Research on Emergency Method of Power Cyber-Physics Risk Area

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Abstract. With increasing emphasis on the economics of power system operation, economic costs have gradually become an important issue to be considered in the research of risk emergency methods. Although the above method of removing the load of key nodes can effectively suppress the spread of risks, this method is also accompanied by a large amount of load loss, which causes economic waste. In response to this problem, considering the state and topology of the system risk area, this paper proposes emergency measures for node injection power adjustment and load shedding. At the same time, it comprehensively considers the effects and costs of emergency measures, puts forward economic and safety evaluation indicators, and builds an emergency model for cyber-physical power system risk areas. Finally, the differential evolution algorithm is used to optimize the emergency model, and the emergency method for cyber-physical power system risk areas with the best control effect and the lowest control cost is obtained.

1. The first section in your paper
With the proposal and continuous development of smart grid and energy Internet strategies, information networks are playing an increasingly important role in power system operation status monitoring, production scheduling, etc. The traditional power system has gradually evolved into a highly coupled power information physical system. My country plans to basically build a strong smart grid in 2020 [1-3]. The traditional power system has significantly increased demand for grid resource allocation, security control capabilities, and interaction between the grid and users. This means that the power information physical system, which is the foundation of the smart grid, is taking on an increasingly important interconnection role. Cyber-physical power system is mainly composed of two parts: power information network and power physical network. Among them, the power information network is used as a channel for carrying services. The real-time monitoring data of the power physical network is uploaded to the corresponding information system, and the management and control information is distributed to all levels of sites [4]. To support the safe and reliable operation of production control business, production management business and enterprise management business. It can be said that the dispatch and intelligent decision-making of power network cannot be separated from the support of power information network [5]. At the same time, the operation of network equipment such as routers in the power information network also needs to rely on the power physical network to provide electrical energy at all times [6-9]. This interdependent relationship creates a close coupling between the power information network and the physical network.

In summary, this paper studies emergency methods for cyber-physical power system risk areas. First, considering economy and safety, the emergency method evaluation index is put forward. Then,
according to the change of the risk area at the time of normal operation and the time of failure, emergency measures are designed that combine node injection power adjustment and overload node shutdown. Finally, the emergency model is solved by the differential evolution algorithm to realize the emergency method in the risk area with lower cost and best effect.

2. Construction of Emergency Model for Power CPS Risk Areas
The evaluation of the emergency model mainly includes economic and safety aspects. Among them, the economic index $C$ is mainly composed of two parts: the cost $C_{normal}$ and the load cut loss cost $C_{unnormal}$ during the normal operation of the system. The specific expression is as follows:

$$C_{normal} = \sum_{i=1}^{V} x_i L_{G_i}^2 + y_i L_{G_i}$$

$$C_{unnormal} = \sum_{j=1}^{V} \rho_k \cdot U_j^k$$

$$C = C_{normal} + C_{unnormal}$$

where $V_i$ and $L_i$ respectively represent the collection of power generation nodes and load nodes in the network; $L_{G_i}$ represents the active power of the $i$-th generating node; $x_i$ and $y_i$ represent the cost coefficient of the power generation node; $\rho_k$ represents the tolerance coefficient of the $k$-th node; $U_j^k$ represents the load lost by $j$ under $k$ risk conditions.

The safety indicators used to evaluate the implementation of emergency methods are as follows:

$$S = \frac{\left( N_{before} - N_{after} \right)}{P_{S_n}}$$

where $N_{before}$ and $N_{after}$ respectively represent the number of nodes in the risk area before and after the implementation of the emergency method; $P_{S_n}$ represents the probability of occurrence of the risk area.

Considering the changes in risk areas and economic costs after the implementation of emergency measures, the following emergency model evaluation indicators can be obtained:

$$E = \frac{C}{S}$$

It can be seen from the above formula that when the value of $E$ is smaller, it indicates that the emergency method has a better risk control effect and lower economic costs after implementation, which proves that the method is superior.

The node injection power considering the system risk state is the priority emergency measure when the system operation state is abnormal. This method affects the operating flow of the system by adjusting the active power and reactive power of the generator nodes, and considers the emergency cost while restraining the spread of the risk area. The specific expression is as follows:

$$M_G = \tau_1 \sum_{k=1}^{N_a} (P_{Gk} + Q_{Gk}) + \tau_2 \left( P_{G,RP} + P_{G,RL} \right)$$

where $P_{Gk}$ and $Q_{Gk}$ represent the active power and reactive power of the $i$-th generating node; $P_{G,RP}$ and $P_{G,RL}$ indicate the power over-limit failure probability and voltage over-limit failure probability of the power generation node; $\tau_1$ and $\tau_2$ indicate safety and economic weight.
The safe operation and optimization condition constraint equation is as follows:

\[
\begin{cases}
    P_{Gi} - V_{Gi} \sum_{j=1}^{V_{Gj}} \left( G_{Gj} \cos \theta_j + B_{Gj} \sin \theta_j \right) = 0 \\
    Q_{Gi} - V_{Gi} \sum_{j=1}^{V_{Gj}} \left( G_{Cij} \sin \theta_j + B_{Gj} \cos \theta_j \right) = 0 \\
    P_{Gi,\text{min}} < P_{Gi}(V, \theta) < P_{Gi,\text{max}} \\
    Q_{Gi,\text{min}} < Q_{Gi}(V, \theta) < Q_{Gi,\text{max}} \\
    V_{Gi,\text{min}} < V_{Gi} < V_{Gi,\text{max}}
\end{cases}
\]

where \( P_{Gi,\text{min}} \) and \( P_{Gi,\text{max}} \) indicate the lower limit and upper limit of the active power limit of power generation node \( i \); \( Q_{Gi,\text{min}} \) and \( Q_{Gi,\text{max}} \) indicate the lower limit and upper limit of the reactive power limit of power generation node \( i \); \( U_{Gi,\text{min}} \) and \( U_{Gi,\text{max}} \) are the lower limit and upper limit of the voltage of power generation node \( i \), respectively.

Compared with node injection power adjustment, the control cost of load shedding is higher. This method physically blocks the continued spread of risks by cutting off nodes with higher risks, which destroys the power supply reliability of the power information physical system to a certain extent, resulting in higher control cost. The specific expression is as follows:

\[
M = \tau_1 \sum_{g=1}^{N} \left( P_g + Q_g \right) + \tau_2 \left( P_{RP} + P_{RU} \right)
\]

where \( P_g \) and \( Q_g \) respectively represent the active power and reactive power of node \( g \); \( P_{RP} \) and \( P_{RU} \) respectively indicate the failure probability of power over-limit and the failure probability of voltage over-limit of the node.

The safe operation and optimization constraints that the measure still needs to meet are shown in the formula:

\[
\begin{cases}
    P_i - V_i \sum_{j=1}^{V_j} \left( G_j \cos \theta_j + B_j \sin \theta_j \right) = 0 \\
    Q_i - V_i \sum_{j=1}^{V_j} \left( G_j \sin \theta_j + B_j \cos \theta_j \right) = 0 \\
    P_{i,\text{min}} < P(V, \theta) < P_{i,\text{max}} \\
    Q_{i,\text{min}} < Q(V, \theta) < Q_{i,\text{max}} \\
    V_{i,\text{min}} < V_i < V_{i,\text{max}}
\end{cases}
\]

3. Emergency model simulation process

Considering that the power CPS system itself has a certain degree of stability and regulation ability, only when the proportion of node failures in the risk area exceeds the system tolerance value, will it cause a wide range of propagation behavior. Otherwise, the security risk is that small nodes may not break the safety threshold of power CPS network disassembly. In response to this situation, the security threshold of the risk area is proposed:

\[
\psi_{ij}(P, U) \leq \delta \psi_{ij}
\]

where \( \psi_{ij}(P, Q) \) is line operation status in risk area. \( \psi_{ij} \) is the maximum capacity of the system in normal operation. \( \delta \) is the tolerance of the system to operational risks.

Considering the operating status of the system risk area and the network topology relationship, the simulation process of establishing the emergency model of the power CPS risk area is as follows:
Step1: Input the current power CPS network topology and operating characteristic parameters, and calculate the system characterization load and constraints.

Step2: Judging the network operation status and predicting the risk area.

Step3: Assess whether the operating status in the risk area breaks the safety threshold. If yes, proceed to the next step; if no, no emergency measures are taken.

Step4: Take node injection power control for emergency intervention in this area, and reassess the state of the system risk area.

Step5: If there is still a risk area that breaks the safety threshold in the system, take optimal load shedding control measures.

Step6: Cycle screening until there is no risk area exceeding the safety threshold in the power CPS system, and the risk area no longer spreads, then the emergency process ends.

4. Experiment and result analysis

The experimental part uses the 9-node (IEEE-9) standard model for simulation. The network has 4 edges and 9 nodes (including 3 power generation nodes). Since the change in the line state of the node in the information network can be represented by the load change of the physical network node under its control, for the convenience of calculation, an information node is connected to each power generation node, and the information node is used to control the load change of the power generation node. The dispatch cost of each power generation node is shown in Table 1:

| Generator node number | Dispatch cost/ (MW/RMB) |
|-----------------------|-------------------------|
| 1                     | 9.3                     |
| 2                     | 9.5                     |
| 3                     | 9.4                     |

![Figure 1: 9-node system diagram](image)

Table 1 Generator scheduling cost parameters

The differential evolution algorithm is used to solve the emergency model of the risk area. In order to facilitate analysis and comparison, the node load rate is used to characterize the operating state of the system. The node load rate calculation method is as follows:

$$\omega \% = \frac{L_{nk}}{L_{nl,\text{max}}}$$

It can be seen from Figure 2 that the load rate distribution of nodes in the initial system is unbalanced. Load node 9 and power generation node 3 have been overloaded, indicating that the node is on the verge of collapse and failure, and some nodes such as 2 and 7 have load rates lower than 0.2,
the resource utilization rate is too low. After the implementation of the emergency method, the effect is shown in Figure 3, the system node load rate is evenly concentrated in the interval between 0.4 and 0.6. This method reduces the load rate of heavy load nodes while increasing the load rate of some low load nodes. The safety of grid operation is improved.

![Figure 2. Initial system node load rate](image1)

![Figure 3. System node load rate after emergency method](image2)

5. Conclusions

This paper first comprehensively considers economy and safety to put forward emergency method evaluation indicators, and then according to the operating state of the system risk area and network topology characteristics, combined with the security risk propagation mechanism, proposes emergency measures that combine node injection power adjustment and overload node cut-off to construct Emergency model for cyber-physical power system risk area. Finally, the analysis of calculation examples shows that the emergency method proposed in this paper can achieve the optimal emergency cost while effectively improving the safety index of the risk area.

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