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Home demand side management integrated with electric vehicles and renewable energy sources

Petra Mesarić[a,*], Slavko Krajcar[b]

[a] Polytechnic of Međimurje in Čakovec, Čakovec, Croatia
[b] Faculty of Electrical Engineering and Computing, Zagreb, Croatia

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ABSTRACT

The microgrid systems will be vital for establishing future smart grid, so important focus will be on their intermittency and availability of energy storage systems. Since in the near future, the number of electric vehicles (EV) will grow considerably, they represent appreciable opportunity as dispatchable energy sources, if battery can be considered as potential energy storage system and connected to grid while parked. Accordingly, foster integration of renewable energy sources and EVs integrated with proper home demand side management can contribute to microgrid stability and decrease grid dependence. The model of a small solar powered buildings is based on the role of active smart grid users referred as energy citizens, whose home demand side management is possible to reduce or postpone demand, due to categorization of home appliances and controlled charging of EVs. The daily load curve will trace daily energy production, cooperating with energy storage system. We develop a mixed-integer program to reach maximum amount of renewable energy sources, scheduling optimal power and operation time for EVs and appliances. Simulation results for different scenarios with different engagement of home demand side management have been presented to demonstrate and verify the effectiveness of the proposed technique.

1. Introduction

The global climate change and the current contaminating generation systems have promoted the use of renewable energy sources, being the most used the wind turbines and the photovoltaic panels. The problem of that generation system is that their energy sources (wind, sun) are intermittent and so the generated power is intermittent too. This fact generates stability, reliability and power quality problems in the main electric grid. Consequently, the electricity supply systems with high shares of intermittent/non-controllable electricity production from renewable sources, like wind and sun, require the additional energy storage [1]. Different developing countries with projected high share of renewable energy sources integrated into the electric gird, have already started to indicate future energy storage need. In this respect, German government has set the targets for share of renewable energy sources up to 80% until 2050, mainly wind and sun. The project stoRE have highlighted that the storage needs for Germany, in 2020 will strongly depend on the flexibility of electricity supply system and the resulting penetration limit for renewable energy. After 2020 the storage needs will rise very fast, declaring that the needed power is higher with a stronger development of PV whereas the needed capacity increased with a favored development of wind power [2].

On the other side, transportation sector has also significant impact on climate changes. Considering the growing exposure of humans and environment to noise and exhaust emissions, there is a growing interest in the application EVs as a replacement for conventional vehicles with combustion engine. Furthermore, the tendency of increasing oil prices could become economically advantage for EVs in long-term. Therefore, the breakthrough of EVs on the market can be expected in the near future, which will bring impacts on existing distribution grids [3]. The battery is a main component of EVs and since EVs are utilized only 4% of time for transportation, and the other 96% of time they are available for a secondary function [4]. Thus, battery can be used as energy storage element, when is connected to the electric grid, providing auxiliary services.

Further, as implication of EVs becomes more numerous, it will be also important to dispatch the additional energy demand. One of the potential solutions is to shift the power consumption of

* Corresponding author.
E-mail addresses: petra.mesaric@mev.hr (P. Mesarić), slavko.krajcar@fer.hr (S. Krajcar).

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Nomenclature

CG_t	conventional generation in time slot $[t-1, t]$
NG_t	net generation in time slot $[t-1, t]$
$\bar{CG}$	nameplate capacity conventional generation
$\underline{CG}$	minimum capacity conventional generation
$isOn_t$	binary state variable for conventional generation
$ramp_t$	occurrence of ramping for time slot $[t-1, t]$
$SOC_{v,t}$	battery state of vehicle v at time t
$\bar{SOC}$	battery capacity
$\gamma_{v,t}$	consumption of vehicle v in time slot $[t-1, t]$
$\mathcal{K}_{v,t}$	charging availability of vehicle v in time slot $[t-1, t]$
$\bar{\Phi}$	maximum charge amount in one time slot
$\Phi_{v,t}$	charging amount of vehicle v in time slot $[t-1, t]$
T	number of time slots
V	number of vehicles
$x_{n,t}$	schedule plan for non-shiftable appliance n in time slot $[t-1, t]$
$x_{p,t}$	schedule plan for power-shiftable appliance p in time slot $[t-1, t]$
$x_{h,t}$	schedule plan for time-shiftable appliance h in time slot $[t-1, t]$
δ_n	hourly power requirement for non-shiftable appliance n
α_p	standby power of power-shiftable appliance p
β_p	maximum working power of power-shiftable appliance p
l_p	daily consumed power of power-shiftable appliance p
R_h	fixed consumption pattern of time-shiftable appliance h
$s_{h,t}$	switch control for time-shiftable appliance h in time slot $[t-1, t]$
D_t	load demand in time slot $[t-1, t]$
P_t	renewable energy sources generation in time slot $[t-1, t]$

EVs from peak to off-peak periods since EVs are not power sensitive loads. However, the electric grid already confronts with this problem without EVs. Energy production and energy demand of consumers must be balanced, so the power quality of the grid is ensured. Typically, the amount of generation units is oversized compared with average demand since utilities optimize generation based on peak load conditions. Dimensioning for the peak periods is inefficient, as the energy demand during average conditions is significantly lower than energy demand during peak periods. The electric grid has no additional storage capacity to fulfill peak demand, excluding its capacity in pumped storage, as 7.7% of generation capacity in case of Croatia [5]. Concluding, generation and transmission, including energy storage systems, must be managed to match fluctuating consumer load. However, the electric power grid and EVs are complementary as systems for managing energy and power. EVs are designed to endure frequent power fluctuations, since that is in the nature of roadway driving. The capital cost of large generators is higher, than the cost for personal EVs, so increasing capacity demand can be provided from EVs batteries, charged from renewable energy resources and not additional new generator units, possibly based on fossil fuels [4].

The key solution for load shifting is the optimization of consumption scheduling, also called as demand side management. Past few decades, in the field of demand side management has been in intensive research, conducted with development in information technology (IT) sector and real-time communication technology. Demand side management can be established centrally, so that grid operators control the load peak centrally, or individually where individual household consumers proactively schedule their consumption. The key element for enabling individual demand side management is the smart meter, not only providing power to every household load, but also for collecting information on appliance's consumption pattern and globally optimize the total power consumption [6]. Accordingly, energy systems are undergoing enormous transformations around the world, aiming to reach the concept of smart grid. Smart grid is technological project, based on real time consumption and generation data to be transmitted in between nodes. In addition, the role of the users in such system is essential, so their contrasting visions of the smart grid are emphasized. The first vision is based on current centralized system, integrating institutional arrangements. Opposed, the second vision is based on an alternative system in which decentralization of generation and control is pursued. The engagement of users in the paper is based on the second vision and as the results will show, they hold out promising results in order.

To provide algorithm for minimizing dependence on the grid, several hypotheses need to be highlighted. When connected to the electric grid, EVs can be used as energy storage system. Household load can be managed by home demand side management to shift energy consumption due to energy production. Energy production is enabled with solar powered building, providing enough energy to fulfill minimum energy needs of household. Small microgrid can ensure and lower grid dependence, so in the paper it is represented how much energy needs to be provided form the electric grid. Thus, the mixed integer linear programming (MILP) method is used for optimization of model consisted of household appliances in solar powered buildings and a sizable number of EVs minimizing. Results will indicate that the usage of conventional generation supplied from the electric grid is minimized. The mathematical model confirms that EVs can be used as energy storage system, buffering the solar energy and the consumption of household appliances can be easily postponed in order to enable future stabile and reliable microgrid systems. The algorithm is tested in GAMS software and can be used to test microgrid stability.

The rest of paper is organized as follows. The demand side management and its part in future grid is described in Section 2. Section 3 presents EVs application in distribution grid. Section 4 describes model of household load and EVs as flexible loads and Section 5 presents model results. Conclusions are drawn in Section 6.

2. Demand side management

2.1. Smart grid

The electric power grid is coping with variety of challenges in the view of sustainable development. The future electric grid, known as smart grid, describes a next-generation electrical power system that is characterized by the increased use of communications, information technology, control and management in the production, distribution and consumption of electrical energy. The aim of this grid upgrade is to allow two-way flow of electricity and information, so the grid would be capable of monitoring and responding to changes resulted from power plant to consumer.

Collaborative effort between U.S. Department of Energy (DOE) and the National Energy Technology Laboratory (NETL) had published the Modern Grid Initiative in order to modernize and integrate the U.S. electric grid. Thus, The Modern Grid Initiative lays out seven attributes of the smart grid, also often referred as the intelligent grid or future grid:

- ability to self-heal;