Appliance Scheduling Optimization for Demand Response: A Review

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Abstract

The research studies the challenge of the electricity consumption management in smart grids. It focuses on different impacts of demand response running in the smart grid engaging consumers to participate. The main responsibility of the demand response system is scheduling the operation of appliances of consumers in order to achieve a network-wide optimized performance. Each participating electricity consumer, who owns a set of home appliances, provides the desired expectation of his/her power consumption scenario to the demand response system. It is accompanied with time limits on the flexibility of controllable appliances for shifting their operational time from peak to off peak periods. The appliance scheduling optimization for demand response is modeled as an optimization problem.

Key words: Smart Grid; Demand Response; Appliance Schedule; Optimization

I. Introduction

The optimal scheduling of power generation, also known as Unit Commitment (UC) problem, is one of the most challenging problems in power systems optimization [1]. In a Microgrid (MG), which is basically small scale power system with the ability to self-supply and islanding, the MG Central Controller (MGCC) has to coordinate the MG distributed generation (DG) sources in order to provide enough power to satisfy the load demand, while striving to achieve some optimal objective. This usually involves determining hundreds of discrete and continuous variables subject to numerous linear, quadratic, and sometimes non-linear constraints depending on the DG source characteristics and load demands. The DG sources can comprise of different technologies including Diesel engines, micro turbines, fuel cells as well as photovoltaics, wind turbines, and hydro turbines, with capacity varying from few kW to 1-2 MWs ([2], [3]).

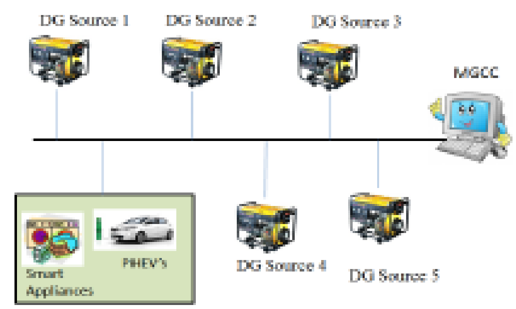

Fig. 1: System under Consideration

In this work, we address the UC problem in the context of an “islanded” MG that supplies electricity for smart homes. The smart homes contain programmable appliances, which can be scheduled for operation [4]. We consider appliance operations as schedulable tasks with power and timing demands. The smart appliances communicate with the MGCC about user-scheduled tasks, for example, over power lines. Fig. 1 depicts an exemplary schematic description of the system under consideration.

We assume that tasks get scheduled on a day-ahead basis, so that the MGCC can schedule the DG sources’ operation for the upcoming day. We do not consider the power demands due to spontaneous small loads, such as TV set, computer, or microwave oven, but rather assume that the MG has reserved generator capacity to produce enough continuous power to meet those needs. Additionally, we only focus on scheduling dispatchable power sources, such as Diesel engines and fuel cells, and we leave the integration of renewable energy sources for future work.

The rest of research paper is design as follows. The overall previous work is described in Section II. Section III describes problem formulation. Performance parameter describe in section IV. Finally, Section V describes the conclusion of paper.

II. Literature Review

This section will provide the brief description and highlights the contribution, remarks and factors of the work done by the researchers. Many attempts have been made in the past to achieve the maximum peak signal to noise ratio.

Sean T. Blake et.al (2018) introduced a model of an industrial microgrid with distributed energy resources (DERs). The model is applied to an existing manufacturing facility in Ireland. The test facility is connected to the main electricity grid but also has onsite generating units; a wind turbine and a combined heat and power (CHP) unit. The model generates a facility load forecast using historical data. A scenario analysis is then performed to investigate the effect of operating DERs, including demand response (DR), on carbon emissions and energy costs in an industrial micro grid.

An energy storage component is then introduced and the viability of installing this technology is investigated. The effect of operating DERs in an industrial micro grid was investigated in this study. A model was developed of an industrial micro grid with a grid connection, dispatchable and non-dispatchable power sources, a controllable industrial load and energy storage system. The model generates a load forecast and analysis is performed investigating the effects of operating DERs in the industrial microgrid on energy cost and carbon emissions. The study has shown that there are benefits associated with operating DERs in an industrial microgrid. When compared with an industrial facility that is supplied with grid electricity only, it is clear that ample savings can be achieved through the utilization of DERs. The results clearly highlight that the largest savings are achieved when onsite generators are used to displace electricity imported from the grid. This is ideal for industrial facilities with large heat loads, as the heat generated by the CHP unit is utilized entirely [1].

Siwar Khemakhem et.al (2017) investigated the possibility of reducing peak demand in household by demand response was presented. The main contribution of this study is to develop a supervision algorithm for household power management with respect of the class of appliances and their priority order. The control strategy of the studied system aims to detect the relationship between electricity price and total load demand in order to shift some appliances form peak hours (high prices) to off peak periods (low prices) ensuring consequently the smoothness of the daily load curve to make it between a limiting power margin without affecting the family lifestyle [2] .

Zaiyue Yang et.al (2015) This paper aims at minimizing economical cost of a microgrid by jointly scheduling various devices, e.g., appliances, batteries, thermal generators, and wind turbines. To properly model the system, the characteristics of all devices is fully investigated; in particular, the chance constraint is introduced to capture the randomness of power generation of wind turbines. Then, this problem is formulated as a large-scale mixed-integer program with coupling constraints. In order to solve this problem efficiently, it is decoupled via dual decomposition into a set of sub problems to be solved distributedly on each appliance, battery, and generator. While the scheduling of generator is well studied in literature, this paper specially proposes an efficient method for appliance scheduling, and then employs Benders' decomposition for battery scheduling. The performance of the proposed approach is verified by numerical simulations. In this paper, an approach improving the operation of large-scale of devices is developed to save the total cost of the micro grid. After introducing the chance constraint to represent the randomness of wind power, the scheduling problem is characterize into MINP, which is decomposed via Lagrange relaxation into three sets of SPs later, i.e., appliance scheduling, battery scheduling and generator scheduling. Since the generator scheduling is well studied in literature, in this paper an efficient method is proposed for appliance scheduling, and Benders' decomposition is employed for battery scheduling. Taking advantage of the distributed nature of proposed approach, parallel implementation is developed to reduce computation time in large-scale situation. Finally, simulation results validate the performance of our proposed algorithms [3] .

Juliette Ugirumurera et.al (2015) studied the problem of optimal power generation scheduling in an isolated Micro grid, exploiting the flexibility to schedule energy-consuming tasks in smart homes. We formulate the problem as a non-linear optimization problem and present two scheduling protocols to solve it: GA-INT, a genetic algorithm that utilizes task interruptions, and PRO-S, a heuristic-based algorithm, which strives to smooth out peaks in the load profile. Numerical simulations demonstrate that PRO-S successfully reduces the complexity of the problem, while guaranteeing performance that approximates GA-INT's. The latter returns optimal or nearly optimal solutions, but with long execution times. This paper formulates the problem of optimal power generation in an "isolated" MG as a non-linear mixed integer problem, and implements two algorithms, GA-INT and PRO-S, to solve it. GA-INT is a genetic algorithm that exploits task interruption and task shifting, and produces optimal or near-optimal solutions. Since GA-INT is time expensive, we also design a heuristic-based algorithm, PRO-S, to reduce the complexity of the problem. Simulation results demonstrates that, in medium to high load situations, PRO-S indeed reduces greatly the time complexity of the problem by solving it in few seconds, while incurring less than 5% in extra cost in comparison to GA-INT. The latter requires at least an hour in low load situations, and can take more than 10 hours when the daily task arrival rate is greater than 200. However, even in low load scenarios, GA-INT cost reduction was no more than 9% over PRO-S [4].

Mosaddek H. K. Tushar et.al (2014) proposed a DRTA scheme of electricity to the homes in a grid connected MG power by mix of renewable and/or nonRES. The MG uses EVs as the electricity storage to improve the energy efficiency and stability of the system. Each home in the MG independently schedules its home appliances and EVs to increase the overall social benefit of the MG. We observed that both DRTA and COPCS outperform the natural allocation scheme UREG, increase energy efficiency, and reduce the total (and average) electricity cost as well as reduce the amount of imported energy from the external grid. We found that the COPCS algorithm is suitable for scheduling home appliances and EVs of a small size microgid and not suitable for a large sized MG, because the execution time of COPCS increases exponentially with the increase of the number of homes. Whereas, the DRTA is a distributed real-time scheme which does not depend on the number of homes in the smart grid or MG because in DRTA scheme, each home independently optimizes its energy cost and increase the overall social benefit. In each time slot,

DRTA modifies or adjusts the energy allocation plan according to the observed and predicted amount of load and energy, and allocates energy to all homes for the current time slot. We have also seen that, in all the cases, DRTA demonstrated and optimal solution close to the COPCS scheme. Similar to the COPCS, DRTA has two very significant properties: 1) load regulation which shifts flexible load from high to the low demand duration; and 2) energy regulation which stores excess energy to EVs batteries (G2V) from off-peak hours, and later use the stored energy (V2G) to meet the peak hours demand.

The DRTA scheme converges to a stable state in few iterations (Fig. 6) and has the flexibility to terminate anytime, therefore, the proposed scheme is suitable and practical for a smart grid or MG operator of any size. The DRTA scheme with a centralized coordinator gives more control to the MG operator for real-time electricity Pricing function, hence it is indeed a more practical approach. Conversely, the coordinator functions can easily be adopted to the customer point. In that case, each customer will send load information to all other customers and the total current load and prices will be calculated locally. Each customer still needs to communicate with the operator to get the current information about the amount of electricity produced. In practical implementation, the information of energy usage pattern of every home is exposed which may raise some privacy issues [5].

Mosaddek Hossain Kamal Tushar et.al (2014) proposed joint centralized optimal scheduling schemes for home appliances and EVs in a grid-connected micro grid powered by renewable energy sources. The micro grid uses EVs as electricity storage to improve the efficiency and reliability of the system. We have observed that the optimal scheduling schemes clearly outperform the naïve scheduling scheme by better managing the electricity consumption and shifting soft loads from high demand (and/or low power generation) periods to low demand (and/or high power generation) periods. For instance, our simulation results show that the performance increase of optimal scheduling EV with or without discharge capability is almost 175% for 400 EVs and 85% for 590 EVs, respectively, compared to naive scheduling.

Also, the optimal algorithm with EV discharge outperforms the decentralized EV charging control method using a non-cooperative game. The running time of the proposed joint scheduling algorithm is small for a residential community. For 500 homes (3500 home appliances) with 1000 EVs, it took from less than a second to 138 seconds for each iteration in a computer (Intel core i5 processor with 4 GB memory). In real-time implementation, upon receiving the requests from the hard load appliances, micro grid allocates energy with no delay. In case of soft load (type B and C), micro grid determines the schedule of electricity allocation and allocates power according the schedule. The interactions may not produce an optimal EV charging schedule due to inconsistencies in the flow of information. The proposed joint scheduling policies are capable to accommodate any energy source model. The optimal joint scheduling is sensitive to the variation of load, load characteristics and stochastic nature of renewable energy generation. We have shown that our proposed model always produces optimal results for a microgrid with renewable, non-renewable, or both energy sources [6].

Ditiro Setlhaoloa et.al (2014) proposed residential demand response is studied through the scheduling of typical home appliances in order to minimize electricity cost and earn the relevant incentive. A mixed integer nonlinear optimization model is built under a time-of-use electricity tariff. A case study shows that a household is able to shift consumption in response to the varying prices and incentives, through which the consumer may realize an electricity cost saving of more than 25%. It has also been shown that at different values of the weighting factor ¸α gives varying costs, from which the consumer is able to choose according to their preferences. Therefore a final decision about participation in the program could be made. The paper gives our preliminary results from a study using MINLP in which consumers reschedule their appliances due to variable electricity prices as demonstrated through a TOU tariff and also by offering an incentive. It has been shown that the consumers shift their load to off-peak times and they also limit their usage during peak times by switching off some appliances. The consumer reduced the cost of electricity by more than 25% and also earned some incentives. It is noted that the amount of savings realized cannot be generalized because the savings may be affected by a number of factors, such as shiftable appliances and a price difference between peak and off-peak times. It has also been shown that at different values of the weighting factor ¸, the consumer has varying costs. From this, the consumer is able to know the inconvenience level that comes with the new schedule and is able to adjust it according to his preferences in regard to the cost and the inconvenience. Therefore a final decision about participation in the program could be made [7] .

Ijaz Hussain et.al (2015) presented a survey of recently published research in the domain of DR. We provide an extensive review on pricing signals and AS schemes used with respect to multiple criteria. The maximum electricity cost saving (24 % to 44.1%) was achieved in [6], while 38% reduction in peak to average ratio was possible .The simulation results of showed that network peak can be shaved for almost 11 years that benefits utility by not requiring any update in their infrastructure [7].

Hee-Tae Roh et.al (2015) studied an electricity load scheduling problem in a residence. Compared with previous works in which only limited sets of appliances are considered, we classify various appliances into five sets considering their different energy consumption and operation characteristics, and provide mathematical models for them. In this paper, we studied the residential electricity load scheduling problem with considering the various appliances. We first provided mathematical models for five different sets of appliances according to their operation and energy consumption characteristics: 1) set of elastic appliances with a memory less property; 2) set of elastic appliances with a full memory property; 3) set of elastic appliances with a partial memory property; 4) set of inelastic appliances with an interruptible operation; and 5) set of inelastic appliances with an uninterruptible operation. We then developed the electricity load scheduling algorithm to maximize the overall net utility, which is defined as the weighted total utility of appliances with elastic energy consumption minus the weighted total cost for the energy consumption, while satisfying a budget limit. The optimization problem is an MINLP problem, which is difficult to solve in general. In order to solve the optimization problem with low computational complexity, we used a GBD approach. Numerical results showed that in the proposed algorithm, each appliance is effectively scheduled according to its energy consumption and operation characteristic while appropriately considering the residence's preference on utility and cost. Note that our framework and algorithm in this paper are quite general. Hence, they can be easily generalized to accommodate new types of appliances that will come out in the future. In addition, we believe that our framework could be used to study more general situations such as a joint DR and pricing problem with multiple residences [8].

F. A. Qayyum et.al (2015) proposed a solution to the problem of scheduling of smart appliances operations in a given time range. We adopt a photovoltaic (PV) panel as a power producing appliance that acts as micro-grid. Appliance operation is modeled in terms of un-interruptible sequence phases, given in load demand profile. An optimization algorithm, which can provide a schedule for smart home appliances usage is proposed. Simulation results demonstrate the utility of our proposed solution for appliance scheduling. We further show that adding a PV panel in the home results in reduction of electricity bill and export of energy to the national grid. In this paper, we formulated the appliance scheduling problem in home area networks (HAN) as a dual-objective problem with constraints. The first objective deals with the lowering of electricity cost and the second objective deals with the minimizing of maximum peak load. The problem for appliance scheduling was shown to be a mixed integer non-linear programming with a binary decision variable for switching an appliance ON and OFF, thus making our optimization problem type a non-convex. We utilized branch-and-bound algorithm to solve our problem. Simulation results showed the effectiveness of our proposed solution in lowering the electricity cost and peak load. We further showed that the addition of PV panel enabled lowering of cost and export of electricity to the main grid [9].

F. A. Qayyum et.al (2015) proposed a solution to the problem of scheduling of a smart home appliance operation in a given time range. In addition to power-consuming appliances, we adopt a photovoltaic (PV) panel as a power-producing appliance that acts as a micro-grid. An appliance operation is modeled in terms of uninterruptible sequence phases, given in a load demand pro_le with a goal of minimizing electricity cost filling duration, energy requirement, and user preference constraints. An optimization algorithm, which can provide a schedule for smart home appliance usage, is proposed based on the mixed-integer programming technique. Simulation results demonstrate the utility of our proposed solution for appliance scheduling. We further show that adding a PV system in the home results in the reduction of electricity bills and the export of energy to the national grid in times when solar energy production is more than the demand of the home. In this paper, we formulated the appliance scheduling problem in home area networks as a problem consisting of two objectives along with constraints. The _rst objective deals with the lowering of electricity cost and the second objective deals with the minimizing of maximum peak load. The problem for appliance scheduling was shown to be a mixed integer programming with a binary decision variable for switching an appliance ON and OFF, thus making our optimization problem type a non-convex. We used seven appliances of different shift able types of load and one micro grid i.e., PV panel. We utilized branch-and-bound algorithm to solve our problem. Simulation results showed the effectiveness of our proposed solution in lowering the electricity cost and peak load. We further showed that the addition of PV panel enabled lowering of cost and export of electricity to the main grid [10].

Arif Onder Isikman et.al (2013) investigated the problem of islanded micro grid operation where a subset of the power grid is designed to operate completely disconnected from the rest of the power grid. Our goal is to make this mode of operation for the micro grid more sustainable by intelligently allocating power among the users and their appliances in accordance with priority levels as configured in the smart meters. To the best of our knowledge, such a modeling of a micro grid power usage optimization with renewable sources and stored energy is the first in the literature. Our model also includes a novel taxonomy of the energy usage by appliances in terms of time and power level adaptability which covers most of the appliances in the grid. Our contributions are in the problem formulation and solution approach as well as in the comparative performance evaluations that show clear advantages, such as smoother power consumption over time and coverage of larger portion of the appliances in the grid, of using intelligent power allocation as compared to the current system [11].

Ishan Gupta et.al (2014) explained for the demand side management strategy. The problem of load shifting in order to minimize the peak demand and reduce the utility cost has been approached in hour wise manner, starting from the first hour till the last hour of the day. To fulfill the objective of load shifting through minimization problem, particle swarm optimization (PSO) algorithm has been modified foe the DSM problem and implemented in three area loads of smart grid i.e. residential, commercial and industrial. Demand side management is gaining a lot of importance due to its benefits to the entire smart grid. It reduces the excess demand of power during peak hours and along with that it also reduces the utility bill of the consumers. In this paper a new approach has been adopted using the particle swarm optimization algorithm which has come out with the reduction in peak demand and also results in substantial savings in utility bills. This approach has been carried out on three area loads, i.e. residential, commercial and industrial of a smart grid [12].

Florian Bahlke et.al (2011) presented a novel scheme for load management in microgrids based on stochastic scheduling of loads under risk-limiting constraints. When trying to enforce adequate power supply in a micro grid, the volatility of renewable resources such as wind energy has to be considered. In the risk of inadequate power supply, loads have to be scheduled, which can be achieved by directly controlling individual loads or by setting pricing incentives to encourage beneficial behavior of the customers. A common drawback of conventional methods lies in the need of sophisticated control strategies and a significant amount of real-time signaling exchange between the micro grid and the central control unit.

To address these issues, we propose a scheme that does not require a direct control of individual loads. Our method relies on sorting the appliances in the network into groups, and allowing these groups to schedule themselves stochastically according to broadcasted scheduling probabilities. In this paper, we propose an optimization problem to determine these group scheduling probabilities, as well as for choosing the best utilization of conventional generators, in a day-ahead planning scenario of an isolated micro grid. Using an outage-risk limiting constraint, we control the risk of inadequate power supply causing network outages. The proposed scheme can be easily implemented with unidirectional communication from a central control unit via simple broadcast messages [13].

Table1. Comparison of DR Techniques based on Selected Quality Criteria

Technique	Objectives	Scheduler	Pricing Scheme	Optimization	Assumptions	Renewable Energy
1.	Minimize energy bill, appliance waiting time and PAR.	Manual	RTP combined IBR	LP	Future pricing parameters are known for the users ahead of time	PHEV as a BES used
2.	Minimize energy bill and user discomfort	Automatic	RTP	Converted - Linear	Temperature band is uniform, Mean error of 10% is assumed in forecasted price	Not used
3.	Minimize energy bill by consumer reward	Automatic	TOU	NLP	Power consumption profile in each house is assumed to be the same	Not used
4.	Minimize energy bill and PAR	Manual	RTP combined with IBR	Nonlinear	Nine kinds of AOAs and 16 operation per day for them	Not used
5.	Minimize energy bill and user discomfort	Automatic	RTP,FIT and Net Sale/Purchase	Linear	Convex cost function, PV generation is able to meet 50% of its load requirement	PV
6.	Minimize energy bill and user discomfort	Manual	RTP	Linear stochastic	Solar power is cheaper than grid	PV and BES

Table 2 Comparison of DR Techniques based on Selected Quality Criteria

Technique	Users	Forecasting	Communication	Requirement	Max Delay	Benefits
1.	Multiple users (10)	Real-time price prediction at the user side	WHAN is used	SM with energy scheduler and price predictor	User defined	25% reduction in EC and 38% reduction in PAR
2.	Single User	Energy and hot water FC	Thermostatic Signal to control appliance	Modeling of equipment	Temperature of water may low	Over 20% in EC
3.	Multiple users	Consumer survey is used	SM and main controller are used	Consumers survey prior to connection	4 minutes or switch off for 15 minutes	Shave the network peak for almost 11 years
4.	Multiple users	Not used	Too much communication involved	HEMS	User defined	26.06% in EC and 35.44% reduction in PAR
5.	Single User	Energy and Load FC	Smart scheduler uses 2 way communication	TOU probabilities of appliances	2 time slot(12h)	10.92% in EC
6.	Single User	Energy FC	SM is used to communicate	VFD and capacity limited energy drives	Instead of delay new trip rate used	24% to 44.1% in EC

III. Problem Formulation

The optimization of the scheduling probabilities is carried out as an economic dispatch problem, which aims to minimize the total network utilization cost. This problem has been studied extensively in the context of micro grids. Formulating the UC problem for MG utilizing a more realistic generators' model, which comprises startup costs and generators states. Our goal is to determine the generating units' states during the T timeslots, so as to minimize the total operating costs, while meeting the tasks' power and timing requirements. The MG operation cost, C, is calculated from the generators' power production cost and the startup costs.

IV. Conclusion

In this paper, we have presented a survey of recently published research in the domain of DR. We provide an extensive review on pricing signals and AS schemes used with respect to multiple criteria. The maximum electricity cost saving (24 % to 44.1%) was achieved in6, while 38% reduction in peak to average ratio was possible in 1. The simulation results of 3, showed that network peak can be shaved for almost 11 years that benefits utility by not requiring any update in their infrastructure.

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