Research and Practice of Resilient Smart Grid Based on Hainan Island in China

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- Project background
- Major technological innovations
- Evaluation of technical indicators
- Application and economic/social benefits
1 Project background

Strategic positioning of Hainan province:
- “Three areas and one center”: Comprehensively deepen the trial area for reform and opening up; National Ecological Civilization Experimental Area; International Tourism Consumption Center; National major strategic service guarantee area.
- “One zone and one port”: China (Hainan) free trade pilot zone; Hainan free trade port.
- “One Belt and One Road”: An important strategic fulcrum for the 21st Century Maritime Silk Road.

Positioning of Hainan power grid:
The only provincial smart grid demonstration zone in China

<table>
<thead>
<tr>
<th>Overview of Hainan power grid before the project in 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sources</strong></td>
</tr>
<tr>
<td>Installed capacity: 3439.5MW; Clean energy ratio: 27.2%; Wind power/photovoltaic installation ratio: 6.0%</td>
</tr>
<tr>
<td><strong>Grid</strong></td>
</tr>
<tr>
<td>Only a single 500kV cable is connected to the main network of China southern power grid, The main frame is 220kV double-loop network structure; strong typhoons, thunderstorms and other natural disasters all year round.</td>
</tr>
<tr>
<td><strong>Loads</strong></td>
</tr>
<tr>
<td>The highest load: 2295MW; Mean peak-valley difference: 42.7%; Multiple super guaranteed power supply loads.</td>
</tr>
</tbody>
</table>
1 Project background

This project needs to solve the following technical problems:

1. The safe and economic operation of the weak-tie power grid affected by the randomness, fluctuation and poor load peak-valley characteristics of intermittent energy
2. Rapidity, reliability and accurate decisions for the safe and stable control of weak and multi-disaster power grid under complex time-varying conditions
3. Monitoring and early warning of multi-disaster risk of power transmission and transformation equipment, and systematic real-time and dynamic prevention of the whole province
4. The coordination and interaction among source, network and load, and the energy management and operation control of the microgrid of far-sea islands and reefs

With the support of the national 863 program and the national science and technology support program, the project team solved the problems of Hainan's unique new energy consumption of multiple types, power grid security and stability under multiple disasters, and independent power supply of far-sea islands and reefs. For the first time, the key technology system of the smart grid in the whole province was established and put into engineering application.
2 Major technological innovations

Innovation 1
Multi-level penetration technology for weak-tie grid with intermittent renewable energy

1-1 Power prediction for intermittent energy sources

A prediction method based on physical and statistical data, which only requires a few parameters of wind farms for model adaptation

A short-term photovoltaic prediction method based on SVM;

Proposed methods ensure accuracy for prediction of wind and photovoltaic power in tropical marine areas under high temperature and humidity environment.

short-term wind power prediction accuracy: 92.09%
ultra-short-term wind power prediction accuracy: 94.90%
short-term photovoltaic power prediction accuracy: 95.1%
ultra-short-term photovoltaic power prediction accuracy: 98.22%

Circumstantial certificate: invention patent ZL201210374.7, etc., 2 papers included in EI
2 Major technological innovations

1-2 Multi-time scale robust optimization dispatch
Multi-time scale robust scheduling techniques based on optimal error bound theory and predictive data driven method, including the day-ahead robust unit combination, Intraday rolling plan and 5-minute-advanced AGC with system safety constraints. These techniques reduce the effect of uncertainty on the grid operation, and realize the optimal output and commitment for multi-type power sources.

Circumstantial certificate: invention patent ZL201410571706.3, 1 SCI paper, 5 EI papers

1-3 Active/reactive power optimization control
Primary and secondary frequency control based on Nash equilibrium coevolutionary algorithm;
Multi-objective reactive power optimization method (tertiary voltage control) using linear weighting efficacy coefficient and ideal point methods, and regional optimal coordinated voltage control (secondary voltage control) method based on dynamic games;
Establishment of active and reactive power optimization control system for weak-tie provincial power grid with highly intermittent renewable energy.

Circumstantial certificate: invention patent ZL201510700286.9, ZL201510598654.3, 1 SCI paper, 2 EI papers
2 Major technological innovations

Innovation 2 Safety and stability coordinated control technology

Real-time state trusted perception  System situation reliability assessment  Safe, stable and accurate online decision making

2-1 Real-time state trusted perception

Proposition of a new theory of state estimation based on set theory, which ensures the credibility of state estimation results.

The real-time state estimation method based on full PMU measurement with high tolerance for the maximum pass rate, solving the credibility problem of the real-time state of provincial power grid with high proportion of renewable energy sources.

Circumstantial certificate: invention patent ZL201210304251.X、ZL201210335879.6, etc.
2 Major technological innovations

2-2 System situation reliability assessment

A probabilistic quantitative evaluation method for system safety and stability, which can effectively avoid the impact of uncertainty/correlation of renewable energy output on the reliability of assessment results, and solve the problem of fast and reliable assessment of power system operation under high permeability of renewable energy.

Circumstantial certificate: invention patent ZL201210303960.6, ZL201210304251.x, etc

2-3 Accurate online decision-making system for safe and stable operation

The emergency control decision method based on trajectory eigenvalues, which can quickly determine the position and size of the control strategy implementation.

Online verification is adopted to ensure the correctness of the control strategy, which guarantees the effect of online decision-making system for safe and stable operation of provincial power grid under rapidly time-varying complex conditions.

Circumstantial certificate: EI paper practical criterion for transient stability based on locus characteristic roots
2 Major technological innovations

Innovation 3 Multiple disaster monitoring and early warning system, and active defense technology

State perception, risk warning and defense decision of transmission line under complex environment is realized.

3-1 Lightning disaster monitoring and early warning system, and active defense technology

Based on characteristics of transient current traveling wave, a fault identification and localization method for transmission line under lightning strike is proposed. A system integrating monitoring with identification functions for lightning strike faults is established.

Using the measured lightning strike data, an optimal calculation method for evaluating the performance of transmission lines against lightning strike is given.

A lightning strike visual warning system is realized by analyzing the movement of lightning cloud, which is based on the empirical orthogonal analysis and cluster identification methods.

Circumstantial certificate: 8 invention patents including ZL201410660310.6, 4 software Copyrights including 2016SR026063, 2 papers included in EI
2 Major technological innovations

3-2 Typhoon disaster monitoring and early warning system, and active defense technology

A typhoon early warning method is presented based on temporal and spatial distribution statistical characteristics. A performance evaluation model is given for transmission lines against typhoon, based on dynamics analysis of tower-line system and module difference method. A hierarchical assessment and risk warning system for transmission line and tower under wind-rain loads is realized, which improves the forecasting and early warning abilities for typhoon impact.

Circumstantial certificate: 2 invention patents ZL201410419598.8, 3 software Copyrights 2015SR284285, 2 papers included in SCI

3-3 Pollution disaster monitoring and early warning system, and active defense technology

A classification method for pollution and humidity degree is given, which comprehensively characterizes the pollution and humidity properties of tropical islands. The numerical relationship between insulator-pollution-flashover voltage and factors including salt density, salt fog salinity and humidity/condensation is established. A pollution-flash-warning model with triple criterion is developed, which improves the accuracy of insulator-pollution-flashover warning and shortens the warning time.

Circumstantial certificate: 2 invention patents including ZL201610261568.8, 1 software copyright, 2015SR062329
2 Major technological innovations

3-4 Security defense and early warning decision system of multiple disasters for wet tropical island power grid

A modification method is proposed for the state assessment model of power transmission and distribution equipment under the environment of high temperature, humidity, salt density and typhoon. A time-varying outage model is built for the equipment operation under extreme disasters.

A defense and early warning decision-making system for wet tropical island power grid under multiple disasters is built in China. By assessing the time-varying outage probability of power components under large-scale natural disasters, the expected fault set is dynamically generated, and the system operation risk assessment is conducted in real time. It realizes active defense and beforehand preventing against disasters.

Circumstantial certificate: 1 software copyright, 1 third-party test report
2 Major technological innovations

Inovation 4

'Source-Grid-Load' coordinated interaction and micro-grid operational control technology for far-sea islands

4-1 Smart distribution network operation control technology

A three-phase state estimation and operational optimization algorithm is developed for active distribution network with radiant or loop topology.

An adaptive protection algorithm for current is provided, which is robust against the distribution system operation modes, distributed source conditions and fault types. A fault self-healing method is given based on the master station.

The problem of fault diagnosis, localization and load recovery of active distribution network is solved. The current protection device for distribution network is developed, which is adaptive to phase-to-phase-short-circuit and single-phase-to-ground faults. The operational control system of smart distribution network is developed and put into operation.

Circumstantial certificate: invention patent ZL201410607042.1, ZL201510546775.3, etc
2. Major technological innovations

4-2 Electric vehicle green roundabout

A dispatching strategy is proposed for coordinated charging of large-scale electric vehicles considering tropical natural disasters under spatial-temporal joint. A price response model of charging service for ev users is built. With the guidance of ordered charging time, natural disaster development track and time-of-use pricing method, the problem of spatial-temporal joint scheduling of ev charging facilities and distribution network is effectively solved, and the changing network for ev in green roundabout is constructed.

Circumstantial certificate: invention patent ZL201410607042.1, ZL201510099203.5

4-3 Military and civilian complementary and intelligent control technology for far-sea island microgrids

A matrix-based method for load demand response analysis is given. Multi-energy complementary strategies is developed. Through communication and power supply for military and civilian complement, the remote monitoring, control and interaction system that suitable for multi-island microgrid groups is built, and the interactive control with seawater desalination, electric vehicles and other flexible controllable loads is realized, as well as the remote centralized operation management of microgrid in multiple remote islands.

Circumstantial certificate: invention patent ZL201210371717.8, ZL201410608218.5, etc
## Evaluation of technical indicators

### 1. Power prediction technology for wind power / photovoltaic

<table>
<thead>
<tr>
<th>Comparison object</th>
<th>Comparison of technical indicators</th>
<th>Evaluation result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind power / photovoltaic power prediction technology</td>
<td>The accuracy for prediction of short-term / ultra-short-term wind power is 92.09% / 94.90%, (Domestic requirements are higher than 80% / 85%) and that of photovoltaic power is 95.10% / 98.22% (International requirements higher than 85% / 90%).</td>
<td>International leading</td>
</tr>
</tbody>
</table>

### 2. Multi-time scale robust scheduling technology

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</tr>
</thead>
<tbody>
<tr>
<td>Multi-time scale robust scheduling technology</td>
<td>The project adopts multi-time scale dispatch plan and robust scheduling method to ensure that the power grid can absorb intermittent energy to the greatest extent. (In China, the method of reserving reserve power directly is used to deal with the uncertainty..)</td>
<td>International leading</td>
</tr>
</tbody>
</table>
## 3 Evaluation of technical indicators

### Online assessment and coordinated control technology for power grid security and stability

<table>
<thead>
<tr>
<th>Comparison object</th>
<th>Technical indicators of the project</th>
<th>Advanced technical indicators at home and abroad</th>
<th>Evaluation result</th>
</tr>
</thead>
<tbody>
<tr>
<td>State estimation method and its accuracy</td>
<td>State estimation model based on set theory and solution algorithm, and the robust algorithm for estimation of PMU aiming at the maximum qualified rate is put into operation.</td>
<td>There is no State estimation model and algorithm of power system based on set theory.</td>
<td>International leading</td>
</tr>
<tr>
<td>Risk assessment method of power system</td>
<td>Consider wind power, photovoltaic and other intermittent energy generation equipment.</td>
<td>Generally, only conventional power generation equipment is considered, but intermittent energy is not involved.</td>
<td>International advanced</td>
</tr>
</tbody>
</table>

China Society For Electrical Engineering Achievement Appraisal Certificate([2017]No. 117)
## 3 Evaluation of technical indicators

### Identification, assessment and early warning of multiple disaster risk

<table>
<thead>
<tr>
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<th>Advanced technical indicators at home and abroad</th>
<th>Evaluation result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification method of fault type</td>
<td>Based on the characteristics of fault traveling wave current, the accuracy of identification of lightning (bypass / counterattack) and non lightning is more than 95%.</td>
<td>It can only identify lightning shielding and counterattack</td>
<td>International leading</td>
</tr>
<tr>
<td>The evaluation method of the ability of transmission line against typhoon</td>
<td>Comprehensive consideration of typhoon numerical simulation and mechanical properties of nodes to achieve hierarchical evaluation.</td>
<td>The maximum wind speed of typhoon is the accounting basis.</td>
<td>International advanced</td>
</tr>
<tr>
<td>Safety defense and early warning decision system of multiple disasters for wet tropical island power grid</td>
<td>In the face of large-scale natural disasters, Hainan power grid realized the probability assessment of time-varying outage and the risk assessment of system operation.</td>
<td>/</td>
<td>International leading</td>
</tr>
</tbody>
</table>

## 3 Evaluation of technical indicators

### Smart distribution network technology of ‘Source-Grid-Load' coordinated interaction

<table>
<thead>
<tr>
<th>Comparison object</th>
<th>Technical indicators of the project</th>
<th>Advanced technical indicators at home and abroad</th>
<th>Evaluation result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation optimization and self-healing control technology of smart distribution network</td>
<td>Considering the resources of distributed generation, energy storage, demand response and so on, a hybrid optimization method based on simulated annealing and cone optimization is adopted</td>
<td>Dynamic planning algorithm, particle swarm optimization algorithm, genetic algorithm, scene decision-making method are used to solve the optimal power flow problem; point estimation method, montacallos method and scene analysis method are used to study the distribution reconfiguration problem, while the research on the comprehensive time sequence optimization of smart distribution network considering multi-objective, multi constraint and multi control means is less.</td>
<td>International leading</td>
</tr>
</tbody>
</table>

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### 3 Evaluation of technical indicators

| 67 licensed patents: 58 invention patents and 9 new practical patents |
| 15 copyrights of computer software |
| Published 18 papers included in SCI and 71 papers included in EI |

**Five demonstration projects have been completed:**

- Demonstration project of intelligent scheduling and control consuming large scale intermittent energy techniques integration.
- Demonstration project of grid security defense and early warning decision system based on real-time operation risk techniques integration.
- Demonstration project of operation and control of smart distribution grid techniques integration.
- Demonstration of coordinated operation of electric vehicle charging and changing facilities and power grid.
- Demonstration project of microgrid control and optimization technology with distributed energy techniques integration.
3 Evaluation of technical indicators

Social Influence

CCTV (news broadcast on May 27, 2018), People’s Daily (9th news page on June 5, 2018), Science and Technology Daily, China Energy News, Hainan Daily and other authoritative medias reported the application of project research results for many times.

The project achievements have been highly recognized by Hainan provincial government, Hainan coast guard, 91154 troops of the people's Liberation Army and other units.

"Since the system was put into use, the power supply has been reliable, and the power quality has met the power demand of the equipment. It has thoroughly solved the problem of low reliability and poor power quality of the original island power supply, and provided a continuous, safe and reliable power guarantee."
4 Application and economic/social benefits

Economic Benefit

The project achievements have been widely used in the business of power grid dispatching operation, security and stability control, disaster prevention and emergency, coordinated operation control of electric vehicles and power grid, etc. These have been applied in Guangdong, Qinghai, Hubei, Jiangsu, Fujian and other provinces. In recent three years, the accumulated new sales volume is 1.843 billion yuan, and the new profit is 787 million yuan.

<table>
<thead>
<tr>
<th>year</th>
<th>New sales</th>
<th>New profit</th>
<th>New tax revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>34989.61</td>
<td>19035.33</td>
<td>——</td>
</tr>
<tr>
<td>2017</td>
<td>68750.37</td>
<td>29424.03</td>
<td>——</td>
</tr>
<tr>
<td>2018</td>
<td>80571.22</td>
<td>30230.73</td>
<td>——</td>
</tr>
<tr>
<td>Accumulated in recent three years</td>
<td>184311.2</td>
<td>78690.08</td>
<td>——</td>
</tr>
</tbody>
</table>
4 Application and economic/social benefits

Social Benefit

The project has achieved a breakthrough in the application of key technologies of smart grid in the humid tropical environment. There are three main achievements.

1. High efficiency consumption of new energy in Hainan power grid has been realized.

2. It realizes panoramic monitoring of power transmission and transformation equipment and visual monitoring and early warning technology of disaster in Hainan Province.

3. The project has built the first intelligent green micro grid of offshore islands in China. In fact, the remote control is realized, and the reliability of power supply is as high as 99.999%.
Thank you!