Power Modeling of BSs Based on Energy Storage Monitoring

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***Abstract*—Current research in base station(BS) energy consumption area is mostly devoted to the study of the static energy consumption or dynamic factor. But it lacks the research on the energy storage efficiency of the BS. In this paper, we propose a power modeling of BSs based on energy storage monitoring. Firstly, the system architecture and networking scheme of energy storage monitoring are presented, and the mathematical model of BS energy consumption is analyzed. Then, based on the current network's data, a large number of real data are collected through the energy consumption analysis system. We analyzed the effect of charge and discharge time on energy storage efficiency of power grid. Based on the monitoring data, we fit the model of energy consumption and get the model of overall power consumption. Finally, based on the use control template, the optimization scheme of reducing the power consumption of authority network is proposed, which has substantial economic and green value.**

***Keywords*—the mobile station; energy consumption monitoring system; energy efficiency of the grid**

I. Introduction

The communications industry is the core industry of our country, and each year's electricity consumption can't be taken for granted. With rapid growth of China's telecommunications industry nowadays, the problem of energy consumption has begun to receive people's attention[1]. How to reduce its power consumption is a problem to be solved at present. Currently, most of the BSs are equipped with batteries, UPS and other energy storage modules[2]. When the city electricity is cut off, it can be used as the reserve energy source of the BS to ensure the continuous power supply of the communication equipment[3-4].

However, the energy storage efficiency of the energy storage module is often closely related to the charge and discharge time. For the operation of the energy storage module, the current research lacks the analysis of the relationship between the energy efficiency and the charge-discharge time of the energy storage module[5-6].

Based on the above problems, this paper will use power consumption detection system to collect a large number of real data, and we will do analysis on these data. From a macroscopic scale of view, we can study the effect of charging and discharging time on power grid's energy storage efficiency and get the best discharge time of the energy storage module.

The rest of the paper is organized as follows. Section II introduces the energy consumption data acquisition system and the process of charge and discharge of energy storage module. Section III creates a model of the charge-discharge process of the BS. Section IV is about the data fitting and gives the optimization suggestion. Section V design and effect analysis of energy saving scheme. Section VI concludes the paper

II. Energy Storage Module

This chapter introduces the architecture of the data collection platform of energy consumption and conclude the charging and discharging process when the city power goes down and gets connected again.

A. Structure of Data Collection System for BS

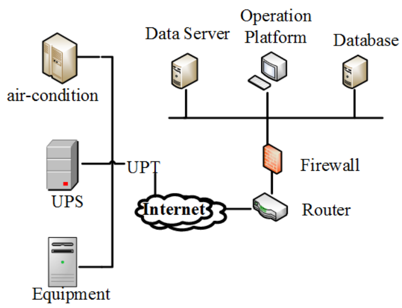

Fig.1. network scheme of energy consumption data acquisition system

To analyze the BS's power consumption, we did statistical analysis on the BS's energy consumption and established a system to collect and monitor energy consumption data. Fig 1 shows its particular architecture. It is used to collect the total power consumption data of the BS's equipment. The sample BS's all data are reported to a temporary public server storage via General Packet Radio Service. Monitoring center retrieves the public server's energy consumption data of BS through local server and stores these data into permanent storage. The center will obtain the stored data through operation platform.

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B. System model analysis

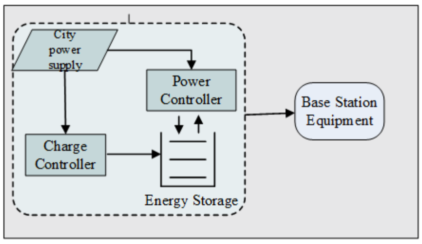

Fig.2. charging equipment of energy storage module

In general, the energy storage module's storage capacity can be expressed by the energy storage efficiency. But in the energy storage stage, the output power is not equal to the energy of entry, and there is energy loss in the process of storage. When the energy storage efficiency is close to 1, the charging efficiency is very high.

In the paper, based on the current monitoring data we studied the relationship between the discharge depth and the energy storage efficiency of the energy storage module. We want to find the most suitable discharge to minimize the energy storage efficiency of the battery.

In the case of city power outage, the storage module will serve as the backup energy for communication equipment to avoid the transmission failure. This is shown in Fig 2.

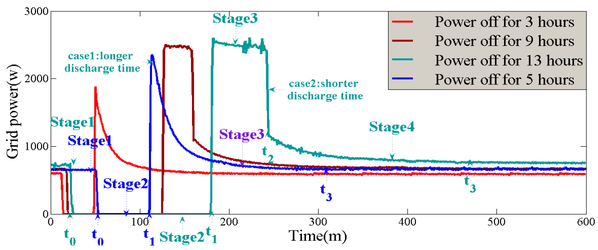

Fig.3 different power outage time curves of BS

When the city power goes down for a period and then goes back again, we can found that the change of energy consumption of communication equipment has certain patterns. The power consumption data of the sample BS gathered by the data acquisition platform is collected every 5 minutes, and the energy consumption data of one day is the research object.

Fig 3 shows the different power outage time curve. We can find that the BS will experience the following stages when the city power got connected, went down, and then got restored:

1) Stage1: under normal circumstances, the BS's energy is from the power grid, and the energy storage module does not work. The battery is in the floating state.

2) Stage2,t_0~t_1: the energy storage module will act as power suply for communication equipment, and it will start to discharge.

3) Stage3,t_1~t_2: the city power supplys electricity to the communication equipment and recharges the energy storage module as well. At this point, the measured room power is the sum of the power consumption of the machine room and the energy storage module. It can be concluded from Fig 4 that different power outages will lead to different charging power characteristics. Case 1:when the discharge time is between 1 to 4 hours and the city power got recovered later on, the machine room power would quickly decline after it reaches a maximum value. This create a peak point in the curve. Case 2: when the discharge time is more than 4 hours, there will be a short stable charging period after machine room power reaches its maximum value and does not have peak point. If the power off time is further extended,there will be a stable charging period as well, and this period will be extended when the power outage time increases.

4) Stage 4,t_2~t_3: When energy storage module is charged to 100%, the city power only supplys electricity for communication equipment

5) $P(t)$ is city electric power consumption; $P_0(t)$ is the power consumption during the operation of the BS; $P_B(t)$ is the energy storage module power consumption; t_0 is the city power outage time; t_1 is the city electricity to restore the power supply time; t_2 is the energy storage module ends smoothly charging time; t_3 is the energy storage module the full power of the time; $f'(t)$ is the city electricity to restore the power supply and stable charging period energy consumption of BS; $f(t)$ is the energy consumption of BS at t time; $f_1(t)$ is energy consumption that exclude the energy storage module.

we set up a comprehensive power consumption model for BS based on energy storage monitoring:

$$\begin{cases} P(t)=P_0(t), stage\ 1 \quad P(t)=0, stage\ 2 \\ P(t)=P_0(t)+P_B(t), stage\ 3\ and\ stage\ 4 \end{cases} \tag{1}$$

After many tests, through the fig3 we can observe that with the different of charge and discharge time the power of the room shows two trends. We will use the energy storage module to reflect the energy efficiency of the energy storage module. So, for different power down time formula 1 in the city after the recovery can be carried out as follows:

$$\begin{cases} P(t)=\int_{t_1}^{t_3} f(t)dt, case\ 1 \\ P(t)=\int_{t_1}^{t_2} f'(t)dt+\int_{t_2}^{t_3} f(t)dt, case\ 2 \end{cases} \tag{2}$$

According to the above analysis, we can get the energy consumption of the energy storage module. In summary, the energy storage efficiency of power grid can be:

$$\eta=\begin{cases} \dfrac{\int_{t_0}^{t_1} f_1(t)dt}{\int_{t_1}^{t_3} f(t)dt-\int_{t_1}^{t_3} f_1(t)dt}, case\ 1 \\ \dfrac{\int_{t_0}^{t_1} f_1(t)dt}{\int_{t_1}^{t_2} f'(t)dt+\int_{t_2}^{t_3} f(t)dt-\int_{t_1}^{t_3} f_1(t)dt}, case\ 2 \end{cases} \tag{3}$$

III. ANALYSIS OF BS ENERGY CONSUMPTION MODEL

Currently, the theory of mobile BS energy consumption model is the following, P_A is the dynamic factor's energy consumption, P_E is the static factor's energy consumption, T_{in} is the indoor temperature, T_{out} is the outdoor temperature:

$$P(t) = P_A(L(t), Tin(t)) + P_E(L(t), Tout(t)) \quad (4)$$

We can draw the conclusion that BS's energy consumption is mainly for the power consumed during the operation and battery consumption when city power changed from being shut down to getting restored. Energy storage efficiency of energy storage module is related to charge and discharge time. So we proposes an improved model for power consumption of BS:

$$P(t) = P_0(t) + P_B(t) \quad (5)$$

Based on the collected data of the BS's energy consumption every five minutes, we draws the graph to express and analyze the relations between the power consumption of the BS and the charging and discharging time.

We conducted the charge and discharge experiment on the energy storage module of several BSs and collected a large number of data and conclude that the charge and discharge of energy storage module mainly present the following two trends:

A. Discharge Time is Short

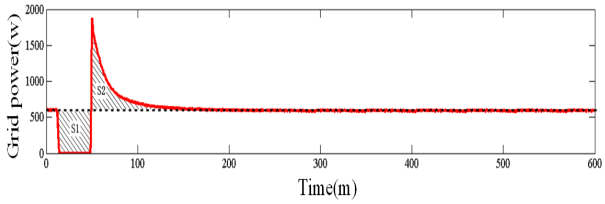

Fig. 4. BSs power outages 3 hours

Fig4 shows the power outage three hours, the relationship between the authority and time of the machine room. In which the horizontal coordinate represents time, and the vertical coordinate indicates the power of the machine room. As is shown in Fig 4. When the discharge time is short, the power of the machine room has three distinct stages. According to the formula3, the energy storage efficiency of the power gird is:

$$\eta = \frac{\int_{t_0}^{t_1} f_1(t)dt}{\int_{t_1}^{t_3} f(t)dt - \int_{t_1}^{t_3} f_1(t)dt} = \frac{S_1}{S_2} \quad (6)$$

B. Discharge Time is Long

Compared to the short power outage time, the power of the machine room will experience four distinct stages when the power off time is longer. As is shown in Fig 5 there is a stable charging period. According to the formula3, the energy storage efficiency of the power grid is:

$$\eta = \frac{\int_{t_0}^{t_1} f_1(t)dt}{\int_{t_1}^{t_2} f'(t)dt + \int_{t_2}^{t_3} f(t)dt - \int_{t_1}^{t_3} f_1(t)dt} = \frac{S_1}{S_2 + S_3} \quad (7)$$

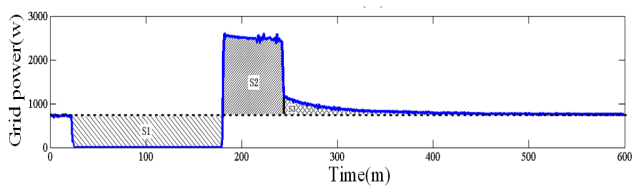

Fig. 5. BSs, power outages 13 hours

C. Fitting Results

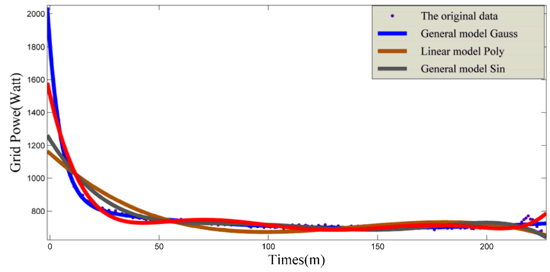

Fig. 6. power off 3 hours charging process curve fitting

So we can use the area of the curve to represent the BS's energy consumption. When the charging time of the energy storage module is stable, the power consumption of the BS can be approximately considered as a fixed value, that is, the power consumption of the BS corresponds to the rectangular area. That is S1 and S2 in the Fig.4 and Fig5. Due to energy storage charging module is the final stage of the irregular curve, so to facilitate the calculation we can fit on the stage, and select a minimum error of fitting function as the integral of a function to the integration, in order to calculate the area of the curve, that is, the BS energy consumption. The actual value is closer to the theoretical value. That is S3 in the Fig.5.

The scattered points represent the real data, and the real curve represents the quantized model. Fig 6 is the fitting that uses the four stage Fourier transform, Gauss function, polynomial function, and sine curve to simulate the charging process curve of energy storage module without electricity for three hours. Table I is the fitting result of four fitting function which is closest to the actual curve transformation. By comparison, it can be found that among the four fitting methods, the variance of Gauss's function is the smallest, and the goodness of fit is the best. So it can be considered to be closer to the real situation.

TABLE I. FITTING RESULTS OF DIFFERENT OUTAGE TIMES

fitting function	SSE	R-square	Adjusted R-square
Gauss	47540	0.9959	0.9958
Fourier	803300	0.9301	0.9292
Poly	4000000	0.652	0.6501
Sin	9034000	0.214	0.2111

Formula 6 is used in the charging process of the fitting formula after applying Gauss:

TABLE II. FITTING RESULT OF DIFFERENT POWER OFF TIME

Power off time	a_1	b_1	c_1	a_2	b_2	c_2	a_3	b_3	c_3
3h	1.55×10^{13}	-664.1	137.6	3.453×10^{15}	-36300	6704	341.1	642.2	456.7
5h	6482	-56.26	46.15	1.003×10^{15}	-4803	904.5	658.3	400	701.2
9h	7.326×10^{14}	-1868	351.5	730.3	-394	2359	20.54	424.2	64.86
13h	2.583×10^{14}	-3246	620.2	754.2	280.9	3475	14.73	871.3	135.9

$$f(t)=a_1e^{\frac{b_1}{c_1^2}-t}+a_2e^{\frac{b_2}{c_2^2}-t}+a_3e^{\frac{b_3}{c_3^2}-t} \qquad (8)$$

$f(t)$ is the machine room energy consumption, t is the charging time. The value of a1······a2, b1······b2, c1······c2 is different due to the different power off time. The s_2 is equal to:

$$s_2=\int f(t)dt=\int a_1e^{\frac{b_1}{c_1^2}-t}+a_2e^{\frac{b_2}{c_2^2}-t}+a_3e^{\frac{b_3}{c_3^2}-t}dt \qquad (9)$$

At this time the battery charging efficiency is: 0.973494

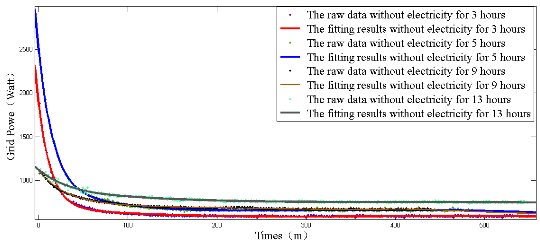

Fig. 7. fitting curve of charging process with different power off time

Fig 7 is the use of the Gauss function to get the BS's comprehensive energy consumption about the time (t) fitting curve during the energy storage module's charging process when the power off time is 3,5,9,13 hours. The scattered points represent the real data, and the curve represents the quantized model. It can be inferred that the Gauss function is appropriate for replacing the charging process function with different power off time. And Table II represents the fitting results using the Gauss function when the power off time is 3,5,9,13 hours.

IV. ENERGY SAVING SCHEME DESIGN AND EFFECT ANALYSIS

Through lots of experiments, the data of each power cut period of the battery is collected. We use the above calculation method to obtain the following curve chart about power off time and battery energy storage efficiency. The horizontal coordinate represents the time, and the vertical coordinate represents the energy storage efficiency of the energy storage module.

We can observe from the battery efficiency curve that the battery energy storage efficiency increases at first and then decreases with the increase of the battery discharge depth. When the release time is between 1 hours and 8 hours; that is, the discharge depth is less than 50%, battery energy storage efficiency decreases with increasing discharge depth. When the discharge depth is 8 hours, the energy storage efficiency is the lowest. If the discharge depth exceeds this range, the energy storage efficiency of the battery will increase with the increase of the discharge depth. And we can observe from the experiment that there will be a period of constant charging

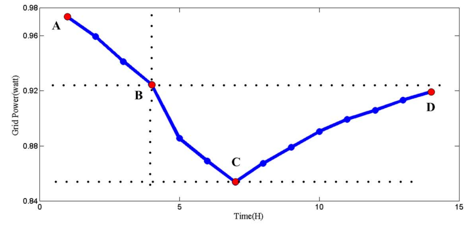

Fig. 8. energy storage module energy storage curve

when the battery discharge depth is relatively large. At thistime, the efficiency of the energy storage module is also a turning point for the decreasing process to increasing process.

V. SUMMARY AND PROSPECT

In this paper, we use lots of data to analyze the effect of the energy storage module's charge and discharge time on the power grid's energy storage efficiency. And the total error is within the allowable range. Then, based on the relationship between the energy storage module's charge and discharge time and the energy storage efficiency of the BS, we propose an effective energy saving plan. Future research will apply the BS energy consumption model to more types of network communication BSs to verify the practicability of this model.

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