

ESS SoC Optimization System Using EV Control

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Abstract— Peak shaving is an important technology in power grid. Many studies on peak shaving are being conducted, using ESS, shiftable load, and V2G. However, they do not consider of the ESS SoC and supply power reduction because they are only for peak shaving. ESS SoC is related to battery life which is directly linked to costs. Reduction supplying power causes problems that uncertainty and inconvenience to customers. Therefore, it is necessary to consider the problems of peak shaving. This paper presents ESS SoC optimization by controlling that charging and discharging of EV. It can reduce supplying power and peak shaving.

Keywords— Smart Grid, ESS, Peak Shaving, V2G, SoC

I. INTRODUCTION

Smart grid (SG) is a major area at power grids. And it has received attention. In contrast to traditional power grids, SG transmits energy by constructing automated and distributed network through two-way flow of electricity and information. Information in SG is used to efficiently power. SG can respond to a wide range of conditions and events [1].

Various peak shaving methods are being studied because of problem which is peak load by suddenly increase power usage. Energy Storage System (ESS) can solve power quality problem by providing service of peak shaving and load shifting in power grid. ESS discharges power when peak load occur [2]. A system is required to balance with supply and demand through intelligent command [3]. Shiftable load has received attention to response demand and reduce peak load [4]. Shiftable load is controlled in two ways: power shift for reduces load and time shift for delays load [5]. In addition, Vehicle to Grid (V2G) system that uses Electric Vehicle (EV) as a resource is proposed as a control of peak shaving. Peak shaving using V2G is effectively controlled [6]. Strategically using V2G for home ESS can reduce maximum load on grid [7].

ESS have minimal power for peak load of response. If ESS State of Charge (SoC) is low when peak load occur, peak shaving is insufficient. Therefore, ESS SoC should maintain specific SoC to respond peak load. Also, ESS is required minimum capacity for self-protecting battery and proper SoC for battery life.

Peak shaving system using shiftable load involve customers and it modifies power consumption patterns. Because resource for peak shaving is power supplied to customer, they have uncertainty about power. Also, delays in control of shiftable load can cause inconvenience to customers [8].

In addition, when peak shaving v through V2G, system use power of charge about customer's EV. Customers with EV does not receive service for power when peak load occurs. Therefore, it is necessary to operate V2G system with minimum EV power consumption.

This paper proposes a system that control charging and discharging of EV to solve problem previously described. So, we propose a system to control of EV charge and discharge. It also calculates criterion for control of EV charging and discharging. It mitigates problem of reducing customer's supplied power. It calculates amount of discharge by considering SoC for each EV.

In this paper, controllable power for peak shaving of ESS is improved. and optimum ESS SoC is maintained. Also, In order to minimize reduction of supplied power, shiftable load control is reduced and power requirements for each EV are achieved.

Chapter 2 discusses research related to peak shaving and ESS SoC. Chapter 3 proposes a system that controls charging and discharging of EV. In Chapter 4, performance of ESS SoC optimization and reduction of supplied power are simulated. Chapter 5 presents a conclusion.

II. RELATED WORK

A. ESS SoC

ESS should have SoC to minimum power (10%) for self-protect [9]. Therefore, additional system is required to maintain power in ESS. In addition, studies have been conducted to schedule SoC for reduce battery stress, extend battery life, and reduce electric bill [10]. This relate cost. When system responds to peak load through ESS, SoC decrease as much as it responds. Therefore, ESS SOC should be maintained through additional peak shaving or power supply.

B. Peak shaving

Method of controlling shiftable load and making peak shaving has long been studied. Recently, research has been carried out to perform peak shaving by link data prediction with shiftable load. in [11], it optimizes user energy consumption through predefined demand energy. Due to uncertainty in existing peak forecast, an energy consumption scheduling model was proposed to minimize customer's energy cost.

In addition, V2G has been proposed to utilize power of EV. In [12], it proposes a method to response with peak load by switching between V2G and G2V. It can be charged during off peak time and discharged during peak time for peak shaving. in [13], EV are linked with PV and ESS for reduce maximum load.

Much research is being done on peak shaving for operation of power grid, but issue of ESS SoC is not considered. Also, as described in [8], peak shaving creates uncertainty and discomfort about power supply to customers. Therefore, it is required to optimize ESS SoC by minimizing reduction of supply power.

III. PROPOSED SYSTEM

Proposed system controls charging and discharging of EV in order to maintain optimum ESS SoC. It also prevents reduction power that customers are supplied.

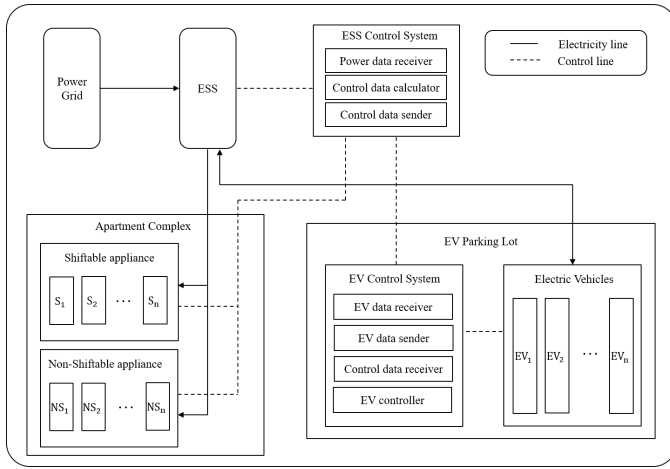


Figure 1. System architecture

A. System Architecture

Figure 1 is overall system architecture. ESS receives power from power grid. It supplies power to Shiftable appliance and Non-Shiftable appliance in apartment complex. Each EV in EV Parking Lot either charges or discharges power from ESS.

Control of charge and discharge for each EV is decided by the following process. 'EV Control System' uses 'EV data receiver' to collect power information for each EV. Then it sends power information to 'ESS Control System' using 'EV data sender'. 'ESS Control System' uses 'Power data receiver' to collect power information from EV, ESS, Shiftable appliance, Non-Shiftable appliance. It determines that each EV charge or discharge power using the 'Control data calculator'. It sends control data from each EV to the 'EV control System' using the 'Control data sender'. 'EV Control System' receives control data from each EV using 'Control data receiver' and uses 'EV controller' to control charging and discharging of each EV.

B. Criterion for Charging and Discharging Control

Procedure for determining charging and discharging of EVs is as follows:

$$L_{n,t}^{ev} = SW_{n,t}^{ev}, \quad SOC_{t-1}^{ess} + C_t^{ess} - L_t^{ess} < SOC_{t-1}^{ess,p} \quad (1)$$

$$L_t^{ess} = \sum_{n \in N} (L_{n,t}^{ev} + L_{n,t}^{s,max} + L_{n,t}^{ns}) \quad (2)$$

Formula (1) is the criterion that requires switching of charge and discharge for EV with considering ESS SoC. $L_{n,t}^{ev}$ is EV load of user n at unit time t. It does not consider control in charging and discharging of EV. $SW_{n,t}^{ev}$ is amount of charge or discharge power of EV in user n at unit time t. It considers control of EV to charge and discharge. SOC_{t-1}^{ess} is ESS SoC at unit time t-1. C_t^{ess} is ESS charging power at unit time t. L_t^{ess} is sum of loads that take ESS at unit time t. $SOC_{t-1}^{ess,p}$ is value of ESS preferred SoC. At unit time t, if SOC_{t-1}^{ess} considering C_t^{ess} and L_t^{ess} is lower than $SOC_{t-1}^{ess,p}$, all $L_{n,t}^{ev}$ is converted to $SW_{n,t}^{ev}$.

Formula (2) means sum of load in (1). $L_{n,t}^{s,max}$ is shiftable appliance load of user n at unit time t and it is maximum load without peak shaving. $L_{n,t}^{ns}$ is non-shiftable appliance load of user n at unit time t. We design EV control system with priority over shiftable load system, in order to minimize customer inconvenience of shiftable load.

$$SW_{n,t}^{ev} = \begin{cases} C_{n,t}^{ev}, & SOC_{n,t-1}^{ev} + C_{n,t}^{ev} \cdot t_{n,t}^{ev} \leq REQ_n^{ev} \\ -D_{n,t}^{ev}, & SOC_{n,t-1}^{ev} + C_{n,t}^{ev} \cdot t_{n,t}^{ev} > REQ_n^{ev} \end{cases} \quad (3)$$

Formula (3) describes the criterion for determining each EV to control of charge and discharge. $C_{n,t}^{ev}$ is charging power of EV of user n at unit time t. $D_{n,t}^{ev}$ is discharging power from EV of user n at unit time t. $t_{n,t}^{ev}$ is time remaining from unit time t until EV of user n leaves. REQ_n^{ev} is required amount of power for EV of user n. Amount of power that can be charged at unit time t until EV of user n leaves is $C_{n,t}^{ev} \cdot t_{n,t}^{ev}$. If amount of rechargeable power in an EV considering SoC is much than amount of power required by EV, discharge of power about EV may ultimately satisfy power required by user. In this case, $SW_{n,t}^{ev}$ is converted to discharge and has a value of $-D_{n,t}^{ev}$. In opposite case, $SW_{n,t}^{ev}$ is switched to charge and has a value of $C_{n,t}^{ev}$.

C. Amount of Discharge Power

Method for calculating a balanced discharge by considering SoC of EVs is as follows.

$$SRR_{n,t}^{ev} = \frac{SOC_{n,t}^{ev}}{REQ_n^{ev}} \quad (4)$$

$$D_{n,t}^{ev} = REQ_t^{ess} \cdot \frac{SRR_{n,t}^{ev}}{\sum_{n \in N} SRR_{n,t}^{ev}} \quad (5)$$

Formula (4) is State of Charge to Requirement of Power Ratio (SRR) which is defined for discharging power considering SoC. $SOC_{n,t}^{ev}$ is EV SoC of user n at unit time t. SRR determines at unit time t how much power user n has over required amount of EV.

Formula (5) calculates discharging power for each EV by considering SRR. REQ_t^{ess} is amount of power that ESS requires for EV at unit time t. Also, formula (5) considers a ratio that consists of SRR of each EV and total value of all SRR.

In this system, control of EV is prioritized over shiftable loads when peak loads occur. However, at unit time t, EV control system may be limited in peak shaving.

$$Mode_t^s = \begin{cases} on, & \text{if } (\sum_{n \in N}^{N=discharge} D_{n,t}^{ev} < REQ_t^{ess}) \\ off, & \text{if } (\sum_{n \in N}^{N=discharge} D_{n,t}^{ev} \geq REQ_t^{ess}) \end{cases} \quad (6)$$

Formula (6) means how to control shiftable load if EV control alone limits peak shaving. $Mode_t^s$ is operability of shiftable load control system at unit time t. If discharging power for all EVs is less than power required by ESS, system controls shiftable load. In opposite case, only EV control system operates.

IV. SIMULATION

A. Data for Simulation

We referred load data from Smart Star Project 2 in this environment of simulation [14]. Load data is power of five apartments from 12:00 on Aug. 26, 2016 to 11:59 on Aug. 27, 2016. The load for each hour is as Figure 2.

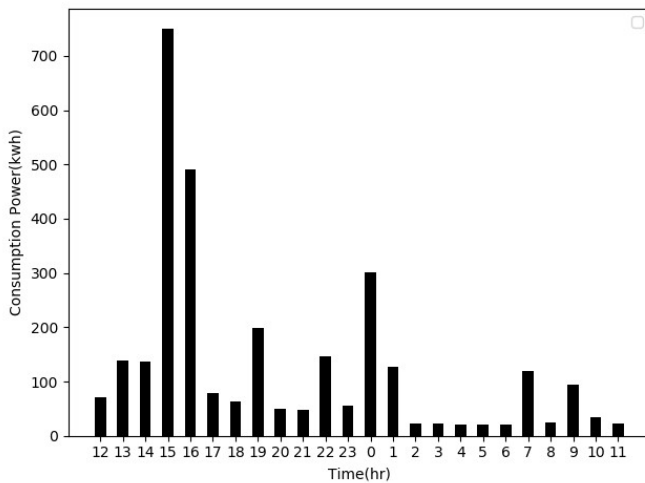


Figure 2. Consumption power at apartments

Shiftable load is set at 20% of total power. ESS SoC range for battery protection is between 10% and 90%. $SOC_{n,t}^{ess,p}$ is 80%. Table 1 shows settings for ESS.

TABLE 1. ASSUMPTION VALUES OF ESS

ESS Assumption	Value(kW)
ESS Volume	1000
$SOC_{n,t}^{ess,p}$	800
SOC_{max}^{ess}	900
SOC_{min}^{ess}	100
C_t^{ess}	110

Number of EVs is set at 10. Charging speed of EV is typically 3 kWh to 7 kWh [15]. This system fixed charging speed at 5 kWh. Maximum value of EV discharge is 5 kWh [16]. Table 2 shows details about setting of each EV in this environment. This is referred to [17].

TABLE 2. ASSUMPTION VALUES OF EACH EV

EV ID (i)	Capacity (kWh)	Initial SoC (%)	Arrival Time (hr)	Departure Time (hr)
1	24	78	18	7
2	24	65	19	7
3	24	66	19	8
4	24	50	16	7
5	24	53	18	8
6	24	45	19	8
7	24	54	19	7
8	24	62	19	8
9	24	50	20	7
10	24	50	19	8

B. Simulation Result

Peak load is largest at 14 o'clock. ESS SoC is most low at 15 o'clock due to ESS SoC reduction.

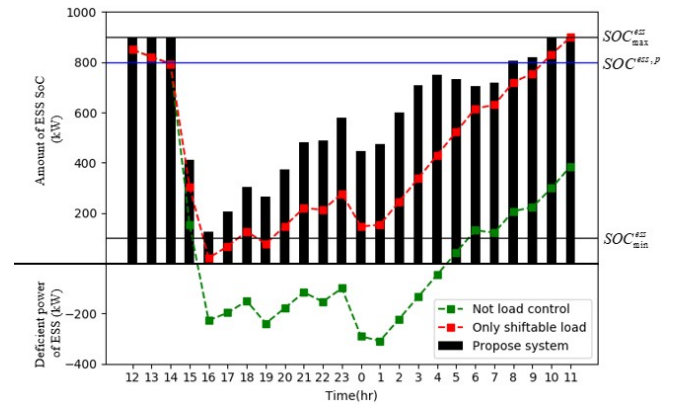


Figure 3. ESS SoC for each system

Figure 3 is amount of ESS SoC. Figure includes 3 systems: proposed EV Control, only shiftable load control and not load control. As shown in the graph, ESS SoC at 16 o'clock is lowest. We compared ESS SoC to each system at that time.

ESS SoC of 'not load control system' was measured on – 226.9 kW at time. Therefore, ESS SoC cannot respond to peak load alone. There is a problem that must require additional power from power grid in this system.

ESS SoC of System that 'only control shiftable load' was measured on 21.24 kW at time. It relatively safer than previous system. However, ESS must have 10% (100kW) SoC to protect itself. Therefore, controlling only shiftable load does not guarantee power Maintenance of ESS in this simulation.

ESS SoC of proposed system was measured on 127kW at time. Result show that minimum ESS SoC is satisfied. In addition, ESS SoC of proposed system is more stable than other systems in all times.

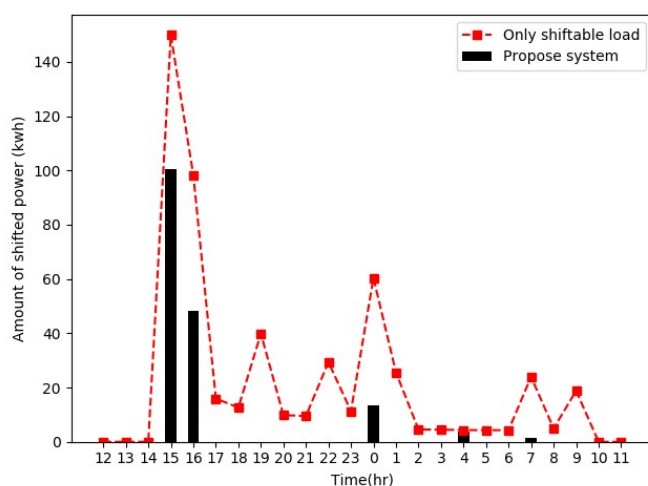


Figure 4. Amount of shiftable load control

Figure 4 is amount of shifted power through shiftable load control. Power which provide to customer is decrease, if amount of shifted power is increase. Therefore, shifted power should be decreased to avoid dissatisfaction of customer. In Figure 4, proposed system decreases shifted power than other systems. This system also has better peak shaving performance as shown in Figure 4. At same time, it minimized shifted power.

V. CONCLUSIONS

The results of simulation, this system induced ESS SoC to optimum value through control charging and discharge of EV. The system also reduced shifted power. Peak load is an important issue in SG and this should be studied continuously. However, ESS life should be considered because it affects cost. Also, customer's satisfaction with power demand is a issue that cannot be ignored. Research is required to improve the performance of peak shaving, while also addressing other problems, such as the proposed system.

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