PAPER

An Automatically Peak-Shift Control Design for Charging and Discharging of the Battery in an Ultrabook

Chun-Hung CHENG[†*a)], ***Student Member and*** **Ying-Wen BAI**[†], ***Nonmember***

SUMMARY As the electricity rates during peak hours are higher, this paper proposes a design for an ultrabook to automatically shift the charging period to an off-peak period. In addition, this design sets an upper limit for the battery which thus protects the battery and prevents it from remaining in a continued state of both high temperature and high voltage. This design uses both a low-power embedded controller (EC) and the fuzzy logic controller (FLC) control method as the main control techniques together with real time clock (RTC) ICs. The sensing value of the EC and the presetting of parameters are used to control the conversion of the AC/DC module. This user interface design allows the user to set not only the peak/off-peak period but also the upper use limit of the battery.

key words: *battery, charging, discharging, peak-shift, fuzzy logic control*

1. Introduction

In summer, normally the annual peak period of power consumption, due to the heavy use of both air conditioners and electronic devices, a typical electricity bill is always higher than during other seasons. By using the peak shift concept, an electronic device automatically shifts the charging period to an off-peak period not only to reduce the bill but also to help reduce the demand for electricity during peak periods [1]–[4].

There is a rechargeable battery in an ultrabook system which is activated if the system operates without an AC power source. The controller automatically switches the hardware circuit to the battery mode. If the system is plugged into an AC power source, the controller automatically switches it to the AC mode [5]–[12].

In addition to an automatic shift of the charging period to an electricity off-peak period, this design has a second focus which is to lengthen the life of the rechargeable battery. The total number of times that a lithium battery charges and discharges is limited. If the battery discharges deeply each time, these discharges reduce its life. For example: a battery of 3 cells, at a full voltage of 12.1V discharging to less than 9.3V, can enter the protected mode against discharging deeply, that is, any voltage lower than 9.3V [13]–[18].

This design allows the user to set the battery's full capacity upper limit, to avoid its remaining in a state of high voltage. The design further extends the life-span of a rechargeable battery by using the integration of both software and hardware modules to prevent it from discharging deeply [19]–[22].

This design is different from the previous design which uses the FLC control method to dynamically adjust the charging current of the battery. This control program uses the MAX-MIN synthetic method for the fuzzy inference and then uses the center law or center of gravity method to solve any fuzzy melting in order to obtain the appropriate output value needed to adjust the charging current. According to the specific characteristic of a rechargeable battery, the FLC control method can smoothly adjust the charging current which helps to lengthen a battery's life [23]–[26]. In addition, this design only uses one input value and output value, which, in turn, can reduce the complexity of the software procedure and maintain the higher speed of this design [27], [28].

Figure 1 shows the FLC is divided into four steps: Fuzzifier, Fuzzy Rule Base, Inference Engine, and Defuzzifier.

The Fuzzifier passes the input value to the membership function and converts this value into the required fuzzy quantity. Usually the input value belongs to the function which can be divided into the discretization and continuous membership function. The fuzzy inference is the fuzzy input via the fuzzy logic operation of the system, which combines in the fuzzy rule base all IF-THEN whereby the rules become fuzzy inference engines, and produce a policy output which is a rational fuzzy output value of the system.

There are many kinds of commonly used fuzzy inference methods. The MAX-MIN rule is the operation rule most often used. When the fuzzy inference is completed, the results received are the fuzzy output value. The FLC converts the fuzzy value and provides the output value, which is commonly used in solving the fuzzy method as follows: Center of Gravity Defuzzification (CoG) or Center of Area

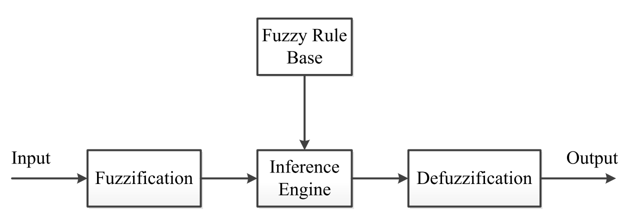

Fig. 1 Structure of the fuzzy logic system.

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[†]The authors are with Fu Jen Catholic University, 24205 Taiwan, R.O.C.
[*]Presently, also with Software Design Department, Research and Development Centre, CLEVO Company, Taiwan R.O.C.
a) E-mail: 400068058@mail.fju.edu.tw

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Deffuzzification (CoA), Center of Maximum Defuzzification (CoM) and Middle of Maxima Defuzzification (MoM).

This FLC design uses the mathematics software tool, and it does not need to specifically install this software tool. Because this FLC design defines the relevant input value, in order to allow the FLC to carry out this operation, it again provides the control mechanism which is in keeping with the output value.

The fuzzy inference uses the MAX-MIN rule, and the defuzzification uses the center of gravity. Because this FLC design uses an input value and an output value which have only one parameter, this FLC can operate very fast. Other control methods can be used too, but as this FLC design input and output value are only one parameter, and as this FLC design tries hard to melt by using a simple procedure, we have chosen this FLC method.

When used, the typical life-span of a lithium battery declines, as a result of several main factors [29], [30]:

a. Temperature: If a battery operates at a higher temperature, then the life-span declines faster.
b. Variation of charge and discharge current: If there is an over specification of the current charges on the battery, its life-span declines sooner. Meanwhile, the larger the electric current the more heat that will be generated, which in turn, will also increase the battery temperature.
c. Over charge and discharge:
   If the battery is overcharged and discharged, the decline of the life-span is faster.

The organization of this paper is as follows. Section 2 is a description of the software design and the peak-shift control method. Section 3 shows the implementation and measurement results. Section 4 shows the comparisons of the related designs and user interfaces. Section 5 both concludes and summarizes this paper.

2. Software Design

This design as shown in Fig. 2 includes the two modules in the ultrabook system: the hardware module and the software module. The hardware module permits the EC control to switch the AC/DC circuit and, when necessary, adds the RTC IC to provide daily accurate schedule control.

For the software module the proposed design uses an application program which allows the user to set both the peak/off-peak period and the upper limit of the battery charge. The flowchart of the peak-shift control method is shown in Fig. 3.

The EC can be adjusted accurately each day from the peak/off-peak through the RTC IC. The peak-shift control method automatically controls, based on the AC/DC circuit, the set parameters of the rechargeable battery and the peak/off-peak period of the system. The application program has been designed with a visual high level programming language, which permits a user's interface to control the rechargeable battery to charge/discharge automatically according to different operating settings and schedules.

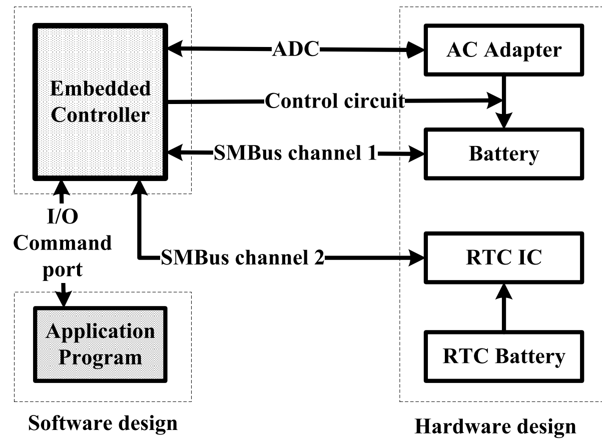

Fig. 2 System architecture of the EC and application program.

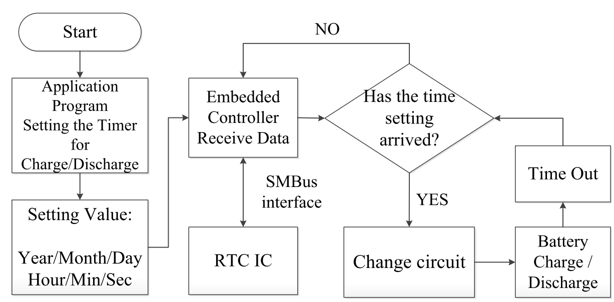

Fig. 3 Flowchart of the peak-shift control method.

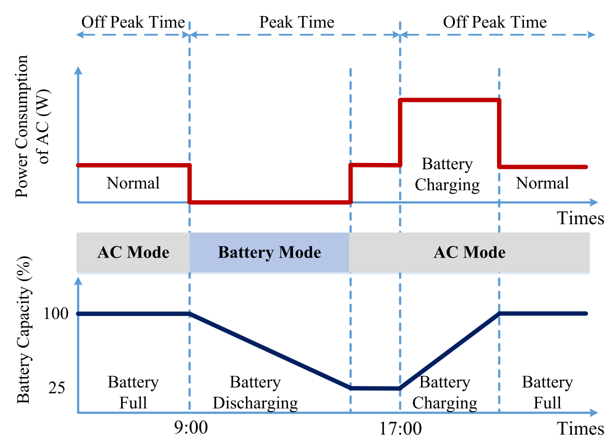

Fig. 4 Power consumption of the peak-shift control method.

Figure 4 shows the operation parameter settings for the peak-shift control method. The off-peak time is an integer time range which is 17:01–08:59 and the peak time is 09:00–17:00; the upper limit of the battery capacity is 100%, and the battery capacity, when it is beginning to be charged, is 25%. These settings are the default values. Different settings may be set for different ultrabooks.

As the typical user often lets the computer run for a whole day, the 24-hour operation of the ultrabook is the de-

Table 1 Battery charging voltages and charging current at different integer temperatures.

Battery temperature	Charging voltage	Charging current
0°C - 10°C	12.6V	0.45A
11°C - 20°C	12.6V	2.25A
21°C - 45°C	12.6V	3.0A
46°C - 55°C	12.0V	2.25A

Table 2 Battery charging voltages and charging current at different integer temperatures for FLC.

Battery temperature	Charging voltage	Charging current
0°C - 10°C	12.6V	0.2A – 0.6A
11°C - 20°C	12.6V	1.7A – 2.6A
21°C - 45°C	12.6V	3.0A – 2.6A
46°C - 55°C	12.0V	2.4A – 1.7A

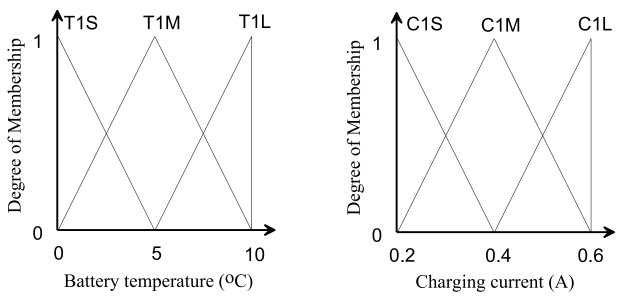

Fig. 5 Membership function of the battery temperature [0°C–10°C] and the charging current [0.2A–0.6A].

fault in this design, which assumes that the ultrabook is to be used instantly.

Table 1 shows the different integer temperatures with respect to different charging conditions. If the temperature of the battery of the ultrabook is increased and exceeds 45 degrees C, this design will reduce the battery charge current. The default settings also include different selections of the charging current with respect to different temperatures.

In the previous design, Table 1 shows that four ranges are used with four previously fixed charging currents. In this new design, as shown in Table 2, FLC is used to control four integer temperature ranges by dynamically charging the current values instead of charging a fixed current value.

Table 1 and Table 2 show the difference with respect to the charging current of the rechargeable battery as compared with the previous design and this design. In keeping with the specification of the charging current of the rechargeable battery, the charging current shall avoid exceeding this specification. To keep charging current within the recommended safe range, this design uses the FLC method, as shown in Figs. 10 and 11, to provide the necessary smooth control for the charging current under different operating temperatures in order to extend the rechargeable battery life.

Figure 5 shows the Membership function design of the battery temperature [0°C–10°C].

The fuzzy rules for the control of the battery temperature [0°C–10°C] are

$$\textit{Rule 1.}\quad \textit{IF } x \textit{ is } T1S \textit{ Then } z = C1S \tag{1}$$

$$\textit{Rule 2.}\quad \textit{IF } x \textit{ is } T1M \textit{ Then } z = C1M \tag{2}$$

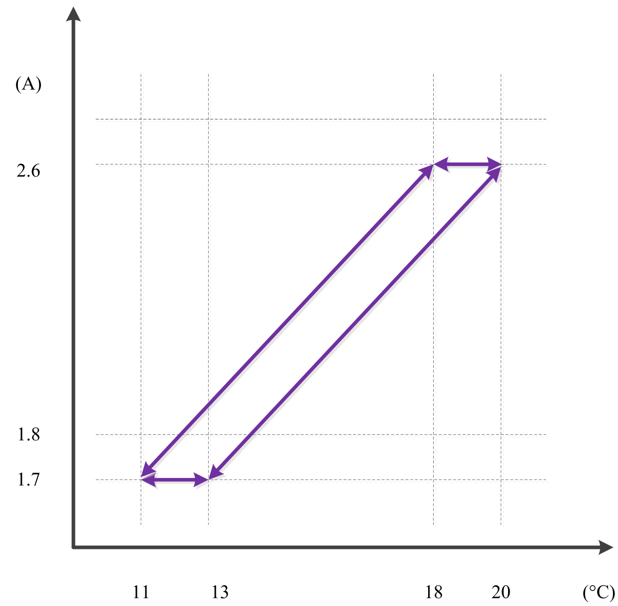

Fig. 6 Hysteresis curve for the charging current control in the [11°C–20°C] range.

$$\textit{Rule 3.}\quad \textit{IF } x \textit{ is } T1L \textit{ Then } z = C1L \tag{3}$$

There are three integer temperature ranges with respect to membership function and fuzzy rules setting: [11°C–20°C], [21°C–45°C], and [46°C–55°C], which have a similar arrangement with Fig. 5 and (1)–(3).

By means of fuzzification purpose, the measurement quantity converts by using fuzzy the intersection of the calculation and the necessary fuzzy value to the intersection of the ownership function that corresponds to the clear value in the FLC. Figure 5 shows the definition of the membership function (input/output value). The membership function of this design's definition consists of four interval definitions: [0°C–10°C], [11°C–20°C], [21°C–45°C], and [46°C–55°C]. This explanation only shows the [0°C–10°C] definition, such as in Fig. 5. The other 3 interval definitions are similar. Figure 5 shows the definition of the input value set up with a fuzzy controller for the battery temperature which is divided into 3 sets: low (T1S), middle (T1M) and high (T1L). The Output value sets up a fuzzy controller for the charge current which is divided into 3 sets: low (C1S), middle (C1M) and high (C1L). The charging current for the membership function ranges between 0.2 A and 0.6A. Figure 6 shows the charging current control where this design uses the hysteresis arrangement to avoid any unstable transition at the border line in the FLC. The proposed hysteresis arrangement interval is to be used in a sensitive, accurate, and stable operation.

The hysteresis method for the charging current control avoids a charging current that switches between high and low. This technique can keep the battery temperature stable, and the variation of the battery temperature will be limited to within 2 degrees. This stable battery temperature will extend the life-span of the battery.

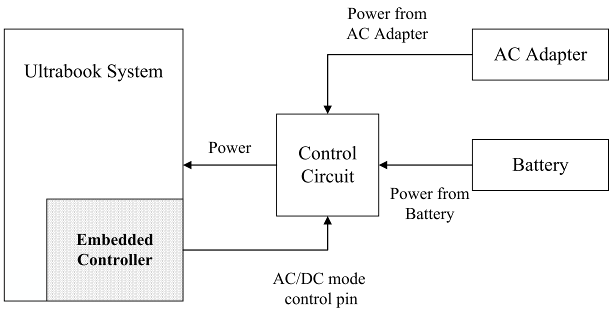

Fig. 7 AC/DC power supply controlled by the EC.

Figure 7 shows that the solution for this problem is to have the AC/DC power supply controlled by the EC. When the system enables the peak-shift function, the EC will change the system setting into the DC mode which can only supply the system power by means of the battery.

The safety issue of the battery operation of the ultrabook consists of three kinds of protection in a design: OVP (Over Voltage Protection), OCP (Over Current Protection) and OTP (Over Temperature Protection). When one of the three conditions has occurred, the protection will start, and in order to protect the battery, it can neither be charged nor discharged.

The EC will detect the state of the battery through a SMBus interface. If the battery is not functioning, the EC will retry to reset the battery. After it is reset, if it can't resume functioning, the EC will stop reading the battery status. The EC will switch to the AC Mode at once, and will cooperate with the application utility to show "The faulty information of the battery" on the LCD screen.

3. Implementation Results, Experiment Measurements

Table 3 shows the ultrabook specifications used for the measurement of this experiment.

For this experiment on ten different occasions this design has measured the power consumption of an ultrabook system within a period of 24 hours. The average measurement results of the peak/off-peak period are shown in Fig. 8 and Fig. 9.

According to the peak-shift rule shown in Fig. 3, the peak time is 09:00–17:00 and the off-peak time is 17:01–08:59. During the off-peak time, this design allows the ultrabook to begin to charge the battery.

After entering a peak period the EC switches the hardware circuit to the battery mode in order to use the battery energy during the peak period. But when the battery has been discharged to a capacity of 25%, the EC protects the battery from a deep discharge by switching to the AC mode to provide a power source for the operation. The rechargeable battery cannot be charged until the beginning of the off-peak period.

Figure 10 shows a battery's temperature change in the three different environmental temperatures: low temperature, room temperature, and high temperature. In the high-environmental temperatures, the battery temperature changes are greater.

Figure 11 shows the battery charging current for the FLC in the three different environmental temperatures. Be-

Table 3 The ultrabook specifications used for the measurement of this experiment.

Platform	Micro-architecture bridge
CPU	Dual Cores Mobile CPU (1.4GHz TDP 17W)
RAM	DDR3L-1600 4GB*1
HDD	SATA III SSD 256GB
Panel	11.6-inch (WXGA) (LED PANEL)
Battery	5600 mAH

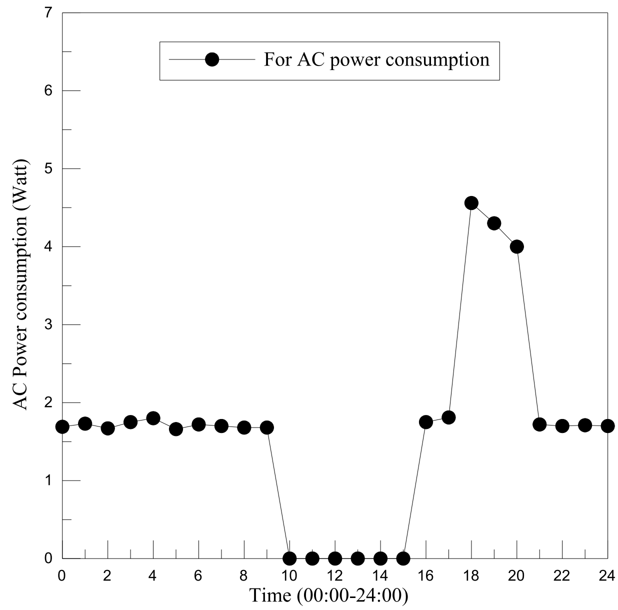

Fig. 8 AC power consumption measurements of the peak-shift control method.

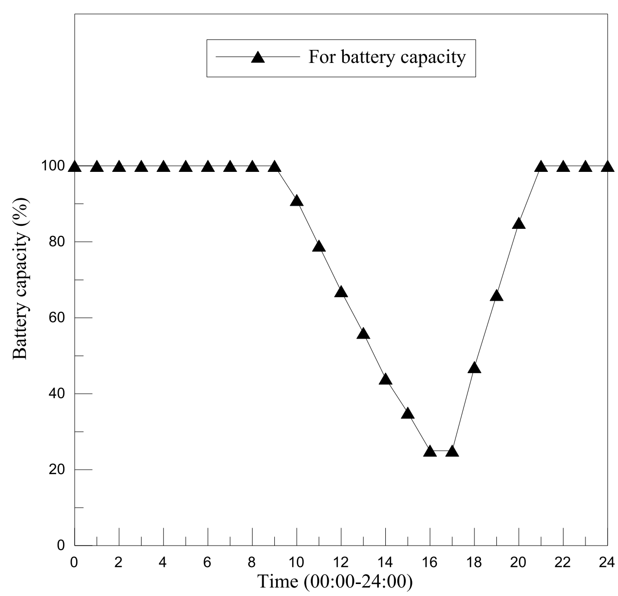

Fig. 9 Battery capacity measurements of the peak-shift control method.

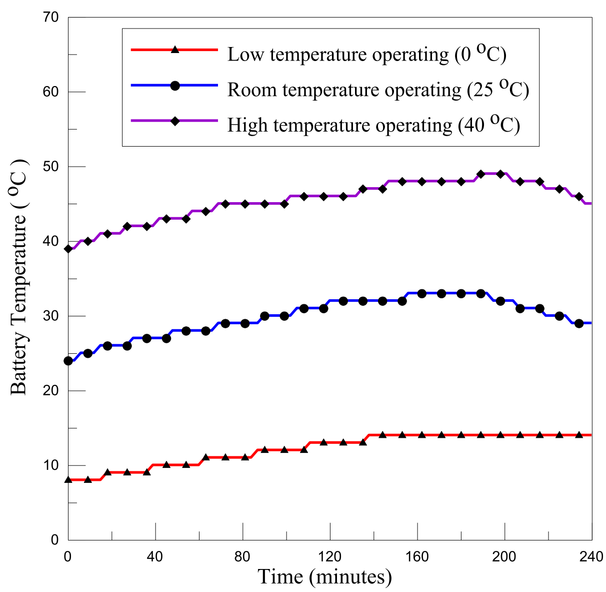

Fig. 10 Battery temperature changes during different environmental temperatures.

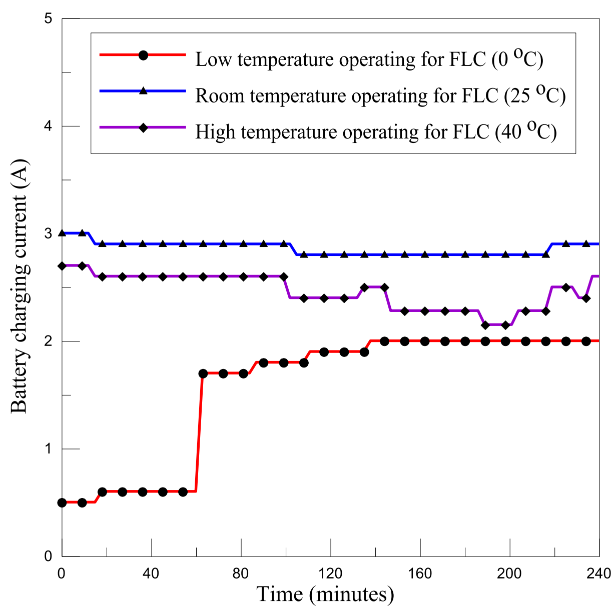

Fig. 11 The battery charging current for FLC during different environmental temperatures.

cause of the FLC method, this design obtains a very small change in each interval charging current as shown in Fig. 10. The FLC method can turn the charging current dynamically into a smooth style.

To balance the control complexity and efficiency, in this design the distribution of the battery integer temperature is divided into four integer ranges: [0°C, 10°C], [11°C, 20°C], [21°C, 45°C], [46°C, 55°C]. Figure 9 and Fig. 10 show the measurement results, while in the next range, this design follows the rule of Table 2 to decide the charging current and to obtain a smooth charging current transition

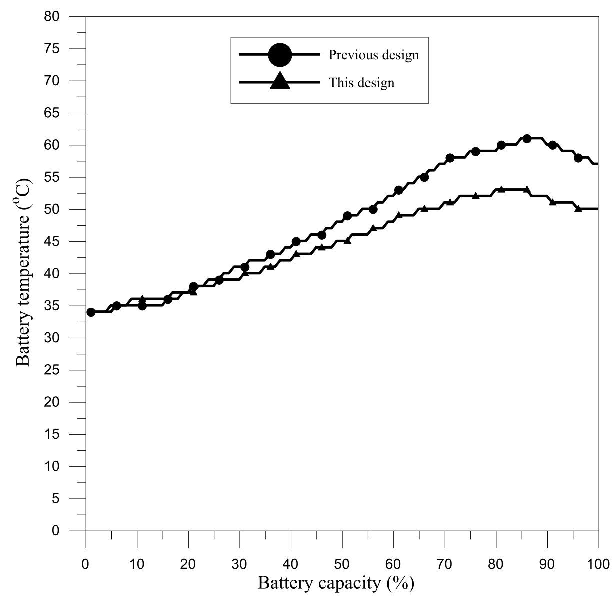

Fig. 12 The battery temperature variation measurement with respect to battery charging capacity of the previous design and of this design.

control.

If the charging current can be controlled and adjusted by a small variation amount with respect to the different temperatures, the battery life can be extended. The advantage of this FLC method is both simple and sensitive enough. Because the input value and output value are the only ones in this application, the FLC method is a better choice.

Figure 12 shows the battery capacity charging 0–100% with respect to the temperature variations at the high temperature operation condition with a 40°C environment.

The measurement results of Fig. 12 shows that the battery temperature of the previous design is higher than that of this design, because this design will dynamically control the charging current of the battery, and thus prevent any increasing of the battery temperature. If the battery temperature stays at a high level for a long time, the full capacity of the battery will decline sooner. In addition, the high temperature will shorten the life-span of the battery. However, this design may extend the charging time of the battery by dynamically reducing the charge current in order to keep the battery operating at a lower temperature that will protect the battery.

Figure 13 shows the measurement results of the battery capacity charging and discharging with respect to the number of the recharge times for the previous design and this design. This experiment provides both a charge and discharge of the battery for 100 times. The measurement shows the battery capacity variation of both the previous design and this design. Each charging and discharging cycle of the battery will slightly decrease the full capacity. If during each discharging cycle the decreasing amount of the full battery capacity can be reduced, then the battery's life-span will be lengthened.

Figure 13 shows our experiment measurement,

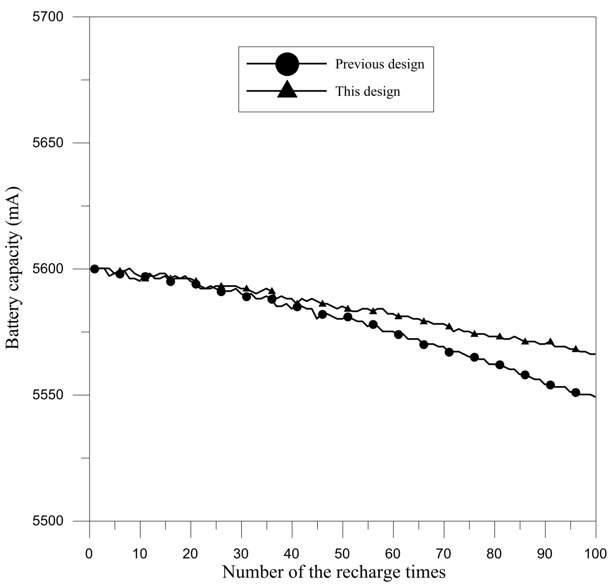

Fig. 13 Full battery capacity with respect to the number of the recharging times for the previous design and this design.

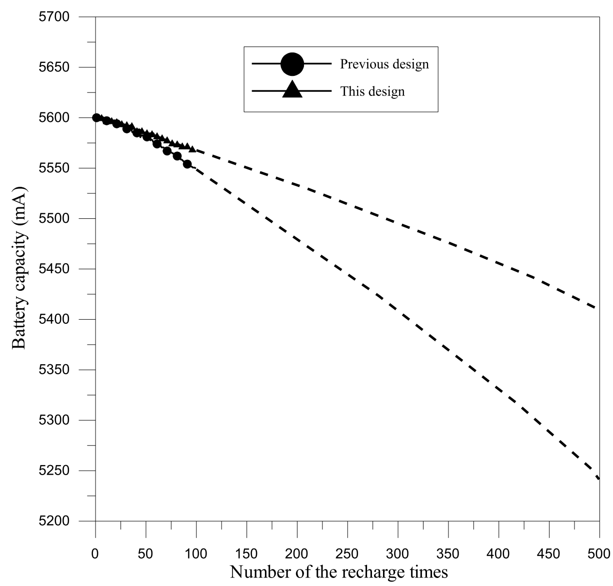

Fig. 14 Battery capacity with respect to the number of the recharging times from the measurement result to the prediction result.

whereby if the battery operates at a higher temperature, the battery capacity will decrease faster. Furthermore, if charging and discharging cycles are increased to 300–500 times, both designs will have an obvious full battery capacity difference.

The experiment also shows that the battery temperature will really influence the battery capacity. In addition, a higher battery temperature causes the decline of the battery life-span. This design dynamically controls the charge current and provides a better charging curve to avoid the battery temperature from becoming too high. The experiment measurement verifies this design's method which provides a lower battery temperature that helps to extend the battery life of a real ultrabook operation.

Because the experiment time is limited, we have performed the battery recharging procedure 100 times during these two months. The measurement of the decreasing battery capacity is shown by the solid lines in Fig. 14. In addition, the dotted lines in Fig. 14, show our prediction of the battery capacity reduction by extending the recharging times to 500 times.

4. Comparisons Design and User Interface

Table 4 compares this design with Design A and the previous design. This design provides a better charging control for the rechargeable battery and reduces the electricity bill.

"Design A", which is from Ref. [1], is a simple peak-shift control design. Our design provides the dynamically charging current control and the protection mechanism with the battery, which is not included in Ref. [1]. At a battery temperature of 0–55 degrees C, the fixed battery charging current and the charging voltage will age the battery and wear out soon, which with the previous designs will also increase the risk of the battery failure.

Table 4 A comparison of the previous design and this design.

	Design A	Previous design	This design
Dynamic control of the battery charge	No	No	Yes
Protection of the battery (Prevention of high voltage/high current when charging)	No	Yes	Yes
Reduced use of peak electricity energy	Yes	Yes	Yes
Reduced electricity bill	Yes	Yes	Yes

The "Previous design" is from the previous paper. This enhanced version includes the following features:

a. This design, which improves Fuzzy Logic Controller (FLC) designs, does not need to specifically define each charging current and charge voltage that the temperature corresponds to. This FLC will automatically set up the electric charge current and the charge voltage based on its sense of the present condition and produce the appropriate output values.
b. This design, which utilizes the hysteresis method for the charge current, avoids any charge current having a high one second and a low the next second at the switching point. Hence, this design will increase the life-span of the rechargeable battery.
c. This design enhances the safety of the rechargeable battery, which has improved three kinds of protection functions: OVP (Over Voltage Protection), OCP (Over Current Protection) and OTP (Over Temperature Protection).

When an abnormal situation among any of them takes place in the rechargeable battery, this design will suspend the abnormal battery charging situation at once, by resetting the charge IC. After the abnormal situation is fixed, this design will resume the charge, and then continue operating the

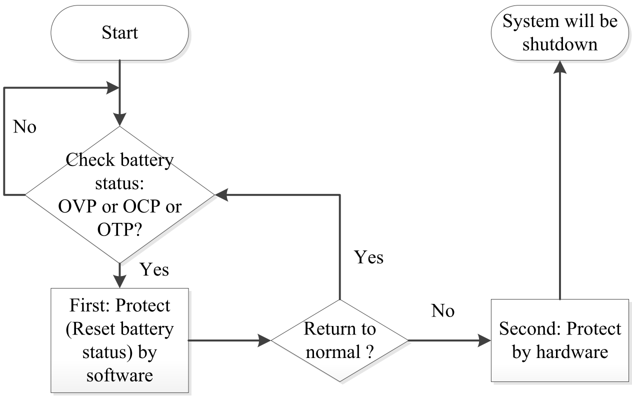

Fig. 15 Flowchart of battery protect by software and hardware.

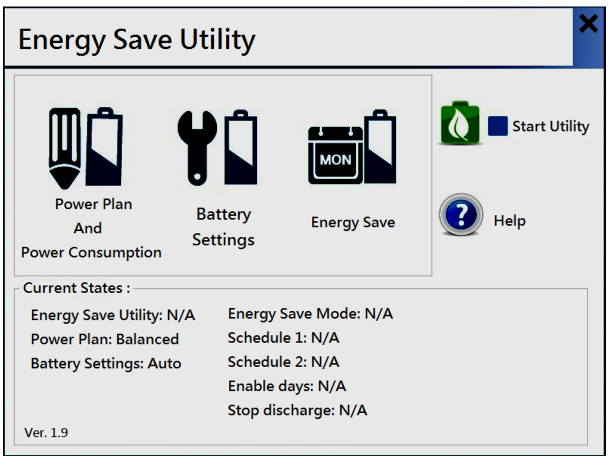

Fig. 16 User interface used in the Energy Save Utility.

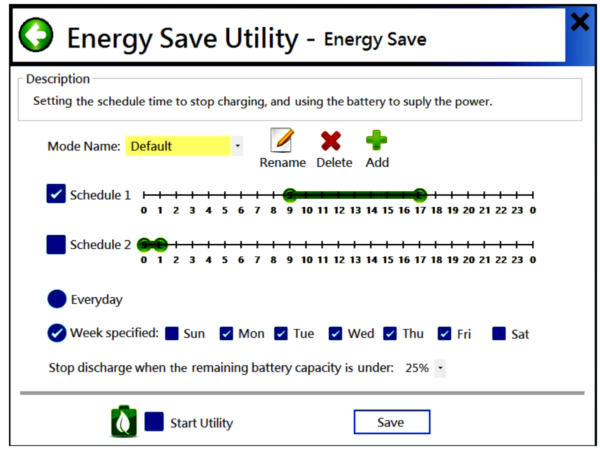

Fig. 17 The user peak-shift function setting.

rechargeable battery again.

A protection system used as a rechargeable battery, such as OVP, OCP, or OTP is a basic protection mechanism which is controlled by the hardware. If the hardware protection mechanism executes and the rechargeable battery is in a time-out state, the protection system must shutdown and turn the power off. When the power is turned on again, the protection system will resume its previous operation status.

This design, by using the FLC method, provides both OVP, OCP, and OTP, which together serve as a software protection mechanism of the rechargeable battery, instead of the hardware protection mechanism.

When the operation of the rechargeable battery requires the hardware protection for OVP, OCP and OTP, the software protection OVP, OCP and OTP, by starting earlier, will recover the error status of the rechargeable battery.

For example: When the operation of the rechargeable battery is controlled by the hardware protection OTP, the software protection OTP will start a fan to operate at a high speed, and, by reducing the battery temperature, will avoid executing the rechargeable battery protection mechanism and instead will start the rechargeable battery OTP and then stop it at the correct time.

Figure 16 shows the user interface of the application program which includes a peak-shift function, a monitoring system consumption function and a power-saving function.

Figure 17 shows the user interface of the peak-shift function which indicates both the peak time and off-peak time setting and which work days should be selected. “The remaining battery capacity” setting provides a user with three selection choices of the lower limits: 15%, 20%, and 25%.

This design also provides a default setting if the user does not desire to select any items, and it will automatically use the peak-shift control method together with FLC to reduce the use of peak electricity energy by the ultrabook systems.

5. Conclusion

This design uses the peak-shift control method together with FLC to reduce both the use of peak electricity energy by the ultrabook systems and the total monthly electricity bill, especially during the summer peak periods of electricity demand. In addition to dynamically controlling both the charging voltage and the charging current, by establishing different conditions for different temperatures, this design prevents the battery from attaining either extremely high current or high voltage states, both of which may shorten the life of a rechargeable battery. This method also prevents the battery from discharging deeply.

This paper is an enhanced version of Ref. [23] which provide the major advantages as follows. This design improves the FLC method to dynamically control the charge current, so the charge current is smooth, in order to extend the life of the rechargeable battery. When the rechargeable battery temperature is high, the control system must either reduce the charging current or stop charging, because the rechargeable battery will have degradation characteristics if it operates at a high temperature. This design, by using the FLC method, fine-tunes the charging current control under different operational temperatures, and thus extends the life of the rechargeable battery.

In addition, this design enhances the protection of the battery, by providing the protection mechanism of either OVP (Over Voltage Protection), OCP (Over Current Protection) or OTP (Over Temperature Protection), which avoids using any high level charging current or charging voltage and therefore keeps the battery at a low temperature in order that the battery will maintain a continuously stable state for the notebook.

In addition, this FLC design provides dynamically charging current based on both the charge voltage and the battery temperature. Overall, this design extends the life of the rechargeable battery by using a better charging current curve based on the operation condition of the battery.

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References

[1] M. Hatori, "Peak-Shift Method for Notebook Computers - a power management approach for load leveling," IEEE International Symposium on Electronics and the Environment, pp.117–121, May 2004.

[2] H. Takahashi, K. Matsuda, Y. Tomita, T. Oda, and E. Isozaki, "Peak-Shift Method for Reducing Facility Cost of Distribution System," IEEE China International Conference on Electricity Distribution, pp.1–4, Sept. 2012.

[3] K. Schmidt, "On the peak-to-mean envelope power ratio of phase–shifted binary codes," IEEE Trans. Commun., vol.56, no.11, pp.1816–1823, 2008.

[4] A. Mutapcic, S. Boyd, S. Murali, D. Atienza, G. De Micheli, and R. Gupta, "Processor Speed Control with Thermal Constraints," IEEE Trans. Circuits Syst. I, Reg. Papers, vol.56, no.9, pp.1994–2008, Sept. 2009.

[5] K. Hansen and C. Reckleben, "Spectral peak shift of Si-drift detectors with integrated JFETs," IEEE Trans. Nucl. Sci., vol.51, no.3, pp.1283–1288, June 2004.

[6] W.C. Karl and H.H. Pien, "High-resolution biosensor spectral peak shift estimation," IEEE Trans. Signal Process., vol.53, no.12, pp.4631–4639, Nov. 2005.

[7] J.K. Son, T. Sakong, S.N. Lee, H.S. Paek, H. Ryu, K.H. Ha, O. Nam, Y. Park, J.S. Hwang, and Y.H. Cho, "Comprehensive study of time-lapsed peak shift in InGaN quantum well structures: Discrimination of localization effect from internal field effect," IEEE Trans. Applied Physics, vol.90, no.5, 051918, Feb. 2007.

[8] D. Dai and J. Liu, "Design of a practical human-powered contactless charger for cellphone," IEEE Trans. Consum. Electron., vol.59, no.3, pp.476–482, Oct. 2013.

[9] T. Mundra and A. Kumar, "An Innovative Battery Charger for safe Charging of NiMH/NiCd Batteries," IEEE Trans. Consum. Electron., vol.53, no.3, pp.1044–1052, Oct. 2007.

[10] K. Qian, C. Zhou, M. Allan, and Y. Yuan, "Modeling of Load Demand Due to EV Battery Charging in Distribution Systems," IEEE Trans. Power Syst., vol.26, no.2, pp.802–810, May 2011.

[11] J. Zhang, G. Song, Y. Li, G. Qiao, and Z. Li, "Battery swapping and wireless charging for a home robot system with remote human assistance," IEEE Trans. Consum. Electron., vol.59, no.4, pp.747–755, Dec. 2013.

[12] T. Mundra and A. Kumar, "Micro power battery state-of-charge monitor," IEEE Trans. Consum. Electron., vol.54, no.4, pp.623–630, July 2008.

[13] S. Armstrong, M.E. Glavin, and W.G. Hurley, "Comparison of battery charging algorithms for stand alone photovoltaic systems," IEEE Power Electronics Specialists Conference, pp.1469–1475, June 2008.

[14] G.-C. Hsieh, L.-R. Chen, and K.-S. Huang, "Fuzzy-controlled Li-ion battery charge system with active state-of-charge controller," IEEE Trans. Ind. Electron., vol.48, no.3, pp.585–593, June 2001.

[15] H.-C. Kim, O. Urhan, and T.-G. Chang, "Post-filtering of DCT Coded Images Using Fuzzy Blockiness Detector and Linear Interpolation," IEEE Trans. Consum. Electron., vol.53, no.3, pp.1125–1129, Oct. 2007.

[16] J. Jiang, C. Zhang, J. Wen, W. Zhang, and S.M. Sharkh, "An Optimal Charging Method for Li-Ion Batteries Using a Fuzzy-Control Approach Based on Polarization Properties," IEEE Trans. Veh. Technol., vol.62, no.7, pp.3000–3009, Sept. 2013.

[17] S.-H. Lee and Z. Bien, "Design of expandable fuzzy inference processor," IEEE Trans. Consum. Electron., vol.40, no.2, pp.171–175, May 1994.

[18] I.-H. Li, W.-Y. Wang, S.-F. Su, and Y.-S. Lee, "A Merged Fuzzy Neural Network and Its Applications in Battery State-of-Charge Estimation," IEEE Trans. Energy Convers., vol.22, no.3, pp.697–708, Sept. 2007.

[19] A.F. Gobi and W. Pedrycz, "Logic Minimization as an Efficient Means of Fuzzy Structure Discovery," IEEE Trans. Fuzzy Syst., vol.16, no.3, pp.553–566, June 2008.

[20] X.X. Fu and X. Xie, "The Control Strategy of Flywheel Battery for Electric Vehicles," IEEE International Conference on Control and Automation, pp.492–496, June 2007.

[21] T.-F. Wu, C.-H. Chang, and Y.-H. Chen, "A fuzzy-logic-controlled single-stage converter for PV-powered lighting system applications," IEEE Trans. Ind. Electron., vol.47, no.2, pp.287–296, April 2000.

[22] X. Li, "Fuzzy adaptive kalman filter for wind power output smoothing with battery energy storage system," Renewable Power Generation IET, vol.6, no.5, pp.340–347, Sept. 2012.

[23] C.-H. Cheng and Y.-W. Bai, "A Peak-Shift Control Method for Charging and Discharging of the Battery in an Ultrabook," IEEE International Conference on Consumer Electronics, pp.296–297, Jan. 2014.

[24] C.-H. Cheng and Y.-W. Bai, "Using Fuzzy Logic and Light-Sensor for Automatic Adjustment of Backlight Brightness in a Mobile Computer," 16th IEEE International Symposium on Consumer Electronics, USA, pp.47–51, June 2012.

[25] H.-C. Chin, "Fault section diagnosis of power system using fuzzy logic," IEEE Trans. Power Syst., vol.18, no.1, pp.245–250, Feb. 2003.

[26] S.K. Yee and J.V. Milanovic, "Fuzzy Logic Controller for Decentralized Stabilization of Multimachine Power Systems," IEEE Trans. Fuzzy Syst., vol.16, no.4, pp.971–981, Aug. 2008.

[27] S. Almukhaizim and O. Sinanoglu, "Dynamic Scan Chain Partitioning for Reducing Peak Shift Power During Test," IEEE Trans. Comput.-Aided Design Integr. Circuits Syst., vol.28, no.2, pp.298–302, Feb. 2009.

[28] T. Fuse, Y. Kawano, M. Suzuki, Y. Aoyagi, and K. Ishibashi, "Coulomb peak shifts under terahertz-wave irradiation in carbon nanotube single-electron transistors," IEEE Trans. Applied Physics, vol.104, no.12, 123515, Jan. 2008.

[29] Q. Xie, X. Lin, Y. Wang, M. Pedram, D. Shin, and N. Chang, "State of health aware charge management in hybrid electrical energy storage systems," Proc. Design Automation and Test in Europe (DATE), pp.1060–1065, March 2012.

[30] T. Yuksel and J. Michalek, "Evaluation of the effects of thermal management on battery life in plug-in hybrid electric vehicles," Proc. Society of Automotive Engineers World Congress, pp.671–680, April 2012.

Chun-Hung Cheng is currently working toward the Ph.D. degree in Graduate Institute of Applied Science and Engineering at Fu Jen Catholic University, Taiwan. His research interests include low power system design, mobile computing, and embedded computer systems. He holds a post in CLEVO Company and takes on the position of software design department of research and development centre at present.

Ying-Wen Bai is a professor in the Department of Electrical Engineering at Fu Jen Catholic University. His research focuses on mobile computing and microcomputer system design. He obtained his M.S. and Ph.D. degrees in electrical engineering from Columbia University, New York, in 1991 and 1993, respectively. Between 1993 and 1995, he worked at the Institute for Information Industry, Taiwan.