Research and analysis of dynamic equivalence of power system

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Abstract. In recent years, with the expansion of power grids, power system interconnection has also expanded. However, it brings many problems to the operation and management of power systems. The dynamic equivalence of power system is a kind of equivalent method of power system, which can keep the area of power system that needs to be studied unchanged and simplify the external area equivalently. Dynamic equivalence is divided into the cohomology equivalence method, the model equivalence method and the equivalent method of estimation. The dynamic equivalence of large-scale power system can improve the calculation accuracy, reduce the computational complexity and greatly improve the grid efficiency. This paper summarizes the dynamic equivalent methods of power systems in recent years, introduces the ideas and methods of various methods, and carries out the simulation analysis.

1. Introduction
Study on the equivalent method of power system, have a very important practical significance on the off-line analysis and on-line analysis. With the development of power grid construction, the formation of interconnected power system brings many new problems to the calculation of power system planning and operation mode. It is very difficult to get all the accurate real-time information of the whole external system when the analysis and computation of the interconnected system are in various running states, but the scale of the mathematic model of the system must match with the real-time information obtained. Therefore, it is necessary to deal with some non-observable parts of the external system as external equivalents.

In the process of large-scale system analysis, it is generally only interested in one of the local systems, called the research system, also known as the internal system. For the area far from the research system, it can be appropriate to simplify the treatment to save manpower and material resources, as long as the dynamic impact of the study system to maintain the same, its internal structure is not necessary to be investigated in detail. This area can be called an external equivalent system. Systematic simplification highlights the main contradiction, which is necessary to master the main features of the research system[1-3].

2. Several methods of dynamic equivalence
The method of dynamic equivalence is closely related to the actual physical problems which are studied after equivalence. Generally, the problems can be divided into three types[4-6].
- Transient Stability Analysis of Large Power System. Its feature is that the system structure and parameters are known, the system transient process should be analyzed in the case of large disturbances, the system was strong nonlinear. The requirement for dynamic equivalence is that the research system should have a similar rocking curve before and after the equivalence.

- Dynamic stability analysis of off-line large power system. Its feature is that the system structure and parameters are known, the system transient process should be analyzed in the case of small disturbances. The requirement for dynamic equivalent is that the research system should have the same or similar motion pattern distribution before and after the equivalence.

- Apply the measured data to the system equivalence. Its feature is that system conditions and structure are various, but there are a lot of measured values available. It is necessary to identify the equivalence of the external system quickly so as to provide sufficient external information support for the on-line stability analysis of the system, and ensure that the research system has similar dynamic safety analysis results before and after the equivalence.

Accordingly, equivalence methods can be divided into three categories:

- Coherency-based equivalents based on relevance concept. According to the transient stability analysis of large power systems, those generators with the same frequency and similar frequency swing (i.e., the same tumbling) are grouped together. All generators in each group are aggregated into one or two equivalent machines. Through the network simplification, a large number of load nodes can be eliminated. At present, it is limited to the combination of constant power, constant impedance and constant current load on the basis of reserved power. Coherency-based equivalents have the advantages of large physical transparency and equivalent system components. The model is the actual power system component model, which can directly apply the original transient stability analysis software. It can adapt to the system of strong nonlinear and large perturbation analysis, and can be applied to large-scale system equivalent; the equivalent value can be carried out on the minicomputer, the speed is very fast; dynamic equivalent precision control is more convenient, the practical application shows that the application effect is better. But coherency-based equivalents also has some shortcomings: Firstly, homology group division and disturbance of the location, type and other factors; Secondly, the network simplification and elimination of the phase shifter operation will bring some errors to the dynamic equivalent; In addition, the coherent generator polymerization is more complex, will lead to a certain polymerization error. In recent years, there have been new developments in the identification of homology groups.

- Modal equivalents based on eigenvalues. It is the use of compression system motion mode number of ways to reduce the physical order of the system, thereby reducing the demand for computing. This method is not only the design of the system, the integration is very effective in the system stability simulation and dynamic safety analysis is also quite valuable. The advantage of modal equivalents is that once the dynamic equivalence of the external system is obtained by this method, the same equivalent result can be used to analyze the large number of accidents in the research system, as long as the fault point is not close to the boundary point. However, due to the mechanism of modal selection is not very clear, it is only limited to obtain the external system state equation model decomposition, try to improve the simulation speed.

- Online recognition based on measured values. Both of these methods have large computational complexity and need to know the difficulty of all the data of the external equivalent system, and often have the small disturbance linearization of the system, and it is difficult to meet the engineering requirements in time and precision. In order to overcome these difficulties, it is considered to use the boundary line to measure the information through the identification method to obtain the external region of the equivalent model. Unlike modal equivalents and coherency-based equivalents, online identification does not require detailed data from external systems, which is what people expect. However, due to the nonlinear time-
varying characteristics of power systems, as well as the special requirements of online identification, the realization of this method there are some difficulties.

3. Equivalent Model
In the early study, the structure of the two regions is generally used, and the equivalent model is a single load. As the model is simple, coupled with the constraints of simulation technology, the accuracy of numerical calculation cannot meet the needs of engineering practice. In recent years, on the basis of this gradually carried out on the multi-regional interconnection system equivalent problem, and put forward a variety of different equivalent structure model[7-10], respectively, as follows.

The actual contact line model retains the actual tie-line, which equates each regional system into a single-load model, as shown in figure 1.

![Figure 1. Actual contact line model.](image)

The equivalent contact line model is obtained from the equivalent model in figure 1 for further processing, as shown in figure 2. This can be further simplified for the equivalent system, of course, compared with the system in figure 1, the accuracy will be reduced.

![Figure 2. Equivalent contact line model.](image)

For large-scale equivalent systems, sometimes single-load model is difficult to meet the accuracy requirements of the analysis. In addition, taking into account the external equivalence of the system and the distance between the research system is not exactly the same, if necessary, the equivalent model can make appropriate adjustments to divide the buffer, as shown in figure 3. Buffers can improve the accuracy of a certain extent, but after the division of the buffer, you need to do more analysis of external systems.

![Figure 3. Multi-machine equivalent model with a buffer.](image)
The results show that the actual contact line model is more suitable for the theoretical equivalent method, and the equivalent contact line model is more suitable for identifying the equivalent method. The multi-machine equivalent model with a buffer can be applied to the problem analysis which needs more precision.

4. Simulation results and discussions
Figure 4 shows the IEEE39-node power system single-line diagram. The system has 10 machines, 19 loads, and node 31 is the balance node. In the PSASP transient stability calculation, all ten generators adopt a third-order model. The system nodes 2, 17 and 18 are the boundary of the equivalence network, and the nodes 1, 3, and 16 are the boundary of the research network. In this part, the power flow calculation and the transient stability calculation of the equivalent network are compared and analyzed respectively.

By the equivalent calculation, the constant potential of the equivalent machine is 1.598, the value of the equivalent potential angle is 43.12° and the inertia constant is 17.9s. The power flow is calculated using the equivalent data set and compared with the equivalent network trend, as shown in Tab. 1. In Tab. 1, the transmission of active and reactive power is the power of the equivalent network boundary to the research network. The positive value indicates that the equivalent network transmits the power to the research network. The negative value indicates the equivalent network to absorb power from the research network.

![Figure 4. IEEE39 bus power system](image)

**Table 1. Boundary flow of the IEEE39 bus system before and after equivalence**

| Equivalence Node | Research system Node | Before Equivalence | After Equivalence |
|------------------|----------------------|--------------------|------------------|
| 2                | 1                    | 1.1598.            | -0.2689.         |
| 2                | 3                    | 4.0679.            | 0.9917.          |
| 17               | 16                   | -1.2778.           | 0.1091.          |
| 18               | 3                    | -0.2586.           | 0.0192.          |

As can be seen from Table 1, the power of the equivalent front and back boundary nodes is almost unchanged, and the voltage phase angle of each node in the research network is similar. EPRI E 'equivalent calculation can meet the requirements of steady-state power flow calculation in engineering calculation, and can save the calculation time by the equivalent research network.

The transient analysis of the equivalent system is carried out by assuming a serious fault of the three-phase ground short circuit. Observe the relative angle δ of the rotor of the generator, and observe
the near point of the distance equalization subsystem and the far point of the fault point distance equivalent subsystem.

Near the point selection bus 16 at the exit, two phase earth fault, the fault occurred at 0.2s, and cut off at 0.35s, observe the generator 35 and 39 rotor relative angle curve Far point selection bus bar 11, three phase earth fault, the other experimental conditions and near point of failure the same.

Figure 5 shows the change of the relative angle of the rotor before and after the near-point fault. Figure 6 shows the relative value of the rotor before and after the fault.

By contrast, it can be seen that the change of the relative angle of the rotor of the system after the original system and the simplified system is consistent within 2s after the system failure, and does not affect the transient stability analysis.

![Figure 5. The curve of relative rotor angle before and after equivalence at vicinity](image1)
![Figure 6. The curve of relative rotor angle before and after equivalence at distance](image2)

5. Conclusion

For simplified calculation, we often simplify some areas that do not need intensive study in power system analysis. By using the PSASP software to process dynamical equivalence calculation in typical example and actual large scale power networks, this paper analyzes the advantages and disadvantages of PSASP dynamical equivalence function. It is convenient to use. It could calculate multiple equivalence and the calculated results are suitable for transient analysis. But in some situations the EPRI equivalent cannot get results, and the equivalent calculation interrupts. The specific causes and improvement measures need to be further studied.

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