International Journal of Smart Home
Vol. 10, No. 11, (2016), pp. 25-38
http://dx.doi.org/10.14257/ijsh.2016.10.11.03

Optimal Scheduling Algorithm for Residential Energy Consumption Considering the Wind-Photovoltaic Power and the Electricity Price of Purchase/Selling Electricity

Zhen Liu[1], Wen-zhu Li[2] and Xin Liu[3*]

School of Information and Electric Engineering, Hebei University of Engineering, Handan, Hebei 056038 China
[3]liux@ieee.org

Abstract

According to extensive development of renewable resources, such as wind power and photovoltaic power, and on the basis of wind-photovoltaic-energy storage hybrid power system, an optimal scheduling algorithm for residential energy consumption scheduling considering the wind -photovoltaic power and the electricity price of purchase/selling electricity is proposed. Firstly, in order to reduce the electricity cost of user and the burden of power supply, the appliances is arranged in the time-slot with purchase price more than selling price and higher wind -photovoltaic power based on the wind -photovoltaic power and the electricity price of purchase/selling electricity; Then, with the constraint conditions that purchase/selling electricity, the coordination strategy of wind-photovoltaic-energy storage grid is proposed. Simulation results show that the proposed optimization can decrease the electricity cost of user and peak-to-average.

Keywords: *wind-photovoltaic-energy storage hybrid power system, purchase/selling electricity model, energy consumption optimization, electricity cost*

1. Introduction

With the increasing consumption of fossil energy and environmental crisis, renewable energy (wind and solar energy) has received extensive attention because of its rich resources, small pollution and so on. The family is maximum scale number of energy consumption system in the energy consumption field, how to use renewable energy instead of fossil energy for the user to provide electricity demand is the urgent requirements .

The following scheduling schemes for the optimal scheduling of residential energy consumption have been studied recently. In [1-3], in order to reduce the user's electricity cost and guarantee the system stability, the different optimization scheduling algorithms for residential energy consumption are adopted. However, researchers focused on reducing electricity cost, without considering the impact of electricity on the environment in these studies. The authors of [4] proposed a optimization of energy management algorithm to coordinate photovoltaic power generation, energy storage, and thermoelectric cold cogeneration system. The algorithm balanced the environment and user's electricity cost. The authors of [5] proposed a scenery energy forecasting of household appliances based on optimization scheduling algorithm and reduce electricity cost. But, its impact on power system stability and reliability caused by the renewable energy power generation was not considered in the study. Due to the wind-solar power generation has the characteristics of indirectness, volatility and randomness and is strongly influenced by the weather [6-7]. Therefore, By considering the complementary characteristics of wind and solar power generation and the dynamic characteristics of the battery energy storage, the

---

[*]Corresponding Author

ISSN: 1975-4094 IJSH

capacity of the combined power generation system is optimized in this paper. It can not only guarantee the stability of the system, but also reduce the system cost [8-11].

On the basis of wind-photovoltaic-energy storage hybrid power system, an optimal scheduling algorithm for residential energy consumption scheduling considering the wind -photovoltaic power and the electricity price of purchase/selling electricity is proposed. In this paper, taking into account the wind - photovoltaic power and the electricity price of purchase/selling electricity, the household appliances are scheduled. Namely, within the scope of the user's tolerance of the appliance, the appliance is arranged in the time of purchase price is higher than the selling price of electricity and the wind- photovoltaic power is higher periods. And, the coordination strategy of the wind-PV hybrid power generation system is presented : when the power purchase price higher than the selling price, wind-photovoltaic-energy storage hybrid power system is consumed firstly. And in the lack of electricity, the electricity is purchased from the grid; when electricity purchase price is lower than the selling price, users directly purchase electricity from the grid, and the power of wind-photovoltaic system is sold to the grid side. The optimal scheduling scheme proposed in this paper can not only reduce the power consumption of users, but also reduce the power load of the power grid, thus reducing the consumption of fossil energy and reducing the environmental pollution.

2. The Wind-Photovoltaic-Energy Storage Hybrid Power System

In recent years, the rapid development of photovoltaic power generation and wind power generation as a clean energy have become a promising energy resource for users.

2.1. Photovoltaic Power Generation

The output power of the photovoltaic power generation system is dependent on the strength of the solar radiation and the environment temperature, the output power of the PV is formula for [12]:

$$P_{pv}^{t} = S\eta_{pv}I^{t}(1-0.05(\mathrm{T}_{out}^{t}-25) \tag{1}$$

Where S is the total area of the solar panels, η_{pv} is solar energy conversion efficiency, I^t is irradiance of solar energy in the time slot t (kW/m^2), T is the outdoor temperature (℃).

2.2. Wind Power Generation

The output power of wind energy:

$$P_{wind}^{t} = \frac{1}{2}\rho A C_{p}\left(V^{t}\right)^{3} \tag{2}$$

Among them, ρ is the density of air, A is rotor swept area, C_p is wind energy utilization coefficient, V^t is the wind speed in the time slot t.

2.3. Storage Battery

The charging power of battery：

$$P_{batt,ch}^{t} \le P_{ch}^{\max} ch^{t} \tag{3}$$

The discharging power of battery：

$$P_{batt,dch}^{t} \le P_{dch}^{\max} dch^{t} \tag{4}$$

Here, ch^t, dch^t are charge and discharge status, $ch^t + dch^t \le 1$.

The output power of battery：

$$P_{batt}^{t}=\frac{P_{batt,ch}^{t}}{\eta_{ch}}-P_{batt,dch}^{t}\eta_{dch} \tag{5}$$

Here, η_{ch} and η_{dch} are battery charging and discharging efficiency, respectively.

3. The Energy Consumption of Appliances Scheduling Algorithm with Distributed Energy Generation Systems

In this section, we provide a mathematical model for the household appliance scheduling problem. We consider a residential unit where a smart meter, a wind-photovoltaic hybrid power system, an energy storage device and electric appliances are equipped. The appliances optimal scheduling algorithm based on hybrid power generation system. The main characteristics of the system is that the power can be distributed directly to the user, the excess or insufficient part of the power supply and demand interaction, and two-way charging, the architecture of which is shown in Figure. 1.

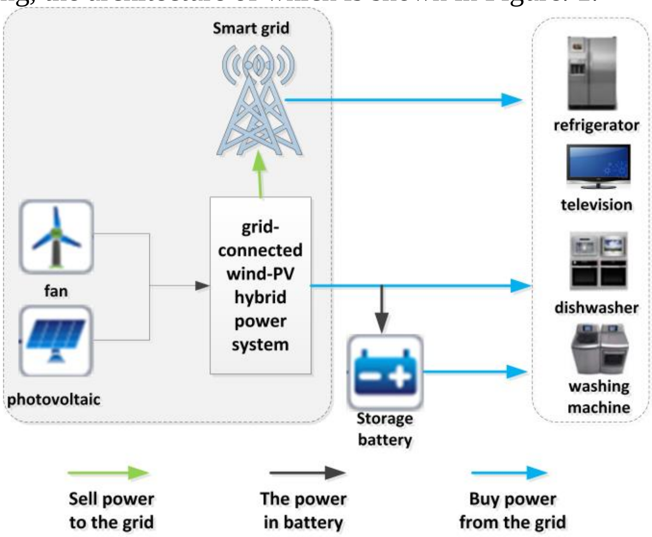

Figure 1. The Proposed Residential Energy Model

3.1. The Parameter Setting

In this section, we classify four types of household appliances consisting of interruptible and schedulable appliances, non-interruptible and schedulable appliances, real-time appliances, and full-time appliances. Some loads such as charging the battery for an electric vehicle are interruptible. That is, it is possible to charge the battery for 1 h, then stop charging for another hour, and then finish the charging after that. However, if the load is uninterruptible, then as soon as the corresponding appliance starts operation, its operation needs to continue until it finishes. Real-time appliances must operate immediately only if users want to use them, *e.g.*, televisions and computers. Full-time appliances operate during the whole day, *e.g.*, refrigerators.

Let A denote the schedulable appliances and T denote the operation cycle. We define time-slot $t \in T = [1, 2, 3, \ldots, 24]$. Let e_{a}^{t} denote the energy consumption of appliance a in time-slot t. The total energy consumption of all schedulable appliances A in time-slot t is given by $\sum e_a^t$ and is denoted by l_A^t. The energy consumption of the residence in the t time-slot is formulated as

$$\sum_{a\in A} e_a^t + E_{real}^t + E_{full}^t = E^t \tag{6}$$

E^t_{real} is the energy consumption of the real-time appliances in the t time-slot, E^t_{full} is the energy consumption of the full-time appliances in the t time-slot, and E^t is the total energy consumption of all appliances in the t time-slot.

3.2. The Coordination Strategy of Wind-PV Hybrid Power Generation System in Smart Home

The total power of the wind power and PV power supply can not only ensure the power supply of the battery and the user but can also be connected to the grid. According to the output condition of wind-PV hybrid power generation system, the grid-connected working model is divided into three work situations: case 1: The output power of the wind-PV hybrid system can meet the requirements of the all appliances and can charge the battery, and the surplus power is connected to the network; case 2: The wind-PV hybrid power system and the storage battery provide the users with electric power to meet the needs of the appliance; case 3: The wind-PV hybrid power system, storage battery and supplier provide users with electric power to meet the needs of the appliance. There are three types of grid-connected working mode, as shown in Figure. 2.

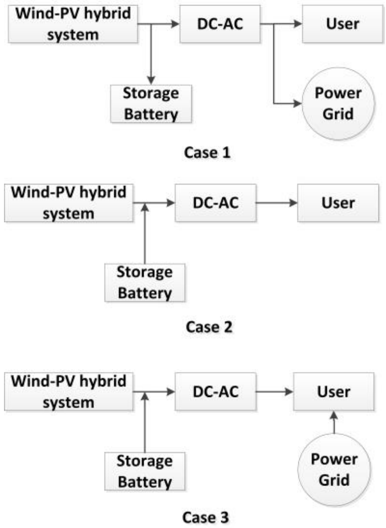

Figure 2. Three Kinds of Grid-Connected Working Mode

According to the wind-PV hybrid power system and the electricity price of purchasing/selling electricity, a detailed coordination strategy for the wind-PV hybrid power generation system is proposed.

(1) when $C^t_{gi}<C^t_{go}$, the power required by the user is provided by the energy storage battery and then provided by the power grid, so that the power supplied by the power grid

$$E^t_{gi} = E^t - E^t_{batt} \tag{7}$$

The power generated by wind-PV hybrid power system is directly fed into the grid.

$$E^t_{go} = E^t_{ren} \tag{8}$$

where C^t_{gi} and C^t_{go} are the purchased and sold electricity, respectively; E^t_{gi} denotes the power that the grid supplies to the user in the t time-slot; E^t_{go} denotes the power that is fed into the grid in the t time-slot; and E^t_{batt} is the power consumption of the storage battery in the t time-slot.

(2) when $C^t_{gi}>C^t_{go}$ and the wind-PV hybrid power system has sufficient output, based on ensuring the user demand, it first charges the battery, and then the excess electricity is

fed into the grid.

$$E_{go}^{t} = E_{ren}^{t} - E^{t} - E_{batt}^{t} \tag{9}$$

(3) when $C_{gi}^{t}>C_{go}^{t}$ and the wind-PV hybrid power system has insufficient output, the users requiring power are first provided by the wind-PV hybrid power system and then provided by the energy storage battery, and the shortage of power is provided by the power grid.

$$E_{gi}^{t} = E^{t} - E_{ren}^{t} - E_{batt}^{t} \tag{10}$$

3.3. The Objective Functions

3.3.1. The Electricity Cost:

(1) when $C_{gi}^{t}<C_{go}^{t}$, the electricity cost is formulated as

$$C_{g1} = \sum_{t\in T_1}\left(C_{gi}^{t}E_{gi}^{t} - C_{go}^{t}E_{go}^{t}\right) \tag{11}$$

(2) when $C_{gi}^{t}>C_{go}^{t}$ and the wind-PV hybrid power system has sufficient output, the electricity cost is formulated as

$$C_{g2} = \sum_{t\in T_2} C_{go}^{t}E_{go}^{t} \tag{12}$$

(3) when $C_{gi}^{t}>C_{go}^{t}$ and the wind-PV hybrid power system has insufficient output, the electricity cost is formulated as

$$C_{g3} = \sum_{t\in T_3} C_{gi}^{t}E_{gi}^{t} \tag{13}$$

Hence, the total electricity cost is formulated as follows:

$$C_{g} = C_{g1} - C_{g2} + C_{g3} \tag{14}$$

3.3.2. The Model of Cost Constraints: To minimize the user's electricity cost, there are several constraints that must be satisfied:

(1) the energy consumption constraints

To make sure that each task is completed during the scheduling time period, the following constraint is imposed, the energy consumption of appliance *a* is given by:

$$E_{a} = \sum_{t=\alpha_a}^{\beta_a} e_{a}^{t} \tag{15}$$

where α_a and β_a are the start and end time-slot of appliance *a* . E_a is the energy consumption of appliance *a*.

To ensure stability of the system, there is generally a limit on the total energy consumption in each time-slot. Hence, the constraint is formulated as follows:

$$E^{t} \le E^{t,\max} \tag{16}$$

where $E^{t,max}$ is the upper bound of the energy consumption in *t* time-slot.

(2) the capacity constraints of the storage battery

$$E_{batt}^{\min} \le E_{batt}^{t} \le E_{batt}^{\max} \tag{17}$$

where E_{batt}^{min} and E_{batt}^{max} are the lower and upper bound of the storage battery capacity.

4. Result Discussions

4.1. Optimal Allocation of Wind-PV Hybrid Power System

On the basis of meeting the needs of users, in order to ensure the superiority and economy of the power supply system, the HOMER simulation software is used to optimize the capacity of the wind-photovoltaic-energy storage hybrid power system. California is chosen as the reference region. A local residential average daily electricity demand is 28.5kw and peak power is 8.15kw. Figure 3 is a simulation model of hybrid power generation system which is built in HOMER. The parameters of the optimal configuration scheme of the simulation model are set as shown in Table 1.

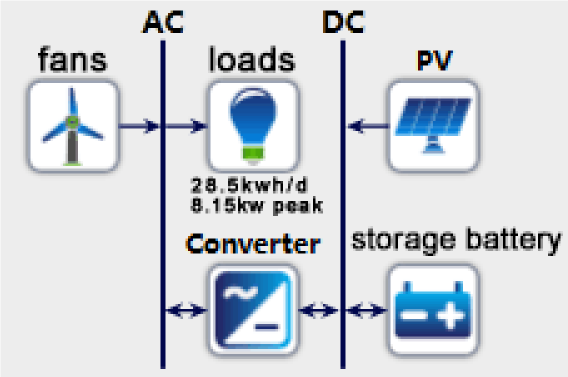

Figure 3. The Wind-Solar-Battery Hybrid Power System Model

Table 1. Main Parameters of Wind Generator/PV Panel/Battery

Parameters of fan	Values	Parameters of PV	Values	Parameters of battery	Values
monomer capacity	3kw	monomer capacity	180w	monomer capacity	2.16kw
number	1	number	84	number	3
V^{min}	3m/s	S	25	rated voltage	6v
V^{max}	24 m/s	η_{pv}	13%	charge efficiency	85%
acquisition cost	5000 $ /set	acquisition cost	5000 $/kw	acquisition cost	1100 $/set
replacement cost	4000 $ /set	replacement cost	2500 $/kw	replacement cost	1000 $/set
running cost	50 $ /year	running cost	3 $/kw/year	running cost	10 $/year

4.2. Data Analysis

The HOMER software is used to configure the capacity of the wind-solar-battery hybrid power system, which improves the reliability of the power supply system. In order to verify the effectiveness of the proposed optimization scheduling algorithm, the paper uses the real weather data (wind speed and solar irradiance) to simulate the performance of the proposed algorithm, which is released by NASA [13]. The California summer weather conditions are shown in Figure 4, and Figure. 5.

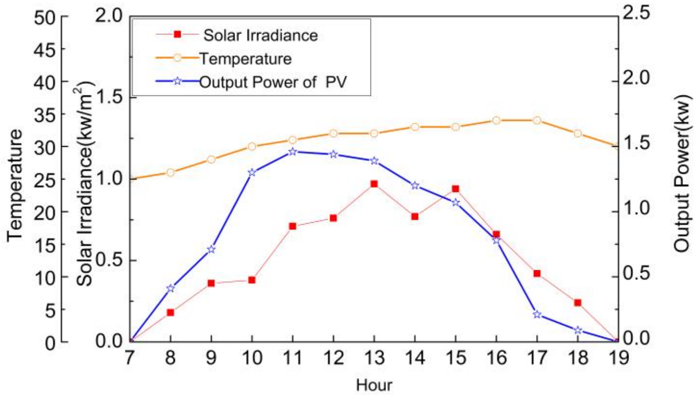

Figure 4. Hourly Average Temperature, Solar Irradiance and Output Power of PV in California

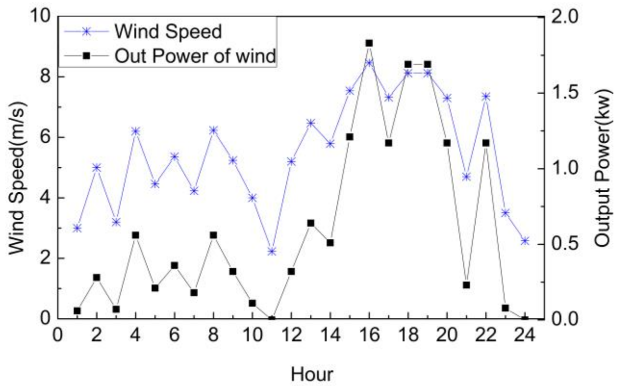

Figure 5. Hourly Average Wind Seed and Output Power of Wind in California

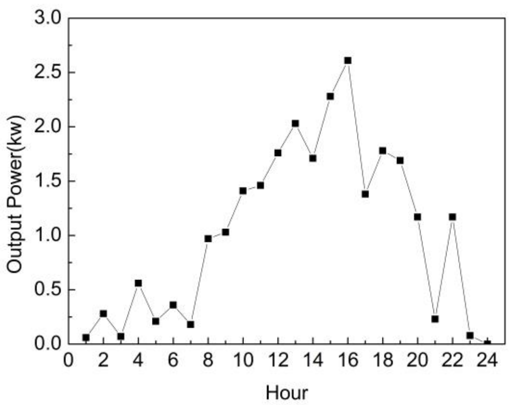

Figure 6. The Output Power of Wind-PV Hybrid Power System

According to the parameters in Table 1, Figure 4, and Figure 5, the output power of wind-PV hybrid power is shown in Figure 6. In the simulations, the family appliances setting are as shown in Table 2 [14]. Appliances 1-14 are schedulable appliances (among them, 7-9 and 11-13 are interruptible, and 1-6, 10 and 14 are non-interruptible), appliances 15 and 16 are real-time appliances, and the refrigerator (appliance 17) is a full-time appliance. The appliances' length of operation time (LOT) is the time to finish the operation. In Table 3, the electricity price of purchase/selling electricity values are presented [15].

4.3. Optimal Scheduling Results

In this section, we present the simulation results and assess the performance of our proposed optimization scheduling algorithm for home appliances. We assume that the number of scheduled-time appliances varies from 10 to 20 and that the same appliances that work in different time-slots denote different appliances. In our paper, the formulated model is solved by MATLAB [16] and CPLEX [17]. $E^{t,max}$ 和 E_{batt}^{max} are the maximum power of each time-slot and the upper bound of the storage battery capacity, which are set as 3.5 kW and 6.48 kW, respectively.

Table 2. Parameters of Appliances Used in the Simulation Process

Appliance *i*	TWT	LOT (min)	Nominal power (kw)
Electric kettle 1	07:00-09:00	10	1.7
Electric kettle 2	17:00-20:00	10	1.7
Coffee machine 3	07:00-10:00	10	1.25
Rice cooker 4	11:00-19:00	30	1.3
Oven 5	07:00-10:00	10	0.9
Oven 6	16:00-20:00	10	0.9
Vacuum cleaner 7	10:00-16:00	30	1.2
Humidifier 8	23:00-03:00	120	0.05
Dishwasher 9	14:00-20:00	120	2
Water heater 10	15:00-21:00	50	1.5
Washing machine11	10:00-21:00	50	0.5
Clothes dryer 12	11:00-21:00	50	1
Electric vehicle 13	18:00-05:00	240	2.2
Hair dryer 14	20:00-23:00	10	1.2
Television 15	19:00-20:00	120	0.2
Computer 16	20:00-22:00	180	0.25
Refrigerator 17	01:00-24:00	1440	0.125

Table 3. The Electricity Price of Purchase/Selling Electricity

Time-solt	C_p	C_s	Time-solt	C_p	C_s	Time-solt	C_p	C_s
1	0.12	0.1	9	0.12	0.05	17	0.08	0.02
2	0.07	0.05	10	0.16	0.1	18	0.12	0.1
3	0.08	0.03	11	0.12	0.07	19	0.11	0.06
4	0.07	0.02	12	0.16	0.18	20	0.1	0.03
5	0.09	0.04	13	0.17	0.10	21	0.09	0.07
6	0.08	0.02	14	0.19	0.23	22	0.06	0.04
7	0.11	0.05	15	0.18	0.09	23	0.07	0.03
8	0.14	0.08	16	0.11	0.05	24	0.07	0.02

Figure 7, shows the appliances operation time and the power consumption in each time-slot by using our proposed household appliances scheduling scheme. In Table 3, and Figure 6, the price is lower and the output power of wind-PV hybrid power system is higher in the 2nd-4th time-slot than the 1st, 23rd, and 24th time-slot, thus the electric vehicle is arranged to the 2nd and 4th time-slot. Though the output power of wind-PV hybrid power system is higher in 12th and 14th, the electricity price is sold to the grid greater than the purchase price of electricity from the grid. So, the result presented in Figure 7, clearly shows that the schedulable appliances are not arranged to 12th and 14th, the output power of wind-PV hybrid power system is sold to the grid. It can slow down the supply pressure of the power supplies.

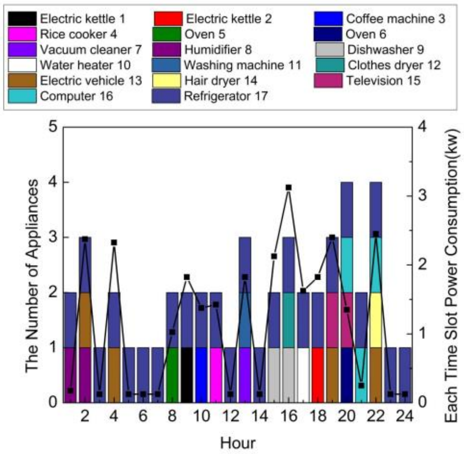

Figure 7. The Appliances Operation Time and the Power Consumption in Each Time-Slot

To further illustrate the advantages of the grid-connected wind-PV hybrid power system, we analyzed the following three cases in Table 4. Case 1: with the premise of not sacrificing the comfort of the user and without the wind-PV hybrid power system for the user to provide electricity. The household appliances are scheduled based simply on the electricity price. Case 2: in the case of the maximum comfort of the user, and with the grid-connected wind-PV hybrid power system for the user to provide electricity. Case 3: without sacrificing user comfort and with the grid-connected wind-PV hybrid power system for the user to provide electricity. The appliances are scheduled based on the output power of the wind-PV hybrid power system and the electricity prices of purchasing/selling electricity.

Table 4. Summary of Case Studies

	wind-PV hybrid system	Smart grid	Appliances scheduling	Real-time price	purchase/selling electricity
Case 1		√	√	√	
Case 2	√	√			√
Case 3	√	√	√		√

Figure 8, is the power consumption of the appliances in each time-slot. In Case 1, the peak value of the user's electricity demand is 3.425 kW, while it is 3.12 kW in Case 3. From the combination of Figure 7, and Figure 8, it can be seen that the use of the proposed algorithm in this chapter can decentralize the working time of the appliances, thus slowing the power supply burden of the grid.

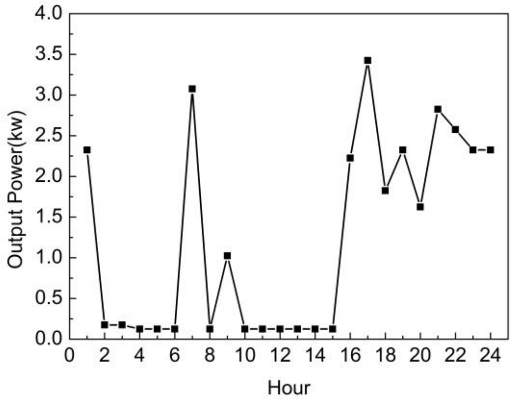

Figure 8. The Power Consumption of Appliances in Each Time-Slot in Case1

In this section, the user's electricity cost does not include the acquisition cost, replacement cost or operating cost of the wind power generation system, and the power cost of the user only considers the power consumption of the various appliances in the home. Figure 9, presents the electricity cost in the 3 cases. A comparison of the Case 1 and Case 2 user payment of electricity shows that the installation of the wind solar hybrid power generation system in the household can greatly reduce the user's payment of electricity, and by comparing Case 2 and Case 3, we can find that the user's cost of electricity is further reduced based on the output power of the wind-PV hybrid power system and the prices of purchasing/selling electricity.

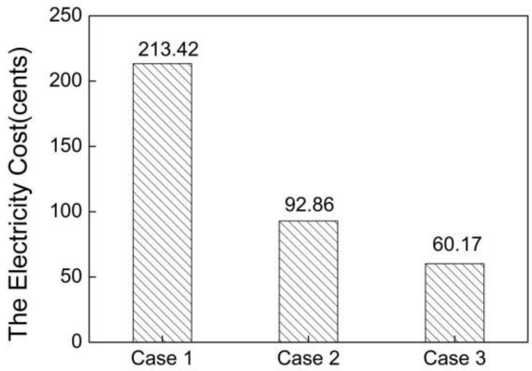

Figure 9. The Electricity Cost in 3 Cases

Figure 10, shows the power of the wind-PV hybrid system, the storage battery and the power grid using the optimization of the scheduling in Case 3. The output power of the wind-PV hybrid system is higher in the 8th-19th time slots, so most of the power the users require is provided by the wind-PV hybrid system during that period, as shown in Figure 10 (a). From Figure 10 (b), we observe that the purchase electricity price is higher than the sale price in the 12th and 14th, so the output power of wind-PV hybrid system is sold to the grid. As shown in Figure 6, the appliances consume less power in the 5th-8th time slots, and in the 13th-15th time slots the additional output power can provide users with enough power. In these two periods, the sale price is lower than the purchase price, so the energy storage battery will store the excess electricity, as shown in Figure 10 (c).

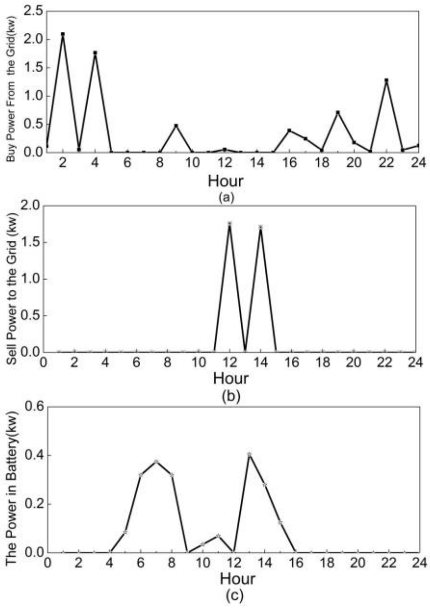

Figure 10. The Electrical of Wind-Solar Hybrid System, the Storage Battery and Power Grid for Case 3

Finally, Figure 8, shows that the peak of the grid power consumption is 3.425 kW without the wind-PV hybrid system and 2.117 kW with the proposed optimal scheduling scheme in Figure 10(a). Hence, by using Equation (18), the peak-to-average (PAR) can be reduced by 28.9% from 5.36 to 3.81 by using the proposed optimal scheduling scheme.

$$PAR = \frac{24\max\left\{E^1, E^2, ..., E^t\right\}}{\sum_{t\in T} E^t} \tag{18}$$

5. Conclusions

1) In order to meet the needs of users and ensure the superiority and economy of the wind-photovoltaic-energy storage hybrid power system, the paper uses HOMER simulation software to optimize the capacity of the wind power generation system;

2) On the basis of wind-photovoltaic-energy storage hybrid power system, an optimal scheduling algorithm for residential energy consumption scheduling considering the wind -photovoltaic power and the electricity price of purchase/selling electricity is proposed. Firstly, according to the level of wind-photovoltaic-energy storage hybrid power system capacity to schedule the household appliances, and then in accordance with the proposed coordination strategy to provide users with power demand. The algorithm reduced the user's payment of electricity and power supply pressure of the grid, at the same time, wind-photovoltaic-energy storage hybrid power system can also reduce the consumption of fossil energy, and reduce the pollution of the environment.

Acknowledgements

This work was supported in part by the National Natural Science Foundation of China (61440001), the Program for New Century Excellent Talents in University (NCET-13-0770), the Research Project of High-level Talents in University of Hebei Province (GCC2014062), and the scientific research projects of the Department of Education of Hebei Province (ZH2012020).

References

[1] Z. Zhao, W. C. Lee and Y. Shin, "An Optimal Power Scheduling Method for Demand Response in Home Energy Management System", IEEE Transactions on Smart Grid., vol. 4, no. 3, **(2013)**, pp. 1391-1400.
[2] C. X. Dao, W. T. Quan and H. S. Yan, "Uncertainty-Aware Household Appliance Scheduling Considering Dynamic Electricity Pricing in Smart Home", IEEE Transactions on Smart Grid, vol. 4, no. 2, **(2013)**, pp. 932-941.
[3] P. Chavali, Y. Peng and A. Nehorai, "Distributed Algorithm of Appliance Scheduling for Home Energy Management System", IEEE Transactions on Smart Grid, vol. 5, no. 1, **(2014)**, pp. 282-290.
[4] F. Brahman, M. Honarmand and S. Jadid, "Optimal Electrical and Thermal Energy Management of A Residential Energy Hub, Integrating Demand Response and Energy Storage System", Energy and Buildings, vol. 90, **(2015)**, pp. 65-75.
[5] A. Tascikaraoglu, A. R. Boynuegri and M. Uzunoglu, "A Demand Side Management Strategy Based on Forecasting of Residential Renewable Sources: a Smart Home System in Turkey", Energy and Buildings, vol. 80, **(2014)**, pp. 309-320.
[6] W. Zhen, L. Z. Xiang and D. X. Bo, "Reliability Model and Indices of Distributed Photovoltaic Power System", Automation of Electric Power Systems, vol. 35, **(2011)**, pp. 18-24.
[7] N. Linna, L. Ji and W. S. Rong, "Frequency Control of Power System with Wind Power Integration", Transactions of China Electrotechnical Society, vol. 26, no. sup. 1, **(2011)**, pp. 235-241.
[8] Q. Y. Zhi and L. Y. Tian, "Output Power Rolling Optimization and Real-Time Control in Wind-Photovoltaic-Storage Hybrid System", Transactions of China Electrotechnical Society, vol. 29, no. 8, **(2014)**, pp. 265-273.
[9] X. Lin, R. X. Bo and Z. B. Han, "An Improved Optimal Sizing Method for Wind-Solar-Battery Hybrid Power System", Proceedings of the CSEE, vol. 32, no. 25, **(2012)**, pp. 88-98.
[10] L. Chong, G. X. Feng and Z. Yuan, "Techno-Economic Feasibility Study of Autonomous Hybrid Wind/PV/Battery Power System for A Household in Urumqi, China", Energy, vol. 55, **(2013)**, pp. 263-272.
[11] C. G. Wei, K. L. Guo and P. Chao, "System modeling of wind-PV-ES hybrid power system and its ontrol strategy for grid-connected", Transactions of China Electrotechnical Society, vol. 28, no 9, **(2013)**, pp. 196-204.
[12] T. Mohammad, G. Hassan and R. K. Ashkan, "Residential Microgrid Scheduling Based on Smart Meter Data and Temperature Dependent Thermal Load Modeling", IEEE Transactions on Smart Grid, vol. 5, no 1, **(2014)**, pp. 349–357.
[13] Surface meteorology and solar energy. [Online]. http://eosweb.larc.nasa.gov/sse.
[14] A public data set for energy disaggregation research, [Online]. Available: http://redd.csail.mit.edu/.
[15] The real-time Electricity Market of New York, [Online]. Available: http://www.nyiso.com/public/markets_operations/market_data/load_data/index.jsp.
[16] MATLAB [Online]. Available: http://cn.mathworks.com/?s_eid=ppc_ 8117
[17] ILOG CPLEX [Online]. Available: http://www-01.ibm.com/software/ commerce/optimization/cplex-optimizer/.

Authors

Zhen Liu received her B.S. degree in Computer Science and Technology from Hebei University of Engineering, Handan, China in 2013. She is currently pursuing her M.S. degree in Hebei University of Engineering. Her research mainly focuses on the appliance scheduling, energy consumption, and real-time price prediction in smart grid.

Wenzhu Li is currently a lecture with the School of Information and Electric Engineering, Hebei University of Engineering, Handan, China. She received her B.Sc. degree in Telecommunication Engineering from Jilin University, Jilin, China, in 2001 and received her MSc degree in Electrical Engineering from Beijing University of Posts and Telecommunications, Beijing, China, in 2006. Her current research mainly focuses on the smart grid and the next-generation broadband access networks.

Xin Liu is currently a full professor with the School of Information and Electric Engineering, Hebei University of Engineering, Handan, China. He received his B.Sc. degree in Telecommunication Engineering from Jilin University, Jilin, China, in 2001 and received his PhD degree in Electrical Engineering from Beijing University of Posts and Telecommunications, Beijing, China, in 2010. From 2001 to 2003, he was a technical support engineer with Huawei Technologies Co. Ltd., Shenzhen, China. From 2010 to 2012, he was a postdoctoral research fellow with Beihang University, Beijing, China. He was the recipient of the 2010-2011 Québec-China Postdoctoral fellowship scholarships and was a postdoctoral research fellow of the Optical Zeitgeist Laboratory, INRS-EMT, Montreal, QC, Canada from September 2010 to September 2011. He was a Visiting Scientist at the Massachusetts Institute of Technology (MIT), Cambridge, MA from July 2014 to January 2015. He received the Nomination Award for the National Excellent Doctoral Dissertation of China in 2012 and the New Century Excellent Talents in University of State Education Ministry of China in 2013. His research interests lie in the area of flexible transparent optical networks, next-generation broadband access networks, and network reliability evaluations.