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Economic and Energy Efficient Design Method for a Green Wireless Telecommunication Power System

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Abstract

This paper presents an energy efficient design and an operational method for a Li-ion battery powered wireless telecommunication power system. Wireless telecommunication service providers have strived for reducing the Operating Expenditure (OPEX) of their Base Stations (BTS) because an urban BTS consumes more power as the data uses of mobile subscribers increase in these days. Thus, in order to reduce the OPEX, mobile service providers have studied for a green BTS which uses less electricity from the main power grid for its normal operation with renewable or alternative energy sources. Because these energy sources require high Capital Expenditure (CAPEX), a green telecommunication power site without a proper design and operational plan may increase the Total Cost of Ownership (TCO) that includes OPEX and CAPEX. Although such capital investment can be retrieved over time, few wireless service providers seem to have focused on the TCO reduction of a green BTS for its planning and designing stage. Therefore, this paper proposes an energy efficient design and an operational method for a green telecommunication power system which uses a Li-ion battery to reduce its TCO. To achieve this TCO reduction, the proposed paper considered various aspects including BTS energy profile, electricity rate, battery health and lifetime, charging and discharging cycle for a battery in the wireless telecommunication power system.

Keywords: CAPEX, Green Telecommunication Power System, OPEX, TCO

1. Introduction

This paper presents an energy efficient design and an operational strategy of a green telecommunication system powered by a Li-ion battery. A worldwide wireless telecommunication industry in 2010 consumed about 120 TWh of which energy expense was equal to $13 billion according to the GSM association manifesto 2012[1]. This mobile telecommunication network used almost 80 TWh electricity from a conventional utility grid, and the reminder (i.e., 40 Twh) was powered by back-up power sources such as diesel generators[1]. This high energy use in the wireless telecommunication power system seems to be attributed to its high speed broadband growth (e.g., LTE, LTE-A, and 5G). Thus, wireless telecommunication service providers have strived for reducing an Operating Expenditure (OPEX) because an urban Base Station (BTS) consumes more power as the data uses of mobile subscribers increase in these days. This power increase tendency is also true for a rural BTS because of its wide coverage area. Thus, in order to reduce an OPEX, mobile service providers and researchers have studied for a green BTS which uses less electricity from the main power grid for its normal operation with renewable or alternative energy sources such as solar, wind, fuel cells, and battery systems[2-4].

However, a green BTS without a proper design or an operational strategy may increase the Total Cost of Ownership (TCO) because these renewable and alternative energy sources typically requires high Capital

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Expenditure (CAPEX)[5]. Although such capital investment can be retrieved over time, few wireless network service providers and researchers seem to have been focused on the TCO of a green BTS. Therefore, this paper proposes a design and operational strategy for a green BTS which uses a Li-ion battery to reduce its TCO which includes both OPEX and CAPEX.

In order to confine its alternative energy source, the scope of this work is limited to a battery powered BTS because the OPEX of the BTS can be reduced with the replacement of a lead-acid battery to a Li-ion battery of which charging and discharging cycle is significantly increased. This BTS powered by a Li-ion battery can still be called by a green BTS because it uses an alternative energy source (i.e., Li-ion battery) which can be actively charged and discharged to reduce the OPEX of a BTS instead of using a back-up battery like a lead-acid battery in the traditional BTS.

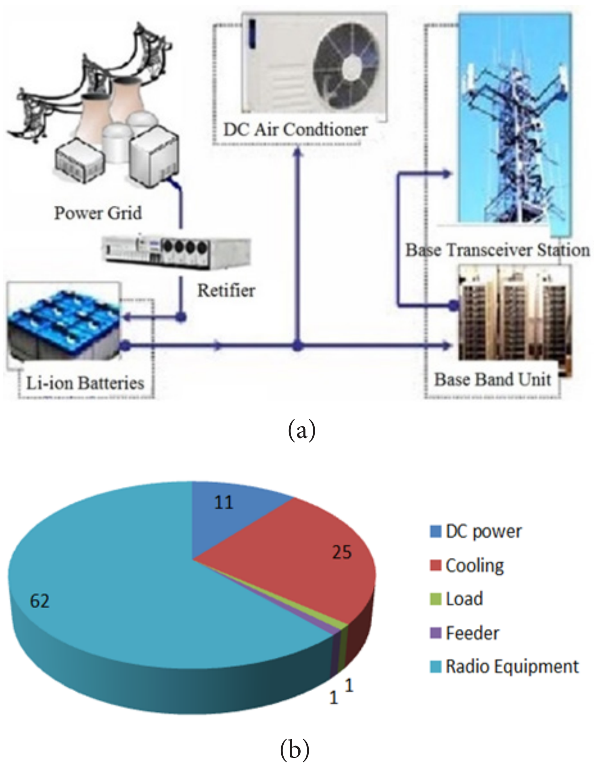

Figure 1. Power flow and energy profile of a Li-ion battery powered BTS, (a) Power flow of a Li-ion battery powered BTS and (b) Energy profile of a Li-ion battery powered BTS.

The organization of this paper is as follows: the Section II discusses the factors influencing on the BTS TCO which includes an energy profile in a green BTS, various electricity rates in a smarter grid, and battery lifetime depending on its charging and discharging cycle. The Section III describes an economic and energy efficient design method and an operational strategy of a green telecommunication system powered by a Li-ion battery. Finally, this paper concludes in the Section IV with the summary of findings.

2. Factors Influencing on BTS Expenditure

In order to reduce the TCO of a Li-ion powered wireless telecommunication power system, the system designer and operator of the BTS should consider various factors influencing on the BTS expenditure including its energy profile, various electricity rates in a smarter grid, and the battery lifetime with its charging and discharging cycle. In this section, the energy profile of a target green BTS and the electricity rate structure are firstly discussed. Then, the battery lifetime with its charging and discharging cycle is described for optimizing the TCO of the green BTS.

2.1 Energy Profile of a BTS

Figure 1(a) shows the power flow of a Li-ion battery powered medium-class BTS which includes a power line from the main grid, a rectifier, Li-ion battery packs, a DC powered air conditioner, a base band unit and a base transceiver station. This medium-class BTS typically consumes power ranged from 1 kW to 2 kW[6]. In order to reduce the TCO of this BTS, its energy profile should be firstly considered because the charging and discharging cycle of its battery packs are required to be optimized by the energy consumption profile. The majority of BTS energy is typically consumed in radio equipment (62%), dc power (11%), and cooling devices (25%) as depicted in Figure 1(b).

2.2 Electricity Rate Structure in a Smarter Grid

In a smarter grid, various electricity rates such as time-of-use rate, day-ahead rate, demand response rate and real-time based electricity rate are expected to emerge in the market. Thus, this complex electricity rate structure should be considered to optimize a charging and discharging schedule for a Li-ion battery to reduce the OPEX of a green BTS.

2.2.1 Time-of-use Electricity Rate

A Time-Of-Use (TOU) electricity rate is not to price electricity in a fixed rate but to price electricity with different rates depending on off-peak, mid-peak, and on-peak time by seasons such as summer and winter as shown in Table 1. This TOU rate is designed by the basic rule that electricity price is reduced during the off-peak time and its rate increases for the peak-time in which electricity demand increases. The off-peak, mid-peak, and on-peak time are different by seasons as shown in Table 1 because electricity demand is different by seasons. Table 1 and 2 shows an example of this TOU electricity rate[7] used by HydroOne which is an electricity service provider in Ontario, Canada. Although this TOU rate may reduce electricity demand during the on-peak time, one of its problems is that an electricity service company still cannot solve the electricity supply deficiency when its demand sharply increases due to a severe daily weather change in summer and winter. Therefore, in order to handle this imbalance problem between electricity supply and demand, electricity service providers present various electricity market prices such as day-ahead rate, hour-ahead rate, demand response rate, and real-time based electricity rate.

Table 1. Time-Of-Use period example

	Summer Pricing (May 1 ~ Oct. 31)	Winter Pricing (Nov. 1 ~ Apr. 30)
Off-peak	19:00 ~ 07:00	19:00 ~ 07:00
Mid-peak	07:00 ~ 11:00 17:00 ~ 19:00	11:00 ~ 17:00
On-peak	11:00 ~ 17:00	07:00 ~ 11:00 17:00 ~ 19:00

Table 2. Time-Of-Use electricity rate example

Symbol	Summer/Spring/Fall Pricing	Winter Pricing
Off-peak	7.5 ¢/kWh	7.2 ¢/kWh
Mid-peak	11.2 ¢/kWh	10.9 ¢/kWh
On-peak	13.5 ¢/kWh	12.9 ¢/kWh

2.2.2 Day-ahead Electricity Rate

A day-ahead electricity rate is to price its tomorrow rate based on the electricity supply and demand a day ahead. As aforementioned, the TOU rate may encounter the problem that electricity supply may be lacking with its demand sharply increase due to a severe sudden weather change because this TOU rate determines the electricity price based on the average electricity consumption in a year. The day-ahead electricity rate can compensate for this TOU electricity rate problem because it is based on the day-ahead weather forecast. For instance, if there is a high chance to be cold or hot tomorrow, the electricity demand tomorrow will increase in a large amount. Thus, the bidding electricity price by electricity suppliers would increase based on the balance between the electricity supply and demand. Therefore, the electricity price may be different by every day in the same season unlike the TOU rate.

2.2.3 Demand Response Electricity Rate

A demand response electricity rate is a method to increase electricity reserve although a new power plant is not installed. In the demand response electricity rate, an electric customer should pay high electricity price during the peak time so that the electricity demand is going to decrease. This demand response electricity rate decreases the construction cost of a potential new power plant. Therefore, this demand response is also called by a virtual power plant.

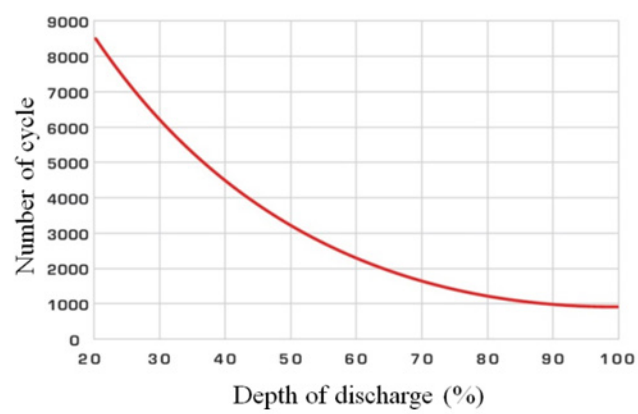

Figure 2. Typical battery cycle life vs. depth of discharge at 20°C

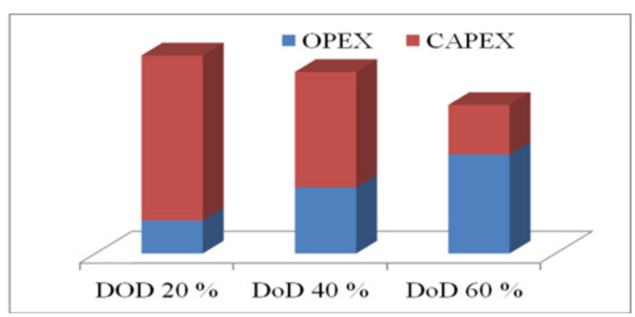

Figure 3. TCO comparison based on different DOD levels.

2.2.4 Real-time based Electricity Rate

A real-time based electricity rate is to price its rate in a real time based on the electricity supply and demand similar to a day-ahead electricity rate. However, the time interval of this real-time based electricity rate is shorter than that of a day-ahead or an hour-ahead electricity rate.

2.3 Battery's Lifetime vs. Total Cost of Ownership

Figure 2 shows the typical battery lifetime according to the Depth of Discharge (DOD) of a battery at 20°C. This DOD represents the percentage of the battery discharge quantity that can be defined as an energy use of the full-charged battery. For instance, if 30% percentage of battery energy is discharged from the full state-of-charge battery, the DOD is 30%. This DOD can also be related with a battery State of Charge (SOC), and their relationship can be defined as follows:

$$DOD(\%) = 100 - SOC(\%), \quad (1)$$

where *DOD* (%) is a percentile depth of discharge in a battery, and *SOC* (%) is a percentile state of charge in the battery. As shown in Figure 2, this DOD is negatively correlated with a battery lifetime which is the capability of charging and discharging cycles. Thus, a battery lifetime increases if the battery is not deeply discharged (i.e., low DOD) whenever the battery is used. This means that less use of battery results in improving battery lifetime.

Figure 4. Optimized battery cycling strategy for improving return on investment.

Therefore, if the battery pack in the green BTS is operated in the low level of DOD at all time, the battery replacement cost which is one of operating expenditure (i.e., OPEX) in the BTS can decrease. Figure 3 shows an example of comparison data on the Total Cost of Ownership (TCO) with different Depth of Discharges (DOD). This TCO can be defined by the sum of the Operating Expenditure (OPEX) and the Capital Expenditure (CAPEX). As depicted in Figure 3, the low level of DOD (e.g., DOD 20%) elongates the battery cycling so that the OPEX of a green BTS in this low DOD is less than that in the high level of DOD (e.g., DOD 60%). As shown in Fig. 3, however, the CAPEX in the low DOD (e.g., DOD 20%) is greater than that in the high DOD (e.g., DOD 60%). This is because the green BTS may need a large number of battery packs to meet the required back-up time of the system with its low energy use. Thus, in the case of the low DOD in the battery, the initial battery installation cost (i.e., CAPEX) may increase as shown in Figure 3.

3. Economic and Energy-efficient Design Method

This section describes an optimized battery charging and discharging cycling strategy for increasing return on investment by transitioning from lead-acid batteries to Li-ion batteries in the wireless telecommunication Base Station (BTS). As discussed in the previous section, a green BTS power system designer should balance between OPEX and CAPEX to decrease the TCO of the green BTS as illustrated in Figure 4. In this way, the green BTS can be operated with an energy efficient and cost-effective method. The drastic strategy for improving the lifetime of a Li-ion battery is that the battery is not always deeply discharged (i.e., low DOD). However, this method increases the TCO of the power system because its CAPEX increases by enlarging its battery capacity to ensure the reliability of the system. Hence, it is important to balance between the OPEX and the CAPEX of a target telecommunication power system.

3.1 Battery Cycling Strategy based on a BTS Location

In addition, different battery charging and discharging strategies should be applied to various target locations in which the green BTS is installed. For example, if a green BTS needs to be installed in India, it should be equipped with a large capacity battery to ensure back-up time for several days as shown in Table 3. This is because the power quality of electricity market in India is very poor so that there are frequent planned blackouts. If the green BTS in India is operated by the low DOD to improve the lifetime of battery (i.e., low OPEX), a telecommunication service provider to install the green BTS in India should sacrifice the CAPEX that requires a large number of battery to support the long back-up time for the target system. This method eventually results in a negative impact on return on investment due to an increased TCO. On the other hand, if the target location of a green BTS is in Europe, the required battery capacity of the green BTS may be small. This is because the back-up time of a BTS in Europe is only about 5 minutes due to its reliable utility grid with good power quality as shown in Table 3. For this reason, the low DOD operation of a green BTS in Europe can decrease the OPEX of the system by improving the battery lifetime without sacrificing the CAPEX. Lastly, the medium capacity of battery is required for a BTS power system in the USA because its back-up time requirement is about 4 to 8 hours due to frequent natural disasters as shown in Table III. Hence, the low DOD operation of a green BTS in the USA can also decrease its OPEX although it may also increase its CAPEX.

Table 3. Battery requirement and CAPEX based on BTS site locations

Location	Required back-up time	Power quality (PQ)	Battery capacity	CAPEX
Europe	5 min.	Reliable	Small	Small
USA	4~8 hr.	Frequent natural disaster	Medium	Medium
India	Several days	Low PQ, Frequent blackout	Large	Large

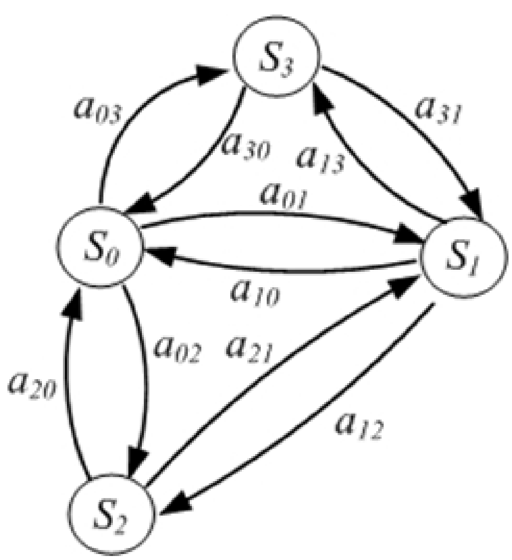

Figure 5. Markov chain state diagram for a TCO optimization method.

3.2 Optimization Method

An optimized charging and discharging strategy is required for improving the TCO of a green BTS. The ultimate goal of this optimized battery cycling strategy is to maximize the use of Li-ion battery which can be quickly charged and discharged actively. In this way, the CAPEX of a green BTS is reduced by the small number of batteries although the OPEX of the BTS is not sacrificed.

The objective function of the optimization method is to increase the battery lifetime of a green BTS and to minimize its TCO. The constraints of this objective function are the energy load profile of the target green BTS, various electricity rates in a smart grid and battery lifetime as previously discussed in the Sections II.A and II.B. Then the objective function can be defined as follows:

$$f(\alpha_n, \beta_n, BL_n, TCO_n) = \min\left(\sum_{i=1}^{N}\sum_{j=1}^{M} f(BL_i, TCO_j)\right), \quad (2)$$

where α_n denotes an energy load profile, β_n represents various smart grid electricity rates, BL_i indicates the battery lifetime, and TCO_j means the total cost of ownership. To solve (2), the particle swarm optimization method proposed by[8] can be used. This optimization method is to use the algorithm of which particles search a solution. Specifically, this algorithm uses candidate solutions which are to be searched for finding the best solution. In addition, a Markov chain algorithm[9] illustrated in Figure 5 can be used to optimize the TCO of the target green BTS. In Figure 5, S_0 represents the grid powered condition in which the battery of the green BTS is neither charged nor discharged. S_1 denotes the grid powered and charging state in which the battery of the green BTS is charged and the BTS also uses the grid energy. S_2 indicates the grid powered and discharging state in which the battery of the green BTS is discharged and the BTS also uses the grid power. Lastly, S_3 is the discharging state in which the battery of the green BTS is only discharged without the grid power.

4. Conclusion

This paper presented an energy efficient design and an operational method of a green telecommunication system powered by a Li-ion battery in order to reduce its TCO. In order to design such operational method of a green wireless telecommunication system, this paper considered its energy profile and various electricity rates in a smarter grid, battery health and lifetime, and charging and discharging cycle for BTS batteries. Based on the analysis presented in this paper, it can be concluded that a green BTS power system designer should balance between OPEX and CAPEX to decrease its TCO.

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