping effect, the rotor motion equation of the i-th generator under the synchronous coordinate condition, can be expressed as followed:

\[ T_i \frac{d}{dt} \Delta \omega_i = P_{m_i} - P_{e_i} \]

\[ \frac{d}{dt} \delta_i = \omega_i - \omega_0 = \Delta \omega_i \]

The rotor motion equation of j-th generator has the same as it, if it transform the motion equation for the unit of G_i-G_j, which can be completely similar to any other unit, therefore for any unit of rotor, the motion equation of rotor can be expressed as followed:

\[ \frac{d}{dt} \Delta \omega_{ij} = P_{m_{ij}} - P_{e_{ij}} \]

\[ \frac{d}{dt} \delta_{ij} = \omega_{ij} - \omega_0 = \Delta \omega_{ij} \]

\[ \Delta \omega_{ij} = \Delta \omega_i - \Delta \omega_j, \quad \delta_{ij} = \delta_i - \delta_j \]
According to the above principle, and extend into multi-machine system. Due to the electromagnetic power is available of various units. The equivalent electromagnetic power $P_{eij}$, which change from single rotor motion to multi-machine rotor motion equation, it can be easy to calculate based on the type (4). According to the approximate relationship of multi-machine system function selection, without considering the damping effect and regarded as a constant, the relationship curve of electromagnetic power was shown in Fig. 2.

![Fig.2 The relationship curve of multi-machine system](image)

For the fault stage, from the beginning to the end of the fault, the system begins from the point (a) and end in point (c), the energy conversion relations in the process of acceleration stage can be expressed as follow:

$$A = \frac{1}{2} T \omega \Delta \theta = \int_{\delta_{ij}}^{\delta_{ij}} (P_{mij} - P_{eij}) d\delta_{ij}$$

After the removal the fault, the system moves from the point (c) to the point (e). If the system can resume to the state of synchronous operation, the energy conversion relations in the stage can be expressed as follow:

$$B = \int_{\delta_{ij}}^{\delta_{ij}} (P_{eij} - P_{mij}) d\delta_{ij}$$

In order to simple the conditions, it adopt performance index ($\eta$) to characterize the Transient stability state, as the start element of coordination agent.

$$\eta = \frac{A - B}{A} \times 100\%$$

The degree of stability is characterized by value of $\eta$, there exists such a conclusion: when $\eta<0$, the smaller the $\eta$, the system is more stable; when $\eta>0$, the greater the $\eta$, the system is more unstable. In order to simple the system observation, according to the above analysis conclusion, the logic switching of coordination agent is shown in Table 1.

<table>
<thead>
<tr>
<th>Performance indicators</th>
<th>$\eta &gt; 0$</th>
<th>$\eta = 0$</th>
<th>$\eta &lt; 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>System steady state</td>
<td>A&gt;B, Out of step</td>
<td>A=B, critical</td>
<td>A&gt;B, stable</td>
</tr>
<tr>
<td>Start state of Coordination agent</td>
<td>start</td>
<td>alert</td>
<td>Not start</td>
</tr>
<tr>
<td>Logic control switch</td>
<td>1</td>
<td>--</td>
<td>0</td>
</tr>
</tbody>
</table>

IV. COORDINATION CONTROLLER OF MULTI-MACHINE SYSTEM (MAS)

In the actual application, operation situation of the subsystems was affected directly by the strong coupling between the system. Therefore, it often required coordinate the action of multi-generator in the design of the controller, which lead to improve the control effect of the system. Based on N interconnection systems, the mathematical model of the $i$-th generator in the system was expressed as followed:

$$v_{fi} = v_{lpss} + v_{spss} = K_r X_i(t) + K_x x_g(t)$$

Where $v_{fi}$ represents decentralized coordinated control of input controller, it included the local distributed control input $v_{lpss}$ and wide-area distributed control input ($v_{spss}$) of the coordinated control system. $X_i(t), X_g(t)$ represent the state variables of local and wide-area system, the control method of the generator excitation control terminal (field Agent) was described as Fig. 3.
V. SIMULATION AND RESULTS ANALYSIS

In this section, it verify the accuracy and efficiency of the MAS-based method described in the previous section. In this experiment, the platform for MAS control is developed in the software development environment, the New-England bus system is used. In order to test the effectiveness and validation of improved decentralized coordination control system when the system undergo different disturbance. The cooperation control methods are simulated and the feasibility and effectiveness are verified on this platform. Fig.4 gives the simulation model with 4 generators in SIMULINK environment.

In the simulation study, it control the failed four machine system by distributed control and coordinated control scheme (MAS). The system is disturbed by a three phase short-circuit occurring on line Bus7-Bus8 (the fault location is close to the busbar Bus7) at 0.15s and then is cleared by tripping the faulted line at 0.85s. Under this situation, the power-angle curve moves to the left and the will produce strong adverse influences to stability due to over-braking. then no obvious deviation of the power-angle curve can be found. A severe fault is used to give the instable case, This disturbance causes instability. The curve of the rotor angle is shown in the Fig.5.
Power system must take all kinds of effective measures to keep voltage in permitting. Hierarchical voltage control comes up with a great model for stability and reliable running of voltage in power system. By means of rotor angular velocity, relative rotor angle between different units, Potential energy index and terminal voltage of the multi-machine system, Through test( the single-phase short circuit and three-phase short circuit of generator). And then analysis the difference between the results of simulation. Considering the constraint of network equation and rotor speed variations of the system, an analytical method based the steady-state equivalent circuits of it to determine the transient stability of distribution network with multi-machine system.

![Operation points trajectory for the system with different clearing time when a three-phase short circuit fault at Bus7 occurs, which is showed in Fig.6.](image1)

Fig.6 Different clearing time when a three-phase short circuit fault at Bus7 occurs, which is showed in Fig.6.

Based on transient potential energy of four generators, an evaluation index set for the seriously disturbed generator is showed in Fig.7, it utilizing the aggregation feature of the index the dominant instability modes of the system can be identified within the very short term after the fault is cleared, and according to the clustering result of critical generating units the transient stability margin of the system under current fault mode is fast calculated by EEAC method. The terminal voltage waveform of synchronous generator for distributed control and coordinated control(MAS) is showed in Fig.8.

![Potential energy index of a short time for 0.15s fault-clear](image2)

Fig.7 Potential energy index of a short time for 0.15s fault-clear

(1) Distributed control method

(2) Coordinated control(MAS) method

Fig.8 The change of terminal voltage when three phase short circuit for synchronous generator
After the three-phase short-circuit fault, transient processing as followed: for distributed control method, from the Fig.8, it oscillate frequently and unable to restore balance in the system. for coordination control(MAS) method, it undergo fierce oscillation at the early stage, it showed that the stability effect is bigger when great disturbance (three-phase short circuit) than single-phase short circuit fault, however, through the effect of coordination control(MAS) method, it can restore stability as soon as possible. Especially, the method has distinct advantages for transient stability control based on all agents information, for unknown operating conditions, which significantly improves the robustness of the transient stability.

VI. CONCLUSIONS

Security and stability assessment is a key issue for power system operation. The traditional time domain simulation method and transient energy function method are difficult to satisfy both the quickness and accuracy requirements in power system. To solve the real time power system security analysis and the security and stability control technology has become the power production, operation, scientific research and manufacturing department's important task. Transient stability analysis of power system on-line design is completely according to the grid operation condition and fault information of the actual system, can be more effective to guide the practical operation of power grids, and can forecast accident in power grid fault condition to create the best accident processing stage, improve power supply reliability. The proposed method based on MAS can be used not only on high performance computers, but also on personal computer for increasing efficiency of daily work. It is anticipated this will play an important role in realizing transient stability simulation.

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REFERENCES