Coordinated Scheduling of Multiple Households' Appliances with Leveled Load Profiles and Consumers' Preferences

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Abstract

This paper addresses the multiple households' residential load scheduling problem through the scheduling of typical home appliances while incorporating more realistic aspects. The objective of this study is to generate an optimal load schedule of home appliances for five households with leveled load profile while considering the consumers' preferences. A myriad of variants of the problem has been addressed in literature, however, studies considering minimization of both electricity cost and peak load while considering the consumers' inconveniences in a multiple-household environment have not received sufficient attention. Ignoring coordination between multiple households while solving the residential load scheduling problem could result in unplanned synchronization of peak loads of the individual consumer, which could result in an unmanaged aggregated peak load. Reducing the overall peak load is an important goal for all the actors in the power grid. This study, therefore, proposes a multi-objective mixed integer programming optimization model under a time-of-use electricity tariff. The objective function minimizes the weighted score of three terms: the electricity cost, the schedule inconvenience, and the peak load over the day. A case study of five households shows that the proposed schedules with coordination between multiple households could realize a significant reduction in the aggregated peak load.

Keywords
Electrical peak load reduction, Household energy management, Multiple households, Inconvenience, Residential load scheduling, Mixed integer programming optimization

1. Introduction
Electricity demand is increasing exponentially all over the world, and especially in Africa. For example, the grid peak load follows an increasing pattern with growth of 37% from 37,500 MWh in 2017 to 61,596 MWh in 2030 (Eskom[a]). Furthermore, Statistics South Africa reported that households using electricity as the main energy source for cooking and lighting in South Africa has increased by around 30% from 1996 to 2016 (Statistics South Africa, 2016). The residential sector represented around 20~25% of South Africa's total load and is a significant contributor to both the morning and evening peak periods, resulting in an overall national load factor of 72% (Eskom[a]).

Demand Response (DR) is becoming a well-known approach that can help utility companies and customers to reduce peak load (Siano, 2014) by managing and scheduling the electricity demand. Effective DR implementation involves planned cooperation between utilities and consumers to adjust load curve resulting in benefits to both the utility and consumers. Additionally, it has been proven that DR can reduce energy consumption significantly in residential sector

(Saele and Grande, 2011). One of the major goals of a DR program is reducing consumption during peak hours and shifting demand to off-peak hours. Consumer participation is encouraged by offering dynamic electricity price policies (Schweppe *et al.*, 1988) and this in turn necessitates system load balancing, which is vital for load reduction during peak times.

Many review papers have discussed the DR and the load scheduling problem (Gelazanskas and Gamage, 2014; Benetti *et al.*, 2016; Haider *et al.*, 2016; Wang *et al.*, 2017). Although numerous management systems and techniques have been proposed and investigated, literature on coordination at the smart neighborhood level has not yet been studied in details. Only Celik *et al.* (2017) have provided a review of coordination for energy management of multiple households.

The majority of the publications in the household appliances load scheduling problem have considered single household or apartment. Few authors solved the problem in a multiple-household environment and considered the coordination between multiple households. Setlhaolo and Xia (2016) proposed a mixed integer non-linear optimization model for the multiple households' appliances load scheduling problem with the objective function that minimizes electricity costs and inconvenience. However, their model was in a non-linear form which could raise a complexity and computation time issues. Also, they did not consider minimizing the peak load. Shakouri and Kazemi (2017) proposed a multi-objective mixed integer linear programming model for the load scheduling problem that consider minimization of peak load and cost simultaneously for a residential area with multiple households. However, they did not consider minimizing the consumers' inconvenience. Maintaining users comfort preferences at the desired level was one of the recommendations raised by Celik *et al.* (2017). However, systems that consider minimization of electricity consumption cost, consumers' inconvenience and peak load simultaneously for a residential area with multiple households have not received sufficient attention. This study, therefore, focuses on filling this gap.

Henceforth, the purpose of this paper is to develop a multi-objective mixed integer linear programming optimization model for multiple households to determine the optimal scheduling of home appliances under Time of Use (TOU) electricity prices. In this model, the objective function minimizes the weighted sum of three terms: the electricity consumption cost, the associated schedule inconvenience level, and the aggregated electric peak load in a multiple-household environment. This model will enable consumers and utility companies to control how they favor the minimization of electricity bill, the scheduling inconvenience and the reduction of the electrical peak load over each other. Thus, this study investigates the influence of the coordination between multiple households on reducing the aggregated peak load. The remainder of this paper is organized as follows: Section 2 focuses on defining the problem and providing the proposed optimization model. Section 3 examines a case study used in this paper and presents results, comparisons and discussions; and lastly, a conclusion is drawn.

2. Proposed multi-objective optimization model

In this research, a multi-objective mathematical model is formulated for the optimal scheduling of multiple households' appliances. This model is an extension of our previous work (Yahia and Pradhan, 2018) with augmented feature of multiple households rather than a single household while considering consumer's preferences and the peak load reduction. The model is concerned with the decision of selecting an optimal on/off status of each of home appliances over the day for each of the households.

Considering a set of households (H) with an index (h), a sampling time (Δt) of 10 minutes and a study period (T) of 24 hours (full-day), the proposed model is presented below. Table 1 summarizes the indices, parameters and decision variables used in the proposed model.

Table 1. Notation summary

Notation	**Description**
Indices:	
i	Index of home appliance, A is the total number of appliances.
t	Index of time/ time slot, $t = 1, \ldots T$, where T is the horizon.
h	Index of household, H is the total number of household.
Parameters:	
P_i^h	The rated power of appliance i in household h.

N_i^h	The required number of time slots to complete the normal operation of appliance *i* in household *h*.
D_i^h	The time duration (in terms of minutes) required to complete the normal operation of appliance *i* in household *h*.
S_i^h	The start of the preferred time interval for operating the appliance *i* in household *h*.
E_i^h	The end of the preferred time interval for operating the appliance *i* in household *h*.
C_t	The electricity price at time *t*.
Δt	The sampling time.
$X_{i,t}^h$	A binary parameter represents consumer's preferred/baseline ON/OFF status of appliance *i* at time *t* in household *h*.
$W_1,$	The weighting factors for the three terms of the objective function respectively.
Main decision variables:	
$x_{i,t}^h$	A binary variable represents the optimal ON/OFF status of appliance *i* at time *t* in household *h*.
Auxiliary decision variables:	
$u_{i,t}^h$	A binary indicator function to guarantee uninterruptible operation.
$y_{i,t}^h$	A binary indicator function for inconvenience.
z_t	A real value represents the total consumed electrical power or load at time *t* considering all the households.
Z	The maximal electrical load/ electrical peak load over the study period T.

The proposed MILP model for the HALSP considering incentives, consumer preferences and peak load reduction can be formulated as:

The objective function is to:

$$Minimize \left[W_1 \cdot \sum_{h=1}^{H}\sum_{i=1}^{A}\sum_{t=1}^{T} P_i^h \cdot \left[C_t \cdot x_{i,t}^h\right] \cdot \Delta t + W_2 \cdot \sum_{h=1}^{H}\sum_{i=1}^{A}\sum_{t=1}^{T} y_{i,t}^h + W_3 \cdot Z\right]$$

Subject to:

$$X_{i,t}^h - x_{i,t}^h \leq y_{i,t}^h \quad \forall h, \forall i, \forall t \quad (1)$$

$$x_{i,t}^h - X_{i,t}^h \leq y_{i,t}^h \quad \forall h, \forall i, \forall t \quad (2)$$

$$z_t = \sum_{h=1}^{H}\sum_{i=1}^{A} P_i^h \cdot x_{i,t}^h \quad \forall t \quad (3)$$

$$Z \geq z_t \quad \forall t \quad (4)$$

$$\sum_{S_i^h}^{E_i^h} x_{i,t}^h \geq N_i^h \quad \forall h, \forall i \quad (5)$$

$$x_{i,t}^h \leq 1 - u_{i,t}^h \quad \forall h, \forall i, \forall t \quad (6)$$

$$x_{i,t-1}^h - x_{i,t}^h \leq u_{i,t}^h \quad \forall h, \forall i, \forall t \geq 2 \quad (7)$$

$$u_{i,t-1}^h \leq u_{i,t}^h \quad \forall h, \forall i, \forall t \geq 2 \quad (8)$$

$$x_{i,t}^h \leq u_{i,t}^h \quad \forall h, \forall t \quad (9)$$

$$x_{i,t}^h, y_{i,t}^h, u_{i,t}^h \in \{0, 1\} \quad \forall h, \forall i, \forall t \quad (10)$$

$$z_t, Z \in \mathbb{R}^+ \quad \forall h, \forall t \quad (11)$$

The objective function aims to minimize three weighted terms. The first term minimizes the electricity cost (EC). To achieve this, appliances should be scheduled as per the dynamic electricity price. The second term minimizes the inconveniences that may come with the obtained optimal schedule. The scheduling inconveniences (IC) seeks to minimize the disparity between the preferred and the optimal schedule. It is assumed that the postponement and advancement of the schedule are both regarded as an inconvenience. The third term minimizes the total hourly electrical peak load over the day (EPL) for all the households. The hourly load results from the sum of the scheduled appliances at each hour for all the households.

The inconvenience indicator function $y_{i,t}^{h}$ is estimated, in constraints (1-2), based on $x_{i,t}^{h}$ and $X_{i,t}^{h}$. Where the former represents the optimal ON/OFF status of appliance *i* at time *t* in household *h*, which equals 1 if appliance *i* in household *h* is ON at time *t* and zero otherwise. And the later is the consumer's preferred ON/OFF status in household *h* of appliance *i* at time *t*, which equals 1 if a consumer prefers appliance *i* to be ON at time *t* and zero otherwise. The inconvenience indicator function $y_{i,t}^{h}$ has a value of one only when the new obtained schedule does not match the consumer preferred schedule.

$$y_{i,t}^{h} = \begin{cases} 1, & \text{if } X_{i,t}^{h} \neq x_{i,t}^{h} \\ 0, & \text{if } X_{i,t}^{h} = x_{i,t}^{h} \end{cases}$$

Thus, the inconvenience term can be modeled using the absolute value of the difference between the preferred and the optimal schedules $y_{i,t}^{h} = \left| X_{i,t}^{h} - x_{i,t}^{h} \right|$. A linear formulation for this function is represented in constraints (1-2).

The third term in the objective function optimizes the electrical peak load (EPL), which seeks to level and smooth the aggregated hourly load profile resulting from the optimal schedule over all the households. The hourly load profile z_t is obtained through constraint (3), which is equal to the sum of the scheduled power for all appliances at each hour over all households. Constraint (4) implies that the *EPL* (*Z*) exceeds each z_t, which ensures that the objective function minimizes the maximal/peak load.

Constraint (5) ensures that the assigned time slots for each appliance in each household are sufficient to execute the appliance operation and are within preferred interval $[S_i^h, E_i^h]$ as well. The set of constraints (6-8) ensures continuous operation of appliances, which ensures that the assigned time slots for each appliance are successive or "uninterruptible". A new auxiliary binary decision variable $u_{i,t}^{h}$ is used to refer to the completion of the operation of appliance *i* in household *h*, where $u_{i,t}^{h}$ is equal to 1 if the operation of appliance *i* in household *h* is already completed during time slot *t*. Hence, the corresponding $x_{i,t}^{h}$ must be zero. Constraint (9) guarantees the logical sequence between any two sequential operations of appliances. Sequential operation between appliances means that an appliance cannot be processed unless its preceding appliance operation have completed. For example, the operation of Tumble dryer follows the operation of the Washing machine.

$$S_{\text{Tumble dryer}} \geq S_{\text{Washing machine}} + N_{\text{Washing machine}}$$

This condition can be conveniently described using the main decision variable $x_{i,t}^{h}$ and the auxiliary decision variable $u_{i,t}^{h}$ as:

$$x_{\text{Tumble dryer},t}^{h} \leq u_{\text{Washing machine},t}^{h}$$

In the general form, this constraint can be imposed as ($x_{i,t}^{h} \leq u_{\tilde{\imath},t}^{h}$). Where $\tilde{\imath}$ is the index of the appliance that must be completed before *i* can start. Constraints (10-11) reflects the binary and real properties of the main and auxiliary decision variables.

3. Numerical results

The performance of the proposed multi-objective optimization model has been tested based on data of five typical households in South Africa. The case study data is an adapted version of the case study considered by Setlhaolo and Xia (2016).

3.1. Case study data

The South Africa's TOU tariff for residential consumers is applied as C_t (peak) = R1.7487 and C_t (off-peak) = R0.5510. Eskom's peak times are 07:00 – 10:00 and 18:00–20:00 (Eskom[b]). Ten appliances are considered and Table 2 provides the information on the model input parameters for each appliance in each household. It must be noted that different power ratings are due to brands and sizes of different appliance. Furthermore, flexibility of appliances differs depending on the consumer, so the timeframe at which appliances may be committed could differ from one household to another. Table 2 also shows the maximum run-time (minute) of appliance i in household h. For example, the information for appliance 1 (Microwave) is as follows. The power rating for the microwave is 0.8, 1.5, 0.6, 1.2 and 0.6 (in KW) for each of the five households, respectively. It is to be switched on for 10 minutes at any time between (17:00) to (21:00) for the first household, and it is to be switched on for 20 minutes at any time between (16:00) to (18:00) for the second household, etc.

Table 2. Appliances data

Appliance	**Power (kW)**					**Duration (Minute)**					**Start and End of the preferred time interval (S_i^h– E_i^h)**				
	h_1	h_2	h_3	h_4	h_5	h_1	h_2	h_3	h_4	h_5	h_1	h_2	h_3	h_4	h_5
Microwave	0.8	1.5	0.6	1.2	0.6	10	20	10	20	10	17:00–21:00	16:00–18:00	08:00–11:00	05:30–09:00	13:00–19:00
Stove	2.2	2	2.4	2	3	50	60	40	50	70	10:30–15:30	10:30–15:30	10:30–15:30	10:30–15:30	10:30–15:30
Dishwasher	1.5	1.2	1.2	1.5	1.5	80	120	110	140	100	20:00–23:00	20:00–23:00	20:00–23:00	20:00–23:00	20:00–23:00
Electric water heater	1.9	2	2.5	3	2.2	180	120	140	160	180	05:00–09:00	05:00–09:00	05:00–09:00	05:00–09:00	05:00–09:00
Washing machine	3	2	2.4	2.2	2	70	90	60	40	80	10:00–15:00	18:00–22:00	15:00–18:00	16:00–22:00	13:00–19:00
Tumble dryer	3.3	2	2.6	2.2	3	30	20	40	30	20	11:00–15:00	19:00–22:00	16:00–18:00	17:00–22:00	14:00–19:00
Vacuum cleaner	1.2	1.8	0.8	1.4	1	30	10	20	30	20	10:00–18:00	09:00–12:00	08:00–15:00	08:00–14:00	13:00–19:00
DVD player	0.025	0.015	0.025	0.015	0.025	120	180	150	120	150	10:00–23:00	08:00–23:00	08:00–23:00	08:00–22:00	13:00–19:00
Kitchen lights	0.11	0.11	0.11	0.11	0.11	As Kitchen appliances									
Laundry lights	0.11	0.11	0.11	0.11	0.11	As Laundry appliances									

3.2. Experimental results

The proposed mathematical model describes the multi-objective multiple households load scheduling problem, which is solved optimally using commercial ILP solver LINGO 12.0 (LINDO Systems Inc.). All tests were run on an Intel Core i5 (2.6 GHz) computer with 4 GB of RAM and Windows 7 operating system. The proposed model solves the appliances load scheduling for the five households simultaneously, so we called this solution as “With Coordination”. Furthermore, the appliances load scheduling problem is solved for each household individually, so we called this solution as “Without Coordination”. The effect of the coordination between multiple households while solving the appliance load scheduling problem is investigated by comparing the “With Coordination” and the “Without Coordination” solutions. The proposed model is solved for three scenarios, based on the values of the weighting factors (W_1, W_2 and W_3). Scenario-1, where $W_1 > W_2 > W_3$, gives higher priority to eliminate the EC and lower priority for minimizing the EPL. Scenario-2, where $W_2 > W_1 > W_3$, gives higher priority to eliminate the IC and lower priority for minimizing the EPL. Scenario-3, where $W_3 > W_1 > W_2$, gives higher priority to eliminate the EPL and lower priority for eliminating the IC. Note that the computation times for most scenarios required only a few minutes, hence the proposed model is efficient to be used on a daily basis.

Figures 1-3 present comparisons between two proposed appliance schedules: “With Coordination” and “Without Coordination” under Scenario-1, Scenario-2 and Scenario-3, respectively. The figures show that the “With Coordination” schedules result in lower EPL. As shown in Table 3, under Scenario-1, the “With Coordination” schedule resulted in a lower EPL of 12.91 KW in comparison to 15.56 KW. The EPL reduction is more significant under Scenario-2 where it is 10.94 KW in comparison to 15.56 KW. Under Scenario-3, the EPL could be reduced from 13.06 KW to 11.6 KW by the “With Coordination” solution. This stands for a reduction of the EPL by around 17%, 30% and 11% under three scenarios, respectively.

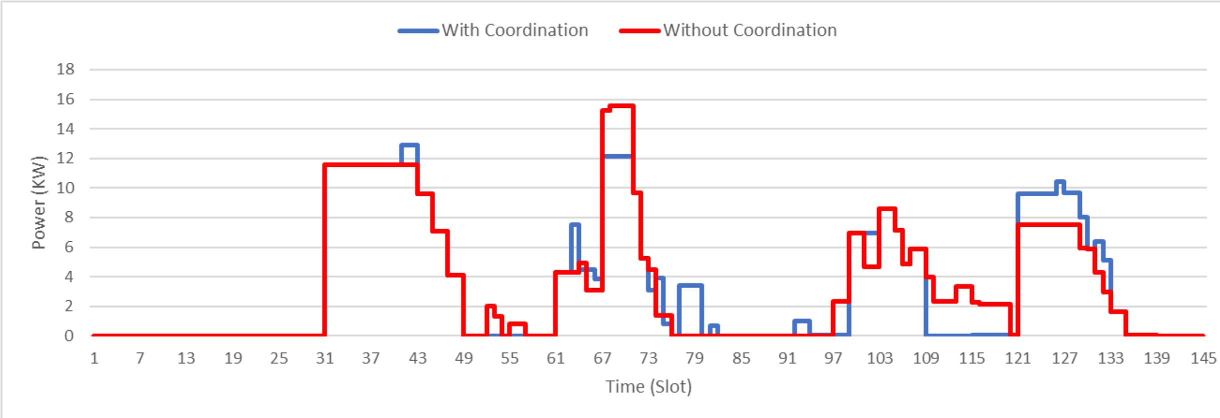

Fig. 1. Comparison between the "With Coordination" and "Without Coordination" resulting electrical load profiles under Scenario-1 ($W_1 > W_2 > W_3$)

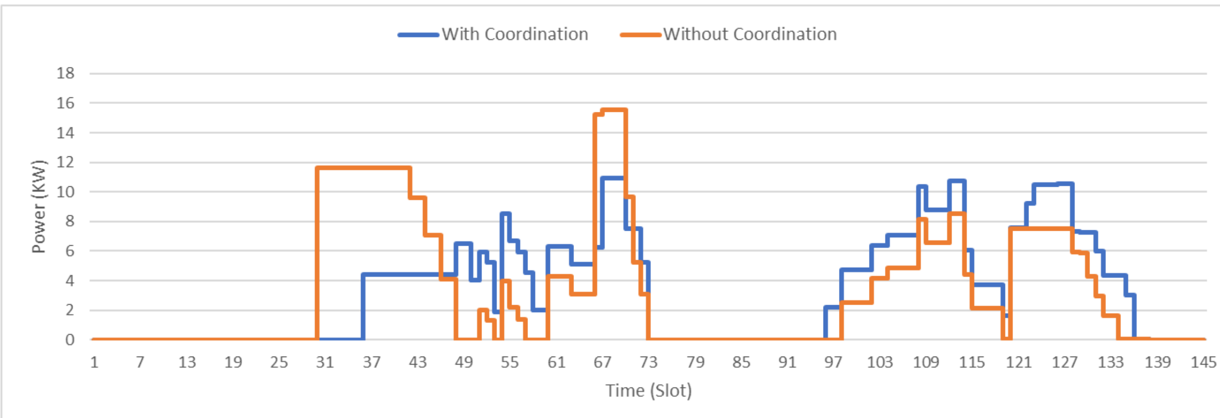

Fig. 2. Comparison between the "With Coordination" and "Without Coordination" resulting electrical load profiles under Scenario-2 ($W_2 > W_1 > W_3$)

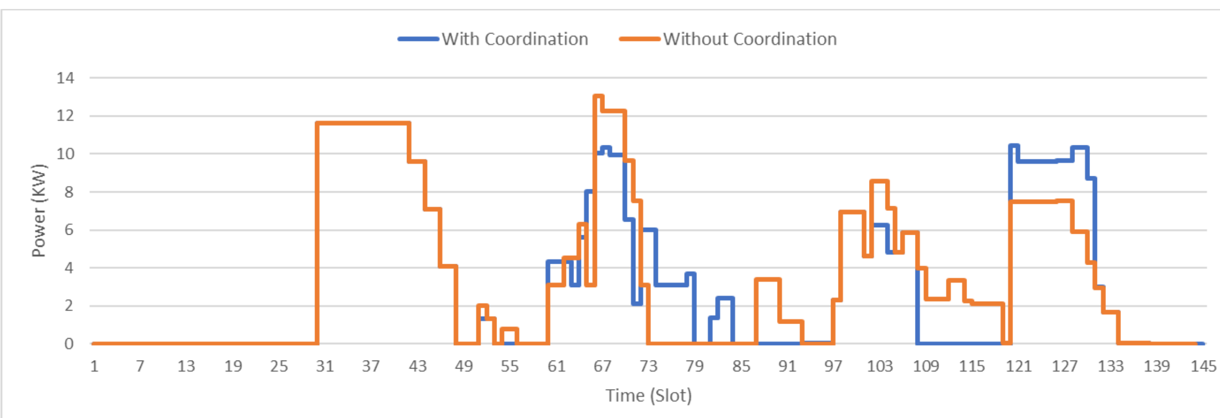

Fig. 3. Comparison between the "With Coordination" and "Without Coordination" resulting electrical load profiles under Scenario-3 ($W_3 > W_1 > W_2$)

Table 3 shows a comparison between the two proposed appliance schedules: "With Coordination" and "Without Coordination" under Scenario-1, Scenario-2 and Scenario-3. The comparison is based on the associated EC, IC and EPL. Under Scenario-1, where a higher priority is assigned to minimizing the EC, the two schedules resulted in almost the same EC for each of the households. However, the "Without Coordination" schedule resulted in little bit lower consumer inconvenience. With the main focus of minimizing the IC, Scenario-2 resulted in the optimum convenience level with the IC value of zero. However, the "Without Coordination" schedule resulted in slightly lower EC for each of the households. Under Scenario-3, where a higher priority is assigned to minimizing the EPL, both the "With Coordination" and "Without Coordination" schedules resulted in almost the same EC for each household. However, the "Without Coordination" schedule resulted in little bit lower consumer inconvenience.

However, there is not enough evidence that the EC and IC means differ significantly between the "With Coordination" and "Without Coordination" schedules. But, comparisons show that the "With Coordination" schedules can reduce the EPL in comparisons with the "Without Coordination" under the three scenarios. The "With Coordination" schedules can reduce the EPL by around 17% (from 15.56 to 12.91 KW), 29.7% (from 15.56 to 10.94 KW) and 11.2% (from 13.06 to 11.6 KW) for the three scenarios, respectively.

Table 1. Comparison between the "With Coordination" and "Without Coordination" in terms of the EC, the IC and the EPL for each scenario

Scenario-1: $W_1 > W_2 > W_3$						
Household	**With Coordination**			**Without Coordination**		
	EC (R)	**IC (Slot)**	**EPL (KW)**	**EC (R)**	**IC (Slot)**	**EPL (KW)**
h_1	11.02	16	12.91	11.21	0	15.56
h_2	7.42	46		12.06	2	
h_3	9.10	26		9.56	0	
h_4	11.96	42		12.71	27	
h_5	12.14	52		12.91	22	
Scenario-2: $W_2 > W_1 > W_3$						
Household	**With Coordination**			**Without Coordination**		
	EC (R)	**IC (Slot)**	**EPL (KW)**	**EC (R)**	**IC (Slot)**	**EPL (KW)**
h_1	13.49	0	10.94	11.21	0	15.56
h_2	14.82	0		12.42	0	
h_3	14.57	0		9.56	0	
h_4	18.14	0		16.56	0	
h_5	15.65	0		15.65	0	
Scenario-3: $W_3 > W_1 > W_2$						
Household	**With Coordination**			**Without Coordination**		
	EC (R)	**IC (Slot)**	**EPL (KW)**	**EC (R)**	**IC (Slot)**	**EPL (KW)**
h_1	11.02	3	11.6	11.25	18	13.06
h_2	7.42	54		12.06	2	
h_3	9.06	27		9.56	0	
h_4	12.48	34		12.71	27	
h_5	12.13	71		12.91	22	

4. Conclusion

This paper addressed the multi-objective and multiple households load scheduling problem of typical home appliances while incorporating more realistic aspects. The objective of this study is to generate optimal load schedule of home appliances for multiple households with leveled load profile while considering the consumer's preferences and convenience level. A mathematical model is proposed with the objective of minimizing the weighted score of three terms: the EC, the IC and the EPL. A case study showed that individual consumers could realize almost the same EC and the convenience level. However, the "With Coordination" approach could eliminate the overall EPL significantly. The proposed model schedules the appliances with coordination between multiple households could reduce the overall EPL by around 17%, 30% or 11% based on the weighting factors combination.

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References

Eskom[a]: COPI7 fact sheet "Utility Load Manager" System, Available: http://www.eskom.co.za/AboutElectricity/FactsFigures/Documents/Utility_Load_Manager_ULM.pdf.

Benetti, G., Caprino, D., Della Vedova, M.L. and Facchinetti, T., Electric load management approaches for peak load reduction: A systematic literature review and state of the art. Sustainable Cities and Society, 20, pp.124-141, 2016.

Celik, B., Roche, R., Suryanarayanan, S., Bouquain, D. and Miraoui, A., Electric energy management in residential areas through coordination of multiple smart homes. Renewable and Sustainable Energy Reviews, 80, pp.260-275, 2017.

Eskom[b]: Tariffs & Charges 2011/12. http://www.eskom.co.za/CustomerCare/Tariffs AndCharges/Documents/Tariff_brochure_20112.pdf

Gelazanskas, L. and Gamage, K.A., Demand side management in smart grid: A review and proposals for future direction. Sustainable Cities and Society, 11, pp.22-30, 2014.

Haider, H.T., See, O.H. and Elmenreich, W., A review of residential demand response of smart grid. Renewable and Sustainable Energy Reviews, 59, pp.166-178, 2016.

Saele, H. and Grande, O.S., Demand response from household customers: Experiences from a pilot study in Norway. IEEE Transactions on Smart Grid, 2(1), pp.102-109, 2011.

Schweppe, F.C., Caramanis, M.C., Tabors, R.D. and Bohn, R.E., Spot pricing of electricity. Springer Science & Business Media, 2013.

Setlhaolo, D. and Xia, X., Combined residential demand side management strategies with coordination and economic analysis. International Journal of Electrical Power & Energy Systems, 79, pp.150-160, 2016.

Shakouri, H. and Kazemi, A., Multi-objective cost-load optimization for demand side management of a residential area in smart grids. Sustainable cities and society, 32, pp.171-180, 2017.

Siano, P., Demand response and smart grids—A survey. Renewable and sustainable energy reviews, 30, pp.461-478, 2014.

Statistics South Africa, Stats SA Library Cataloguing-in-Publication (CIP) Data, Community Survey 2016, Statistical release P0301. Available: http://cs2016.statssa.gov.za/wp-content/uploads/2016/07/NT-30-06-2016-RELEASE-for-CS-2016-_Statistical-releas_1-July-2016.pdf.

Wang, J., Zhong, H., Ma, Z., Xia, Q. and Kang, C., Review and prospect of integrated demand response in the multi-energy system. Applied Energy, 202, pp.772-782, 2017.

Yahia, Z. and Pradhan, A., An optimal load schedule of household appliances with leveled load profile and consumer's preferences. In 2018 International Conference on the Domestic Use of Energy (DUE) (pp. 1-7). IEEE, 2018.

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