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Review article

Optimal scheduling of isolated microgrid with battery switching station for electric vehicles

Abstract

Since entering the 21st century, China has been developing rapidly, and electric vehicles have gradually entered the public eye as an alternative to gasoline vehicles. At present, the issue of battery swapping in electric vehicles is becoming the main factor restricting their development, and the rational development and research of new energy has become the top priority. Microgrid has become a reasonable product that meets the requirements. However, microgrid systems are not perfect. Today's battery swapping stations have integrated charging and discharging storage functions, which interact with microgrids to form energy exchange. However, microgrid systems today face issues such as tight energy supply and demand relationships and unstable loads. How to coordinate the good interaction between the two operating entities of microgrid and electric vehicle swapping station, ensure their respective interests, and ultimately achieve the goal of energy conservation and emission reduction, which is beneficial to society development has strong practical significance.

This article conducts research on the economic dispatch strategies of electric vehicle battery swapping stations and isolated microgrids. Establish an economic dispatch model based on the dual layer optimization theory, treating the converter station and isolated microgrid as two independent entities; integrating the two into a system based on multi-objective optimization theory to study the economic benefits of isolated microgrids.

Keywords: microgrid, battery replacement station, coordination and optimization

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Introduction

At present, both domestically and internationally, research on issues related to electric vehicle charging, refueling, battery swapping stations, and combined optimization operation has been carried out, and significant achievements have been made.

With the increasing number of electric vehicles and the uncertainty of new energy generation, traditional microgrid scheduling strategies are no longer fully applicable to this situation. Therefore, relevant scholars have shifted their research focus to microgrid systems containing electric vehicle access. The School of Chemical Engineering at Tianjin University conducted a detailed analysis of the development status, advantages, and disadvantages of electric vehicle battery swapping technology as the research object. Security and compatibility.

Key points of work, etc., and propose ideas and suggestions for future development.[1] On the basis of existing research, Chengdu University of Information Science and Technology focused on studying and analyzing the scenario where time-sharing rental loan users need to charge at public charging stations when they encounter errands or traffic jams during their driving process. The evaluation was conducted by establishing a model.[2–11]

Zhimin Wang analyzed the current development status and trend of electric vehicles in China from several aspects, including the production and sales status of electric vehicles, infrastructure scale, policy support, and facility planning overview. Anhui University of Technology has proposed an integrated intelligent device for automatic battery replacement, which has the advantages of cost reduction, wider range of use, and higher space utilization compared to existing technologies.

In terms of foreign affairs. Sanchari Deb et al. proposed a novel improvement method by using function convolution to plan with the objective function as the cost. And it was tested on a testing network with 25 node paths.[12] Priyanka Ray et al. proposed a charging station design aimed at maximizing profits. For the first time, the hybrid crow search algorithm and particle swarm optimization algorithm were used to optimize the installation and operation costs of the charging station, and performance indicators were estimated based on this algorithm.[13] Vishu Gupta et al. proposed an operational strategy for PV assisted charging stations in their study, allowing electric vehicles to use solar energy for charging.[14–16]

The microgrid is a small power generation and distribution system that organically combines distributed power generation devices such as renewable energy, micro gas turbines, fuel cells, loads, and energy storage devices. It can operate in parallel with the external power grid or independently in the event of external power grid failures or needs.

Methods

Explanation

Solar and wind energy, as representatives of clean energy, are preferred in microgrid systems when there is a demand for electricity load.

First use clean energy to generate electricity output. When the output of wind and solar power generation cannot balance the power supply demand during peak load periods, diesel generators (DE) can be started to operate. Due to the intermittent capture of light and wind energy and the instability of load demand, batteries are considered as energy storage systems to absorb excess electricity and balance load fluctuations. During peak electricity consumption periods, when the output of distributed power sources within the microgrid system is insufficient to support the huge load demand, the energy storage system can timely feed power to the microgrid, alleviate load pressure, improve the stability of the microgrid system, and enhance users' electricity experience and satisfaction.

Grid connected operation: When the PCC switch is in the closed state, it can achieve interconnection between the microgrid and the main grid.

When the overall load shows an upward trend, the main grid and distributed power sources allocate output to jointly share the load pressure and achieve energy exchange in this operating mode. When the internal load of the microgrid is high and relying solely on the output of distributed power sources is insufficient to maintain the overall electricity demand of users, if there is excess electricity inside the main grid, the microgrid can purchase electricity from the main grid to alleviate the load pressure, and the main grid can also obtain certain economic benefits; When the internal load demand of the microgrid is too low and there is excess electricity after balancing the load power with renewable energy output, according to the electricity price policy formulated by the main grid, it is possible to consider selling electricity to the main grid during periods of high electricity prices, in order to expand the spatial share of the electricity market while ensuring maximum benefits. In the grid connected operation mode, the microgrid and the main grid cooperate with each other and support each other during the overall operation process. The overall power supply reliability of the system is strengthened, and the operating efficiency of the system is also improved, alleviating the tense situation of load supply and demand, and improving users' evaluation of electricity satisfaction.

Island operation: Island operation refers to the state where PCC is in a disconnected state and the microgrid is disconnected from the main grid. At this time, the microgrid is a small power generation system that is isolated from the outside world for energy exchange. The microgrid operates in an isolated state, and the internal power generation of the system is always balanced with the load power. The energy management system (EMS) within the microgrid is responsible for analyzing system data, coordinating scheduling, and achieving centralized management, thereby optimizing and adjusting the output of each power source in real time. Microgrids typically operating in islanding mode are unable to meet users' electricity demands during peak load periods, resulting in frequent power outages of varying degrees. Therefore, microgrids will prioritize internal loads according to their importance to local economic development. The overall load priority will be in the order of first level load, second level load, and third level load from high to low. When the generated electricity is insufficient to meet the user demand during this period, microgrids will cut off the electricity supply to third level loads and redirect excess electricity to the utilization of higher-level loads, with the aim of minimizing losses caused by power outages.

The model

There are three main types of distributed power generation models, namely wind power model, photovoltaic power generation model, and diesel generator model.

A photovoltaic power generation model is a physical model used to demonstrate and simulate the process of photovoltaic power generation, typically used in teaching, research, and exhibitions. This model can help people understand the basic principles and working methods of solar photovoltaic power generation.The principle of photovoltaic power generation model is the photoelectric effect and semiconductor physics. Photovoltaic cells convert light energy into electrical energy through the photoelectric effect. When light shines on semiconductor materials, photon energy excites electrons, forming electron hole pairs. These electrons separate under the electric field formed by the P-N junction and flow towards the external circuit, generating direct current. In addition, photovoltaic power generation models can be divided into solar photovoltaic power generation models and solar thermal power generation models; this photovoltaic power generation model directly converts light energy into electrical energy without involving thermal processes. The solar thermal power generation model first converts solar radiation energy into thermal energy, and then converts thermal energy into electrical energy. There are mainly tower systems, trough systems, disc systems, solar pools, and solar tower thermal airflow power generation methods.

In practical applications, microgrids have many influencing factors on photovoltaic power generation. To simplify analysis, external environmental temperature and light intensity are usually used as limiting factors for photovoltaic output. The output model of photovoltaic generators is represented by the following equation.

$$P_{PV}(G_C,T_C)=P_{STC}\frac{G_C}{G_{STC}}[1+k(T_C-T_{STC})] \qquad (1)$$

The meanings of each in the above formula are as follows. (Table 1)

Table 1 Explanation of formula (1)

Categories	Explanations for each category
PV	Output power of photovoltaic generator under specific conditions
GS_{TC}	Standard pyranometer
GC	At a certain moment, the radiation intensity
PS_{TC}	Maximum power of photovoltaic power generation under standard conditions
k	Temperature regulation factor
TC	At a certain moment, the actual temperature of the photovoltaic cell
TS_{TC}	Reference temperature under standard conditions

As one of the modules that maintain stable supply of internal load demand in microgrids, diesel generator sets have the characteristics of high sensitivity and fast response speed. However, compared to the use of clean energy for wind and solar power generation, diesel generators have lower power generation efficiency and can cause environmental pollution. When the output of prioritizing clean energy generation cannot meet the load demand of users, diesel generators can be used to maintain the stability of the internal environment of the microgrid. The fuel characteristics of diesel generators are as follows:

$$D_{DE}=M_1P_D+M_2P_{de} \qquad (2)$$

The meanings of each in the above formula are as follows. (Table 1.1)

Table 1.1 Explanation of formula (2)

Categories	Explanations for each category
D_E	Fuel quantity of diesel engine
M_1	Coefficient1
M_2	Coefficient2
P_D	Rated power output
P_{de}	Actual output power of diesel engine

For the energy storage system model, a typical microgrid is a stable system that integrates power loads, distributed power sources, and energy storage systems.

For the energy scheduling within the entire microgrid system, the energy storage system is responsible for controlling the entire optimization process to improve the quality of electrical energy, ensure the quality of power supply, and enhance the reliability of system operation. The energy storage system stores excess electrical energy within the microgrid through internal batteries. When the distributed power sources in the microgrid system have insufficient output to provide power support, the energy storage system can use the stored excess electrical energy to release the system, alleviate system load pressure, and improve system operation coordination.

The charge state model during charging and discharging is as follows. (Table 1.2)

Table 1.2 Explanation of formula (3)and(4)

Categories	Explanations for each category
P_{ch}	charging power
p_{dc}	Discharge power
n_{ch}	Charge efficiency
n_{dc}	discharge efficiency
W	Rated capacity of battery

$$SOC(t) = SOC(t-1) + \eta_{ch} \frac{P_{ch}(t-1)\Delta t}{W} \tag{3}$$

$$SOC(t) = SOC(t-1) - \frac{P_{dc}(t-1)\Delta t}{\eta_{dc} W} \tag{4}$$

Double layer optimization theory

Due to the fact that isolated microgrid systems are composed of wind turbines, photovoltaic units, diesel units, and power exchange stations, and the capture of wind and solar energy is discontinuous throughout the day, it directly leads to uncertainty in wind and solar power output and uneven output of electrical energy. Diesel generators are controllable power generation units that can be reasonably arranged according to the output of wind and solar power within the microgrid system. Therefore, isolated microgrids and battery swapping stations can be treated as two different economic entities operating within their respective business scopes. The economic dispatch between the two needs to use the electricity price set by the microgrid as an interactive condition to guide the output of the lower level battery swapping station. After the upper level isolated microgrid receives the output plan, it optimizes the output of the diesel engine and adjusts the electricity price. Therefore, we make the following assumptions.

We use the double-layer optimization theory here. The essence of the double-layer optimization problem is that it is a system optimization problem with second-order progressive properties, and multi-layer programming is also derived from it. Double layer programming is actually composed of upper and lower layer models, each layer containing corresponding objective functions and constraint conditions, and forming a mutually progressive whole. The decision variables of the upper level model can affect the constraints and final decision objectives, and the optimization results of the lower level model can also affect the strategy of the upper level model, and vice versa. The upper level can to some extent determine the optimization trend of the lower level, providing guidance without interference, while the lower level will determine its own decisions based on the guidance of the upper level, thus achieving the goal of mutual restraint between the two levels.

As the research object of the upper level optimization model, isolated microgrids collect the output of diesel generators dominated by the lower level model during each scheduling period, and formulate reasonable real-time electricity prices based on unbalanced power. This model optimizes with the goal of minimizing the net cost of an isolated microgrid throughout the day, using the output limit range of each distributed power source as a constraint. It schedules various distributed power sources in the system to help the isolated microgrid reduce energy consumption, avoid cost losses reasonably, and maintain its daily cost at a low level. It achieves the coordinated scheduling function of isolated microgrids for lower level battery swapping stations.

Wind turbine (WT) power generation cost

$$C_{WT_0} = \sum_{t=1}^{T} k_{WT_0} P_{WT}(t) \tag{5}$$

$$C_{WT_m} = \sum_{t=1}^{T} k_{WT_0} P_{WT}(t) \tag{6}$$

$$C_{WT} = C_{WT_0} + C_{WT_m} \tag{7}$$

By imitating the cost of wind turbine power generation, we can also obtain the cost of photovoltaic power generation and diesel engine power generation.

Power balance constraint

$$P_{WT} + P_{PV} + P_{DE} + P = P_L + P_{WT}^{D} + P_{PV}^{D} - P_C \tag{8}$$

Power constraint of diesel generator

$$P_{DE}^{\min} << P_{DE} << P_{DE}^{\max} \tag{9}$$

Summary and outlook

With the increasing maturity of distributed generation technology, microgrid systems rely mainly on clean energy as their energy input, satisfying user load supply and optimizing the scheduling of distributed energy within the system are important guarantees for stable system operation. This article takes isolated microgrids as the research object, starting from the internal distributed power structure and mathematical model of the system, and adding an electric vehicle battery swapping station model to participate in the interaction of isolated microgrids. Research on the Economic Dispatch Problem of Isolated Microgrids and Converter Stations in Two States: Independent and Systematic.[17–19]

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Conflicts of interest

The author declares that there is no conflict of interest.

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