ISBN: 978-981-18-5852-9
WCSE 2022 Spring Event: 2022 9th International Conference on Industrial Engineering and Applications
doi: 10.18178/wcse.2022.04.067

A Novel Idea of Power System Designing for Nuclear Plant with Small Modular Reactor

Chen Fan [1], Sun Weidong [1], Guo Chao [1], Zhou Shuqiao [1], Zhang Yuanhe [2]

[1] Institute of Nuclear and New Energy Technology, Tsinghua Unversity, Beijing, China
[2] Purchasing department, China Zhongyuan Engineering Corp

Abstract. When the massive earthquake and ensuing tsunami damaged the Daiichi nuclear power plant at Fukushima in Japan, the safety issues of nuclear power plant became the focus of the world again. This accident also urged the nuclear power plant designer to reexamine their designs before. The power system especially the emergency power system is responsible for providing power sources to all the electrical loads of the plant. The failure of emergency power supply could endanger the reactor, which was proved by the Fukushima crisis. Since the crisis was principally a result of flooding brought by the tsunami, in the future designing methods against flooding should be considered. The paper introduces a new concept of power system designing. Via systematic equipment layout, multiple power sources deployment, flexible water-resist cable route planning and predesigned mobile power source connecting interface, the stability and safety of the power system could reach another level.

Keywords: Nuclear power, power system, small modular reactor

1. Introduction

Since 1950s, the nuclear energy has been the cornerstone of the base load electricity generation. By entering the 21st century, nuclear power has become the key to tackle climate change and protect energy security. In the history of nuclear power utilization, safety issue is an eternal topic around which the discussions and questions never stop. Along with those discussions and questions, two major accidents of the nuclear power plant also significantly changed the designing concepts of nuclear power plant.

The reactor core meltdown accident happened in Three-Mile Island nuclear power plant in 1979 caused people to reconsider the importance of containment of the reactor. The massive explosion of Chernobyl nuclear power plant in 1986 caused people introducing different safety methods in nuclear power plant designing in order to avoid this kind of disaster. Several revolutionary concepts were brought after both accidents respectively, which promoted the reactor designing into another generation.

In March 2011, the massive earthquake attacked Fukushima. Reactor buildings with anti-seismic designing survived in this earthquake. However, when the earthquake induced tsunami flooded the emergency diesel generator room, reactors lost its ultimate emergency power source. When the batteries of UPS system ran out of power, all the safety-related systems and devices failed to work, which caused the meltdown of the reactor cores and radioactive contamination eventually.

This horrible tragedy demonstrated the power of nature. A 13m high tsunami generated by the earthquake could easily overwhelm the plant's seawall which was only 10m high. This situation allows people to reconsider the designing philosophy of the power system of nuclear power plant.

2. New Challenges for aSMRs

Modular reactors (SMRs) are reactors with an equivalent electric power of less than 300MW(e). Advanced small modular reactors (aSMRs), which are based on modularization of advanced reactor concepts, may provide a longer-term alternative to traditional light-water reactors and near term small modular reactors, which are based on integral pressurized water reactor (iPWR) concepts. aSMRs are conceived for applications in remote location for diverse missions that include providing process or district heating, water desalination, and hydrogen production [1].

In recent years, SMRs have generated great enthusiasm. By modularization, capital exposure during construction is limited. Factory fabrication of units becomes possible. SMRs are more suitably sized than large reactors for missions that go beyond traditional electrical generatioof designs and operational conditions [1]. For power system designing for aSMRs, several principles are required to be followed.

(1) The system should be composed with different subsystem in order to supply power to different types of electrical loads.

(2) The subsystem which is responsible for supply emergency power sources to safety-related electrical loads should be class 1E and fits all requirements of relevant standards.

(3) Different types of power sources should be introduced to the system, such as regular power source, reserve power source, emergency power source and mobile power source.

(4) The system should contain several independent power supply zone. Each zone should also have multiple power sources including predesigned interfaces for mobile power source to connect.

(5) Placement of devices and systems should consider flood condition. Vital devices or systems should be installed at higher locations of the building. Cables and connectors between those devices and systems should consider water-resistant measures.

(6) In extremely accidental conditions, the integrity of the power system could not maintain. However, the system fragments should still be able to operate when power sources recover properly.

3. Diversified Power Sources

Traditionally, electrical loads of nuclear power plant are divided into three categories:

(1) First class loads: This kind of loads requires uninterrupted power supply, which is also very important to the reactor safety.

(2) Second class loads: This kind of loads allows power interruption for a short period of time, which is also very important to the reactor safety.

(3) Third class loads: This kind of loads has no specific requirement for the power supply, and they are not relevant to the reactor safety.

For the first class loads, other than a regular power source, a reserve power source such as UPS device is necessary. For the second class loads, a power supply coming from emergency diesel generator is required. For the third class loads, there are no specific requirements, and a regular power source is enough. However, when a tsunami happens, some of these requirements would not be satisfied. Just like what happened to Fukushima Daiichi nuclear power plant. The emergency diesel generator room was flooded. The power source of safety-related electrical loads, which were essential to the safety of reactor had to rely on UPS devices. When the UPS devices ran out of their battery power, the safety-related electrical loads lost all power sources, and then the tragedy occurred. In order to manage this situation, diversified power sources are required.

For safety-related electrical loads, since they are relevant to the safety of reactor, other than regular power source, a reversed power source from emergency diesel generator or UPS device is necessary. Additionally, an extra connecting interface for mobile power source should be added to the system. In that case, even the power sources of diesel generator or UPS devices are lost due to certain reasons, when the mobile power source is attached, the safety-related electrical loads are still able to operate, that guarantee the safety of reactor.

4. Placement of Devices

In principal, the safety-related electrical loads, the power sources which are responsible for supplying power to these loads, the corresponding power distribution devices and the power cables connecting these devices should be installed in higher floors of the building. However, some devices are not able to be installed in higher floors. Such as emergency diesel engine, due to its size, weight and arrangement of its auxiliary subsystems, it could only be able to be installed on the ground floor or in the basement. Therefore, even the safety classification of this device is a class 1E device, and it should still be treated as a device that might be unable to operate during extremely accidental conditions.

When the safety-related electrical loads have to be installed in lower floors, which might be flooded during tsunami, water-resistant measures should be considered.

5. Mobile Power Sources

Mobile power source is the key equipment to help the reactor survive the tsunami. Emergency diesel generator might fail because of flood. The key factor to extend the power supply period of safety-related electrical loads is mobile power source.

Figure 1 is a demonstration of class emergency power system configuration. Under normal circumstances, the emergency bus could receive power from either auxiliary bus or emergency diesel generator. In extremely accidental condition, both power sources could fail to operate. Without mobile power source connecting to the system, all safety-related electrical loads would lost power supply eventually, which would jeopardize the reactor.

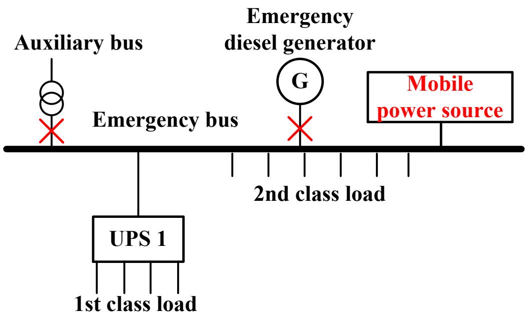

Fig. 1. Emergency power system configuration with mobile power source connection

Mobile diesel generator, as Figure 2. These mobile plants have different parameters and characteristics, and are suitable for different types of reactors.

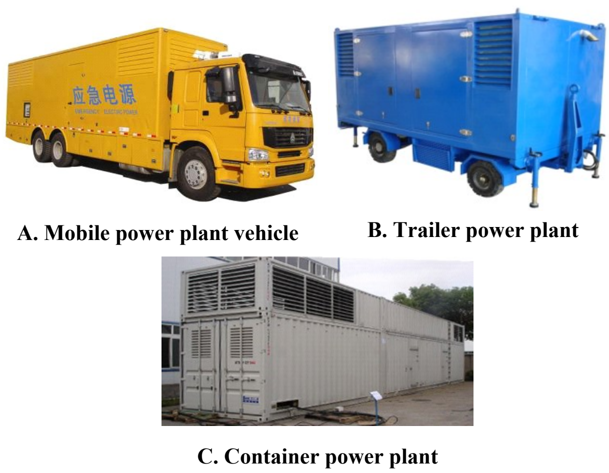

Fig. 2. Different types of mobile power source

6. Interface between Mobile Power Source and Power System

When the structure of power system and type of mobile power source are determined, the interface between power system and mobile power source requires further research. In extremely accidental condition, the integrity of power system could be compromised. The system would be divided into several fragments. Without early consideration, connecting mobile power source to the system recklessly could deteriorate the situation.

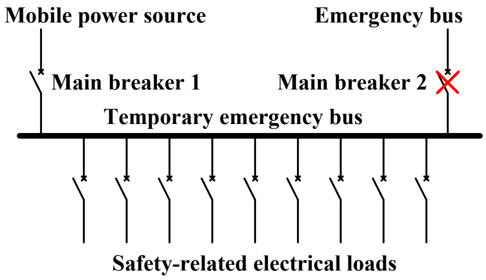

Fig. 3. Mobile switchboard layout

Figure 3 presents a feasible mobile switchboard plan. A temporary emergency bus is place inside the switchboard. Two breakers connect the temporary bus to mobile power source and emergency bus respectively. When the emergency bus lost its power supply, operator would switch main breaker 2 off. Then the mobile power source would be connected to the temporary emergency bus via main breaker 1. When mobile power source establish voltage buildup, switch main break 1 on, the temporary emergency bus regains its power supply.

All safety-related electrical loads are connected to the temporary emergency bus via industrial plugs on the operational panel of the switchboard, or using directly cable connection. This important mobile switchboard would be installed in a higher floor of the reactor building in order to avoid the flood of tsunami. The designing, manufacturing and testing of this equipment would follow standards for class 1E electrical equipment to guarantee the performance and reliability.

7. Water-resistant Measures

In order to maintain the system performance during tsunami, critical electrical devices and connections between critical electrical devices should consider water-resistant measures. Important electrical devices which are constrained to be installed in lower floors of the building should use high ingress protection level to resist water infusion. Cable connections between electrical cables to these devices should use water safe plug and socket-outlet. Electrical cables connecting these devices should use water-proof cables.

Utilizing those methods list before, could greatly enhance the ability of emergency power system against tsunami induce floods. By maintain the safety class of emergency power system as class 1E, could ensure the system performance and reliability during earthquake within the lifespan of reactor.

Fig. 4. Water safe plug and socket-outlets

8. Emergency Response Procedure

During extremely accidental conditions, the emergency power system might face great challenges. Maintaining the functions and performance of the system is crucial to reactor safety.

In this condition, the operator should check the availability of emergency power sources and integrity of emergency power system first. If all the emergency power sources are lost, onsite mobile power source should be connected to the system instead.

If the onsite mobile power source is lost as well, offsite mobile power source should be transported to the plant site. For example, a mobile container diesel generator power plant could be transported by helicopter and installed on the roof of the reactor building. Electrical cables brought with the container power plant are able to connect this mobile power source to the switchboard containing temporary emergency bus.

Connecting all important and safety-related electrical loads to this switchboard via industrial plugs or directly cable connections, the safety of reactor could be ensured.

Though lots of challenges has emerged to the nuclear engineering society through those years. The safety and security issues are the most important and critical issues that demand most of the attentions of the public groups. Therefore scientists and engineers have dedicated lots and lots of efforts to make those reactors safer and tougher than ever before. aSMRs sacrifice some economic incomes to exchange for a higher level reactor safety. From the bigger picture, reducing the capacity of reactors make them easy to deploy, feasible for most of the scenarios and easy to be accepted. With the future development of aSMRs, those small scale reactors could be designed, manufactured, installed and operated modularly, which could potentially cause a revolutionary situation in the power industry, and bring a huge contribution to the human society.

9. Conclusions

Tragedy happened to Fukushima Daiichi nuclear power plant demonstrates that conventional auxiliary power system plan could not survive the extremely accidental condition. New philosophy of power system designing especially the emergency power system designing should be introduced to the aSMRs.

The main reason which caused Fukushima tragedy was the flood induced by tsunami. In future designing of aSMRs, water resistant measures should be considered.

In the paper, a novel idea of aSMRs power system designing combining system classification, diverse power source arrangement, important device placement, mobile power source connecting, temporary emergency bus designing and utilizing water safe plug and socket-outlets and water-proof electrical cables could greatly enhance the performance and reliability of emergency power system.

With all the efforts the nuclear industry put into the aSMRs development and research, the future prospective blooming of this area is foreseeable. It might become a solution to resolve the confusing between the public opinion and energy requirement.

Human society requires more and more energy to develop a higher level of living condition and also requires a cleaner world. Nuclear energy is not only necessary but also essential. If we bring our mind to an even larger scale, we will find if our race need to evolve to a higher level, study and manage to control the unlimited power from atom is a unavoidable route.

10.Acknowledgement

This research was supported by National Natural Science Foundation of China (Grant No. 71801141), Ling Chuang Research Project of China National Nuclear Corporation, and National Science and Technology Major Project of China (Grant No. ZX069).

11.References

[1] R.M. Meyer, J.B. Coble, and P. Ramuhalli. “Requirements for Prognostic Health Management of Passive Components in Advance Small Modular Reactors,” Proceedings of IEEE Conference on Prognostics and Health Management, 2013: 1-8.

[2] Zhang Z, Sun Y. Economic potential of modular reactor nuclear power plants based on the Chinese HTR-PM project. Nuclear Engineer and Design, 2007: 237, 265-274.

[3] Zhang Z, Yu S. Future HTGR developments in China after the criticality of the HTR-10. Nuclear Engineering and Design, 2002: 218, 249-257.

[4] Haipeng Li, Xiaojin Huang, and Liangju Zhang. Operation and Control Simulation of a Modular High Temperature Gas Cooled Reactor Nuclear Power Plant. IEEE Transactions on Nuclear Science, 2008, 55(4): 2357-2365.

[5] Xiaodong Liang, Wilsun Xu, C. Y. Chung, Walmir Freitas, and Kun Xiong. Dynamic Load Models for Industrial Facilities. IEEE Transactions on Power System, 2012 27(1): 69-80.

[6] Wu Z, Zhang Z. “World development of nuclear power system and high temperature gas-cooled reactor,” Chinese

journal of nuclear science and engineering, 2000, 20(3): 211-231.

[7] Li F, Wei C, Zhou X, Wang Y, Guo J, Jing Y. "Physics property of modular high temperature gas-cooled reactor," 20th Conference on Reactor Physics, 2008: 176-183.

[8] Fu X, Wang J. "Summary on the development of high temperature gas-cooled reactor in China," Modern Electric Power, 2006, 23(5): 70-75.

[9] Chen F, Sun W, Sun L. "Design of the Emergency Power System and Monitoring Device of HTR-PM Nuclear Station," Proceedings of IEEE Power Engineering and Automation Conference, 2011: 120-123.

[10] Chen F, Sun W, Sun L. "Capacity Calculation Method Study on the Emergency Diesel Generator Applied in HTR-PM," Proceedings of the 21st International Conference on Nuclear Engineering, 2013:1-4.

[11] S H Hwang, B H Kim, S H Joung, and H S Jang. "Detectability analysis of open phase condition in Korea's standard nuclear power plant," International Journal of Smart Grid and Clean Energy, vol. 8, no. 4, July 2019: pp.443-452

[12] Soonhyun Hwang, Balho H. Kim, Sanghoun Joung, Hongseok Jang. "Simulation and detectability analysis of power system open phase condition in Korea's standard nuclear power plant," International Journal of Smart Grid and Clean Energy, vol. 9, no. 2, March 2020: pp.282-289

[13] Xiong Zheng, Li Xu, Yang Fang, Junting Fang. "Simulation and research on control methods for the secondary system of civil nuclear power ship," International Journal of Smart Grid and Clean Energy, vol. 10, no. 1, January 2021: pp.44-50