# Research on the application of intelligent under-frequency/under-voltage load shedding considering demand response

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***Abstract*—With the installation and application of smart meters, smart appliances, and other smart devices in the user side, the dynamic information measued by these devices can be obtained and used for power system security and stability analysis&control. Based on the summary of intelligent underfrequency/undervoltage load shedding technology, the intelligent appliance load types and the role of smart appliances in the grid control were analyzed firstly.Using the intelligent measurement and control technology, the traditional underfrequency/undervoltage load shedding schemes was improved. And a combined with intelligent demand response technology was proposed with consideration of intelligent home appliances in response to new types of underfrequency/under voltage load shedding schemes, realize rapid response resources and under-frequency/under-load shedding schemes coordinated control. Time-domain simulation results showed that the under frequency load shedding project can adapted grid complex operating environment, quickly and avaliably inhibit falling-down of fault frequency, reducing the loss of load shedding, improves the flexibility and reliability of the system. The poposed intelligent low-frequency voltage load shedding scheme was verified by the simulation of Jiangsu province grid, and the simulation result verified the effectiveness of this novel under frequency and under voltage load shedding algorithm.**

***Index Terms*—intelligent load shedding, demand response, intelligent home appliances, under-frequency/under voltage load shedding**

## I. BACKGROUND OF INTELLIGENT OF LOAD SHEDDING

In traditional measures of under frequency and under voltage load shedding, load is cut off in a different setting value order, according to pre-set power distribution shedding device partial removal of load distribution of power in order to protect network security.

The load shedding has a tremendous impact on the economy and the environment. The related papers studying on Sri Lanka grid showed, in the case of annual growth 8%GDP, as planned and unintended interference 0.9% inadequate energy supply will cause the loss of Sri Lanka's GDP. Because of unintended interference (including momentary power failure) brought economic losses of nearly 0.3%GDP, beyond planned loss of 1.6 times. In some factories, instantaneous losses due to unexpected disturbance is an important component of all losses. Because of these disturbances, many industrial facilities have invested in alternative power supply units. This not only increases the cost of production, and increases human health and environmental problems caused by environmental radiation [1]–[3]..

So using intelligent devices making the traditional passive load in the load shedding mode becomes active load, can improve the economics. Intelligent control technology with the development of modern science and technology, the rapid development of application and popularization of the interconnected power system and communication equipment, the smart grid and demand-side response technology began to appear and become a hot spot in today's power system research, transmission networks and distribution networks of technology, which is more and more important [4]–[6].

## II. INTELLIGENT HOME APPLIANCES CONTROL RESPONSE

Since 2009, United States proposed smart grid as a national development strategy. Smart grids and related developments in the field of the world's attention. Appliance electricity consumption accounted for about 1/3 of social power consumption in developed countries, smart grid developments will have a major and far-reaching impact on the household appliances industry.

Smart devices, using high-performance computing , advance measurement and sensor technology, intelligent bi-directional terminal, new energy storage components, digital intelligence, real-time communications technologies and coordinated strategy to power advanced terminal users become important part of the power grid, and bi-directional interaction with network information and power.

Smart grid in different countries, power grid and electrical appliances there are many different ways to interact. Europe smart grid demand response in the area of home appliance products and measures adapted to the characteristics of smart grid technology to achieve efficient management of client power state .However, for China to improve the reliability of power system as the main goal of the smart grid scenario, realize the direct interaction of household electrical appliances and electrical network still need to create a lot of conditions[8][9].

Smart appliances have the following features:

1 The user can receive dynamic pricing information, so that you can choose Adaptive power consumption needs.

2 Smart appliances can respond to network signal in two ways: provides recommendations for users on a daily basis using household appliances when electricity prices low; based on the user's previous settings or manually removing or reducing the use of power control.

3 Intelligent home appliances when emergencies arise in power systems automatically adjust its work to help the grid to prevent blackouts and other incidents occurred.

4 In order to ensure the comfort of intelligent home appliances use, users can ignore all set before the procedure and instructions issued by the smart grid.

5 The intelligent home appliances when connecting to your home network or through a residential energy manage system controls, users can get their energy use, and through the use of these data for intelligent home appliances efficiency and effectiveness of the highest.

6 Smart appliances can be controlled through the user of power load in the optimal time to quell renewable energy (wind power, solar power) power fluctuations.

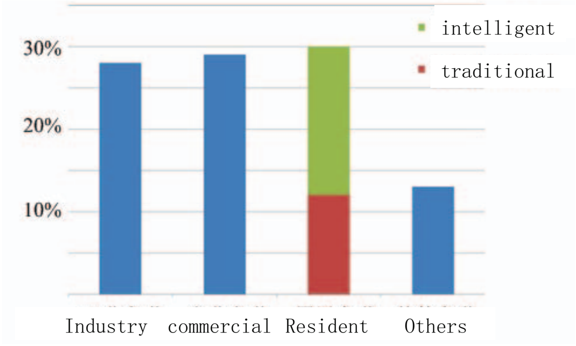


Figure 2-1 United States consisting of load a typical peak load day

According to statistics, the United States one day typical load composition, residential electricity consumption load 30%, intelligent appliance load 18%.In recent years, the total electricity consumption of the whole society in the household appliance power consumption accounted for about 12% and air conditioning in which the largest proportion, followed by refrigerators. This paper studies the temperature type of load[10][11].

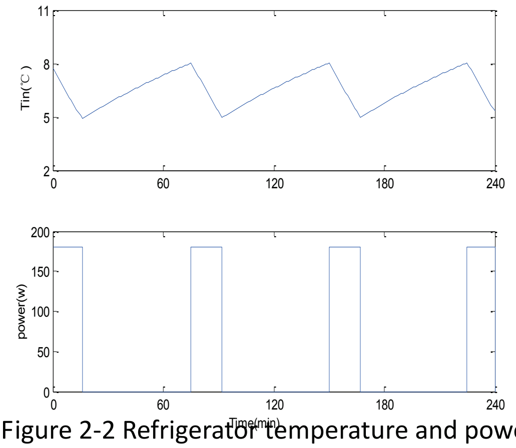


Figure 2-2 Refrigerator temperature and power curve

Organization for economic cooperation and development provide refrigeration storage equipment power consumption of 13% per cent of total domestic consumption. Refrigerators refrigerated indoor temperature and power is shown in Figure 2-2 the curve changes over time. Drop section shows a refrigerator compressor running cooling in the fridge, and part of the curve that when the refrigerator compressor is not running freezer not cooling, refrigerator compressor "on" and "off", refrigerators, respectively in the heated and unheated State, electric refrigerator freezer temperature is decreased and increased, respectively. System controller can send control signals directly on the refrigerator of the whole group, in order to ensure the function of a refrigerator less affected, load control signals can be temperature setting, more intuitive than direct control load power[12].

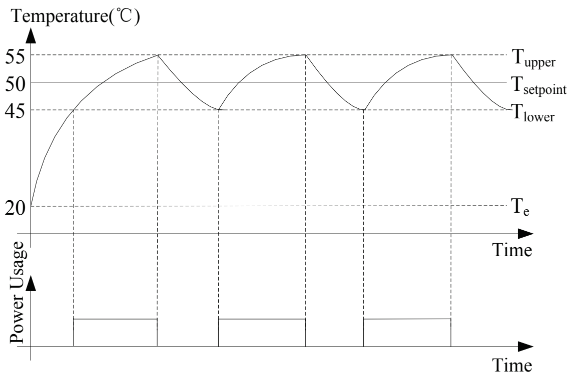


Figure 2-3 typical water heater temperature and power curve

Electric thermal storage type water heaters in water in the water tank, part of the rising temperatures that the water heater in a heated State, part of the decline that the decrease of the temperature of the hot water in the water tank (this reduced heat transfer, thermal radiation and other causes).As the water heater "on" and "off", respectively in the heated and unheated State of the water heater, the temperature of the water in the storage tank with increased and decreased, respectively. Change the temperature setting value Tsetpoint, given temperature from top to bottom border adjusting load.

In this paper, we focus on control feasibility and control, not to discuss the details of intelligent home appliances control mathematical model. Bi-directional communication on the basis of the smart grid, home appliances from a mechanical appliances become intelligent household appliances and equipment, to achieve direct control over temperature load. Electric water heater, intelligent home appliances such as refrigerators. Smart appliances response can be divided into two categories, based on price signals and triggered based on an event. On the demand side management for load control can also be divided into direct control and indirect control.

Indirect load control spot price adjusted temperature rather than turn off the load the load point, price and power consumption is a very complex relationship, cannot achieve precise control. Direct load control system scheduling directly control the power consumption of the load. This method is very easy to achieve precise adjustments to the system when the user comfort are affected, this method must be authorized [13].

## III. PROVINCIAL LEVEL INTELLIGENT UNDER VOLTAGE LOAD SHEDDING STRUCTURE DESIGN BASED ON WAMS

Load shedding equipment as avoid significant decline in accidents of power system frequency, an important measure to ensure the safety of the system, has decades of history, and has accumulated a wealth of experience. But still revealed some deficiencies in the actual application, mainly poor adaptability during system power shortfall, as well as causing the system frequency overshooting or hover, and so on.

By comparing the under voltage load shedding schemes in various countries worldwide found that specific implementation details are quite different. This is mainly due to the comparatively stable frequency, and voltage stability in most cases more of a local stability, greatly influenced by local area network structure and load characteristics. WSCC made it clear that in its research reports, members of the power company to which it belongs and under voltage load shedding scheme is not necessary, nor a general scheme applicable to all Member companies. If the Member companies decided to implement under voltage load shedding, corresponding principle should be determined according to the situation around the grid[14][15].

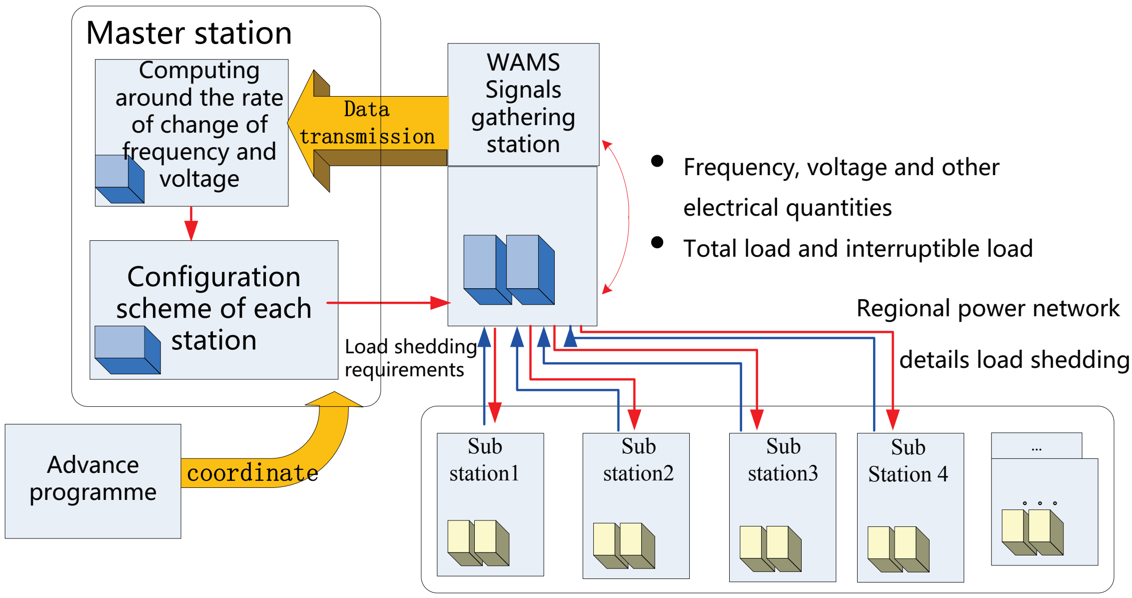


Figure 3-1 Provincial level intelligent under voltage load shedding structure

Traditional methods of under-frequency and under-voltage load reduction of the following shortcomings: 1.The third line of Defense control set value setting is completed, remain constant over a long period of time. Study on the configuration options, impossible to exhaust all ways to adapt to different operating modes. 2. Based solely on offline information to adapt with complex stability characteristics of power, such as identifying the cause of the accident, and optimization of control measures taken, such as least-cost safety operation of power grid.

So assumed load side participate in the system of emergency control Jiangsu Province, possible also in cases that meet user needs, appliance load (refrigerators, air conditioners, washing machines, and so on) can be affected without users comfort under short-cut off in response to the regulatory requirements of the system. Based on provincial power grid integrity failure occurs after the study on under voltage load shedding scheme and design the structure of the system. Design of based on wide-area monitoring and real-time delivery of information through online real-time analysis, taking into account the various constraints, control measures are calculated and distributed execution. But limited to technical conditions, preconfigured scenarios can be put as a backup[16].

So design of intelligent under voltage load shedding scheme structure at the provincial level is proposed as above. Consider intelligent control and communication center can meet the speed and response time requirements. Collect more information sources of electric signals, including those from EMS,WAMS, and to deal with individual station data upload access frequency, voltage, frequency rate, rate of change of voltage, according to configure Intelligent under-frequency voltage load shedding scheme and issued[17][18].

## IV. APPLICATION OF INTELLIGENT LOAD SHEDDING BASED ON WAMS

Intelligent home appliances as an active response of load, its action often before the under-frequency load shedding device. Because of the early response of intelligent home appliances, may change the response characteristics of the system, effectively restrain the frequency drop depth, accelerating the recovery of system frequency.

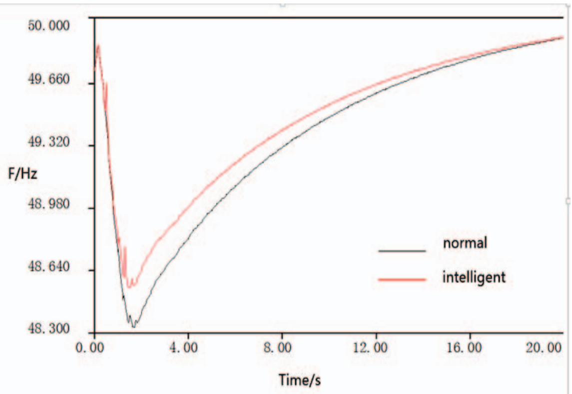


Figure 4-1 Intelligent home appliances effect of response on frequency drop

Proposed intelligent under-frequency load shedding program.

1. Smart appliance response round in 49.3Hz, delay 0.5 seconds
2. Subsequent rounds and rounds the same under frequency load shedding in East China power grid, according to the station's frequency sensitivity of different Tf configure load-shedding weight, keeping unchanged the total rounds, principles and processes as shown in table 4-1.

According to the provincial power grid frequency dynamic response of partition information is different, you can configure the percentage of load shedding by District.

Table 4-1 Provincial power grid under frequency load shedding scheme

| | Start frequency [Hz] | Delay [s] | Load ratio [%] |
|---|---|---|---|
| Intelligent round | 49.3 | 0.5 | Meet demand |
| 1 round | 49 | 0.5 | 6.5 |
| 2 round | 48.75 | 0.5 | 4.5 |
| 3 round | 48.5 | 0.5 | 5.5 |
| 4 round | 48.25 | 0.5 | 3.5 |
| 5 round | 48 | 0.5 | 3.5 |
| Additional round | 47.5 | 0.5 | 3.5 |
| Special 1 | 49 | 20 | 3.5 |
| Special 2 | 48.5 | 20 | 3.5 |

Studying in Changzhou area, Jiangsu Province, taking into account the Changzhou area network and external network of the 500kV line three-phase short circuit fault in 0.1s, 0.3 seconds and disconnect, resulting in Changzhou area, isolated network operation.Vacancy for power 759.4MW, 26.3% percent of total load in the area.

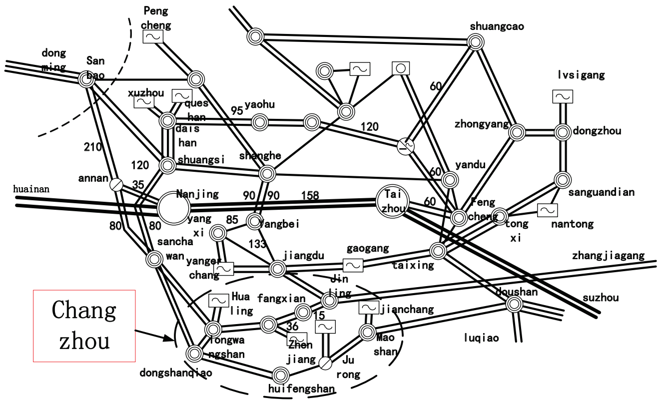


Figure 4-2 Changzhou, Jiangsu Province power network GIS

Figure4-3 is the system under different load shedding scheme of frequency response curve. As can be seen, if only the intelligent electrical home appliances response, amount of load shedding is unable to meet the power shortfall, frequency will drop to an unacceptable degree. Traditional low frequency load shedding program of action after 4 rounds of total resection of 655MW, frequency recovery slow and intelligent low-frequency load reduction scheme, intelligent home appliances-response load shedding action 213MW, low frequency load shedding action only 2 rounds of total resection of 453MW action, almost the same total load, but frequency response much better.

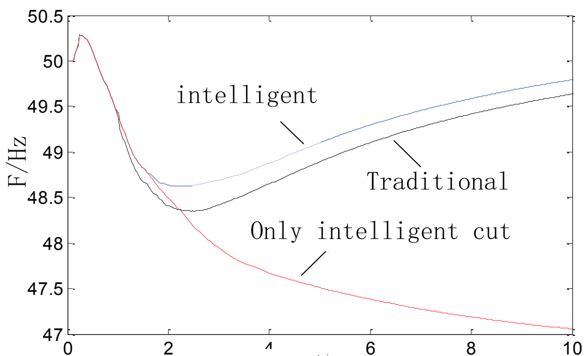


Figure 4-3 System f esponse curves under different load shedding schemes

Proposed intelligent under-voltage load shedding program.

1. Smart appliance response round in 0.93p.u.delayed 0.5 seconds.

2. Subsequent rounds have the same original low frequency load shedding, in accordance with the voltage sensitivity of the different configuration load, maintaining total rounds do not change

Under-voltage load shedding configuration is shown in table 4-2.

Table 4-2 Provincial power grid under voltage load shedding scheme

| | Intelligent round | 1 round | 2 round |
|---|---|---|---|
| Start voltage [p.u.] | 0.93 | 0.88 | 0.8 |
| Delay [s] | 0.5 | 0.5 | 0.5 |
| Load ratio [%] | Meet demand | 20 | 16 |

Simulation of power system voltage stability problems encountered in Changzhou area, if not consider the responses of intelligent home appliances, after a certain delay, under-voltage load shedding device removal of load. Voltage curve in Changzhou area set 5 voltage observation point: Dong Shan Qiao, back to the Hill, Zhenjiang, visit Xian, Jin ling.

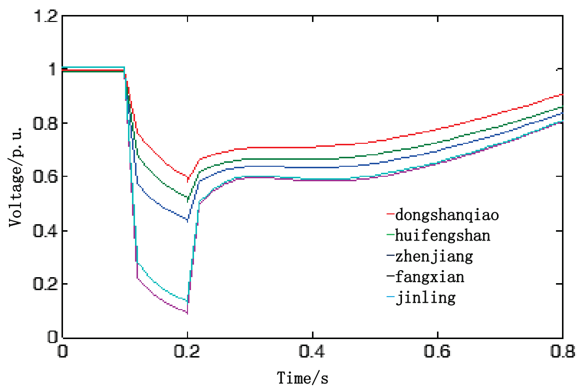


Figure 4-4 Voltage response curve of wihtout the intelligent electrical home appliances

Assuming interruptible capacity of 250MW of intelligent household appliances in Changzhou area, sets the detected voltage drops to 0.93p.u.Shi, after delay of 0.5s disruption, under voltage load shedding device removal motion load. The voltage curve in figure 4-5 recovery is much better than figure 4-4.

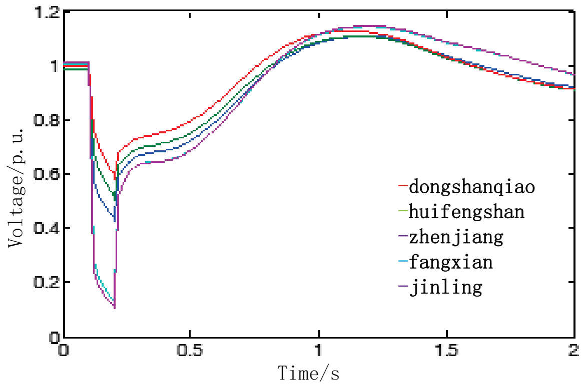


Figure 4-4 Voltage response curve of wiht the intelligent electrical home appliances

## V. CONCLUSION

In this article, based on intelligent home appliances, the impact of observability and controllability of intelligent appliances on the under-frequency load shedding of power system was analyzed. Considering the actual situation of China grid, the proposed provincial power network intelligent load-shedding implementation scheme was feasible by simulation verification.

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