Power Management System Based on Virtual Power Plant

Xiaofeng Chen¹, Guanlu Yang², Yajing Lv³ and Zehong Huang⁴

College of Information and Science Engineering, Huaqiao University, Xiamen, China
E-mail: 410417815@qq.com

Abstract. In recent years, the temperature-controlled load capacity has increased rapidly in China, and it has also brought huge regulatory potential. In order to effectively dispatch and manage a large number of demand response resources, this paper studies the energy efficiency management system based on virtual power plant based on demand response technology and virtual power plant theory, and effectively uses the management system to temperature. Collecting and controlling the power parameters of the load-control resources, making full use of the potential for reducing the demand side load, to achieve the “shift peak filling” of electricity, which is conducive to alleviating the contradiction between power supply and demand and ensuring the safe and stable operation of the power grid.

1. Introduction
In the context of power reform, a “virtual power plant(VPP)” technology introduced to accelerate the development and utilization of new energy sources and effective grid-connected purposes, which aggregates and coordinates the management of distributed energy resources (DERs) units within the jurisdiction, using DERs Fast and flexible adjustment features and complementary functions can improve the economic and security of the power system [1-2]. The essence of VPP is to combine advanced advanced management, control, communication and information technologies with traditional power system technologies to improve the safety, reliability, economy and stable operation of the power grid.

With the advancement of power system marketization reform and the adjustment of national energy policy, based on smart grid technology support, cooperation and information exchange between power network and power market, power network and power users are getting closer and closer [3]. Demand Side Management (DSM) is an effective method and measure to reduce power consumption and reduce voltage shortage in the same power consumption scenario, thereby ensuring balance between supply and demand and reducing power and electricity costs. In order to effectively dispatch and manage a large number of demand response resources, this paper studies the energy efficiency management system based on VPP based on demand response technology and VPP theory, and effectively utilizes the management system for temperature control load. Energy parameter collection and control of resources to achieve energy efficiency management of demand side loads, and thereby further enhance the power system's ability to adjust.

2. Overall design
This scheme designs a three-phase three-phase electric load energy parameter acquisition system, including voltage, current, various types of electric power, active power, reactive power, power factor, voltage imbalance, current imbalance, zero sequence Current, power outage time, and the maximum value of voltage and current in 15 minutes and the moment of occurrence. In terms of control, the 3-way load is switched and lifted to support independent control. In the wireless transmission function...
of the data, the measured data can be transmitted to the upper computer through the ZigBee wireless module, and the command control load can be received from the upper computer. The overall design framework is shown in Figure 1.

![Overall design framework](image)

**Figure 1.** Overall design framework

3. **NIOS module design**

According to the design requirements, the components to be added from the SOPC Builder are mainly included: CLK, CPU, SDRAM memory module, EPCS storage, ID number, button KEY, UART interface, LCD display, control signal, etc. After adding the components required by the system, assign the base address of each component of the Nios II system. The module configuration and its base address are shown in Figure 2.
In Figure 2, CLK is the clock module, CPU is the system control unit module, SDRAM stores the running program, EPCS stores the program after curing, ID is the ID number of the CPU, KEY is the button module, UART is the serial port module, and data is carried out with ZIGBEE The transmission and interaction, the LCD display is used to control the screen display, and the R series pins collect 3 channels of measured data, including voltage, current, phase, frequency, and so on. On_off and on_down are control signals for switching and lifting.

(1) RMS measurement
The rms measurement includes voltage rms measurement and current rms measurement. The rms measurement mainly applies the square and re-opening operation. In this design, the RTL function simulation of the squared summation of the rms measurement is shown in Figure 3.

In Figure 3, rst_n is the reset signal, clk provides the clock signal to the module, and dat_en is the enable signal. 16-bit dat data signal input, Mult0 performs the product of the dat input signal, product_value completes the buffering of the product result. With the participation of the dat_en enable signal, the dat_cnt register controls the number of superpositions, and the dat_cnt register and the enable signal dat_en jointly control the product_value. The accumulation operation, the sum of the operations is stored in the sum_value register. When the dat_cnt counts to a certain value, the value_o register latches the value of the sum_value register as the squared data output.

(2) Frequency measurement
There are two main methods for measuring the frequency. This paper mainly uses the period measurement method. In the design, the sig_reg register and the sig_reg_1 register respectively collect the rising edge of the clock input signal, and the detection of the rising edge is completed by the
pos_sig gate circuit, and the clock sys_clk is counted between the two rising edges, and the obtained technical result and sys_clk are obtained. The period is multiplied to measure the period value of the signal, and the reciprocal is the frequency. The Add0 adder and ref_cnt implement the superposition of the rising edge data, and the cnt_sys outputs the measurement result. The functional simulation RTL diagram of frequency measurement is shown in Figure 4:

![Figure 4](image)

**Figure 4.** Functional simulation RTL diagram of frequency measurement

4. Simulation analysis
This design uses Modelsim10.1c to perform functional simulation verification and functional simulation of AD module sampling. The AD sampling simulation diagram is shown in Figure 5.

![Figure 5](image)

**Figure 5.** AD sampling simulation diagram

In the simulation diagram, ad_convsta and ad_convsta share the convst signal to achieve data synchronization sampling of 8 channels. Ad_busy is a busy signal, cs/rd is a read/write signal, and data:db is a data bus. When the ad_convstab signal is a rising edge, the ad_busy signal becomes high. When both the ad_cs bit and the ad_rd signal become low, the first_data signal is simultaneously asserted high, and the chip will read the eight channels of the converted data in turn.

5. Design of power parameter calculation module
Combined with the electrical parameters measured by this design, this paper will introduce the calculation methods of voltage RMS, current RMS, active power, reactive power, apparent power, power factor, frequency and three-phase unbalance.

According to the definition of the effective value of the periodic function, for any one of the periodic functions \( x(t) \), the effective value is usually defined by the root mean square value of the \( x(t) \) period, as follows:

\[
M_{rms} = \sqrt{\frac{1}{T} \int_{t_0}^{t_0+T} x^2(t)dt}
\]  \hspace{1cm} (5.1)

According to the above formula, the effective values of voltage \( u(t) \) and current \( i(t) \) of the periodic function can be defined as:
In the formula, \( T \) is the period of the voltage and current signal. In order to make the calculation applicable to the computer processing system, the above formula needs to be discretized, and the result is:

\[
U_{\text{rms}} = \sqrt{\frac{1}{N} \sum_{m=0}^{N-1} u^2(m)}
\]

\[
I_{\text{rms}} = \sqrt{\frac{1}{N} \sum_{m=0}^{N-1} i^2(m)}
\]

The meaning of \( N \) in the formula is the total number of samples after a period of dispersion, and \( u(m) \) and \( i(m) \) are the sampled values of the voltage signal and the current signal at time \( m \), respectively. After discrete, the effective values of voltage and current can be calculated simply by computer control system.

In an AC circuit, the apparent power does not represent the power actually consumed by the AC circuit, but only the maximum power that the circuit may provide or the maximum active power that the circuit may consume. We refer to the product of the rms voltage and the rms current in the AC circuit as the apparent power. The formula is:

\[
S = U_{\text{rms}} I_{\text{rms}}
\]

In an AC circuit, active power is also referred to as average power, meaning the average of the integrals of instantaneous power consumed or emitted over a period. Record the active power as \( P \), the formula is

\[
P = S \cos \varphi
\]

Reactive power is relatively abstract, and we believe that reactive power is used in electric and magnetic fields in circuits and is used to establish and maintain electrical power in electrical equipment\(^{[4]}\).

\[
Q = S \sin \varphi
\]

In the actual situation, the load connected to the three-phase circuit is not necessarily symmetrical, resulting in the asymmetry of the three-phase circuit. Therefore, the calculation method of the three-phase total active power of the present design is to add the active power of each phase to obtain the true three. The total active power of the phase.

\[
P_{\text{total}} = P_1 + P_2 + P_3
\]

Similarly, the calculation method of total reactive power and total apparent power can be obtained.

\[
Q_{\text{total}} = Q_1 + Q_2 + Q_3
\]

\[
S_{\text{total}} = S_1 + S_2 + S_3
\]

The three-phase unbalance degree refers to the degree of three-phase unbalance in the three-phase shop system, and is expressed by the root mean square percentage of the negative-sequence fundamental wave component or the zero-sequence fundamental wave component of the voltage and current and the positive-sequence fundamental wave component\(^{[5]}\). Generally, we can roughly judge the operating condition of the three-phase circuit according to the magnitude of the three-phase unbalance rate. If the unbalance rate is lower than 2%, it is generally caused by the single-phase load.
imbalance of the three-phase circuit\(^{[6-7]}\). The calculation formula for the three-phase voltage and current imbalance is as follows:

\[
\beta_u = \frac{U_2}{U_1} \times 100\% \tag{5.12}
\]

\[
\beta_i = \frac{I_2}{I_1} \times 100\% \tag{5.13}
\]

Since the input power of the data center adopts a three-phase four-wire system, when the three-phase system is unbalanced, the zero-line current will flow through the zero-sequence current, that is, there is a zero-sequence component in the three-phase system. Therefore, when calculating the imbalance of the three-phase four-wire system, the symmetrical component method must be used to determine the components of the positive and negative sequence of the fundamental voltage and the fundamental current, respectively, and then according to the formula (5.12), (5.13) Find the imbalance of the three-phase voltage and current. The formula for calculating the positive sequence component and the negative sequence component is as follows:

\[
\dot{U}_1 = \frac{1}{3} \left( \dot{U}_A + \alpha \dot{U}_B + \alpha^2 \dot{U}_C \right) \tag{5.14}
\]

\[
\dot{U}_2 = \frac{1}{3} \left( \dot{U}_A + \alpha^2 \dot{U}_B + \alpha \dot{U}_C \right) \tag{5.15}
\]

\[
\dot{I}_1 = \frac{1}{3} \left( \dot{I}_A + \alpha \dot{I}_B + \alpha^2 \dot{I}_C \right) \tag{5.16}
\]

\[
\dot{I}_2 = \frac{1}{3} \left( \dot{I}_A + \alpha^2 \dot{I}_B + \alpha \dot{I}_C \right) \tag{5.17}
\]

In the above formula, \( \alpha \) is the twiddle factor, \( \alpha = \frac{1}{2} + j \frac{\sqrt{3}}{2} \), \( \alpha^2 = \frac{1}{2} + j \frac{\sqrt{3}}{2} \), \( \dot{U}_1 \) and \( \dot{I}_1 \) are the positive sequence components of voltage and current, respectively, \( \dot{U}_2 \) and \( \dot{I}_2 \) are the negative sequence components of voltage and current, respectively, and \( \dot{U}_A \), \( \dot{U}_B \) and \( \dot{U}_C \) are the fundamental components of the three-phase voltages of A, B and C, respectively. \( \dot{I}_A \), \( \dot{I}_B \), and \( \dot{I}_C \) are the fundamental components of the three-phase currents of A, B, and C, respectively.

There are two main methods for calculating the zero-sequence current detection, namely zero-sequence current transformer detection method and three-phase current synthesis method\(^{[8]}\). Both methods have their own advantages. In this paper, the three-phase current synthesis method is used to calculate the zero-sequence current according to the current conditions, and the calculation formula can be obtained as

\[
I = \frac{I_a}{k} + \frac{I_b}{k} + \frac{I_c}{k} \tag{5.18}
\]

\( I \) is the zero sequence current, \( I_a \) is the phase A voltage, \( I_b \) is the phase B voltage, \( I_c \) is the phase C voltage, and \( k \) is the ratio of the three, three, and four phase current transformers.

6. Conclusions

In the traditional power system, energy flows from the power generation side to the user side only, and the emergence of demand response technology enables the demand side resources to participate in the power market, that is, to achieve energy interaction, reduce power generation costs, and make power
supply more efficient, clean. At the same time, the concept of VPP brings together a variety of distributed power sources, controllable loads and energy storage units to participate in the dispatching and management of the electricity market and grid operation as another special power plant. Based on the integration of temperature control load, demand response and VPP concept, based on demand response technology and VPP theory, the temperature control load is taken as the research object, and the energy efficiency management system based on VPP is built, which effectively utilizes the management system to load resources. The power parameter acquisition and control is used to fully utilize the potential side load reduction potential, thereby further enhancing the power system's regulation capability.

7. References
[1] Yu Shuang, Wei Zhinong, Sun Guoqiang, et al. A Bidding Model for a Virtual Power Plant Considering Uncertainties[J]. Automation of Electric Power Systems, 2014, 38(22): 43-49.
[2] PANDZIC H, KUZLE I, CAPUDE T. Virtual power plant mid-term dispatch optimization[J]. Applied Energy, 2013, 101: 134-141.
[3] Zhang Qin, Wang Xifan, Fu Min, et al. Smart Grid from the Perspective of Demand Response[J]. Automation of Electric Power Systems, 2009, 33(17): 49-55.
[4] Bu Weizhong. Reactive power compensation and power factor improvement[J]. China High-Tech Enterprises, 2009, 1(07): 110-111.
[5] National Standardization Management Committee. GB/T 15543-2008, Power quality three-phase voltage imbalance[S]. Beijing: China Standards Press, 2008.
[6] Jing Yong, Liang Chen, Shuangyan Chen. Modeling of Home Appliance for Power Distribution System Harmonic Analysis [M]. IEEE Trans. Power Delivery, vol. 25, pp. 3147-3115, 2010
[7] Roger C. Dugan, Mark F. McGranaghan, et al. Power system power quality[M]. Ouyang Sen, Translation. Beijing: China Electric Power Press, 2013.8
[8] Feng Xiaoguang. On the Protection of Zero Sequence Current[J]. Journal of Library and Information Science, 2009, 19(27): 210-211