Intelligent Energy Scheduling with Considering Battery Storage System Using Particle Swarm Optimization

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Abstract

Prosumer which not only consumes energy but also generates renewable energy has played an important role in the smart city. However, numerous non-renewable energies are still used due to the mismatch problem of the energy load and generation. Therefore, this paper studies the energy scheduling problem that focuses on the minimization problem of the non-renewable energy usage through considering the battery storage system (BSS) including charge and discharge. Firstly, we formulate an optimization problem for minimizing the non-renewable energy usage in the smart city. Secondly, to solve the problem, a particle swarm optimization (PSO) based approach is proposed, in which PSO is utilized to scheduling the amount of energy in charging and discharging of battery. Finally, the evaluation result shows the proposed method can significantly improve the overall usage of non-renewable energy in the smart city.

1. Introduction

In the modern development of urban technology, prosumer has become an essential part of smart cities for renewable energy generation to achieve the minimum usage of non-renewable energy. However, due to the generation of renewable energy is random over time, and the consumption of smart city users is uncertain [1], the demand requirement of each prosumer cannot be fulfilled. Therefore, it is important to schedule energy to solve such a problem.

In recent years, energy scheduling has received huge interest in different researches. For instance, a method based on meta-reinforcement learning was proposed in [1] to schedule the renewable energy generation, demand, and non-renewable energy. In [2], the distributed algorithms were proposed to make decisions for energy scheduling to get the optimal usage of renewable energy. Different from previous studies, energy scheduling with considering battery storage system (BSS) is proposed in this paper to reduce the usage of non-renewable energy such that to improve the balance of energy demand and generation.

The main contributions are summarized as follows:

- We formulate energy scheduling problem to minimize the non-renewable energy usage of entire smart city forms by solar energy generated prosumer. Where we schedule the battery charge and discharge such that to reduce the unbalance of generation and demand. However, it is a big challenge to know the optimal charge and discharge.
- To address such a challenge, we propose a method based on particle swarm optimization (PSO) to obtain the optimal battery charge and discharge for minimizing non-renewable energy usage.
- Finally, the evaluation result for the proposed PSO based scheduling shows that the total energy generation can fulfill the total demand through scheduling battery charge and discharge.

The rest of this paper is organized as follows. The system model and the formulation is shown in Section 2. Section 3 illustrates the detailed solution. Section 4 provides the evaluation result. Finally, Section 5 gives the conclusion.

2. System Model and Formulation

This section discusses the system model and the formulation for the smart city composed of prosumers with considering the battery storage system.

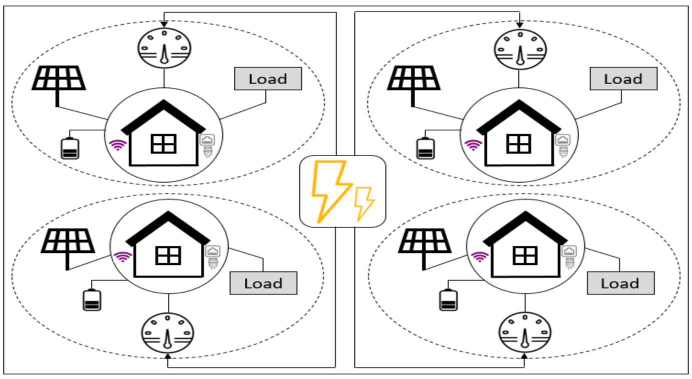

Fig. 1. System Model for Smart City

Fig.1 shows the system model for a smart city that includes the power supplier, multiple households $H =$

$\{1,2,\ldots,H\}$ with related connections. In this model, smart meter is used to record the energy consumption and communicate with home energy management system (HMS) and the power supplier. A set of the load $L=\{1,2,\ldots,L\}$ per household is assumed to connect to HMS by wired connections or wireless connections, for example, power line communication or Zigbee [3]. A finite time interval $T=\{1,2,\ldots,T\}$ that per time slot t consists of one-hour duration is considered[1].

For frequently used battery, its self-discharge can be ignored per month without any big errors [4]. Hence, only charge and discharge are considered in this work. A binary decision variable X is defined as (1) to indicate these two processes.

$$\mathrm{X}=\begin{cases}1, & if\ charge\\ 0, & if\ discharge,\end{cases} \tag{1}$$

where $X=1$, if charge occurs, and 0, otherwise.

The energy of next time slot saved in battery $P_{h,b}^{s}$ can be defined as follows [5],

$$P_{h,b}^{s,t+1}=\begin{cases}X\left(P_{h,b}^{s,t}+\lambda_{inv}\lambda_c P_{h,b}^{c,t}\right), & if\ \ X=1\\ (1-X)\left(P_{h,b}^{s,t}-\dfrac{P_{h,b}^{d,t}}{\lambda_{inv}\lambda_d}\right), & otherwise,\end{cases} \tag{2}$$

where λ_{inv}, λ_c, λ_d indicate the efficiency of the inverter, battery charge and discharge, respectively, while $P_{h,b}^{s,t}$ is the energy saved in the battery, $P_{h,b}^{c,t}$ is the charge, $P_{h,b}^{d,t}$ is the discharge at time slot t.

For each household h, the energy consumption of total load can be represented as (3), while the energy that can be used is showed as (4).

$$P_h^{l,t}=P_h^{d,t}+P_{h,b}^{c,t}. \tag{3}$$

$$P_h^{u,t}=\lambda_{inv}P_h^{g,t}+P_{h,b}^{d,t}. \tag{4}$$

Hence, the usage of non-renewable energy $P_h^{n,t}$ per household can be given as (5)

$$P_h^{n,t}=\begin{cases}P_h^{l,t}-P_h^{u,t}, & if\ \ P_h^{l,t}\geq P_h^{u,t}\\ 0, & otherwise.\end{cases} \tag{5}$$

The objective is to minimize non-renewable energy of smart city through battery charge/discharge scheduling. The detailed formulation is as follows.

$$\min_{P_{h,b}^{c,t},\,P_{h,b}^{d,t}} \quad \sum_{h=1}^{H}\sum_{t=1}^{T}P_h^{n,t}, \tag{6}$$

$$\mathrm{s.t.} \qquad 0\ <\ \lambda_{inv},\lambda_c,\lambda_d\ <\ 1, \tag{6a}$$

$$\sum_{h=1}^{H}b_{min}\ \leq\ \sum_{h=1}^{H}P_{h,b}^{s,t+1}\leq\ \sum_{h=1}^{H}b_{max}, \tag{6b}$$

$$\mathrm{X}\in\{0,1\},\mathrm{t}\in\mathrm{T}. \tag{6c}$$

In problem (6), constraint (6a) shows the range of the efficiency of the inverter , battery charge and discharge are $[0,1]$, while constraint (6b) ensures the energy saved in the battery at next time slot is not less than the minimum battery capacity b_{min} and not greater than the maximum battery capacity b_{max}. Finally, (6c) is the constraint that defines the decision variable X as the binary variable.

Algorithm 1: PSO-based Energy Scheduling

Input: ω, c_1, c_2, λ_{inv}, λ_c ,λ_d ,b_{min}, b_{max}, S, maxIteration, demand_hourly, generation_hourly

Output: P^*

Step 1: Initialization
randomly generate battery initial capacity
for each time slot $\mathrm{t}=1,\ldots,\mathrm{T}$ do
  for each particle $\mathrm{k}=1,\ldots,\mathrm{S}$ do
    randomly generate P_t^c, P_t^d $s.t.(6b)$
    Initialize personal best: $pbest_k$
  end for
  get global best: gbest
end for
Step 2: Iteration
repeat{
  for each time slot $\mathrm{t}=1,\ldots,\mathrm{T}$ do
    for each particle $\mathrm{k}=1,\ldots,\mathrm{S}$ do
      using eq.(6): $\mathrm{F}(p_k)$
      if $\mathrm{F}(p_k)<\mathrm{F}(pbest_k)$ & $s.t.(6b)$ then
        $pbest_k=\ p_k$
      end if
      if $\mathrm{F}(pbest_k)<\mathrm{F}(\mathrm{gbest})$ then
        $\mathrm{gbest}=\ pbest_k$
      end if
    end for
    for each particle $\mathrm{k}=1,\ldots,\mathrm{S}$ do
      update velocity (7) and position (8)
    end for
  end for
}utill maxIteration

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3. Solution with Particle Swarm Optimization

The proposed energy scheduling with considering the battery storage system based on PSO is illustrated in this section. PSO is a population-based method that originally is attributed to Kennedy and Eberhart in 1995, which gets the local position (personal best) and best position (global best) by moving particles fly around the solution space [6]. The movement of the particles is described by position P and velocity V, shown as follows [7].

$$V_k^{t+1}=\omega V_k^t+c_1r(pbest_k^t-p_k^t)+c_2r(gbest_k^t-p_k^t). \tag{7}$$

$$P_k^{t+1}=p_k^t+V_k^{t+1}. \tag{8}$$

where ω is the momentum, while c_1 and c_2 are the constants determine the effects of the personal best and the global best, respectively. r is a uniform random value from $[0,1]$.

The performance of the PSO is determined by evaluating the fitness function $F()$. Here, the objective (6) is defined as the fitness function and the observation per time slot is denoted by $P_t = \{P_t^c, P_t^d\}$, where P_t^c is the total battery charge of smart city and P_t^d is the total battery discharge. The detail of the solution is showed in Algorithm 1.

4. Performance Evaluation

In this research, the proposed energy scheduling method is implemented on the Python platform. To evaluate the proposed approach, we used a solar panel dataset [8] for solar energy generation and residential dataset [9] for energy consumption of the smart city. The parameters used in this paper are $\lambda_{inv} = 0.96$, $\lambda_c = 0.958$, $\lambda_d = 0.958$, $b_{min} = 0$, $b_{max} = 13.5$ [10].

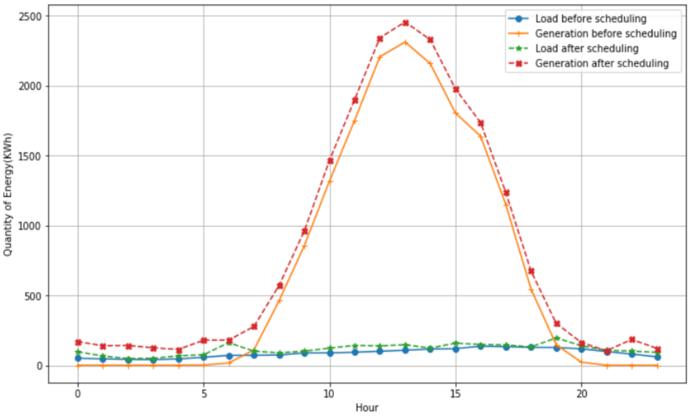

Fig.2. Energy Scheduling via PSO

Fig.2. shows the energy load and generation without considering battery storage, and also it shows the load and generation after scheduling by PSO based method. In this figure, it can be seen that from 0:00 to 6:00 and after 21:00, the solar generation tends to be zero before considering battery which causes the phenomenon of using non-renewable energy, while the generation is much more than consumption at other times. After introducing the battery storage and applying the proposed PSO-based energy scheduling, the solar generation can fulfill the energy demand required by the entire city. Specifically, the total usage of non-renewable energy is reduced by around 665.97 kWh.

5. Conclusion

The PSO-based energy scheduling method for the smart city was proposed in this paper to minimize the usage of non-renewable energy such that to reduce the unbalance between demand and generation. The evaluation result shows our proposed method for charge and discharge scheduling can significantly reduce the unbalance of demand and generation.

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References

[1] M. S. Munir and C. S. Hong, "Meta-Reinforcement Learning for Proactive Energy Demand Scheduling in Smart City with Edge Computing", Korea Software Congress 2018, pp. 495-497, December 2018 (in Korea).

[2] Y. Wu, V. K. N. Lau, D. H. K. Tsang, L. P. Qian and L. Meng, "Optimal Energy Scheduling for Residential Smart Grid With Centralized Renewable Energy Source," in IEEE Systems Journal, vol. 8, no. 2, pp. 562-576, June 2014.

[3] S. A. Zahr, E. A. Doumith and P. Forestier, "Advanced Demand Response Considering Modular and Deferrable Loads Under Time-Variable Rates," 2017 IEEE Global Communications Conference, December 2017.

[4] M. Chen and G. A. Rincon-Mora, "Accurate Electrical Battery Model Capable of Predicting Runtime and IV Performance," in IEEE Transactions on Energy Conversion, vol. 21, pp. 504-511, June 2006.

[5] M. Pilz and L. Al-Fagih, "Selfish Energy Sharing in Prosumer Communities: A Demand-Side Management Concept," arXiv:1905.04996 [eess.SP], May 2019.

[6] J. Kennedy and R. Eberhart, "Particle swarm optimization," Proceedings of ICNN'95 - International Conference on Neural Networks, pp. 1942-1948, 1995.

[7] M. A. A. Pedrasa, T. D. Spooner and I. F. MacGill, "Scheduling of Demand Side Resources Using Binary Particle Swarm Optimization," in IEEE Transactions on Power Systems, vol. 24, no. 3, pp. 1173-1181, August 2009.

[8] Online: "Solar panel dataset", UMassTraceRepository: http://traces.cs.umass.edu/index.php/Smart/Smart, (visited on 25 Oct, 2019).

[9] Online: "USA_LA _*," RESIDENTIAL_LOAD_DATA_E_*, https://openei.org/datasets/files/961/pub/, (visited on 25 Oct, 2019).

[10] M. Pilz and L. Al-Fagih, "A Dynamic Game Approach for Demand-Side Management: Scheduling Energy Storage with Forecasting Errors," Journal of Dynamic Games and Applications, April 2019.