International Journal of Smart Grid and Clean Energy

Self-Healing of smart grid for new energy

Mei Sun[a], Yongchao Sun[a,b*], Minghong Wei[a], Chunxiao Li[c]

[a] *Corporate Social Responsibility Institute, Business School, Sichuan University, No.29 Wangjiang Road, Chengdu, Sichuan and 610064 China*

[b] *State Grid Sichuan Electric Power Research Institute, No.24 Qinghua Road, Chengdu, Sichuan and 610072 China*

[c] *School of Information Technology, Yangzhou University, Yangzhou, NO.196, West Huayang Road, Yangzhou, 225127, China*

Abstract

The exploitation of new energy has been global trend and common task through the world in recent years, which will deal with energy crisis and environmental pollution. Solar energy technology, wind energy technology and other new energy technology has appeared and developed rapidly in this situation. Most of these new energy resources will be transformed to electricity and join into the power system, which will raise all kinds of safety problems. In order to consume new energy, the power grid has to be updated to smart grid which is more steady, flexible and compatible. Having presented the status and development trend of new energy, the differences between new energy and traditional energy are proposed. Despite of the advantages of new energy, the safety problems in power grid caused by new energy are illustrated in detail. Thence the self-healing of smart grid is important to the development of new energy. And the present situation and key technologies of self-healing are introduced. With self-healing and new energy, smart grid will be further updated to energy internet. Energy internet will bring sharing economy mode into resource and power areas, which will also support the utilization of new energy.

Keywords: New energy, power grid, smart grid, self-healing, automation, real-time-monitoring, self-adjustment, SPID

1. Introduction

The up-to-date public crisis with the widest range hitherto encountered by human includes environmental pollution, global warming and energy crisis. Energy conservation and demission reduction has come to the fore either in government policy or applied technology. Because most of new energy is renewable, new energy has been a key part to achieve these goals. The exploitation of new energy especially renewable energy will give solution to energy crisis. The substitution of new energy for traditional energy especially fossil fuels will prevent global warming and environmental pollution. Compared to other measures such as closing high-pollution low-efficiency enterprises, new energy will not bring negative effects to economy development. Actually the development of new energy will stimulate economic growth and provide a large number of jobs. Therefore new energy has been attached to great significance and developed profoundly.

2. Status and Development Trend of New Energy

Now around the world, renewables are established as mainstream sources of energy as shown in Fig. 1. Though challenges remain, particularly beyond the power sector in the last year, 2015 was an extraordinary one for new energy, with the largest global capacity additions seen to date according to the Renewables 2016 Global Status Report (REN21_GSR2016) [1]. An estimated 147 gigawatts (GW) of renewable power capacity was added in 2015, the largest annual increase ever [2]. Due to continued

*Manuscript received January 21, 2017; revised May 5, 2017.
Corresponding author. *E-mail address*: yongchaosun@foxmail.com.
doi: 10.12720/sgce.6.3.157-164

advances in renewable energy technologies and increased use of smart grid technologies, the power sector experienced its largest annual increase in capacity ever with significant growth in all regions. Wind and solar PV had record additions for the second consecutive year, accounting for about 77% of new installations, and hydropower represented most of the remainder as shown in Fig. 2. Electricity is the world's fastest-growing form of end-use energy consumption, as it has been for many decades. Thus the utilization of new energy for electricity is an indispensable part of new energy technology.

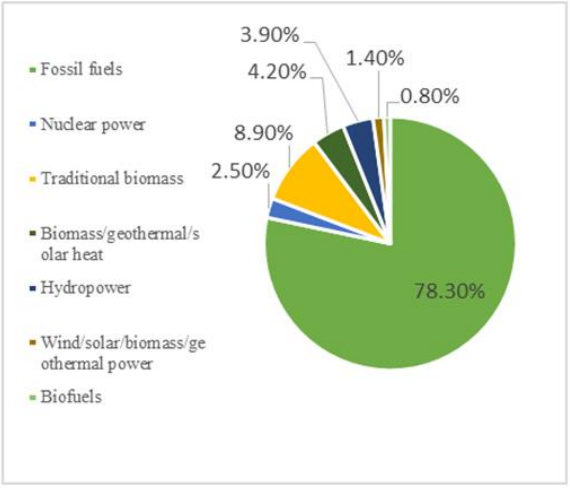

Fig. 1. Estimated renewable energy share of global final energy consumption, 2014.

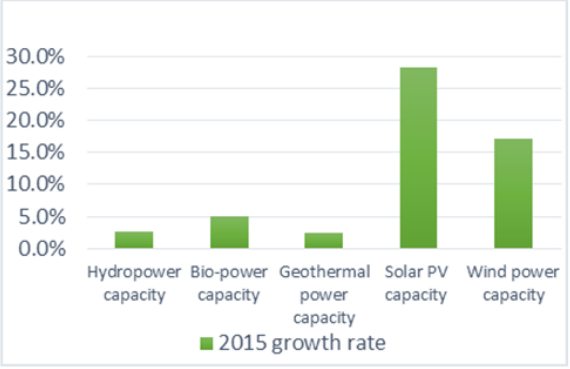

Fig. 2. Growth rates of renewable energy power capacity.

According to the International Energy Outlook 2016 (IEO2016) Reference case [3], which projects significant growth in worldwide energy demand over the 18-year period from 2012 to 2030, much of the world increase in energy demand occurs among the developing non-OECD nations (outside the Organization for Economic Cooperation and Development), as shown in Fig. 3. Renewables are the world's fastest-growing energy source over the projection period with consumption increasing by 2.8% per year between 2012 and 2030 as shown in Fig. 4. Nuclear power is the world's second fastest-growing energy source with consumption increasing by 3.0% per year over that period. Therefore new energy is the world's fastest-growing energy source over the projection period.

3. Advantages and Disadvantages of New Energy

All kinds of new energy have the same advantage of less pollution and large reservation. Most of new energy is renewable except nuclear energy. But they also have some disadvantages in common as shown in the following listing:

- Low energy density. Thus it takes large space to exploit and utilize new energy.
- Wide distribution. It is conducive to distributed small-scale use.
- Intermittent supply. The great volatility of new energy makes it difficult to achieve long-term steady energy supply without large energy storage.
- High cost. The cost of new energy is mostly higher than fossil energy.

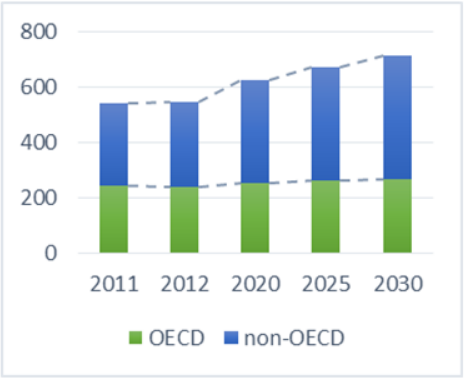

Fig. 3. World energy consumption, 2011–2030 (quadrillion Btu).

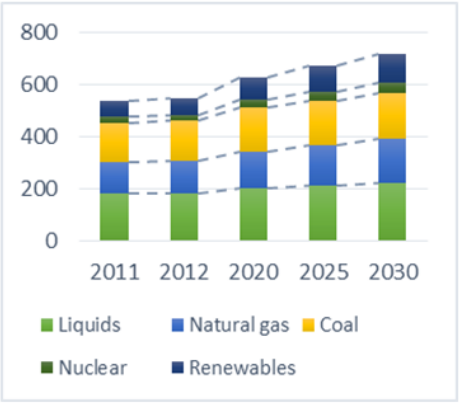

Fig. 4. World total energy consumption by energy source, 2011–2030 (quadrillion Btu).

The disadvantages of new energy are main obstacles in new energy exploitation, which will be encountered by ongoing energy efficiency improvements and significant progress in supportive hardware and software, as well as progress in energy storage development and commercialization. However in the present, the integration of new energy brings lots of safety problems into existing energy system, especially in the power grid area.

As we all know, electricity is the important and extensive secondary energy, whose application has penetrated into everywhere of daily life. Electricity can be transferred in light speed but cannot be reserved in large scale, so that generation, transformation, distribution and consumption of electricity should be carried on and balanced at the same time all the way. Once the balance is broken down in large scope, catastrophic nationwide power failure can occur in very short time such as the “8.14” America and Canada Blackout that brought about the chain disaster in energy, transportation, communication, finance and so on, jeopardizing the safety of society.

Based on the characteristics of power grid, there are two kinds of use in correspondence to the features of new energy. One is large-scale exploitation and long distance transmission, which can deal with low energy density and huge utilization space. The other is distributed integration and local consumption, which meets the feature of wide distribution. However there are still many problems to be solved such as low capacity of peak regulation and new energy power prediction. The most serious influence is current

relay protection is not suit for the integration of new energy. The volatile output of new energy makes the relay protection settings more instable. The distributed access of new energy makes the power network structure more complex. To improve the safety of power grid with new energy, the protection must be updated with communication, information and computer technologies, which is what self-healing of smart grid intends to achieve.

4. Status and Key Technologies of Self-Healing

Up to now, there has not been a unified definition about smart grid all over the world. And the key technologies have been realized in different structures around the world. In May 2009, State Grid Corporation of China raised the plan to achieve Smart Grid to optimize energy configuration and raise the operation efficiency of power system. This is a milestone in the development of Chinese State Grid, leading the upgrade of techniques and devises in the industries related to energy and constructing an energy supplying system.

In China, smart grid is supposed to be highly integrated modern grid with information, automation and interaction features on the platform of communication and information techniques as support, based on UHV (Ultra-High voltage) power grid as the backbone grid coordinating with all levels of power networks. According to this understanding, Smart Grid generally has five key features as followed [4]:

- Self-healing

Self-assess the operation status of the grid on-line continuously, adopt precautious means of control, detect, rapidly diagnose and eliminate hidden faults timely. Insulate accident and self-heal without or with little human intervention quickly once accidents happen to avoid blackouts.

- Interaction

Coordinate grid operation with electricity market closely to support all kinds of electricity transaction configuring energy resources better thereby. On the other hand, motivate consumers to participate in security management of power system by wide-spread market transaction in order to assure safety of power system.

- Optimization

Realize the whole optimization of power system in full life cycle, arrange power facility reasonably to improve the whole efficiency of power system.

- Compatibility

Adapt to both centralized power generation and distributed power generation, realize the interaction with the load side, aggrandize the optional energy resource range of grid by supporting introduction of renewable energy like wind power.

- Integration

Realize the integration of production management, dispatching automation, enterprise management and electricity market management by optimizing process and integrating information to achieve a comprehensive decision-making assistance system.

Among all the features of Smart Grid, self-healing is the most important and most foundational feature. According to the statistics concerning power failures in USA from 1984 to 1997 provided by the North American Electric Reliability Corporation, power failures influencing 10,000 to 100,000 consumers happens 5 to 10 times every year, those influencing 100,000 to 1,000,000 users occurs 1 to 5 times every year, those concerning 1,000,000 to 10,000,000 customers comes into being 0.1 to 1 times every year, 40% of what are mentioned above resulted from the cascade of events [5]. The evolution of the cascades occurs because of manual processing. Most of the evolution from incident to disaster is determined by improper handles. Obviously, the integration of new energy will increase the resources of electricity and dispose energy efficiently. But the integration of new energy in power system increases the potential hazard of large-scale blackout. To minimize the potential hazard, manual processing should be cut down in the handle of accidents, which we cannot expect to be timely exact every time. Therefore one of the key technologies of self-healing in smart grid is automation [6].

As is known by all, precautionary measure is always better than afterwards healing, because any slight

accident in power system can lead to certain loss of individuals and organizations. In addition to the traditional static security analysis including transitional stability, voltage stability and frequency stability, the imminent task of energy networks is to enable precautious control software to track the running state of power networks regularly. Thus before failure occurs, the security strategy such as network reconstruction, safety threshold value self-adjustment and stability remedy scheme can be executed once vulnerable section is discovered. The WAMS (Wide Area Measurement System) derived from telemetry of power angle draws a lot of attention in this area. WAMS on the basis of PMU (Phasor Measurement Unit) can not only estimate the system state rapidly and precisely making it possible to monitoring voltage instability and low-frequency oscillation, to ascertain dynamic stability transmission power limits, but also cooperate with stability control terminal device to constitute fast protection system of wide-area stability control. Therefore the key technologies of self-healing in smart grid contain real-time-monitoring and self-adjustment.

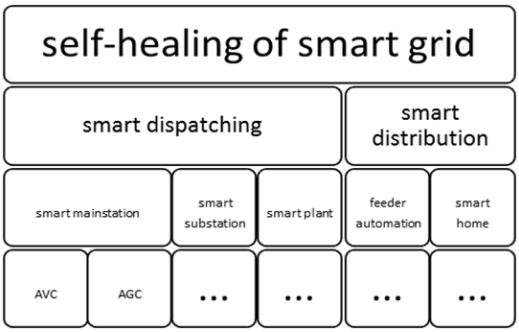

Fig. 5. Self-healing structure of smart grid in China.

In China, the self-healing of smart grid is realized by smart dispatching and smart distribution as shown in Fig. 5. Smart dispatching [7] contains smart mainstation, smart substation and smart plant. Smart distribution contains feeder automation and smart home [8]. Smart mainstation contains AVC (Automatic Voltage Control) and AGC (Automatic Generation Control) and other advanced functions [9]. There are lots of functions in other sectors which will not be illustrated in detail.

In America and Europe, the security of power networks transforming from only hardware-oriented to natural and social factors involved, demanding the utilization of intelligent solutions of knowledge engineering techniques such as multi-agent. The SPID (strategic power infrastructure defense system) invented by USA is a pioneer in this area, adopting AO (agent-oriented) technique which is an advanced software engineering technique after PO (process-oriented) and OO(object-oriented) [10]. It has a three-level-structure of multi-agent, the lowest of which is reaction level including generation and protection, the midst is cooperation level including event filtering, model updating, accident insulation, frequency stabilization and order interpretation, the highest is cognition level including event anticipation, vulnerability assessment, hidden fault monitoring, network reconstruction, recovery, programming and communication. As shown in Fig. 6, SPID achieved self-healing through event reaction, network reconstruction and self-adaptive load-off [11]. To conclude, precautious protection of power networks attaches great significance to self-healing in the Smart Grid.

The conception of self-healing in America and Europe was explicitly proposed in GICUR (government-industry cosponsorship of university research) coming into practice in SPID mentioned above. The self-healing strategy in SPID was adopted and developed in following research of self-healing in Smart Grid. And in the project of IECSA [12] (integrated energy and communication architecture) and afterwards IntelliGrid architecture, smart grid was further developed profoundly in aspects of both function and architecture. During these projects, experts of power system function have proposed the functions of current and future power grid, divided into 7 areas such as market, electricity transmission, power distribution, high-voltage generation, DER (distributed energy resource), user service and IT service, listing more than 400 application functions.

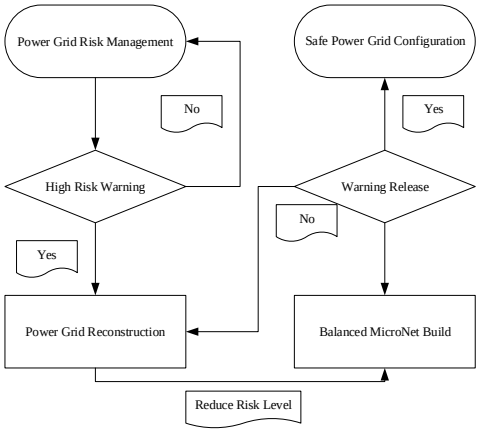

Fig. 6. SPID self-healing process.

The demands of information technique for these functions are proposed in the same time such as the configuration of router and the management of data. According to these demands, experts in power system architecture study the architecture of Smart Grid to include the newest standards and the best methods in practice, in order to instruct the construction of future power grid basic facilities and avoid the adoption of private systems and non-standard protocols. Among those functions, the current goal of self-healing function is real-time self-assessment of power grid, proper reaction to all possible types of accidents, prohibition of blackouts and fast recovery from urgent states to normal state. And the methods to realize self-healing can be summarized into three parts such as fast simulation decision, coordination/self-adaptive control and DER, among which fast simulation decision and coordination/self-adaptive control is key and basic techniques.

There are two directions in the research of fast simulation decision, the analysis and computation combining static models and dynamic properties and the real-time direct reckoning based on signal analysis, both of which put forward new demands for signal measurement precision, data transportation speed and computation methods. The RtPM (Real-time Performance Management) of OSIsoft achieved a big progress in this area, which can make prediction based on analysis of and simulation of series of events. The disturbance of power system contains a lot of information. Through the FFT (Fast Fourier Transformation) or wavelet transformation, we can attain data on both frequency domain and time domain during any period and predict the trends of power grid.

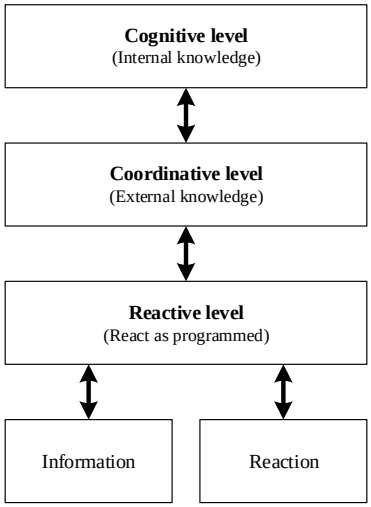

Fig. 7. Three-level-structure of multi-agent in SPID.

In the area of coordination/self-adaptive area, the agent-oriented three-level-structure of multi-agent adopted by SPID is a great innovation to realize the self-adaptive adjustment of threshold values and the distributed intelligent control of micro net including generation after disconnection. As shown in Fig.7, the agent-oriented three-level-structure containing reaction, coordination and cognition is a widespread hybrid agent combining reactive agent and cognitive agent [13]. The strategy of multi-agent can also be applied to the coordination among EMSs, DMSs and substation automation system in China [14].

Though in different countries, the emphasis and structure of self-healing have their own characteristics, the functions and targets of self-healing are the same. The final aim of self-healing is to control and protect the power gird automatically regardless of grid structure, energy resources and running status. Its realization all needs computing methods, communication, information and hardware updating.

5. Conclusion and Prospect

Recently, new energy has developed profoundly and will still develop rapidly. Though new energy has the advantage of less pollution and large reservation, it also has the disadvantages of low energy density, wide distribution intermittent supply and high cost. The first three disadvantages makes the integration of new energy into power grid bring in lots of safety problems which cannot be solved by current control and protection system. The self-healing of smart grid gives a solution to these problems, which will update the control and protection system of power grid. In China, self-healing focuses on automation, real-time-monitoring and self-adjustment. And in America and Europe, self-healing emphasize on fast simulation decision, coordination/self-adaptive control. The future development of self-healing technologies will depend on advanced control, big data and artificial intelligence.

With the development of new energy and self-healing, the modern power grid, smart grid can be updated to energy internet. In energy internet, billions pf people can produce green energy in their homes, offices and factories. And they can share their green energy on the energy internet. The energy internet is sharing economy in energy and power area. Sharing economy is the newest development conception in the world.

Acknowledgement

This work was supported by the Fundamental Research Funds of Sichuan University for the Central Universities (Skyb201305), (skzx2015-sb19), (skzx2015-gb46) and the funds for Academic and technical leaders of Sichuan province (2016-183-9).

References

[1] *International Energy Outlook 2016*, U.S. Energy Information Administration, Washington, USA, 2016.
[2] Renewables 2016 Global Status Report, REN21 Community, Paris, France, 2016.
[3] Renewables 2016 Global Status Report Key Findings, REN21 Community, Paris, France, 2016.
[4] Luo C, Hua F, Shen H. Research and implementation of intelligent power system fault isolation strategies. *Microcomputer Information*, 2011; 27(4):177-179.
[5] Massoud A. Toward self-healing energy infrastructure systems. *IEEE Computer Applications in Power*, 2001; 14(1):20-28.
[6] Li D. Analysis and prospect of the self-healing function of the smart grid. *Hubei Electric Power*, 2010; 34(z1):12-1411.
[7] Du G, Wang Z. Design and research on power network dispatching integration of smart grid. *Power System Protection and Control*, 2010; 38(15):127-131.
[8] Al-Ali AR, El-Hag AH, Dhaouadi R, Zainaldain A. Smart home gateway for smart grid. In: *Proc. International Conference on Innovations in Information Technology*, United Arab Emirates, 2011.
[9] Guo Q, Sun H, Zhang B, *et al*. Research and development of AVC system for power networks of Jiangsu Province. *Automation of Electric Power Systems*, 2004; 28(22):83-87.
[10] Liu CC. Strategic power infrastructure defense. *IEEE Power Engineering Society General Meeting*, 2004.
[11] Wang M. Self-Healing grid and distributed energy resource. *Power System Technology*, 2007; 31(6):1-7.
[12] Liu M, He G, Shen C, *et al*. Brief introduction to the IECSA project. *Automation of Electric Power Systems*, 2006; 30(13):99-104.

[13] Wang M. Hidden failure, vulnerability and adaptability of relaying automations in large interconnected power systems. *Electric Power Automation Equipment*, 2005; 5(3):1-4.

[14] Zhang K, Ji X, Chen P. Application of dynamic information database in EMS/WAMS. *Automation of Electric Power Systems*, 2007; 31(S):92-96.