Study on Stability Control Strategy Based on Island Micro-Grid of Small Nuclear Power Plants

Bo Jiang¹, a, Zhong Zhang², *, Xintao Xie², b and Yong Kang³, c

¹Wuhan Second Ship Design and Research Institute, Wuhan, China
²ShenZhen Wellreach Automation Co., Ltd, Shenzhen, China

*Corresponding author e-mail: zhangzhong@wellreach.com, a jb_263@163.com,
b xiexintao@wellreach.com, c kangyong@wellreach.com

Abstract. For the island microgrid with limited load capacity, especially after the nuclear power generator set is connected, it is very important to control the grid safely and stably. This paper is aimed at the island micro-grid after the nuclear power generator set is connected. Firstly, the influence of the nuclear power plant on the topology of the power grid after it is connected to the grid is analyzed. Then, through the development of a topology analysis strategy, effective grid conditions are obtained. And the related stability control strategy is proposed that the corresponding CASE is triggered when the grid is faulty, such as generator trip, grid disconnection, generator/transformer overload, etc., to unload the range to ensure smooth operation of the grid. Simulation analysis shows the effectiveness of the proposed stability control strategy.

1. Introduction
Due to the poor peaking characteristics and frequent peak shaving of the nuclear power unit significantly affects the performance of the generator set [1-3]. According to the operating characteristics of the nuclear power, it is most efficient and economical to operate at rated capacity, and the operation mode is simple and convenient for operation. When the nuclear power generator is connected to the island micro-grid, the single nuclear power unit accounts for a large proportion of the marine microgrid capacity [4]. The sudden load shedding or cutting of the nuclear power unit will cause the system to lose more power, which will have a greater impact on system stability, voltage and frequency [5], and makes it more difficult to control the stability of nuclear power generators connected to the island grid. To ensure that the nuclear power platform can quickly integrate with the island microgrid, it is necessary to study a set based on the island microgrid stability control strategy of small nuclear power plants optimizes the functions of the island microgrid energy dispatching and management system.

In terms of stability control strategy, there have been many scholars' research results. Literature [6] studies the stable operation strategy when the local power grid decoupling with main grid after an accident. Literature [7, 8] mainly studied the control strategy of wind power, photovoltaic and other distributed energy into the large grid. Literature [9, 10] studied the safety and stability control strategy of DC grid. Literature [11] expounded the operation management mode and cutting machine principle of nuclear power plant safety and stability control system, but only considered mode that the nuclear
power unit decoupling with grid under the stability system. Literature [12] proposed the function of the stability system for Hainan Power Grid with nuclear power unit, but did not explicitly propose a control strategy. In summary, there is little research on the stability control strategy of the island microgrid with nuclear power plants at present. This paper firstly studies the operating conditions of the island microgrid connected to the nuclear power unit and develops a topology analysis strategy to obtain effective grid conditions. Then, the stability control strategy under different working conditions is proposed, which improves the parallel operation stability of the island microgrid connected to the nuclear power.

2. Topology analysis strategy

Topology analysis strategy is the basis for developing a stable control strategy, it mainly by determining the topology of the power connection between the power platform and the non-power platform, and then screening the effective working conditions. After determining the grid operating conditions, the preset parameters of the relevant stability control strategies for different CASEs under various operating conditions will be set.

The development of the topology analysis strategy mainly includes the following steps:

(1) Determine the topology that the nuclear power platform connected to the grid.
(2) Number each platform, distinguish between power platform and non-power platform, and calculate the total platforms’ number n of the power grid (including nuclear power platform).
(3) List all the permutations and combinations according to the number of the platform:

**Figure 1.** Topology analysis strategy processing flow chart.

- Start
- Get the grid topology
- Number each platform, distinguish between power platform and non-power platform
- Get the total platforms’ number n of the power grid (including nuclear power platform)
- \( i = 1 \)
- List all the permutations and combinations \( \mathcal{C}_n \)
- \( i = i + 1 \)
- Screen out combinations with the power node
- Screen out combinations with correct connection relationships in the combinations containing the power nodes
- Store the filtered combination in a valid file
- \( i = n? \)
- Y
- End
- N
3. Stability control strategy

The island microgrid stability control strategy based on small nuclear power plants is based on the real-time operating conditions, trigger conditions and rotating hot standby of the offshore power grid. Through the refined management of the unloading level, the system can be completed in one scan cycle of the PLC. When the preset range of the user is unloaded, when the power station occurs such as generator trip, grid disconnection, generator/transformer overload, etc., the corresponding CASE is triggered to perform range unloading to ensure smooth operation of the grid. According to the CASE trigger condition, it can be divided into the jump class CASE, the disjoint class CASE and the overload class CASE.

3.1. The CASE of generator tripping

There are two cases of single generator tripping and multiple generator tripping.

(1) Single generator tripping

When the system detects that a generator has tripped:

\[ \text{RPI} = \text{APT} - \text{APS} - \text{OLT} - \Delta \]  

Where RPI is hot standby (total output of total online generator minus actual output); APT means maximum output of total online generator; APS means maximum output of single generator; OLT means total real-time load; Δ means correction value; \( \text{Level}_n \text{kW} \) is the total power of the unloadable device with the unload level \( n \); ALT is the load that can be unloaded.

If \( \text{RPI} \geq 0 \), the hot spare is enough, and no load is required to be unloaded.

If \( \text{RPI} < 0 \), it should be judged: When \( \text{RPI} + \text{ALT} < 0 \), it means that the “hot spare + detachable load” is insufficient, which is the generator will still be overloaded after all unloadable loads are unloaded, so the standby generator should be considered. When \( \text{RPI} + \text{ALT} \geq 0 \), the program performs calculation \( \text{RPI} + \sum \text{Level}_n \text{kW} \) according to the priority, until \( \text{RPI} + \sum \text{Level}_n \text{kW} \geq 0 \), which determines the unloading level and then can trip according to the pre-calculated unloading level.

The specific process is shown in Figure 2:

(2) Multiple generator tripping

When the system collects multiple generators to trip:

\[ \text{RPI} = \text{APT} - n \times \text{APS} - \text{OLT} - \Delta \]  

Where \( n \) is the number of trip generators, \( n > 1 \).

The operation logic of the multiple generator tripping CASE refers to the logic of the single generator tripping CASE, but the judgment of the unloading level is different from the single generator tripping CASE.

Assume that the interval of multiple generator trips is determined to be \( t \) seconds. After a single generator trips in the grid, the control system will first perform a single generator tripping CASE. The system cannot judge whether there will be a trip of the second generator in the next \( t \) seconds,
therefore, performing a multiple generator tripping CASE will occur after performing a single generator tripping CASE. When the trip interval exceeds $t$ seconds, the system will perform single generator tripping CASE repeatedly to ensure the stability of the grid.

\[ RPI = APT - APS - OLT - \Delta \]

(5)

Where TIDE is the decoupling point trend value.

Arithmetic logic of power grids decoupling CASE refers to the logic of the single-machine trip CASE, pay attention to the following three points:

1. After a decoupling point is decoupled, the entire grid is divided into two units. At this time, all the generators of the two units will trigger the corresponding CASE of power grids decoupling, but the CASE unloading range of different units is different.

2. Judgment of unloading range: After the grid is disconnected, the load belongs to two or more power station units. For each power station unit, the unloading range will only involve the load inside

**Figure 2.** Single generator trip CASE processing flow chart.

3.2. The CASE of power grids decoupling

For the CASE of power grids decoupling:

\[ RPI = APT \pm TIDE - OLT - \Delta \]

(5)
the power station range, and the unloading range is automatically determined based on precomputed calculations.

(3) The debugging of the power flow direction is extremely important, and the positive or negative sign of the decoupling point in the above formula is determined.

3.3. The CASE of overload type
The CASE of overload type includes single generator overload, transformer overload and submarine cable overload, etc.

(1) Single generator overload
Here is an example of single generator overload. Generally, single generator overload is caused by single generator failure, misoperation or load transfer after other generator trips.

The determination of the single generator overload CASE is based on the load rate of the generator and the trip delay time, moreover, the load rate is inversely proportional to the delay time. The unloading level of overload CASE is preset by the user, and the setting basis is:

$$P_{UL} = (\beta_N - \beta_S) \times P_N - \Delta$$

Where $P_N$ is the rated power; $\beta_N$ is the rated percentage; $P_{UL}$ is the unloading power; $\beta_S$ is the overload percentage.

According to the unloading power calculation result, the level range that needs to be uninstalled can be determined.

For a single generator overload caused by single generator failure and misoperation, the load rate of the generator is gradually increased with time. Before the generator is heavily overloaded, the system has enough time to trigger the single generator overload CASE to unload part of the load, in order to ensure the stability of the system, as well as remind the user to carry out related power operations.

For a single generator overload caused by other generator tripping causes load transfer, it is characterized by instantaneous overload. Because the delay time of the single generator overload CASE is much larger than the trigger time of the generator trip CASE generally, the generator trip CASE is triggered first which controls the generator load rate within a certain light overload range. At this time, the single generator overload CASE will not execute or have reasonable enough time to execute.

(2) Main transformer overload, submarine cable overload, etc.

When the overload level is not high, the equipment that flows into the target platform should be manually tripped according to the preset trip level. When the overload level is high, the tripping is completed by itself according to the preset level of the priority tripping system.

4. Simulation and discussion
An offshore oil platform is located in an area of Bohai Sea. It is the largest offshore island power grid for offshore oil and gas production operations. There are 4 independent power stations and 16 turbine units with a total installed capacity of 165MW, which supplies power to about 28 oil platforms. It is planned to add two nuclear power generators with a total installed capacity of 50MW.

In Fig.3, the dashed box indicates the unpowered platform, and the solid line frame indicates the power platform. To verify the effectiveness of the proposed stability control strategy, there is an example which the working conditions of the grid including S36-1CN, WM, S36-1WG and nuclear power platform as follow.

The simulation model based on ETAP power simulation software is shown in the figure below. In the model, there are four main generators, each rated power at 12.98MW, and two nuclear power generators, each rated power at 25MW.
Assume that generator A in the S36-1CN platform trips at 2.0 seconds due to a fault, causing other generators to be overloaded. At 4.0 seconds, the stability control strategy is applied to unload part of the load, then the generator's active power and frequency curve are obtained as shown in the following figure.

In Fig.5, at 2.0 seconds, the active power of other running generators begins to fluctuate after generator A trips. At 4.0 seconds, the stability control strategy is applied to unload part of the load, then the active power gradually stabilizes. In Fig.6, the frequency begins to dip after generator A trips, but the frequency gradually rises and eventually stabilizes after 4.0 seconds. In summary, generator tripping and overload CASE can stabilize the system through the stability control strategy. At the same time, some similar simulation analysis is performed on the generator tripping CASE and the power
 grids decoupling CASE, which still proved the strategy valid. Due to space limitations, it is not described in detail here.

![Figure 5. The curve of the generator active power.](image)

![Figure 6. The curve of the generator frequency.](image)

### 5. Conclusion
Taking the island microgrid connected to the nuclear power generator set as the research object. Firstly, a topology analysis strategy was developed to determine the grid operating conditions. Then an island microgrid stability control strategy based on small nuclear power plants is proposed. At last, the simulation results show that the control strategy can effectively maintain the grid stability of the island microgrid in the event of generator trip, overload and grid decoupling in the system.

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### References
[1] Ju Liwei. The Research on the Optimization Mode and Benefit Evaluation Mechanism for
Multi-Clean Energy Absorptive Considering Demand Response [D]. North China Electric Power University (Beijing), 2017.

[2] Zou Lanqing. Multi-angle Economic Analysis for Deep Peak Regulation of Thermal Units with Large Scale Wind Power Connected Power system [D]. North China Electric Power University (Beijing), 2017.

[3] Fang Chen, Xia Qing, Sun Xin. Generation Maintenance Scheduling with Significant Wind Power Penetration [J]. Automation of Electric Power Systems, 2010, 34(19):20-24+74.

[4] Huang Chao, Liu Zhoufeng, Hu Shuangjin, et al. Research of Voltage Fluctuation Suppression Methods Used for Offshore Nuclear Power Platform [J]. Marine Electric & Electronic Engineering, 2018, 38(12):27-29.

[5] Kirby, B., Kueck, J., Leake, H., Muhlheim, M. Nuclear Generating Stations and Transmission Grid Reliability [P]. Power Symposium, 2007. NAPS '07. 39th North American, 2007.

[6] Yang Baoqi. Regional Isolated Grids Safe Strategy Analysis [J]. Electrical Engineering, 2013, 14(6):93-97.

[7] He Yuqing. Optimal capacity assignment and Control of Wind-Solar-Diesel-Battery Hybrid Power Generation [D]. Hunan University, 2016.

[8] Tian Huiwen, Li Xianshan, Chen Tie, et al. Comprehensive control strategy of hybrid energy storage-based photovoltaic island microgrid [J]. Power System Protection and Control, 2014(19):122-128.

[9] Wang Huawei, Han Minxiao, Fan Yuan yuan, et al. Sending End Frequency Characteristics Under Islanded Operation Mode of HVDC Transmission System from Hulun Buir to Liaoning and Corresponding Control Strategy [J]. Power System Technology, 2013, 37(5):1401-1406.

[10] Xu Aidong, Liu Yongjun, Wu Xiaochen. Study on Security and Stability Control Strategy for ±800kV Yun-Guang UHVDC Transimission [J]. Southern Power System Technology, 2008, 2(5):14-18.

[11] Qiu Liwei, Chen Jian. Application of Security and Stability Control System in Nuclear Power Plant [J]. East China Electric Power, 2014, 42(7).

[12] Chen Benlin, Wu Yunlong, Wang Kang-an, et al. Study on the NPP Stability Strategy for the Large Capacity of Hainan Nuclear Power Plant vs the Small Capacity of Hainan Power Grid [J]. China Nuclear Power, 2018, 11(03):111-115.