

A novel spontaneous self-adjusting controller of energy storage system for maximum demand reductions under penetration of photovoltaic system

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HIGHLIGHTS

- A spontaneous self-adjusting controller is for BESS to reduce maximum demands.
- The controller can reduce at least 72.40% of the ideal reductions.
- The proposed controller achieves extra 10.52% closer to the ideal reductions.
- The proposed controller performs better than the preceding controllers.

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ABSTRACT

Customers are subject to varying charges for their electricity consumption (kWh) as well as monthly maximum demands (kW) depending on the charging schemes for commercial and industrial customers. Generally, maximum demand charges may account for as high as 30% of the total electricity bills. Although on-site photovoltaic (PV) systems can help customers reduce their maximum demand charges, PV may not be as effective in reducing some of the peak demands due to the intermittent power output of PV. The inclusion of a battery-based energy storage system (BESS), on the other hand, can reduce those unexpected peaks by supplying power at the appropriate time and magnitude. Research efforts have therefore been carried out to develop control strategies for BESS to reduce the peak demands of PV customers. However, some of the existing controllers that rely on forecasted next-interval net demands to supply power for the next interval may fail to reduce peak demands effectively when the actual next-interval net demands are different from the forecasted ones. Hence, a spontaneous self-adjusting controller has been developed and presented in this paper to overcome this issue. It employs model predictive control and dynamic programming with *anticipatory*, *preparatory* and *recovery actions* to achieve a maximum demand reduction of at least 11.00% over the monthly maximum demand. Throughout an experimental peak reduction period of 4 months, the controller has also proven to achieve a reduction of at least 74.11% of the ideal reductions as compared to 68.00% and 65.00% reductions demonstrated by the preceding active and fuzzy controllers.

1. Introduction

In tandem with the rapid economic growth, fast-paced urbanization and a steady increase in the populations around the globe, the demands for electricity have been growing tremendously in the recent years as illustrated in Fig. 1(a) and (b). Hence, maximum power demands are also expected to rise significantly in the coming years. Utility companies will normally be faced with the pressing need to invest on new power plants and also reinforce their existing electrical networks regularly to cater for the growing maximum power demands. Subsequently, the investment costs will be passed to the customers through

the increase in the electricity tariffs [1].

In Malaysia and many other countries, commercial and industrial customers are subject to differential electricity charges (USD/kWh) and monthly maximum demand charges (USD/kW) based on the tariff categories for commercial and industrial customers. The maximum demand charges can be as high as 30% of the total electricity bills [3]. Customers can cut down their electricity bills if they reduce their monthly maximum demands by using methods such as demand-side management (DSM) [4,5], demand response (DR) [6,7] and distributed energy resources (DER) for example photovoltaic systems [8,9]. In addition, reducing maximum demands can benefit the utility companies

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Nomenclature

PDR_a	actual daily peak demand reduction [kW]	aMD	actual maximum demand after the reductions carried out by the spontaneous self-adjusting controller [kW]
MDR_a	actual monthly maximum demand reduction [kW]	MAPE	mean absolute percentage error between the actual and the forecasted net demands [%]
SOC	batteries state-of-charge [%]	maxPD	maximum PD [kW]
InvRating	BESS power rating [kW]	maxE _{con}	maximum E _{con} [kWh]
P_{bess}	BESS power output [kW]	K_{PDR}	daily peak reduction factor [%]
d	day or date of the day [-]	K_{MDR}	monthly maximum demand reduction factor [%]
E_{con}	energy consumption during peak periods [kWh]	n	Nth day of historical data [-]
fP_{pv}	forecasted next day PV generations [kW]	P_{grid}	real-time grid supply from utility [kW]
fP_{load}	forecasted next day load demands [kW]	P_{pv}	real-time PV generations [kW]
fP_{nd}	forecasted day ahead net demands [kW]	P_{load}	real-time load demands [kW]
hP_{nd}	historical net demands [kW]	P_{Th}	real-time peak reduction target [kW]
hP_{pv}	historical PV generations [kW]	P_{nd}	real-time net demands [kW]
hP_{load}	historical load demands [kW]	PD	peak demand before the reductions [kW]
P_{Th}	ideal peak reduction target [kW]	aPD	actual peak demand after the reductions carried out by the spontaneous self-adjusting controller [kW]
iPD	ideal peak demand obtained post-experimentally [kW]	K_{Cb}	peak-to-energy ratio's weighing factor [-]
iMD	ideal maximum demand obtained post-experimentally [kW]	PDE_{ratio}	peak characteristic of the net demands [-]
PDR_i	ideal daily peak demand reduction obtained post-experimentally [kW]	R	PDE_{ratio} from the previous year same day and week of $d + 1$ [-]
MDR_i	ideal monthly maximum demand reduction obtained post-experimentally [kW]	t	Time [minutes]

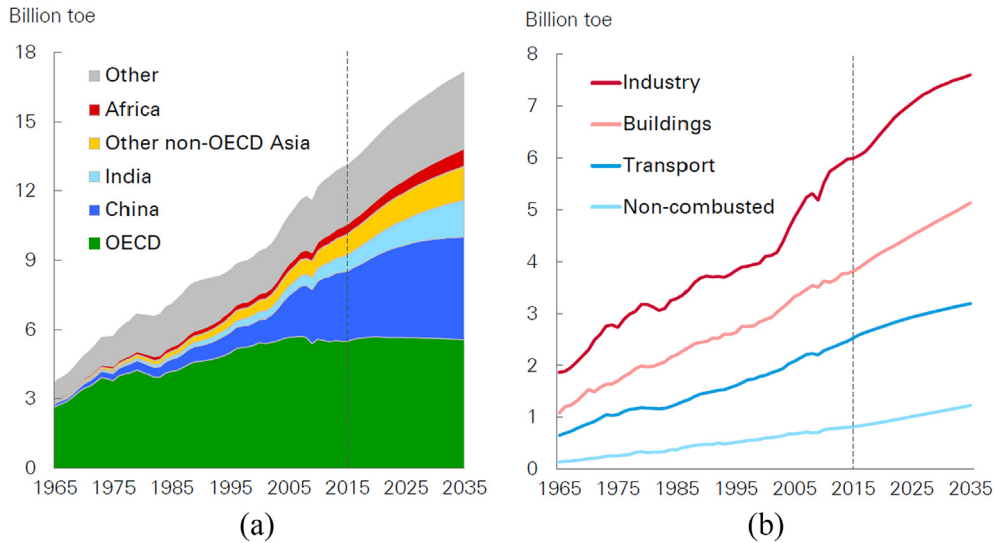


Fig. 1. Retrieved from [2], the above is the total energy consumption in billion toes by (a) region and (b) industry projections from 2015 to 2035.

financially because they can choose to defer the upgrades of power system networks and avoid building new power plants, hence cutting down their investment costs and greenhouse gas emissions substantially.

Although on-site photovoltaic (PV) systems can help customers reduce their maximum demands, PV system alone may not be sufficient to reduce the peak demands satisfactorily due to its intermittent output. As shown in Fig. 2(a), solar production during the day supports the reduction of energy consumption (kWh) as well as lowers the peak demands (kW). The peak demands are however not completely reduced and the sudden drop in the power output of PV causes a rise to a new peak demand. On the other hand, a battery-based energy storage system (BESS) can be used either as a sole device or to complement the PV system to reduce the non-coincidental peak demands such as shown in Fig. 2(b).

The success rate of BESS in reducing the peak demands lies in the ability the BESS's controller charge and discharge the batteries at the right time to meet the non-coincidental peak demands. As presented

later in Section 2, literature survey has been carried out to show the different control strategies for BESS so far to reduce the daily peak demands for customers. Some of the existing controllers such as described in [10–13] rely heavily on the next-interval forecasted net demands to supply the power output of BESS for the next interval which often fail to reduce the peaks completely, particularly under a situation where the next-interval actual net demands do not match closely with the forecasted ones. Therefore, a new control strategy, namely the spontaneous self-adjusting controller, is proposed for BESS to adjust the power output of the storage system for the next interval more accurately by anticipating the next-interval net demand under the intermittent PV system while preparing BESS to tackle any unforeseen peak demands with the ability to replenish the energy storage optimally throughout the operation.

As far as financial benefits to the customers are concerned, it would make more sense to focus on reducing the monthly maximum demands as the main target instead of reducing the daily peak demands since utility companies determine the maximum demand charges for the

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