# Economic dispatch of microgrid with the access of electric vehicles

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**Abstract.** In the economic dispatch model of microgrid, the battery of an accessed electric vehicle is treated as a kind of mobile distributed energy storage device. The power units in the microgrid system include photovoltaic array, wind turbine, diesel engine, micro turbine and electric vehicle. First, the generation characteristics and cost functions of each micro power generators are analyzed. Then, a power economic dispatch model considering the access of electric vehicles is proposed. The objection function of the model is to minimize the operating costs, including the depreciation costs of the batteries of electric vehicle. Finally, particle swarm optimization (PSO) algorithm is used to solve the optimization model. The results show that the proposed model can reduce the operating costs and promote the optimal operation of microgrid.

**Keywords:** microgrid; economic dispatch; electric vehicles; time-of-use price; particle swarm optimization

## 1. INTRODUCTION

The economic dispatch of microgrid refers to the reasonable arrangement of different distribution generations (DGs) output and the transmission power between microgrid and the main power grid, thus achieving the lowest total cost while meeting kinds of constraints and load demand of system. The battery of electric vehicle (EV) is a kind of mobile distributed energy storage device, so it can be treated as a part of the economic dispatch of microgrid based on the vehicle-to-grid（V2G） mode (Kempton and Tomić, 2005). EV can improve the stability of grid through peak load shifting, and the reasonable arrangement of the charging and discharging of EV can reduce the electricity cost for users. In addition, EV can also provide a reliable backup power for the user to reduce the loss caused by power outages.

Currently, there have been some research efforts that focused on the economic dispatch of microgrid with EVs. Li et al. (2009) pointed out that the grid will be affected by large-scale charging of EVs, and the use of new energy dispersive charge is a potential solution to this problem. Liu et al. (2010) proposed a new DC micro-grid system, which fully utilized the renewable energy and EV for smart energy delivery. Mao et al. (2011) proposed an energy dispatching model and strategies for microgrid with wind generators (WT), photovoltaic (PV) system, battery storage and EVs. The simulation results showed that the incorporation of EVs in microgrid can not only reduce the capital cost of storages and operation cost of the microgrid, but also save the cost of EVs' owners. Zhuang et al. (2014) established the load models of EVs under the uncoordinated charging mode and the orderly charging-discharging mode. Their simulation results showed microgrid system with EVs under the orderly charging and discharging mode has better economics than the disorderly charging mode.

However, most of the existing studies have not considered the depreciation cost of the batteries of EV, and the constraint conditions of EVs are not complete. To fill this gap and construct a more reasonable model, this study focuses the economic dispatch problem of microgrid with PV, WT, diesel engine (DE), micro turbine (MT) and EV under the time-of-use (TOU) price mechanism. The objection function of the optimization is to minimize operating cost, including the depreciation cost of the batteries of EV, and the constraints of EVs are also considered. Then the simulation experiment is carried out to optimize the distribution of the 24 hours load of microgrid using particle swarm optimization (PSO) algorithm. The experimental results show the correctness and effectiveness of this model.

## 2. OPTIMAL LOAD DISTRIBUTION MODEL OF MICROGRID

### 2.1 Generation Characteristics of Distribution Generations

(1) The model of PV

The output power model of the PV (Gavanidous and Bakirtzis, 1992) can be described as follows:

$$P_{PV} = P_{STC}\frac{G_{ING}}{G_{STC}}\left[1+k\left(T_c - T_r\right)\right] \tag{1}$$

where $P_{PV}$ is the actual output power of PV, $G_{ING}$ is the actual light intensity received by PV. $G_{STC}$ is the light intensity received by PV under standard test condition (STC), $P_{STC}$ is maximum output power of PV under STC, $k$ is power generation temperature coefficient of PV, $T_c$ is the actual temperature of PV cells, $T_r$ is the rated temperature of PV cells.

(2) The model of WT

The output power model of the WT (Chedid et al., 1998) can be described as follows:

$$P_{WT} = \begin{cases} 0 & V < V_{ci} \\ a\times V^3 - b\times P_r & V_{ci} < V < V_r \\ P_r & V_r < V < V_{co} \\ 0 & V > V_{co} \end{cases} \tag{2}$$

where $P_{WT}$ is the actual output power of the WT, $a$ and $b$ are the coefficient of $P_{WT}$, $a = \frac{P_r}{V_r^3 - V_{ci}^3}$, $b = \frac{V_{ci}^3}{V_r^3 - V_{ci}^3}$, $V_{ci}$, $V_r$ and $V_{co}$ are cut-in, rated and cut-out wind speeds respectively, $P_r$ is rated output power of WT.

(3) The model of DE

The fuel cost of DE can be described as follows:

$$C_{DG} = \sum\left(\alpha + \beta P_{DG}(t) + \gamma P_{DG}^2(t)\right)\Delta t \tag{3}$$

where $C_{DG}$ is fuel cost of DE, $\alpha$, $\beta$, $\gamma$ are the coefficient of DE, $P_{DG}$ is the output power of the DE, $\Delta t$ is the length of each time period.

(4) The model of MT

The efficiency of MT can be described as follows:

$$\eta_{MT} = x\left(\frac{P_{MT}}{P_R}\right)^3 + y\left(\frac{P_{MT}}{P_R}\right)^2 + z\left(\frac{P_{MT}}{P_R}\right) + c \tag{4}$$

where is the efficiency of MT, $x$, $y$, $z$ and $c$ are the coefficient of MT, $P_R$ and $P_{MT}$ are rated and output power respectively.

The fuel cost of MT can be described as follows (Wu et al. 2014):

$$C_{MT} = \frac{C_{GAS}}{LHV}\sum\frac{P_{MT}(t)\Delta t}{\eta_{MT}(t)} \tag{5}$$

where $C_{MT}$ is fuel cost of MT, $C_{GAS}$ is the price of natural gas supplied to the MT, $LHV$ is the low calorific value of natural gas, $P_{MT}(t)$ and $\eta_{MT}(t)$ are the output power and efficiency of MT at the moment $t$ respectively.

### 2.2 Objective Function

The objective of optimization is to minimize the total costs, which include the fuel cost, operational and maintenance cost, cost of the interaction between microgrid and the main power grid, and depreciation cost of the batteries of EV, that is:

$$minC = \sum_{i=1}^{N}\sum_{t=1}^{T}\left[F_i\left(P_i(t)\right) + OM_i\left(P_i(t)\right)\right] + C_{GRID} + C_{BAT} \tag{6}$$

where $C$ is operating cost of the microgrid, $i$ is the number of DGs, $N$ is the total number of the DGs in the microgrid, $T$ is the total number of periods in scheduling cycle, $t$ is the number of period. $P_i$ represents the actual power output of $i$th DG, $F_i(P_i)$ denotes the fuel cost of the $i$th DG, $OM_i(P_i)$ denotes the operation and maintenance cost of the $i$th DG, $C_{GRID}$ is the cost of the interaction between microgrid and the main power grid, $C_{BAT}$ is depreciation cost of the batteries of EV.

The operation maintenance cost of DGs (Mohamed & Koivo, 2007) can be described as follows:

$$OM_i\left(P_i(t)\right) = K_{OM_i}P_i(t) \tag{7}$$

where $K_{OM_i}$ is coefficient of the operation and maintenance of the $i$th DG.

The cost of the interaction between microgrid and the main power grid can be described as follows:

$$C_{GRID} = \sum_{t=1}^{T}\left|P_{GRID}(t)\right|S_t \tag{8}$$

where $P_{GRID}$ is the transmission power between microgrid and the grid, $S_t$ is the electricity price at period $t$. If it is positive, it indicates that microgrid is purchasing power, while if it is negative, it means the microgrid is selling power.

With the increase of charging capacity of each time, the number of cycles of battery charge will be decreased, so it difficult to calculate the number of cycles. In order to facilitate the calculation, we assume that the total charge-discharge capacity of battery in its life cycle remain unchanged, so the depreciation cost of the batteries of EV can be described as follows:

$$C_{BAT} = \sum_{j=1}^{n}\left(\frac{C_{REP}}{E_{PUT}}\int_{t_{j1}}^{t_{j2}}\left|P_j^{EV}(t)\right|dt\right) \tag{9}$$

where $n$ is the total number of EVs, $C_{REP}$ is replacement cost of the battery of EV, $E_{PUT}$ is the total charge-discharge capacity of battery in its life cycle. $t_{j1}$ and $t_{j2}$ represent the starting and ending time of the $j$th EV access to the microgrid, $P_j^{EV}(t)$ represents the status of charging (positive value indicates discharging, negative value indicates charging).

## 2.3 Constraints of the System

(1) Power supply and demand balance constraints

$$\sum_{i=1}^{N} P_i + P_{GRID} + P_{EV} = P_{LOAD} \tag{10}$$

where $P_i$ is the actual output of $i$th DG, $P_{GRID}$ is the transmission power between microgrid and the main power grid, $P_{EV}$ is net output power of EVs, $P_{LOAD}$ is total load demand.

(2) Generation capacity constraints

$$P_i^{\min} \le P_i \le P_i^{\max} \tag{11}$$

where $P_i^{\max}$, $P_i^{\min}$ are the upper and lower power out limits of $i$th DG, respectively.

(3) Ramp rate limits of DGs

$$\left|P_i(t) - P_i(t-1)\right| \le r_i \tag{12}$$

where $P_i(t)$ is the output of $i$th DG in period $t$, $P_i(t-1)$ is the output of $i$th DG in period $t-1$, $r_i$ is the upper limit of ramp rate of $i$th DG.

(4) Capacity constraint of EV batteries

$$SOC_j^{\min} \le SOC_j \le SOC_j^{\max} \tag{13}$$

The state of charge (SOC) of the battery refers to the ratio of the residual energy to the rated energy. In the formula (13), $SOC_j$ is the SOC of battery of $j$th EV, $SOC_j^{\min}$ and $SOC_j^{\max}$ are the lower and upper limits of SOC of $j$th EV, respectively.

(5) Charge-discharge constraints of EV batteries

$$P_j^{\min} \le P_j \le P_j^{\max} \tag{14}$$

where $P_j$ is power of charged or discharged of $j$th EV, $P_j^{\max}$ is upper limits of discharge, which is positive value. $P_j^{\min}$ is upper limits of charge, which is negative value.

(6) Capacity constraint of EVs when leaving the microgrid

$$SOC_{t_{j2}} \ge SOC_{t_{j2}}^{\min} \tag{15}$$

where $SOC_{t_{j2}}$ is SOC of battery of $j$th EV when leaving the microgrid, $SOC_{t_{j2}}^{\min}$ is the lower limit of SOC for normal running.

(7) Constraints of the line transmission capacity between the microgrid and the main power grid

$$-P_L^{\max} \le P_{GRID}(t) \le P_L^{\max} \tag{16}$$

where $P_{GRID}$ is the transmission power between the microgrid and the main power grid, $P_L^{\max}$ is the upper limit of the transmission power

# 3. SIMULATION EXAMPLE

## 3.1 Example Setup

The TOU electricity price is shown in Table 1. The basic parameters of the EV are shown in table 2. The output power curve of PV, WT and the load curve of microgrid are shown in Figure 1

Table 1: TOU

| Type | Period | Purchase price | Sale price |
|---|---|---|---|
| Peak | 08:00-13:00<br>17:00-22:00 | 1.07 | 0.66 |
| Flat | 06:00-08:00<br>13:00-17:00<br>22:00-24:00 | 0.68 | 0.40 |
| Valley | 00:00-06:00 | 0.42 | 0.28 |

Table 2: Parameters of EV

| Type | Numerical value |
|---|---|
| Battery capacity/kWh | 50 |
| SOC lower/upper limits/% | 10/100 |
| Charging power limit/kW | 5 |
| Discharging power limit/kW | 5 |
| Replacement cost of battery | 3000 |

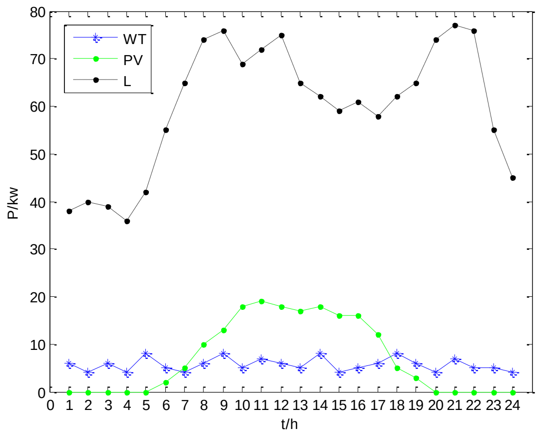


Figure 1: Output power curve of PV, WT and the load curve of microgrid

### 3.2 Simulation Results

(1) Scheduling strategy 1: Economic dispatch of microgrid with the access of EVs.

Particle swarm optimization (PSO) algorithm is used to solve the optimization model in this paper. In the simulation example, PV and WT adopt Maximum Power Point Tracking (MTTP) mode (Esram & Chapman, 2007) to output power. It is assumed that there are 3 EVs access to the microgrid, and the parameters of the vehicle are shown in Table 2. The SOC of EV when access to the microgrid is set to 0.6, the minimum SOC of EV when leave microgrid is set to 0.7 in order to meet the need of driving. The time period for EV1 to leave the microgrid is 08:00-13:00, and the time period for EV2 and EV3 to leave the microgrid is 08:00-19:00. Dispatch results are shown in Figure 2 and Figure 3.

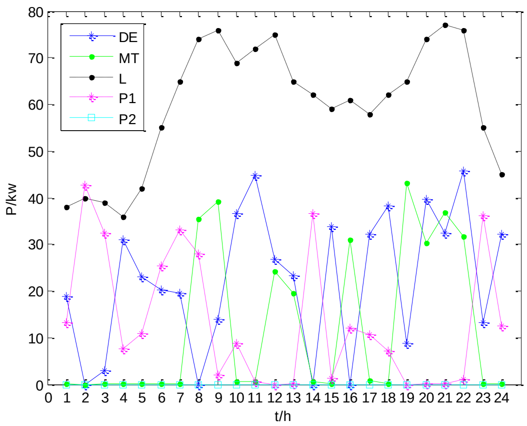


Figure 2: Dispatch results of DGs

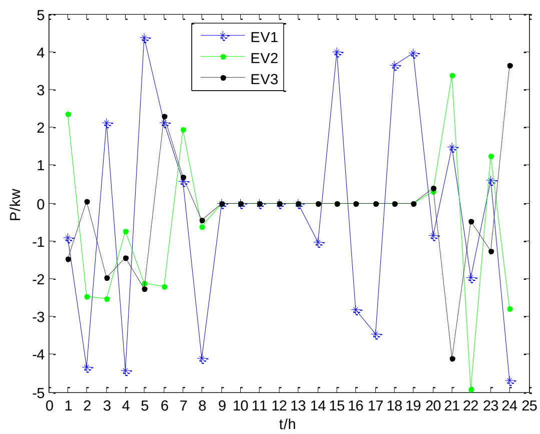


Figure 3: Dispatch results of EVs

In Figure 2, P1 is the purchase power from the main power grid, P2 is the selling power to the main power grid. It can be seen from Figure 2 that almost no sale of electricity to the main power grid. The reason is that the total generating capacity of PV and WT cannot meet the load demand in every periods in scheduling cycle, system can only purchase power from the main power grid or output power by DE and MT. And we can see that the purchase power is small at 9-13h and 18-22h, because the price of electricity in peak period at that time, and system output power by DE and MT in order to reduce the cost.

The dispatch results of charging and discharging of EVs are shown in Figure 3 (positive value indicates discharging, negative value indicates charging). And we can see that the power of charging and discharging of EV is zero value when EV have not accessed to microgrid.

(2) Scheduling strategy 2: Economic dispatch of microgrid without the access of EVs.

We compare this method with the economic dispatch of microgrid without the access of EVs. PSO is also applied to solve the optimization model, dispatch results are shown in Figure 4.

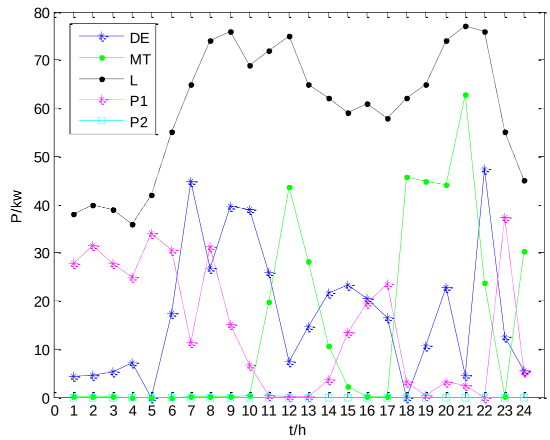


Figure 4: Dispatch results of microgrid without the access of EVs

The total cost of strategy 1 and strategy 2 are 897.82 and 893.93, respectively. In order to compare these two strategies, the total cost of strategy 2 is added to the charging cost and the depreciation cost of the batteries of EV. The power of charging of EV1, EV2 and EV3 in strategy 1 are 5.78kWh, 9.18kWh and 6.48kWh, respectively. We calculate the depreciation cost is 0.64. According to the electricity price of EVs begin to access to microgrid, we calculate the cost of charging is 20.69. So the total cost of strategy 2 is 915.26. The cost of scheduling 1 is reduced by 1.9% compared to the cost of scheduling 2. Therefore, the results show the effectiveness of the scheduling strategy 1.

## 4. CONCLUDING REMARK

In this paper, the battery of EV is treated as a kind of mobile distributed energy storage device to access the microgrid. We proposed an economic dispatch model for microgrid with PV, WT, DE, MT and EV under the TOU price mechanism. The proposed method can achieve the economic management of the batteries of EV, reduce the operating costs and promote the optimal operation of microgrid. The proposed power economic dispatch model is based on the objective function of the minimum operating costs, but the optimal dispatching problem of microgrid has other objectives and constraints, such as environmental cost, safety and time efficiency, so the objective function and constraints of this paper is not perfect. Therefore, the optimal dispatching problem of microgrid needs to be further studied.

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