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

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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

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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;

- motivates and includes the consumer;
- resists attack;
- the increase in power quality;
- the ability to integrate all generation and storage options;
- the ability of the grid to economically enable markets;
- optimizes assets and operates efficiency.

To carry out the attributes mentioned above, advanced monitoring, forecasting, decision making, control and optimization, fast scalable and dynamic algorithms are required [7,8].

With the integration of significant amounts of fluctuating power injection from renewable energy sources, balancing the local power demand and supply sets in a challenge for power system operators. In future distribution systems, the adoption of enhanced energy management method will be essential to preserve grid reliability and to provide new opportunities to minimize the cost of grid improvement. The focus of local energy management systems such as microgrid, small scale energy zones and virtual power plants, lay upon grid-independent power supply trough islanding operation, minimizing line and transformation losses, and increasing the use of local renewable energy [9].

Forecasting load and energy production has always been crucial for effectiveness of power system planning and operation. Lots of electric power companies are now forecasting power load based on traditional prediction methods. However, since the relationship between power load and factors influencing power production is nonlinear, it is difficult to identify its nonlinearity by using traditional prediction methods. Renewable energy sources have increased the complexity of this scenario due to their stochastic and dynamic nature. Consequently, it has been proposed to develop an optimal management system, including demand response, with advanced forecasting techniques integrated into an optimization algorithm [7].

2.2. Definition of demand side management

The primary goal of demand response, for the electric grid, is to reduce peak load and enhance grid stability and reliability. On the other hand, demand response will motivate and include the consumers, so they will become active and participate in energy market. The optimization of consumption scheduling can be achieved centrally, so that grid operators can control peak load, or individually, so that household consumers proactively schedule their consumption plan. Accordingly, future smart users can be referred as energy consumers or energy citizens depending on the level of engagement in demand side management [10].

Smart grid has the potential to also fundamentally change the social dynamics of the energy system. Two opposing visions can be realized and established. The first vision is relied on centralized and hierarchical paradigm based on energy systems of the last century, so called as 'centralized demand side management'. Targets of centralized demand side management are providing of accurate usage information to consumers, including dynamic pricing tariffs and the remote control of electricity load devices in order to extend generator control of consumption. The second vision involves blurring the distinction between generators and end-users, establishing microgrids realized through distribution generation and proper self-management, called as distributed generation microgrids. Thus, energy consumer frame is based on the same paradigm as centralized demand side management. Conversely, energy citizen's frame is based on distributed generation microgrids. The research [10] proposes that the energy citizens holds out much greater potential, so the focus of the work in this paper is on energy citizens role and their demand side power consumption scheduling. The approach in our model is based on energy citizen's behavior.

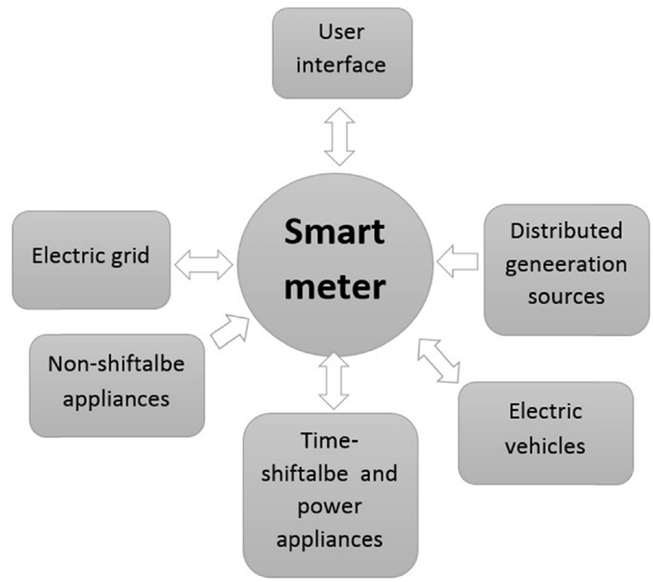

Fig. 1. Main components of home demand side management system integrating electric vehicles [6].

2.3. System description

The algorithm modeled in Section 4, can be applied to the home energy management unit embed in the smart meters, which will probably work as a load control unit. If applied to a group of interconnected consumers, in the grid, it can be achieved coordinated management. As mentioned before, the key component of establishing demand side management is the smart meter, Fig. 1. Smart meter is connected with all home appliances to measure electricity consumption and also to determine the total power requirements based on power consumptions of all appliances. On the other side, is also connected with user interface to collect user's own power consumption plan so scheduling information can be displayed. Combining all input data, smart meter will optimize the hourly consumption and schedule all appliances [6].

Home appliances can be divided in three categories, depending on their power consumption pattern, excluding EVs, Table 1. Non-shiftable appliances such as TV or fridge have a fixed operational period and power requirement, so they are not suitable for optimization. Time-shiftable appliances such as washing machines

Table 1
Appliances and power consumption patterns [6].

Type of appliance	Operating time [h]	Hourly consumption [kWh]
Non-shiftable		
Fridge with freezer	24	0.0171
Oven	1	0.348
Stove	2	0.8
TV	4	0.031
Entertainment system	2	0.088
Lighting	7	0.2
PV system	24	0.03
Time-shiftable		
Clothes washer	2	For 1st: 0.2589 For 2nd: 0.2071
Clothes dryer	2	For 1st: 0.72 For 2nd: 0.36
Dishwasher	2	0.62
Power-shiftable		
Laptop	Daily requirement: 0.75	0–0.075
Water boiler	Daily requirement: 24	0–1.5
Heat pump	Daily requirement: 24	0–2

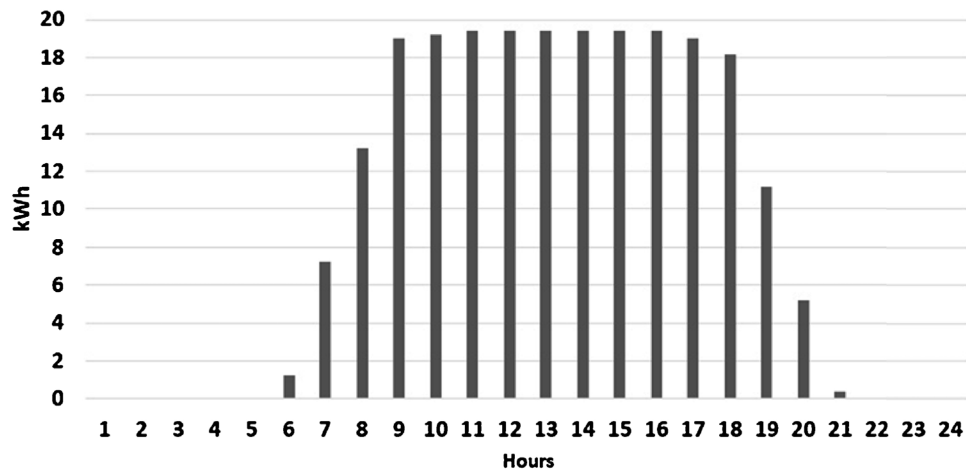

Fig. 2. PV production for typical summer day.

can be scheduled to suitable time, but their power pattern must be followed. Power-shiftable appliances such as water boilers have a set start time but their power pattern can be adjusted depending on optimization needs. EVs are declared as a separate category due to battery life time saving. It is necessary to enable effective home area communication network for the system [11].

3. EV application in distribution grid

Against the background of large-scale EV integration, the question arises, how existing distribution grids cope with this increasing requirements will. Existing distribution grids were designed to distribute electricity within municipal areas and to supply residential industry, business as well as household customers. Due to recent technical advancements and extensive political incentives, the supply of renewable energy is increasing. Since existing distribution grids are designed for low penetration levels of dispersed generation, grid developments are considered as necessary [3].

EV can be divided into Hybrid EV (HEV), Plug-in Hybrid EV (PHEV) and Battery EV (BEV). HEV use a small electric battery to optimize an internal combustion engine, so fuel efficiency can be increased. The battery is recharged using the gasoline engine and regenerative braking. Regenerative braking converts kinetic energy that otherwise would be lost as heat in the brake pads into electricity to charge the battery. PHEV are dual-fuel vehicle in which both the electric motor and the internal combustion engine can power the vehicle. The battery pack is larger and it is charged directly from the power grid, by the gas engine or regenerative braking, increasing the amount of electric power available to the vehicle. BEV are all electric. They do not have internal combustion engine and must be plugged into the electric power grid for recharging. They are growing in terms of knowledge and number [7].

Main differences between EVs and conventional vehicles are the energy storage and the traditional drive. While conventional vehicles are usually powered by oil-based fuels, EV utilize a three-phase electric traction drive supplied by battery storage. An essential advantage of this traction drive is that the energy recovered from declaration can be fed back to the battery as electrical energy (recuperation).

Based on statistical data in Ref. [3] the evaluation reveals that driving behavior as a whole is likewise stochastic, daily periodic, aim oriented and strongly related to the day of week as well as to the season. The prevailing parking spots as either at home, at parking lots, at work and at shopping malls or at some other not further specified locations dominated by leisure activities. The high average availability of EVs as storage devices becomes evident.

Comparing conventional loads with electric loads, many attributes can be listed. For most conventional loads, such as lightning, motors and electronic devices, users are sensitive to load power at every moment, unlike for EVs charging load, when they only care about the energy provided by power system over a period of time. EVs can be charged in the night, since they can be connected in the distribution network for much longer time than needed. Consequently, those features allow EVs chargers to be regulated by power system. Hereafter, chargers for EVs are power electronic converters, so its active and reactive power can be adjusted rapidly. This feature gives EVs chargers ability to stabilize power fluctuations. Finally, with appropriate regulation, EVs as an energy storage devices, can feed back energy to the power system when necessary, so EV batteries can be treated as distributed generators or emergency sources [12].

Next obstacle for distribution grid is designing an infrastructure solution that allows intelligent charging. The charging process in a distributed system is done locally, as defined by scheduling. Requirements for present and future charging stations have to be basically to provide security and communication features [13].

4. Model of EV as flexible load

Hereafter is presented testing model of 4 residential buildings with integrated renewable energy sources. For representative testing model it is selected self-sustainable house of the University of Zagreb, designed for international competition Solar Decathlon Europe 2014 since one of authors were part of project team [14]. The aim of “Concept Membrain” was to satisfy energy needs out of renewable energy sources, primarily Sun. The house was designed guiding the concept of “my first home”. The inspiration for the house was membrane as the vital components of all living organisms which are directly contacting with the environment, while substances selectively circulate in and out of the intracellular space. The concept intended to be a model for a future building as a self-sustainable prefabricated house, in region of Croatia. In this respect, photovoltaic cells were designed, to precisely 5 kW, each, so study was based on those parameters. Simulated energy production of one house, for typical summer day in Croatia, it is shown in Fig. 2.

It is supposed that each house owns 2 EVs, since it is supposed to be employed, modern family. Capacity of EV’s battery used in simulation process is 30 kWh. Availability of EVs is shown in Fig. 3. While parked, EVs is connected to microgrid of the house [15]. Typical daily traveled distance and energy consumption for their lifestyle is showed in Fig. 4.

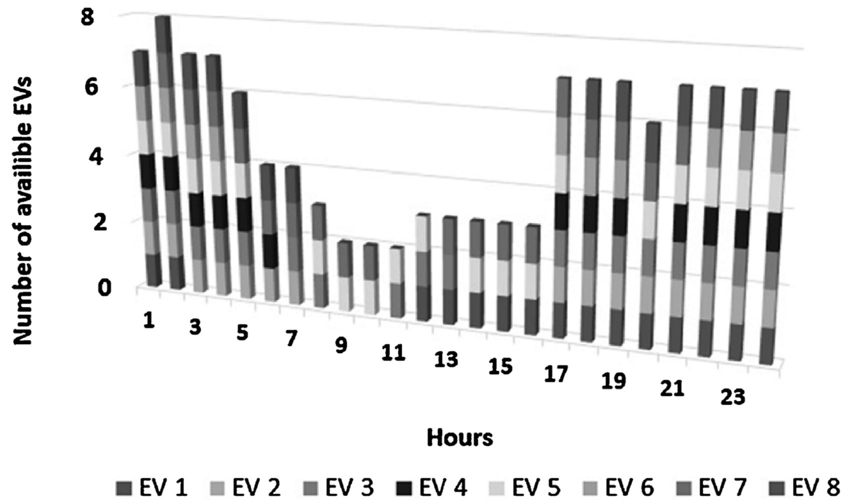

Fig. 3. PV production for typical summer day.

The centralized coordination approach is involved for charge scheduling and it is assumed that future trips, household load and power generation are known for day ahead. In analysis the amount of conventional generation is minimized, while household and vehicle load are satisfied. Only the load flexibility of the EV is employed to increase the utilization of renewable energy, according contributing to the minimization objective. Optimization is done using software GAMS, a high-level modeling system for mathematical programming and optimization. GAMS is tailored for complex, large scale modeling applications, and allows to build large maintainable models that can be adapted quickly to new situations [16].

Since the capacity of EVs battery is 30 kWh, and assumed consumption of EV is 0.15 kWh/km, maximum range amounts 200 km. In the model simulation, it is assumed maximum charging power of 11 kW, due to the Croatia three phase standards. Furthermore, charging losses are not considered, since the focus is on the general properties of intermittent generation patterns. In the model simulation, only PV power is considered as the available intermittent energy source.

One of the aim is to schedule the charging a fleet of EVs such that amount of electricity for charging is provided from renewable energy sources. If charging needs of the EVs and the households exceed the amount of electricity from renewable energy sources, conventional generation has to be used. It is optimal, from an economic perspective, to first use electricity from renewable sources, as their variable costs are very low. In addition, this operation strategy can reduce the emissions caused by EVs charging and can help to stabilize the power grid under certain conditions.

The scheduling problem can be formulated as the minimizing the amount of conventional generation, while ensuring the household load and EVs mobility requirements, Eq. (1). A mixed-integer program with knowledge of future renewable generation, household appliances and trips over the time horizon of one day, describes the scheduling problem:

$$\min_{\Phi,ramp,isOn,D} f = \sum_{t\in[1\ldots T]} CG_t \tag{1}$$

Subject to the following constrains ($t \in [1...T]$, $v \in [1...V]$, $\forall n \in a$, $\forall p \in a$, $\forall h \in a$ where n, p and h are defined as non-shiftable, power-shiftable or time-shiftable individual appliance in a set of appliances. The power-shiftable appliances allow both time and power optimization parameters, the time-shiftable appliances reduce the overall potential for optimization of power consumption as they have fixed power usage scheme so only the initial start time is an optimization parameter. Eq. (2) defines non-shiftable appliances and its fixed hourly power requirement during the preferred working period. For power-shiftable appliances p with standby power $\alpha_{p,t}$ and maximum working power $\beta_{p,t}$, together with a possibly preferred working period, the consumption requirement can be defined as in Eq. (3). A time-shiftable appliances denotes $h \in a$ in order to distinguish it from other appliances. The appliance can have present power consumption power $r_h = [r_{h,1}, r_{h,2}, \ldots, r_{h,24}]^T$. The operation can be postponed, but the power consumption pattern should remain the same. Hence the scheduling result $x_{h,t}$ has to be exactly the same as one of the cyclic shifts of the pattern r_h. All possible shifts can be put together as in matrix in Eq. (5). The

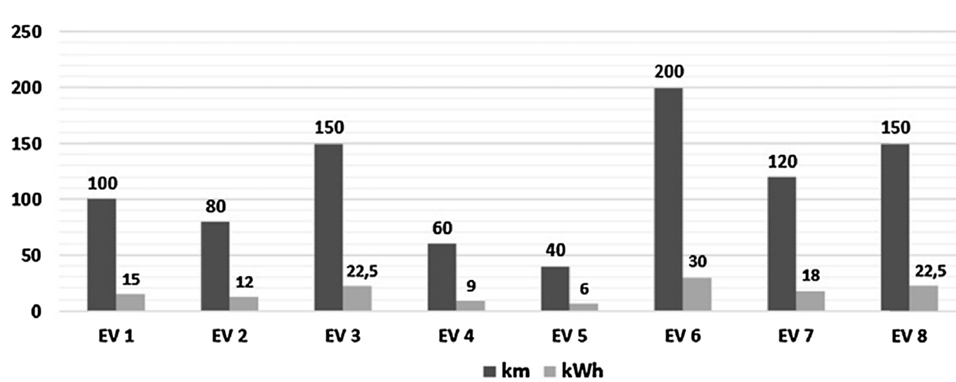

Fig. 4. EV daily traveled distance and energy consumption.

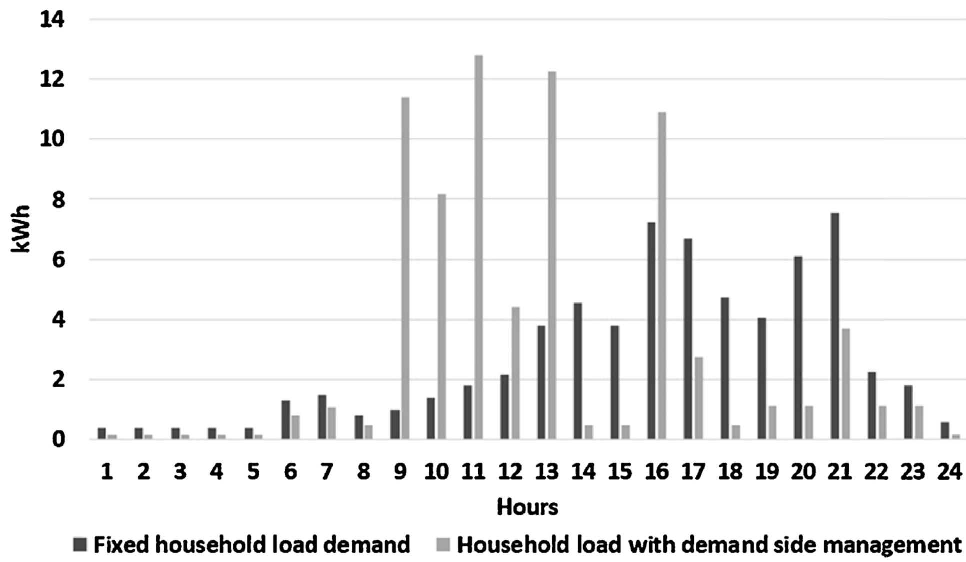

Fig. 5. Household load demand for both cases.

binary integer vector $s_h = [s_{h,1}, s_{h,2}, \ldots, s_{h,24}]^T$ is defined as switch control for the time-shiftable appliance h. There is only one non-zero element in the vector s_h which is equal to one. The vector s_h is an optimization parameter which chooses the appropriate column of R_h to optimize the energy consumption, Eq. (6). Equations from 1 to 6, include constrains in establishing demand side management of household load.

$$x_{n,t} = \delta_n \tag{2}$$

$$\alpha_{p,t} \le x_{p,t} \le \beta_{p,t}, \quad \sum_{p \in a} x_{p,t} = l_p \tag{3}$$

$$R_h = \begin{bmatrix} r_{h,1} & r_{h,t} & \cdots & r_{h,3} & r_{h,2} \\ r_{h,2} & r_{h,1} & \cdots & r_{h,4} & r_{h,3} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ r_{h,t} & r_{h,t-1} & \cdots & r_{h,2} & r_{h,1} \end{bmatrix} \tag{4}$$

$$x_h = R_h \cdot s_h, \ 1^T \cdot s_h = 1 \tag{5}$$

$$D_t = \sum_{n \in a} x_{n,t} + \sum_{p \in a} x_{p,t} + \sum_{h \in a} x_{h,t} \tag{6}$$

$$NG_t = P_t - D_t \tag{7}$$

$$NG_t + CG_t - \sum_{v \in [1..V]} \emptyset_{v,t} \ge 0 \tag{8}$$

$$isOn_t \le isOn_{t-1} + ramp_t \tag{9}$$

$$isOn_{t+1} \ge ramp_t \quad \forall \quad i \in \{1, 2, 3\} \tag{10}$$

$$\underline{CG} \cdot isOn_t \le CG_t \le \bar{CG} \cdot isOn_t \tag{11}$$

$$SOC_{v,t} = SOC_{v,t-1} + \Phi_{v,t} - \gamma_{v,t} \tag{12}$$

$$O \le \Phi_{v,t} \le \mathcal{K}_{v,t} \cdot \bar{\Phi} \tag{13}$$

$$O \le SOC_{v,t} \le \bar{SOC} \tag{14}$$

$$\mathcal{K}_{v,t}, ramp_t, isOn_t \in \{0, 1\} \tag{15}$$

Net generation is defined as the difference between renewable generation and the controllable household load, so constraint in Eq. (8). requires the total generation in any time slot to match the electricity demand of residential and EVs charging load. Ramping constrains, to save battery life time, are covered in Eqs. (9) and (10). Since non-monetary objective function is used, ramping costs are not explicitly considered. However, the minimum run constraint avoids frequent ramping activity. Eq. (11) ensures the conventional generation's minimum and maximum utilization levels. Constraint in Eq. (12) ensures continuity of the battery level of each vehicle over time. Charging availability and maximum charging power are constrained in Eqs. (13) and (14), valid range of the battery level [11,17]. Results of model simulation are presented in next section.

5. Results

Results have been represented for three different scenarios. The first one is base scenario, where no management and no control of household load and EVs are present. The second scenario is based on controlled charging of EVs, but household load is fix, so home management is excluded. Finally, the third scenario as represented in previous Section, includes controlled charging of EVs integrated with home demand side management. The second and third scenario, equally represents different engagement of energy citizens in smart grid.

Household load with fix energy consumption and integrated demand side management is shown in Fig. 5. Almost quarter, precisely 24.35% of load is shifted in periods with high penetration of renewable energy sources. Only 7.79% of household load is settled with conventional generation integrating home demand side management, unlike 21.7% of household load with fix household load. Dependence on the electric grid in third scenario is even decreased twice and electricity is only used for non-shiftable appliances, Fig. 6. Accordingly, Figs. 7 and 8 show how time-shiftable and power-shiftable appliances energy consumption was managed by home demand side management. Time-shiftable appliances like clothes washer, clothes dryer and dishwasher are postponed from afternoon and night periods to morning and afternoon periods, so functionality of household is preserved, since the work is done. Power-shiftable appliances like heat-pump, water boiler and laptop are shifted in periods with high penetration of renewable energy. The demand is satisfied. As seen, those two categories represent enormous potential to manage and balance energy consumption with energy production.

Employed conventional generation, for uncontrolled charging with fix household load amounts 144.75 kWh, for controlled charging with also fix household load is 23.27 kWh and controlled

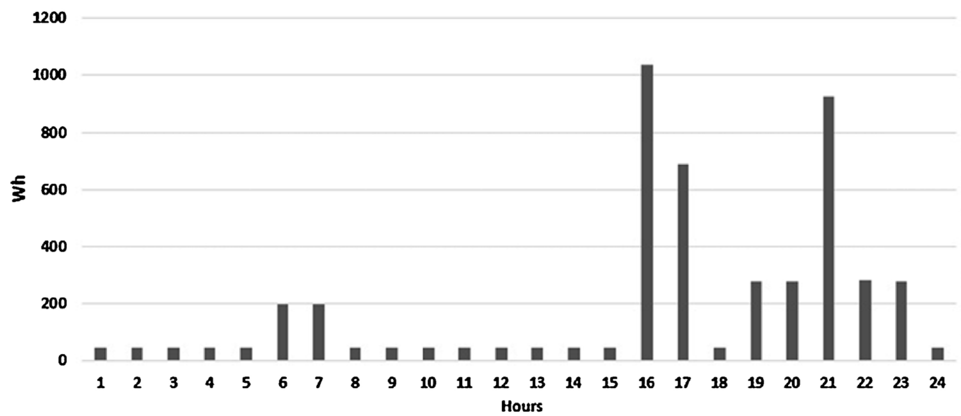

Fig. 6. Energy consumption of non-shiftable appliances.

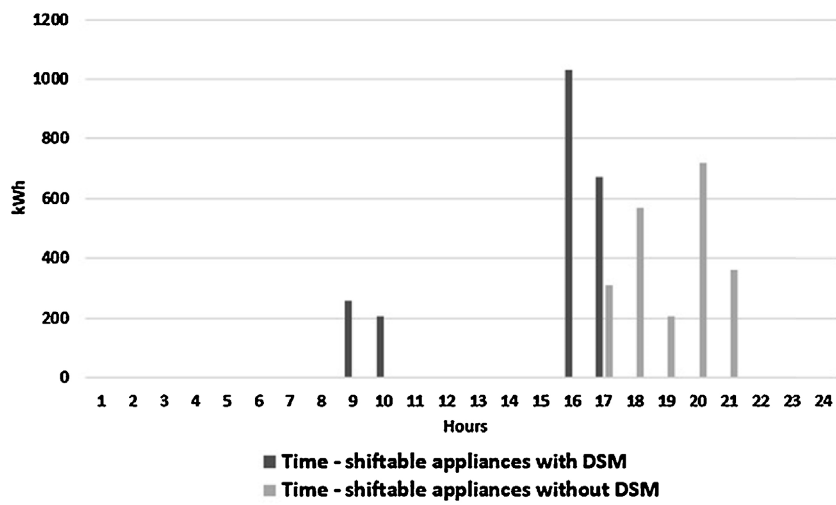

Fig. 7. Energy consumption of time-shiftable appliances.

charging with home demand side management 6.6 kWh, as shown in Fig. 9. Results show that dependence on the electric grid can be enormously decreased, if EV charging is postponed and home demand side management is applied. Main characteristic of controlled charging of electric vehicles is that electric vehicles do not charge at the moment when they connect to the electric grid, but that depends on the electric grid parameters. As the numbers represent, controlled charging will be significant and inevitably for future grid if want to be labeled as smart grid.

Charging amounts for uncontrolled charging with fix household load (242.9 kWh), controlled charging with fix household load (165.32 kWh) and controlled charging with home demand side

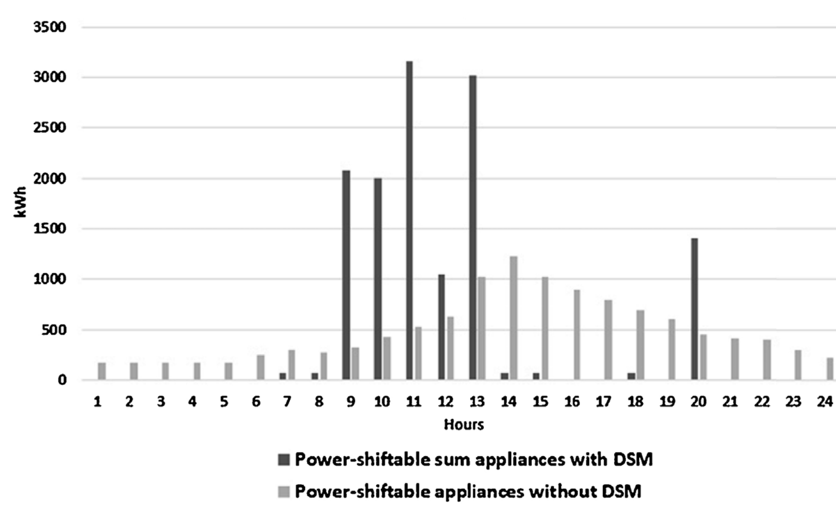

Fig. 8. Energy consumption of power-shiftable appliances.

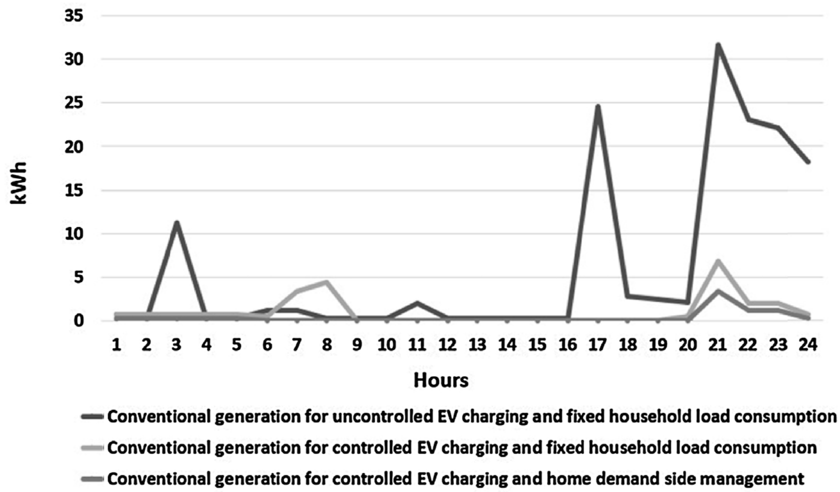

Fig. 9. Conventional generation for different types of load demand.

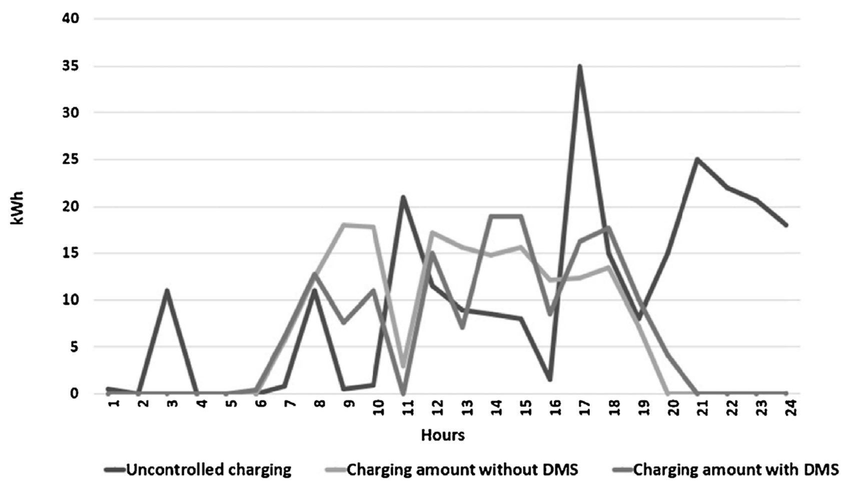

Fig. 10. Amounts of charging EV for different types of load demand.

management (154.45 kWh) are shown in Fig. 10. Most of the EV charging is provided during renewable energy production. Average renewable energy share for uncontrolled charging with fix household load is 68.20% but for controlled charging with fix household load and controlled charging with home demand side management is 100%. The percentage of renewable energy share is significantly increased including demand side management. Gottwalt et al. in their research did not include home demand side management and renewable energy source was wind, so share was about 30% lower. Our simulation results represent better integration of renewable energy sources into the grid.

As already mentioned in Section 1, the challenge of realizing the smart grid is at least as much institutional, as technical. The core of this concept lies in two conflicting visions of the “demand side”. In one of a largely passive consumers hand limited control of some devices to the grid. So named, energy consumers here are a “managed” by demand side and essentially the user remains passive and dumb, as it is presented in based scenario. The contrasting vision is of an active citizen, who becomes “manager” in the process of consumption, as well as potentially generation.

In this case, energy citizen is active and involved in both problem and solution, as represented in second and third scenario where different level of their engagement is represented. Of course, the full engagement is resulted with greater potentials. Conclusively, the visions are not maturely exclusive, so policy makers in practice can outcome with combination, where they are likely to co-exist. Ultimately, the best effective smart grid will be one in with intelligence is sourced from users as well, as devices, because even the most efficient device can waste energy if the user is not behaving in efficient way.

6. Conclusion

Based predisposition in the research was that home demand side management and EVs load flexibility can significantly improve balancing of intermittent generation and increase the direct utilization of renewable sources. As represented in the paper, the proposed model of small residential, solar powered buildings is able to schedule daily household load integrating home demand side management base on three different categories of appliances and performing the batteries of electric vehicles as an energy storage system. MILP is found to be successful schedule technique in helping the utilities to manage energy consumption in sensitive microgrids with EV fleet. Minimization objective was employed conventional generation capacity, excusal energy consumption provided from the electric grid. Results outcome that conventional generation can be significantly reduced in order to decrease the electric grid dependence and ensure base for microgrid systems. Base scenario, without any management was compared with controlled charging and with or without home demand side management, so conclusively three scenarios were tested.

Finally, decreased the electric grid independence, according to user preferences and the power consumption patterns of individual appliances. The modeled EVs were capable of charging during the highest renewable energy sources penetration. It was observed that the charging amount, if EVs are controlled, it can consist of 100% renewable energy. In future work the model needs to be extended by larger microgrid, introducing shorter optimization time horizons and incorporating the uncertainty of trip and generation information, tested thru more different scenarios.

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