# Peak Shaving Control of EV Charge Station with a Flywheel Energy Storage System in Micro Grid

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***Abstract*— In this study, peak shaving control is applied for load balancing using micro grid and flywheel energy storage system (FESS). The proposed method is applied to an EV charge station with an unbalanced load curve. FESS is charged during the low energy demand period and discharged during the high energy demand period. The FESS is determined by considering the required energy capacity, input power, and output power. When the Peak shaving control has been performed using the specified FESS, it has been noticed that an unbalanced load between 7 and 230 kW could be successfully balanced. It has been observed that the balanced load fluctuates between 13 and 123 kW. Thus, a more balanced load demand for the EV charge station has been generated from the electricity grid.**

***Keywords*— *Peak Shaving, Flywheel Energy Storage System, Smart Grid, Micro Grid, EV Charge Station***

## I. INTRODUCTION (*HEADING 1*)

In recent years, electric vehicles (EVs) have received a lot of attention as an environmentally and economically beneficial alternative to conventional vehicles powered by internal combustion engines. They are seen to reduce the current reliance on fossil fuels and reduce pollution emissions in the transport sector. However, their widespread use still faces numerous hurdles. First, EVs are still more expensive to purchase than conventional vehicles, but their operating expenses are lower than conventional vehicles. Second, public access to charging stations is still poor and installing a charging infrastructure will be very costly. In addition, EVs need extra power from the grid when charging because they want to be charged quickly. Thus, uncoordinated charging of large numbers of EVs can have a detrimental effect on the functioning of the electrical grid, causing harmonic pollution, voltage fluctuations, blackouts, unstable power characteristics and more [1].

With the use and development of technology, the need for electrical energy is increasing while the availability of fossil fuels is decreasing. Therefore, it is believed that obtaining electrical energy from both non-renewable and renewable energy sources is the best option. With the increase in energy demand, efficiency in energy consumption, expansion of existing energy resources without harming the environment and system integration have gained importance. Electricity grids must be made smarter to meet increasing demands. One of the topics that has recently attracted attention is smart grids. Fig. 1 shows the general structure of smart grids. Smart grids facilitate the use of renewable energy sources and help generate ecologically beneficial electricity. By improving grid integration and using energy storage devices, renewable energy sources can be used more effectively and widely [2].

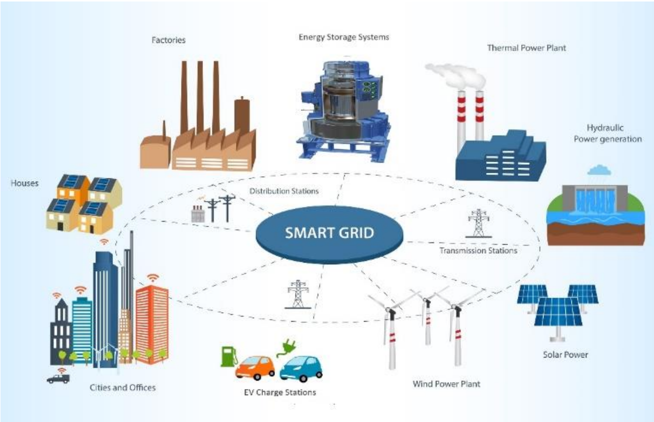


Fig. 1. General Structure of Smart Grid

One of the most important parts of smart grids is the energy storage system (ESS). Some of the benefits of ESSs used in smart grids against the grid are as follows [3].

* Time and peak shifting
* Improving power quality
* Peak shaving, load shifting and dynamic pricing
* Sustainability of energy

One of the most interesting EESs in recent times is FESS. Due to its many benefits, FESS is a preferred alternative to conventional battery storage systems. The capacity to efficiently store and release large amounts of energy is one of the main advantages of FESSs. Unlike batteries that can take hours to charge and discharge, FESSs can react almost instantly to changes in demand, making them an excellent choice for applications such as grid stabilization and uninterruptible power supply that require fast response times. FESSs are a more affordable and reliable option for energy storage as they last much longer than batteries and require very little maintenance. Smart grids using ESS such as FESS are being used to solve some of today's problems [4].

Today, as EVs become more widespread, they can have a major negative impact on the electricity grid. Especially during peak demand, the increased electricity demand from EV charging can overload the grid and cause blackouts. However, ESSs play a crucial role in mitigating these negative impacts. By charging during peak electricity use and discharging during peak demand, energy storage systems reduce the risk of overloads and outages and balance the load on the grid. Therefore, ESSs are crucial to ensure the affordability or reliability of electricity for the increasing use of EVs. There has been a lot of work on this recently. D. Sbordone et al. investigated the load that charging EVs adds to the electricity grid. They added an ESS to the charging station and built a microgrid. The study shows that the ESS improves the performance of the grid by implementing the peak shaving function [5]. R. Martins et al. have designed and optimized an ESS to reduce cost across a variety of industrial load profiles. It has been seen that the designed ESS reduces the energy cost [6]. F. Díaz-González et al. performed frequency regulation thanks to FESS integrated into a renewable energy source [7]. M. Shible et al. proposed a charging management system to solve the overload, power loss and voltage fluctuation problems caused by charging many EVs. In the study, it has been observed that the load curve is flattened and the charging cost is reduced with the proposed charging management system [8]. U. Shahzad investigated the impact of EVs on the security of smart grids. Communication technologies, challenges and prospects for smart grid are discussed [9]. W. Fang et al. investigated the effect of EV charge station on the voltage stability of the grid. Real charging station data have been used in the study [10]. A. Lucas et al. examined the effects of fast charging stations on the electricity grid. They observed that smart grids and ESSs provide frequency regulation and uninterruptible power service [11].

In this study, a peak shaving control is presented for an EV charge station with an unbalanced load to have a more balanced load. For this purpose, a FESS integrated into the micro grid is used. The FESS stores energy during periods of low energy demand and releases the stored energy during periods of high energy demand. Thus, a more balanced load demand is created. A suitable FESS has been determined by considering input power, output power, and energy storage capacity. When the FESS is included in the micro grid and peak shaving is performed, it is seen that an unbalanced load in the range of 7-230 kW is successfully balanced.

## II. Impacts of EV Charge Stations on the Electricity Grid

As EVs become more popular, concerns are growing about the potential harms of charging them from the grid [12]. One of the main problems is the risk of overloading local distribution grids when many EVs are charged simultaneously in a certain area. Sudden unbalanced loads can cause various problems in the electricity grid, including voltage ripples, current unbalances, and increased losses in the distribution system [13]. In addition, the increased losses caused by unbalanced load in the distribution system led to reduced efficiency and increased costs for electricity suppliers. In addition, it can cause power quality problems such as voltage drops, ripple and harmonic disturbance, which can cause problems with sensitive electronic equipment. Fig. 2 shows the daily load curve of an EV charging station for April 13, 2021. EV charge stations with such unbalanced load can damage the grid. Therefore, eliminating this unbalanced load will be beneficial for grid quality [14].

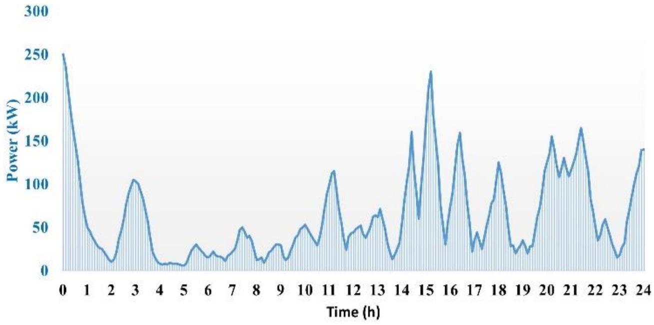


Fig. 2. Daily Load Curve of EV Charge Station on April 13, 2021

According to a study by the National Renewable Energy Laboratory, the cost of upgrading the electricity grid to support high numbers of EVs could be between $13 billion and $21 billion in the United States. This includes investments in new transformers, substation upgrades and other infrastructure improvements needed to support the growing demand for electricity from charging EVs [15]. It is assumed that this problem will be solved with lower costs by using ESS in a distributed system with micro grid integration.

## III. Flywheel Energy Storage System (FESS)

Innovative technology called FESS provides a special way to store and release energy. These systems work on the idea of kinetic energy, which stores energy by making a rotational motion. A flywheel is a mass that rotates rapidly while storing energy. When energy is needed, the flywheel slows down and releases the stored energy. Compared to more traditional energy storage techniques such as batteries or capacitors, FESSs provide several advantages [16]. They are more robust, charge and discharge faster and do not degrade over time. They can also operate at efficiencies of up to 95 [17]. Fig. 3 shows the structure of the FESS.

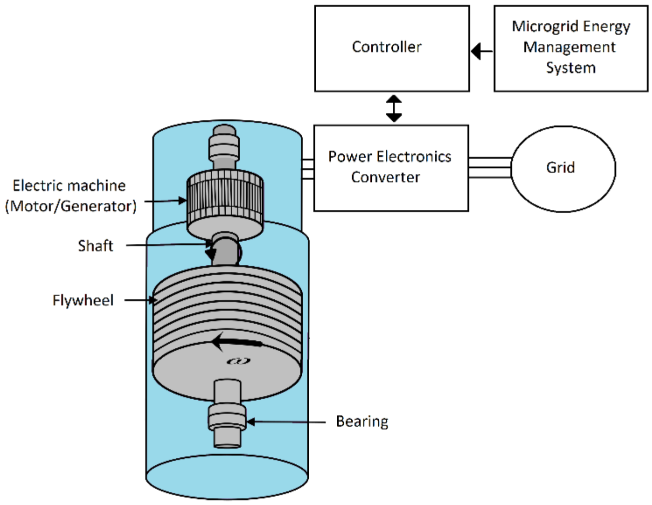


Fig. 3. Structure of the FESS

As shown in Fig. 3, the FESS consists of a flywheel, a shaft, an electric machine that works as both a motor and a generator, bearings, and a driver. For the FESS used in this study, a previously designed electric machine used [18]. In the study, 6 of the previously designed FESSs have been used together to store the energy at the required level and provide the instantaneous power required.

### A. Determination of FESS

The energy stored ($E_{tot}$) in the FESS depends on the moment of inertia ($J$) and angular velocity ($\omega$) as given in equation 1. As seen in Equation 2, the release of stored energy ($E_{diff}$) is related to the variation of the flywheel speed.

$$E_{tot} = \frac{1}{2} J \omega^2 \quad (1)$$

$$E_{diff} = \frac{1}{2} J (\omega_{max}^2 - \omega^2) \quad (2)$$

A FESS group with a capacity of $6 \times 40\ kWh$ ($8.4 \times 10^8\ Joule$) is used to regulate the instantaneous power consumption and peak shaving at the targeted charging station. The specifications of the FESS are shown in Table 1.

TABLE I. THE SPECIFICATIONS OF THE FESS

| Parameters | Values |
|---|---|
| Flywheels velocity ($\omega_{max}$) (rad/s)/(rpm) | 1486/14190 |
| Capacity of energy ($E_{tot}$) (Joule) | $8.4 \times 10^8$ |
| Max Power Transferred to the Grid (kW) | 490,2 |
| Max Power Transferred from the Grid (kW) | 102.85 |
| Charge-discharge time (minute) | 140-60 |

The parameters shown in Table 1 are determined by considering the energy capacity, power input and power output for the EV charge station shown in Fig. 2.

### B. Determination of Electric Machine for FESS

One of the most important parts used in a FESS is the electric machine. This machine must work both as a motor and as a generator. Due to the advantage of high efficiency and low price, the magnet-assisted synchronous reluctance machine (PMaSynRM) is considered a suitable choice for energy storage systems. PMaSynRMs are suitable for high-speed applications, so they can be safely used in applications requiring high speed, such as FESS. The use of this machine offers high energy efficiency to the system. Table 2 shows the specifications of the electrical machine used in the FESS.

TABLE II. SPECIFICATIONS OF THE ELECTRIC MACHINE USED IN FESS

| Parameters | Values | Parameters | Values |
|---|---|---|---|
| Number of slots | 48 | Maximum current rms (A) | 185 |
| Number of poles | 8 | Maximum speed (rpm) | 14500 |
| Number of phases | 3 | Peak power (kW) (Generator) | 81,7 |
| Voltage (V) | 380 | Peak efficiency (%) (Generator) | 98 |

Fig. 4 shows the power-speed-efficiency map for the period when the electric machine used in FESS operated as a generator. When the figure and Table 2 are examined, it is seen that the electric machine operates with high efficiency over a wide area. The peak power given in Table 2 is 81.7 kW, but the electric machine cannot produce this power at every speed. At high speeds, the peak power varies between 20 and 81,7 kW. Since this power level will not be sufficient during peak hours of the EV charge station, more than one FESS will be used to meet the required power.

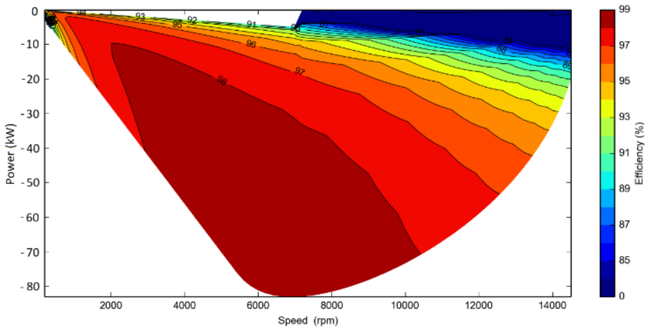


Fig. 4. Power-Speed-Efficiency Map of the Electric Machine (Generator Mode) Used in FESS

## IV. PEAK SHAVING CONTROL OF EV CHARGE STATION

Unbalanced loads can cause many problems in the distribution grid. Therefore, a more balanced load demand is desired by the energy user [19]. For the EV charge station shown in Fig. 2 to operate at a more balanced load on the distribution grid side, a peak shaving control has been realized. For this purpose, FESS integrated into the microgrid is used. The FESS helps to create a more balanced load demand on the grid side by storing energy and discharging it when needed.

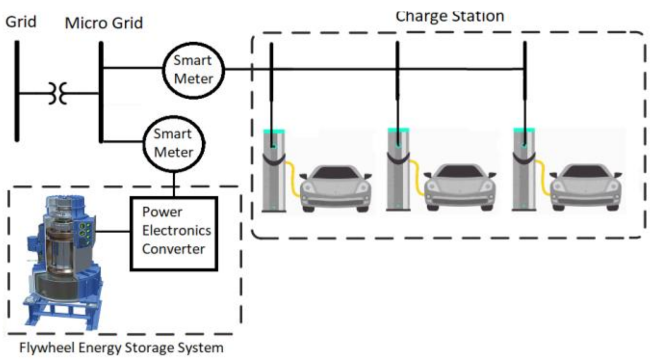


Fig. 5. Structure Established for Peak Shaving Control

A more stable load curve is estimated to replace the sudden load imbalance. This load curve is generated by using moving average, one of the demand estimation methods. The formula of the moving average is as shown in equation 3. Where $F_t$, $A_{t-1}$, $A_{t-2}$, $A_{t-n}$, and $n$ are estimated value, 1-unit previous value, 2-units previous value, n-unit previous value, and number of periods, respectively.

$$F_t = \frac{A_{t-1} + A_{t-2} + .. + A_{t-n}}{n} \quad (3)$$

The FESS is set to charge when the estimated load is higher than the real load and discharge when the real load is higher than the estimated load. The estimated load is shown in Fig. 6.

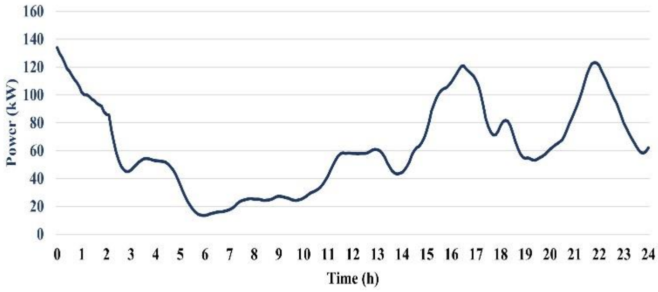


Fig. 6. Estimated Load Curve for the EV Charge Station

The instantaneous power and energy storage for the FESS when peak shaving is applied is shown in Fig. 7.

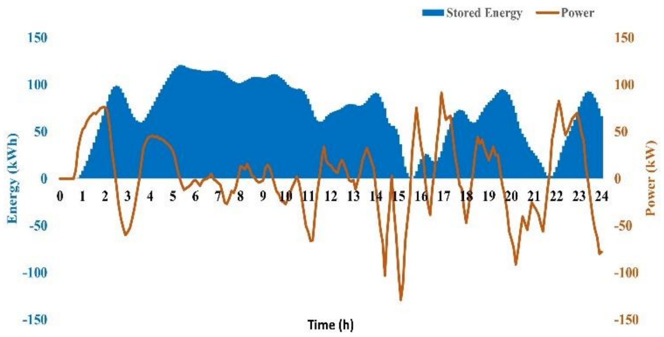


Fig. 7. Curves of Stored Energy and Power for FESS

By storing energy using FESS and using it when needed, more suitable energy demand from the electricity grid is realized. With the control of peak shaving, unbalanced loads are eliminated and the grid is made safe. A more stable load curve in Fig. 8 is obtained by performing peak shaving.

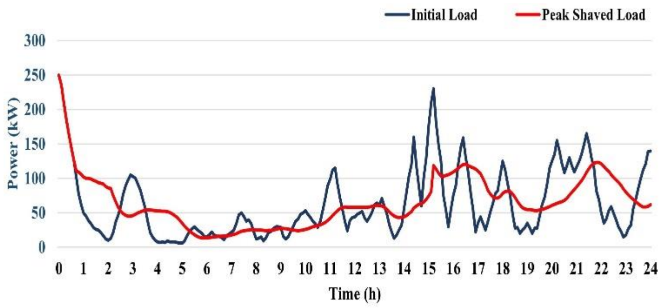


Fig. 8. New load curve obtained by applying peak shaving

The load curve of the charging station for EV has been made more balanced by peak shaving. After the FESS started to operate at approximately 1 o'clock, the peak power points have been shaved. Thus, a load in the range of 7 - 230 kW has been balanced to the grid as a load in the range of 13 - 123 kW. This more balanced load helps the grid to operate more stably. In addition, this application has many advantages such as eliminated power failures, energy savings, increased equipment lifetime and increased grid security.

## V. CONCLUSION

This paper presents the control of peak shaving to make an unbalanced load more balanced using a FESS integrated into a micro grid. Due to the increase of EVs, peak energy demand may occur at some times of the day. This unbalance in energy demand can be absorbed by using an ESS. An ESS connected to the microgrid creates a more balanced load with peak shaving control. For this purpose, FESS is determined by considering the energy storage capacity, input power and output power. Using FESS, energy is stored when the energy demand is low, and energy is released to support the grid when the energy demand is high. With peak shaving, an unbalance load between 7 and 230 kW has been successfully balanced load between 13 and 123 kW.

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