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Research on Energy Storage of Super Capacitor, Accumulator and Lithium Batteries in Distributed Systems

WANG Wen-Xing
North China University of Water Resources and Electric Power
Zheng Zhou, 450011, China
E-mail: lf6660506@sohu.com

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Abstract: In order to maintain power quality and system reliability, distributed power supply system must maintain the dynamic balance of power, energy storage systems ensure stable and reliable quality of power supply system. This paper briefly analyzed the current situation and development of energy storage technologies, described the meaning and value of distributed power supply system suitable for ultra capacitors and lithium hybrid energy storage structural studies, more comprehensive descripted common models of the super capacitors, lithium batteries and accumulators illustrate, and compared the advantages and shortcomings.

Keywords: Super capacitors, Lithium batteries, Accumulator, Micro-grid, Distributed power, Hybrid energy storage.

1 Introduction

Energy is the main basis for human survival, life and development. Currently over 85 per cent of total global use of energy is fossil fuels, including coal, oil and natural gas. Fossil fuel reserves are limited, as coal, oil and natural gas are depleted, it will face a serious energy shortage crisis and can not even maintain decades. With the increase in world population and improve of the living standards of the requirements, demand of human for energy is increasing. Future development of renewable energy requires sufficient reserves to meet the needs of human survival and development, and environmental problems will not affect the survival of mankind.

Including wind and solar energy, distributed energy supply technology has become the focus of research and development, as natural conditions, distributed generation with characteristics of intermittent power supply, output of rapid change, with increasing the proportion of new energy resources in electricity, grid stability requirements conflict has more prominent with the randomness of distributed power generation, needs of the industry promote the development of energy storage technologies, making it solve these bottleneck in distributed power generation.

In the distributed power generation supply system, at this stage due to technical and cost advantages of lead-acid batteries is relatively obvious, but the longer term, with a gradual increase in the price decline, the technology matures and environmental requirements, the super capacitor, lithium batteries will be more widely used in distributed power generation systems. Electromagnetic energy storage, sodium sulfur

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batteries, flow battery technology is not yet mature, and have not yet entered large-scale commercial stage, so this paper chose super capacitors, batteries and lithium batteries as the object of study, mainly through the analysis of the model, revealing the battery electrochemical properties, how to select the appropriate storage device.

The commonly model used have electrochemical battery model, thermodynamic model, coupled model and performance model of these four. The first three models need to build on the electrochemical mechanism of cell has a very profound study, and relatively complicated, too much consideration, it is generally not used in batteries online management. Correspondingly, the battery performance model only describes the external characteristics of the battery through a relationship work, easy to use structural diversity, and universal application.

2. Super Capacitor Energy Storage Characteristics

Super capacitor induced using an electric double layer capacitor formed between the electron conductor made of activated carbon and an organic or inorganic electrolyte ionic conductor.

When the applied voltage is applied to two super capacitor plates, as the conventional capacitor, the positive electrode plates are stored positive charge, negative charge stored in the negative electrode plate, the electric field in the bipolar plate super capacitor charge generated in forming an interface between the electrolyte and the electrodes on the opposite charge, in order to balance the electric field within the electrolyte, the positive and negative charges that the contact surface between two different phases, a very short gap between the positive and negative charges are arranged in the opposite position, the distance is smaller than a conventional capacitor charge can be achieved from a dielectric material, the charge distribution layer is called the electrical double layer , the presence of which the surface area activated carbon electrode leaving the magnitude of the increase, there is a very large the electrostatic capacity, so a very large capacity, which is the capacitance of the "super " is located.

Super capacitors state of charge (SOC: State of Charge)) constitute a simple function with the voltage, battery state of charge includes a variety of complex conversion. Super capacitor energy transfer can be repeated without any adverse impact pulse.

2.1. Equivalent Circuit Model Ultra Capacitors

2.1.1. Model Introduction

Super capacitors monomer having low power density devices, energy storage is small, the characteristics of low voltage side, and therefore required in engineering applications, the plurality of single super capacitors were in series and parallel combinations to form a super-capacitors. Equivalent model super capacitor is shown in Fig. 1. Wherein, EPR for the equivalent parallel resistance, ESR is the equivalent series resistance, C is an ideal capacitor, L is a capacitive reactance. The main influence of the leakage current EPR super capacitor, thus affecting the performance of long term storage capacitor, EPR is generally large, up to tens of ohms, so that the leakage current is small, the super capacitor is faster and more frequent charging and discharging process, the impact can be ignored. L represents the emotional component of the capacitor, which is related to the operating frequency component. ESR in the charge – discharge process produces energy loss. RC equivalent model of the structure is simple, can be more accurately reflected in the super capacitor charging and discharging process of external electrical characteristics [1, 2].

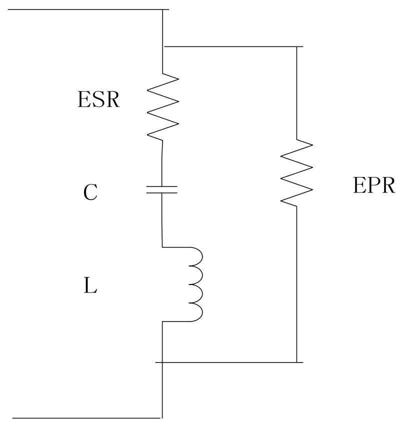

Fig. 1. Supercapacitor equivalent model.

Major factor limiting super capacitor applications is a capacitor equivalent series resistance ESR, if the resistance is too large, output capability is limited its high current [3]. Electric double layer capacitor ESR is an important indicator of the performance [4]. The equivalent resistance of the capacitor is mainly constituted by the internal resistance of the electrode material, the solution resistance, the contact resistance.

2.1.2. Energy Storage

According to the capacitive principle,

$$I = C \frac{dV_C}{dt}, \tag{1}$$

where I is the current; dt is the discharge time variation amount; C is the capacitance; dVc is the voltage variation caused by capacitor discharge.

$$dV_C = I\frac{dt}{C}, \quad (2)$$

Equivalent series resistance caused voltage drop part: dv: total voltage change of the super capacitor terminal

$$dV = I\frac{dt}{C} + IR_{ES}, \quad (3)$$

Super capacitor capacity charging decreases with current increases, the effective capacity and the conversion efficiency is impacted by resistance and its charging and discharging currents. Therefore, in the constant current charging mode, selected of the charging current should not be too big.

During the constant current charging mode is set , the capacitor C does not change with the terminal voltage, the energy storage of super capacitor is Et, then:

$$E_t = \frac{C[V_0 + I(R + \frac{t}{C})]^2}{2}, \quad (4)$$

Obtained by fitting analysis [5]: When using a small current (less than 50 A) and a moderate current (50-70 A) remains substantially constant. With the increase of the charge and discharge current, reaching more than 70 A, power reserves decreased rapidly, and a large decrease in the gradient. Therefore, when using a large charging current, super capacitor energy storage will have a greater impact, so when the current charging control strategies are designed, it must be selected the appropriate charge current.

2.2. RC Equivalent Circuit Model of the Super Capacitor

Major role of ultra capacitor hybrid power in the distributed power system is load shifting [6], for fast charging and discharging, the capacitor parameters and resistance parameters are mainly affected by super capacitor voltage, temperature, time and frequency of use and other factors. Experimental results show that the model can be ignored or supercapacitors integrate many factors to consider only the equivalent resistance and capacitance associated components (RES) of the impact, so it can be equivalent to the model RC branch form, it is shown in Fig. 2, according to equivalent circuit diagram, relevant mathematical models can be created.

Where C is the equivalent capacitance of super capacitors, R is the equivalent resistance super capacitors, and their size is determined by the temperature and state of charge (SOC: State of Charge) inputting function model, it is determined by the following formula:

$$R = F(SOC, Tess), \quad (5)$$

$$C = f(SOC, Tess), \quad (6)$$

F(*) and f(*) is the function of two-dimensional look-up table with interpolation function, the relationship of super capacitor charge and discharge resistance, SOC, temperature relationship and relationships of the equivalent capacitance of supercapacitors with temperature, SOC are established by look-up table based on experimental.

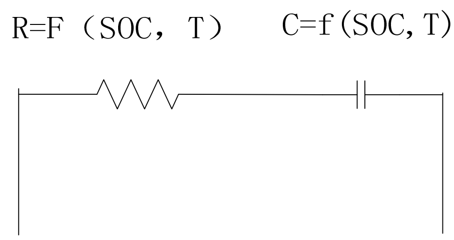

Fig. 2. Super capacitor equivalent RC model.

Ultra capacitors SOC is calculated by the voltage model, calculating relationship formula as followed:

$$SOC_{UC} = \frac{V_{OC} - V_{MIN}}{V_{MAX} - V_{MIN}}, \quad (7)$$

where in the capacitor V_{OC} is open-circuit voltage; V_{MIN} is the minimum voltage of the capacitor; V_{MAX} is the maximum voltage of the capacitor. Super capacitor R, C parameter can be obtained according to the U.S. Department of Energy (DOE) "super capacitor electric vehicle test manual" analysis by the experimental data, a different temperature and charge and discharge currents is set in the experiment.

2.3. Helmholtz Simplified Model of Two-tier Structure

Super capacitors are based on the theory of German physicist Helmholtz (Helmholtz) interface proposed electric double layer capacitor. In chemical electrolysis, when the electrode is immersed into an electrolytic solution, a charge separation and charge accumulation phenomenon in the boundary face of the electrode. Reversely charged electrolyte ions to compensate the accumulated residual charge on the electrode are surfaced. This interface is called Helmholtz layer (Helmholtz layer). Capacitance is developed on the basis of the storage layer structure, based on Helmholtz double-layer structure, in order to accurately describe the external characteristics of a capacitor, theoretical models have been proposed to study the characteristics of the capacitor. Ultracapacitors theoretical model focused on the Characteristics of the electric double layer. By using a network of simple electrical components, to study the input and output characteristics of super-capacitors, respectively, Physical meaning and chemical components.

3. Battery Energy Storage Characteristics Modeling

Lead-acid battery electrode is composed mainly of lead oxide and the electrolyte. The state of charge, the main component of lead dioxide positive electrode, a negative electrode mainly composed of lead; discharged state, the main components are the positive and negative lead sulfate, a density of 1.28 ~ 1.32 g/mL (at a concentration of 27 % ~ 37 %) sulfuric acid solution as the electrolyte, collectively known as the lead-acid battery (also known as "lead-acid batteries").

VRLA battery electrochemical reaction is as follows

Charge:

$2PbSO_4 + 2\ H_2O = PbO_2 + Pb + 2\ H_2SO_4$ (cell)

Anode:

$PbSO_4 + 2\ H_2O - 2e- = PbO_2 + 4\ H + + SO_42-$

Cathode: $PbSO_4 + 2\ e- = Pb + SO_42-$

When the density of the solution rose 1.28 g/ml, should stop charging

Discharge:

$PbO_2 + Pb + 2\ H_2SO_4 = 2PbSO_4 + 2\ H_2O$ (cell)

Negative: $Pb + SO_42 - 2e- = PbSO_4$

Cathode: $PbO_2 + 4H + + SO_42- + 2\ e- = PbSO_4 + 2\ H_2O$

Lead-acid battery research is currently focused on power system applications and the power peaking, improve system stability and improve power quality.

As the main energy storage devices distributed generation system, the state of charge of the battery SOC and terminal voltage prediction is an important part of the whole generation of distributed generation planning and economic equilibrium problems. Therefore, it has a very important significance to the establishment an appropriate model to predict these external battery characteristics for power system operation and planning. When the lithium-ion battery charge and discharge its internal process of change is a very complex electrochemical process, there was a clear non-linear and time-varying characteristics, using a simple mathematical model is difficult to accurately reflect its complex nonlinear process. Distributed generation systems in complex dynamic state of energy supply and demand conditions, in order to achieve a balance, we must predict the battery state of charge, power, resistance, etc., it needs to establish the appropriate model.

The modeling process is mainly from the battery characteristics, in close connected battery status, described the behavior of the battery, depending on the load requirements change, by controlling the relevant parameters, to achieve effective management purposes.

Dynamic modelings of several major existing methods are followed as: electrochemical models, neural networks, equivalent circuit model. The equivalent circuit model can be divided into linear and nonlinear equivalent circuit model equivalent circuit model, it is one of the most commonly used in engineering analysis. Common equivalent circuit model include: resistance equivalent model, simplified equivalent model, PNGV model, Peukert, Shepherd model.

Battery internal resistance is the most widely used model of the application, features of this model is equivalent to the battery as an ideal voltage source in series with a resistance physical model with R0 of UOC to simulate battery, R0 is resistance ohmic resistance and polarization resistance sum. Formula derived by the physical model by fitting the experimental data to do the calculation equation coefficients [7, 8]. Polarization within the battery, even ignoring the temperature aging effects and other factors, it is difficult to use UI features lumped circuit characterization [9]. Lithium iron phosphate can be simplified equivalent circuit representation [10]. Fig. 3 is an equivalent circuit model of resistance, i.e., a near-ideal voltage source in series with a resistance. Since the charge-discharge process, the battery internal resistance and the temperature of the electromotive force and the battery state of charge by (SoC) of a great impact, therefore the internal resistance and open circuit voltage as a function of the temperature and SOC.

The circuit configuration is shown as Fig. 3.

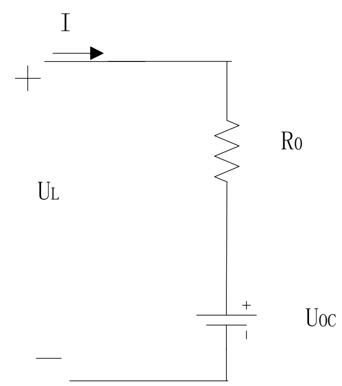

Fig. 3. Resistance equivalent circuit model.

$$UL = U_{OC}-R_{OI}$$
$$P = U_{LI}$$

Through the above two equations, the parameters can be solved.

Calculation model is divided into thermal calculations, voltage and SOC calculation, three main parts are followed as.

l) the thermal calculations: the thermal calculations of the battery module of the temperature control system to simulate and calculate the battery temperature.

2) Voltage calculation: calculation module is responsible for calculating the voltage of the battery terminal voltage and internal resistance.

3) SoC computing: Most models using Ampere time integration method. SOC defined as the percentage of remaining capacity and total capacity.

4. Lithium Battery Energy Storage Characteristics

4.1. PNGV Lithium Modeling

Standard Test Specification (battery Manual Version 3.0) available lithium batteries RC model parameters: (Partnership for a New Generation of Vehicles PNGV) [11], according to a new generation of vehicles Partner Program. So far, the model used to describe the world photovoltaic system or wind power system battery behavior is still the most popular model in 1965 by the CM to push Sheffield (Shepherd) proposed [12], it is the battery terminal voltage estimation equation. PNGV model is the 2001 "PNGV Battery Test Manual" standard battery model, it follows for the 2003 "Freedom CAR Battery Test Manual" standard battery model. Shown in Fig. 5, compared with Thevenin model of its salient, features are described with capacitance C0 cells absorb and release electricity, in order to reflect the characteristics of the open circuit voltage variation with time of the cumulative load current is generated, and this reflects the size of the capacitor battery the capacity size.

Wherein, U_L and I_L, respectively, and the battery terminal voltage when the battery current, Uoc the open circuit voltage of the battery; battery is used to describe the resistance ohmic resistance R0. Because of the physical and chemical processes of the lithium-ion battery is quite complex, quite difficult to describe clearly. In the RC circuit model used to describe aspects of lithium-ion battery activities are hindered or exhibit impedance. The RC time constant is smaller impedance to describe aspects of the electrode material and the lithium ions between the electrodes when the transfer is by diffusion impedance, C0 is used to describe the capacity of the battery.

$$U_L = U_{OC} - C_0 \int I_L dt - R_0 I_L - R_P I_P, \quad (8)$$

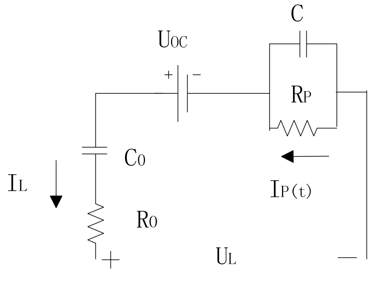

Fig. 4. PNGV model.

4.2. Peukert

Peukert empirical formula (also known as battery capacity decay equation) is an estimate of the capacity of the empirical formula:

$$I^n \times t = K, \quad (9)$$

$$n = \frac{\lg t_2 - \lg t_1}{\lg I_1 - \lg I_2}, \quad (10)$$

$$C = I \times t = K \times I^{1-n}, \quad (11)$$

where I is the discharge current; t is the charge and discharge currents corresponding to the charge and discharge time; I_1, I_2 are the different charge and discharge current, t_1, t_2 are the values corresponding to the charge and discharge as of the time of charge and discharge; n and K are the parameter for the specific cell by the obtained experimental data. When the calculated values of n and K, you can get the maximum capacity of the battery current I C under an arbitrary.

Due to slight differences in the value of n in the case of different current, in order to improve the accuracy of the model, the discharge current is usually divided into large, medium and small three regions, respectively, in the regions with different n and K values.

5. Conclusion

Distributed power supply system in the course of their systems required to maintain the dynamic balance of power, energy storage systems as constituting an important part of the system, serve to enhance system stability and improve power quality in an important role. This paper summarizes the current situation and the important role of super capacitor energy storage technology and battery energy storage system in the whole distributed generation systems, focusing on the analysis of the super-capacitor equivalent circuit model, RC model, Helmholtz double-layer structure model and the battery internal resistance, etc. efficiency model, PNGV lithium models and empirical formulas Peukert model. In the storage system, the use of super capacitor overcome the lack of electrical power transmission, the use of lithium batteries to store energy to overcome the limitations, hybrid power lithium batteries and super capacitors composed solve a wide range of power and energy needs, integrated hybrid power as both energy system, as people search for new energy solutions and effective solutions for sustainable development.

With the rapid development of distributed power energy storage technology on the nature of the people will have a better understanding of the invention will be more in the form of continuous development and progress of energy storage technologies, technology, energy storage technology will further promote the existing advantages of play, thus be more widely used in distributed power system.

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