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Analyses on the impact of consumers' participation by demand response for flexibility procurement

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Highlights

- Developed optimization model finds a real-time demand response scheduling.
- Model simultaneously minimizes consumers' cost and maximizes aggregator's profit
- Participation status of consumers including response fatigue was modelled
- Participation status affects economy of stakeholders and procurable flexibility
- Various electricity prices and incentive schemes were compared

Abstract

Penetration of renewable energy resources is expected to increase further for a sustainable future. However, its intermittent nature creates differences between electricity supply and demand, endangering the stability of the power system. Demand-side management is becoming more crucial in maintaining the balance by procuring flexibility to the grid through demand response (DR) program by regulating the residential consumers' distributed energy resources usage such as heat pump water heater, battery storage, etc. Coupled with economic incentives such as dynamic electricity pricing, cooperative consumers are also capable of reducing their energy costs. Although the potential of procuring flexibility through residential consumers is massive, the consumers are expected to participate in the DR program aggressively and consistently, which is practically impossible to expect of all consumers. This study presents a constructive DR model in procuring flexibility when viewed from a different angle, by considering the participation status of consumers (PSC). As PSC can depends on many different economical and psychological factors, there are complexities in modelizing it. In this study, two representative factors, achievable consumers' cost reduction and response fatigue are considered. Those participating are given generous electricity rates to optimize their electricity usage while providing flexibility. By acknowledging different participation levels among consumers and offering generous electricity rates to participants, the program can enhance the overall success of renewable energy integration while fostering grid stability and cost savings. The simulation results further reveal the behavioral patterns of consumers within the DR program and their influence on other stakeholders involved in the initiative.

Section snippets

Abbreviations and nomenclature

Abbreviations.

RES

Renewable energy system …

PV
: Photovoltaic …

DER
: Distributed energy resources …

VRE
: Variable renewable energy …

DSM
: Demand-side management …

DR
: Demand response …

PSC
: Participation status of consumers …

RTP
: Real-time pricing …

TOU
: Time-of-use …

CPP
: Critical peak pricing …

PTR
: Peak time rebate …

DA
: Day-ahead …

ID
: Intra-day …

JEPX
: Japan electric power exchange …

SO
: System operator …

BT
: Battery energy storage …

HP
: CO_2 Heat pump water heater …

WM
: Washing machine …

DW
: Dishwasher …

GWH
: Gas water heater …

HVAC
: Heat, ventilation, and air conditioning …

TES
: Thermal …

…

Demand response

DR is a demand-side management measure that can assist in reducing the fluctuations caused by high penetration of VRE. Its service is offered by the aggregator to the consumers to adapt their load profiles to meet specific external requirements to achieve specific outcomes on the power system at varying levels. Rather than having adjusting the power generation to meet the demands from the system operator side, which usually needs additional cost, DR allows the demand to be adjusted instead to …

Stakeholders and trading schemes

Fig. 1 illustrates the framework of the proposed trading scheme within the DR program, depicting the relationships between four different stakeholders. The aggregator plays the role of mediator between consumers, the electricity market, and SO. It acts as a retailer that buys electricity at the day-ahead (DA) and intra-day (ID) markets within the electricity markets and sells them to the consumers at time-of-use (TOU) or RTP rates. By making use of the lower electricity price of the electricity …

Outline

To evaluate the effectiveness of the developed DR model, operation simulations of three different scenarios with different electricity rates as shown in Table 1 were performed. Two scenarios (Scenarios 1 and 2) were compared with scenario 0, which represents the base scenario at which the consumers do not participate in the DR program and thus offered TOU rates. In general, those who participate in the DR program are offered RTP rates and incentives, otherwise, TOU rates would be offered. In …

Conclusions

In this study, in anticipation of high PV penetration in the future that may lead to instability of supply and demand for the grid, a DR model that could procure flexibility from the consumers through the aggregator while considering the PSC was developed using MILP. The consumers were considered to possess DERs that could procure flexibility when the demand for it arises according to the electricity rates (RTP) assigned by the aggregator. The consumers were able to choose their daily …

CRediT authorship contribution statement

Muhammad Zakwan Bin Mohd Zahid: Software, Investigation, Validation, Writing – original draft preparation. **Hirohisa Aki:** Methodology, Conceptualization, Writing – reviewing and editing, Supervision. …

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

Acknowledgments

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>
> …Work-based on analyses (load/energy user clustering, profiling, aggregation, detection) and simulations (based on mathematical or stochastic models of end-user energy use processes), also computer simulation studies of consumer control methods (within HEMS), also proposals for DR algorithms and strategies, including with EV and energy storage systems (e.g. Refs. [100,101]), studies of the elasticity of energy consumption from the grid based on the design of incentive prices for appropriately classified users [102]. In addition, work discussing the development of flexibility models through aggregation taking into account prosumption in the area of residential user communities, providing flexibility when demand arises [103,104]; Modeling participation in DSR activity based on energy use data and socioeconomic attributes of residential users, simulating energy demand in a given area and flexibility and potential changes in end-user behavior [105]. The first category is in the nature of studies of the preliminary design stage of DSR solutions, the second is based on studies of pilot projects, and the third uses the results from studies conducted under the previous groups, simulating and modeling the extent of the effects of implementing DSR elements at different scales.…

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