Northumbria Research Link

Citation: Marzband, Mousa, Azarinejadian, Fatemeh, Savaghebi, Mehdi, Pouresmaeil, Edris, Guerrero, Josep M. and Lightbody, Gordon (2018) Smart transactive energy framework in grid-connected multiple home microgrids under independent and coalition operations. Renewable Energy, 126. pp. 95-106. ISSN 0960-1481

Published by: Elsevier

URL: https://doi.org/10.1016/j.renene.2018.03.021 <https://doi.org/10.1016/j.renene.2018.03.021>

This version was downloaded from Northumbria Research Link: http://nrl.northumbria.ac.uk/33849/

Northumbria University has developed Northumbria Research Link (NRL) to enable users to access the University's research output. Copyright © and moral rights for items on NRL are retained by the individual author(s) and/or other copyright owners. Single copies of full items can be reproduced, displayed or performed, and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided the authors, title and full bibliographic details are given, as well as a hyperlink and/or URL to the original metadata page. The content must not be changed in any way. Full items must not be sold commercially in any format or medium without formal permission of the copyright holder. The full policy is available online: http://nrl.northumbria.ac.uk/policies.html

This document may differ from the final, published version of the research and has been made available online in accordance with publisher policies. To read and/or cite from the published version of the research, please visit the publisher's website (a subscription may be required.)

CUSTOMER SERVICE EXCELLENCE CSE UniversityLibrary

Smart Transactive Energy Framework in Grid-connected Multiple Home Microgrids under Independent and Coalition Operations

Mousa Marzband[a,b], Fatemeh Azarinejadian[b], Mehdi Savaghebi[d], Edris Pouresmaeil[c], Josep M. Guerrero[d], Gordon Lightbody[e,f]

[a]*Faculty of Engineering and Environment, Department of Maths, Physics and Electrical Engineering, Northumbria University Newcastle, Newcastle upon Tyne NE1 8ST, UK*
[b]*Dept. of Electrical Engineering, Lahijan Branch, Islamic Azad University, Lahijan, Iran*
[c]*Dept. of Electrical Engineering and Automation, Aalto University, 02150 Espoo, Finland*
[d]*Dept. of Energy Technology, Aalborg University, DK-9220 Aalborg East, Denmark*
[e]*Control and Intelligent Systems Group, Department of Electrical and Electronic Engineering, UCC, College Rd., Cork, Ireland*
[f]*SFI Research Centre for Marine and Renewable Energy, MaREI, Ireland*

Abstract

This paper presents a smart Transactive energy (TE) framework in which home microgrids (H-MGs) can collaborate with each other in a multiple H-MG system by forming coalitions for gaining competitiveness in the market. Profit allocation due to coalition between H-MGs is an important issue for ensuring the optimal use of installed resources in the whole multiple H-MG system. In addition, considering demand fluctuations, energy production based on renewable resources in the multiple H-MG can be accomplished by demand-side management strategies that try to establish mechanisms to allow for a flatter demand curve. In this regard, demand shifting potential can be tapped through shifting certain amounts of energy demand from some time periods to others with lower expected demand, typically to match price values and to ensure that existing generation will be economically sufficient. It is also possible to obtain the maximum profit with the coalition formation. In essence the impact of the consumption shifting in the multiple H-MG schedule can be considered while conducting both individual and coalition operations. A comprehensive simulation study is carried out to reveal the effectiveness of

---

Email address: `mousa.marzband@northumbria.ac.uk Corresponding author` (Mousa Marzband)

the proposed method in lowering the market clearing price (MCP) for about 15% of the time intervals, increasing H-MG responsive load consumption by a factor of 30%, and promoting local generation by a factor of three. The numerical results also show the capability of the proposed algorithm to encourage market participation and improve profit for all participants.

Keywords: Coalition formation, demand side management, electricity market, home energy management system, home Microgrid, profit allocation, Transactive Energy.

Nomenclature

Acronyms

ABC	artificial bee colony
CHP	combined heat and power
EB	electrical boiler
EHP	electrical heat pump
ES+/ES-	energy storage (ES) during charging/discharging mode
GB	gas boiler
UG+/UG-	buying/ selling power from/to H-MG *i*/ the upstream grid (UG)
MCP	market clearing price
RLD+, RLD-	amount of responsive load demand (RLD) that goes/come from/to other time period to/from t
STP	solar thermal panel
TES	thermal energy storage
WT	wind turbine

Symbols

@	the coalition formation among the H-MGs i and j (j$\neq$i)
{A@B}$\equiv${AB}	coalition formation between H-MGs A and B
{A}	H-MG *A* is in individual operation
k $\longmapsto$ i	distributed energy resource (DER) k installed in H-MG *i*

Indices

i+, i-	buying/ selling power from/to H-MG j/H-MG *i*
e/h/D	electrical/ thermal/ non-responsive load demand

$i \in \{ES\text{-}, WT, CHP, GB, STP, EHP, EB, TES\text{-}, UG\text{-}\}$, $\{i,j,k\} \in \{1,2,\cdots,n\}$, $j \neq i$

j	all H-MG except H-MG *i*

Constants

α, β	amount of demand that will be added/subtracted to/from the primary demand forecast for relevant hours
$\zeta_e^{k,i}$, $\zeta_h^{k,i}$	electrical/ thermal efficiency of the thermal DER k in H-MG *i* (%)
$\overline{P}_e^{k,i}$, $\overline{P}_h^{k,i}$	maximum electrical/thermal power generated by dispatchable/non-dispatchable DER k in H-MG *i* (kW)
π^{ng}	natural fuel price offer (£/kWh)
ζ^{TES}	heat loss efficiency value (%)
$\underline{SOC}^x$, $\overline{SOC}^x$	the lower/ upper limit of state-of-charge (SOC) in x ($x \in \{ES, TES\}$) (%)
$SOC_{INI}^{ES,i}$, $SOC_{INI}^{TES,i}$	the initial value of ES/TES SOC in H-MG *i* (%)
S	the collector surface area
a_1, a_2	the first/ second order thermal loss coefficients (kWm^2/k^0)
η_0	the zero thermal loss efficiency
κ	part of excess/ shortage power generated/ required by H-MG *i*/ upstream grid

Parameters

$\tilde{P}_{t,h}^{STP,i}$	the predicted generated thermal power by STP at time t in H-MG *i* (kW)
$\tilde{P}_{t,e}^{WT,i}$	the predicted generated power by WT at time t in H-MG *i* (kW)
$\tilde{P}_{t,e}^{D,i}$, $\tilde{P}_{t,h}^{D,i}$	the predicted consumed electrical/thermal load demand at time t in H-MG *i* (kW)
$\tilde{\lambda}_{t,e}^{MCP}$, $\tilde{\lambda}_{t,h}^{MCP}$	the electrical/thermal of MCP at time t (£/kWh)

$G_t^{\star}$	the solar radiation (kW/m^2)
Tem_t^c, Tem_t^a	the collector mean/ ambient temperature

Decision variables

$P_{t,e}^{k,i}$, $P_{t,h}^{k,i}$	thermal/electrical power generated/ consumed by dispatchable/non-dispatchable DER k in H-MG *i* (kW)
$\pi_{t,e}^{k,i}$, $\pi_{t,h}^{k,i}$	electrical/ thermal price bids of dispatchable/non-dispatchable DER k in H-MG *i* (£/kW)
$X_t^{CHP,i}$	binary variable, 1 means CHP on, otherwise CHP off
$FU_t^{k,i}$	fuel consumption rate of dispatchable DER k in H-MG *i* at time t (kW)
$P_{t,e}^{RLD+,i}$, $P_{t,e}^{RLD-,i}$	the value of added RLD consumed load in time interval t (RLD+) and shifted load to another time interval (RLD-)
$\lambda_{t,e}^{MCP}$, $\lambda_{t,h}^{MCP}$	the electrical/thermal of MCP calculated by *ABC-1 unit* at time t (£/kWh)
$\lambda_{t,e}'^{MCP}$, $\lambda_{t,h}'^{MCP}$	the electrical/thermal of MCP calculated by *ABC-2 unit* at time t (£/kWh)
$P_{t,e}^{i+,j}$, $P_{t,h}^{i+,j}$, $P_{t,e}^{i-,j}$, $P_{t,h}^{i-,j}$ $\forall j \neq i$	the electrical/ thermal power sold/bought from/to H-MG *i*/H-MG j at time t (kW)
$P_{t,e}^{UG+,i}$, $P_{t,e}^{UG-,i}$	the value of power sold/ bought from/to upstream grid/ H-MG *i* at time t (kW)

1. Introduction

While smart grids are known as the future of power systems, home Microgrids (H-MG) can be considered as a vital technology to deliver the functional blocks of smart grid on a local scale. In developing this system, a large number of elements, currently just passively connected to the grid, will become actively involved in negotiation and complex coordination tasks [1–3]. The big challenge for executives is how to handle an unbounded number of intelligent elements, each with their own objectives and perspectives, into a cohesive and efficient system [4–6]. In this context, Transactive energy (TE) concepts and adaptation into the distribution-level of the electricity grid can be profoundly effective; thus, is considered as an area of recent research interest [7]. Indeed, TE is facilitated by a set of intrinsically transferable and shared economic and control mechanisms that guarantees equilibrium between supply and demand among trading partners in the entire electrical infrastructure [8, 9].

In addition, clusters of actively managed H-MGs may be grouped together into so-called energy coalitions in the multiple H-MG [10–13] for participation in local or system-wide energy and power system services markets. Formation of such coalitions may be beneficial for operators of the multiple H-MG. As a result, they may reduce transaction costs of participation in such markets, reduce uncertainty (given the benefits from aggregation and diversity in energy demand and supply, especially in the presence of variable renewables) and avoid the grid usage fees through local energy trading [14–17]. For society as a whole, formation of such coalitions can also be beneficial as day-ahead coordinated market participation of H-MGs can reduce price volatility and average price levels through increased market liquidity, improved reliability and reduced peaks in demand from the upstream grid; thus, potentially expensive investment can be avoided [18–21].

Coalitions may be formed or broken depending on the conditions of the moment [22]. For example, a group of H-MGs may conclude they can achieve more profit at a particular moment through cooperation and hence form a coalition. At a future time, H-MGs may decide that higher profit may be achieved by breaking the coalition and forming an alternative coalition, or possibly even by operating independently. Assuming that the considered H-MGs are rational economic entities, cooperation can only be implemented if each rational player can expect to obtain a higher profit by joining the coalition. A crucial consideration in the decision to join a coalition is therefore the mechanism through which coalition profit is allocated, once the coalition can extract value from market participation. If the mechanism employed by a coalition for allocating profit is perceived to be unfair, the result of the coalition forming process may be sub-optimal, for both individual H-MG and the coalition as a whole. Hence, it is necessary to find a way to fairly allocate the profit obtained from the coalition among all players. In the method proposed in this paper, it is shown that because of the ineffectiveness of the independent decisions, H-MGs may have interest in cooperating with each other by coordinating their energy supplies and the demand rate consumption, which leads to an increase in their aggregated utilities. As a result, the pay-off of each H-MG can be increased by cooperation. In this context, it is worth mentioning that since some players may contribute more to the coalition than others or may exhibit different bargaining power exchange methods for transactive energy balance etc. This raises the following key questions:

1. How should the generated surplus be distributed among the players (i.e. each H-MG) for any particular coalition?
2. How important is each player to the overall cooperation?

Furthermore, it is important to consider responsive load demand (RLD) in H-MG which can be defined as the change in electric usage by a customer from the normal consumption pattern in response to the electricity price variations over time, or to the incentive payments designed to induce lower electricity use at times of high wholesale market prices [10, 23]. RLD models presented in the literature generally refer to the quantification of the RLD potential with highly increasing penetration rate of renewable energy sources and load demand into the electrical power grids [24, 25]. However, the methodology proposed in this paper goes further on making possible for the consumers to participate in the consumption shifting scheme under coalition formation in multiple H-MG systems. It also allows H-MGs to adequately manage the coalition formation process together with RLD programming. In addition, the characteristics of distributed energy resource (DER) with RLD resources integrated inside each H-MG are taken into account, respectively as input parameters and technical constraints of the optimization model. It is developed to perform a joint between both H-MG and RLD resources scheduling under coalition formation, in a multiple H-MG architecture.

In this paper, a multi-stage stochastic programming based on artificial bee colony (MSSP-ABC) algorithm is applied for multiple H-MG applications, to simulate the formation of possible coalitions. A local home energy management system is implemented in the control centre by using an MSSP-ABC algorithm. According to the several advantages of ABC such as simplicity, accuracy and short calculation time [26–28], it is applied in this paper for the optimization of the multiple H-MG operation in terms of performance, generation scheduling, and economic power dispatch. This can provide economic results with excellent reliability because of its high convergence speed and ability of finding general optimum solution compared with other innovative optimum methods (e.g. gravitational search algorithm, ant colony optimization, imperialist competition algorithm) [26]. The total profit of each possible coalition from participation in a distributed energy market is also calculated. Subsequently, the cooperation of H-MGs is discussed and an algorithm based on MSSP-ABC is implemented for deciding coalition formation. The proposed algorithm is then used for logical and grid-wise distribution of profits for each of the H-MGs in the coalition.

With regards to the proposed approach, H-MGs are able to reasonably predict in advance that how much gain they can obtain from participating in a coalition. In order to do that, each H-MG seeks to calculate its contribution of expected marginal value to the coalition. This value can then be used to assess the profitability of available coalitions and inform the decision to join a coalition or not. Furthermore, a group of H-MGs can cooperate and form a larger coalition if this formation increases the pay-off of at least one of the H-MGs without decreasing the pay-off of any of the others involved in the coalition. In an analogous manner, a coalition can decide to split and divide itself into smaller coalitions if splitting is preferred by H-MGs.

The main contribution of this paper is the development of a modeling framework for profit allocation across H-MG participating in HM-MG coalition which can answer the question of what a “fair” distribution of profit should be, and which coalitions are likely to form. Applications of the proposed concepts are various, from H-MG portfolio design to optimal contract design by aggregators, H-MG operators and energy service companies.

An illustrative grid connected case study application with three electrical/thermal coupled H-MGs is presented here to demonstrate the models introduced. The different coalition formation rules are then compared with each other in order to evaluate the profit that each H-MG that can be obtained by joining the coalition. The results show that the disconnection of H-MGs resulting from pricing decisions allows them to collaborate together to achieve higher profits due to excess production and avoid penalties due to production shortages. It is also demonstrated that significant increase in the profit may persuade H-MGs to form a coalition.

In summary, the main contributions in this work are as follows:

1. The formulation of a particular coalition formation strategy combined with RLD programming based on framework of TE;
2. The formulation of a special demand side management (DSM) strategy based on solving optimization problem for maximizing the total profit of a multiple H-MG system by taking into account the variable uncertainties;
3. The development of a modeling framework for profit allocation across H-MG participating in multiple H-MG coalition to have a “fair” profit distribution.

This paper is organized as follows:

The proposed algorithm is developed and explained in Section 2 while conceptual design of the proposed problem is outlined in Section 3. Simulation results and discussions are presented in Section 4. Finally, the paper is concluded in Section 5.

2. Proposed MSSP-ABC algorithm

A general picture of the multiple H-MG connected to the several conventional building (CB) is shown in Figure 1. Multiple H-MG is designed as an active cluster of H-MGs and each of them is configured by dispatchable/non-dispatchable DER resources, storage devices and associated RLDs. Non-dispatchable DERs (such as wind and photovoltaic resources) are based on renewable energy resources which inherently suffer from a lack of the dispatch capability due to inherent stochastic behaviours of these resources. Under these conditions, each H-MG having an aggregator has the ability of supplying its power shortage from other H-MGs. CBs are the buyers of power from multiple H-MG and/or upstream grid and their consumed loads are uncontrollable. When an H-MG has the excess generation, it has the ability of selling power to other H-MGs within multiple H-MG system, the upstream grid and CBs connected to this system. This excess power can be allocated to supply each of them according to the terms of their bids. Otherwise, when an H-MG has the generation shortage, it means that it does not have the ability of supplying its internal demand and must import power from other H-MGs and the upstream grid and/or possibly shift the loads. The operation and management of the corresponding H-MG can be controlled and monitored by a control centre as shown in Figure 1. A control strategy is developed in the control centre for coordinated operation of networked H-MGs in a multiple H-MG distribution system. The control centre is considered as a distinct entity with individual objectives to maximize the profit for all H-MGs taking into account the possibility of coalition formation between them.

The flowchart of the proposed algorithm is shown in Figure 2. Various parameters such as load demand, renewable power generation, and MCP are treated as uncertainties in the proposed structure. In order to handle the uncertainties, Taguchi′s orthogonal array testing (TOAT) approach is utilized which enhances a trade-off between the accuracy of the solution and the computational burden [10, 29, 30]. The TOAT method selects the minimum number of scenarios while preserving the main statistical information of the entire dataset. More details on the stochastic framework of this study can be found in [31–34]. As observed in Figure 2, this structure is made up of *TOAT*, *ABC-1*, *DSM-ABC*, *ABC-2* and *MCP units*. Since the *TOAT* and *MCP units* are explained in detail in [10], only the *ABC-1*, *DSM-ABC* and *ABC-2 units* are discussed in the following. At first, the rated capacity of the existing DERs and their operational constraints will be required to exhibit ABC algorithm. Then, prediction data including solar radiation, wind speed, electrical/thermal load demand and the electricity price will be sent to the *TOAT unit*. Then, *ABC-1 unit* is executed for determining the value of MCP-1. After calculating the MCP-1 value, demand side management is again conducted to deliver both energy efficiency gains and peak demand reductions based on the objective function defined in *ABC-2 unit*. After levelling the load demand curve and assuring the MCP reduction due to implementation the RLD program, MCP-2 is calculated and is declared to the market operator.

In Figure 2 the solid black lines show the execution trend of *ABC-1 unit* and dashed grey lines state the execution of *ABC-2 unit* for determining MCP-2 [1].

2.1. ABC-1 unit

Input information: $\tilde{P}^{STP,i}_{t,h}$, $\tilde{P}^{WT,i}_{t,e}$, $\tilde{P}^{D,i}_{t,e}$, $\tilde{P}^{D,i}_{t,h}$, $\tilde{\lambda}^{MCP}_{t,e}$, $\tilde{\lambda}^{MCP}_{t,h}$.

Variables: Produced electrical/thermal power by the generation resources, ES and TES charge/discharge power, electrical/thermal power exchanged between H-MGs and upstream grid, all the buying/selling offers related to DERs, H-MGs and the consumers, binary variables, $\lambda^{MCP}_{t,e}$, and $\lambda^{MCP}_{t,h}$.

Objectives: Determining the electrical/thermal optimum values of the generated power such that the profit obtained by these resources becomes maximum. The defined objectives in this unit are to maximize the profit, resulting from the H-MGs individual operation or interactive performance under different coalition formation patterns, to achieve electrical/thermal balance, as well as to improve the SOC condition in ES/ TES.

2.2. DSM-ABC unit

Input information: $P^{D,i}_{t,e}$, $\lambda^{MCP}_{t,e}$.

Variables: $P^{RLD+}_{t,e}$, $P^{RLD-}_{t,e}$.

Objectives: to smooth demand curve applying a strategy that considers the shifting of certain amounts of energy demand from some time periods (with higher MCP) to other time periods with lower expected demand (lower MCP), typically in response to price signals.

2.3. ABC-2 unit

Input information: $P^{STP,i}_{t,h}$, $P^{WT,i}_{t,e}$, $P^{D,i}_{t,e}$, $P^{D,i}_{t,h}$, $P^{RLD+,i}_{t,e}$, $P^{RLD-,i}_{t,e}$, $\lambda^{MCP}_{t,e}$, $\lambda^{MCP}_{t,h}$.

Variables: $P^{k,i}_{t,e}$, $P^{k,i}_{t,h}$, $\pi^{k,i}_{t,e}$, $\pi^{k,i}_{t,h}$, $X^{CHP,i}_{t}$, $FU^{k,i}_{t}$, $P^{RLD+,i}_{t,e}$, $P^{RLD-,i}_{t,e}$, λ'^{MCP}_{t}, λ'^{MCP}_{t}, $P^{i+,j}_{t,e}$, $P^{i+,j}_{t,h}$, $P^{i-,j}_{t,e}$, $P^{i-,j}_{t,h}$, $P^{UG+,i}_{t,e}$ and $P^{UG-,i}_{t,e}$.

---

[1] The solid black lines demonstrate the execution trend of Stage 1, the solid gray lines indicate Stage 2 and dashed grey lines state the execution of Stage 3.

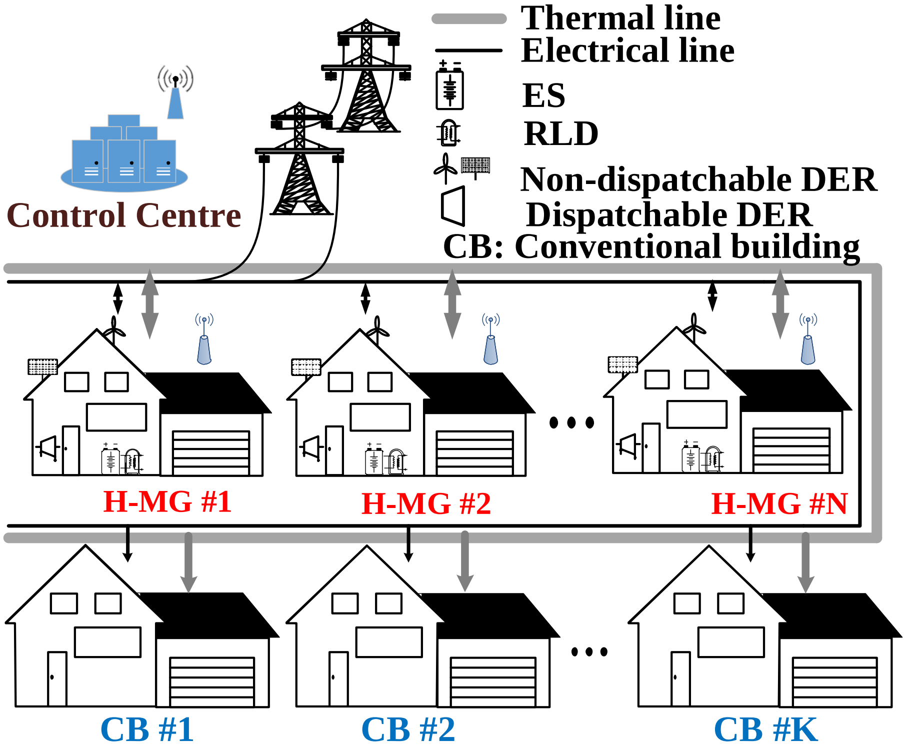


Figure 1: General structure of multiple H-MG

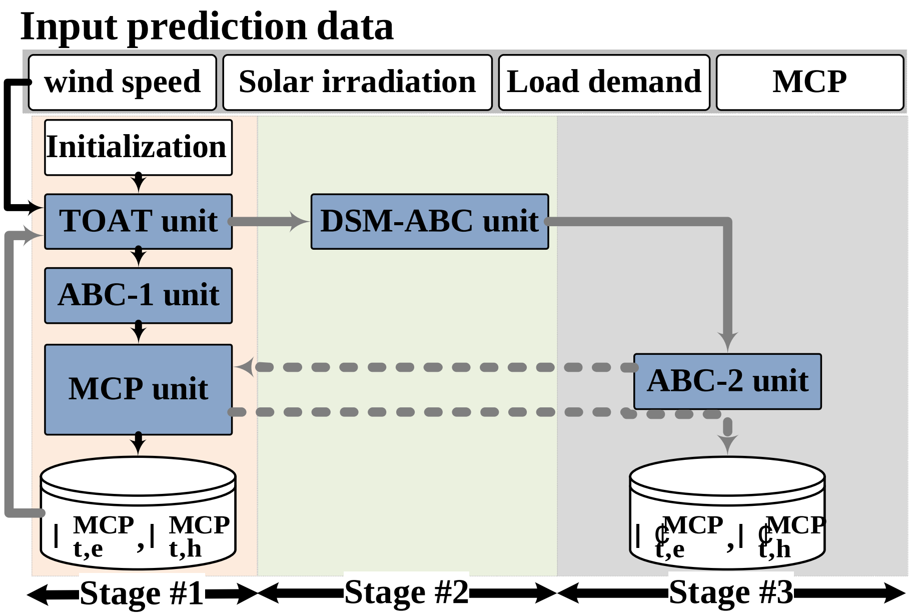


Figure 2: Proposed MSSP-ABC algorithm

Objectives: Determining the amount of consumers participation of in RLD program and the value of the power produced by generation resources such that their profit becomes maximum.

To achieve these objectives, load demand profile improvement is considered by using $\lambda^{MCP}_{t,e}$ and $\lambda^{MCP}_{t,h}$. Under these conditions, shifted load demand (i.e. RLD-) from time interval with higher MCP (peak hours) is evenly distributed among lower MCP (off-peak hours) by using *ABC-2 unit*. In addition, the quantity of shifted load at each hour is proportional to the demand at that hour.

The performance of demand side management proposed by *ABC-2 unit* has been shown in Figure 3. As it can be seen, when the MCP value goes up to a certain limit, *ABC-2 unit* could reasonably assume that further optimization efforts with a demand shifting rate would improve the load demand profile while all the constraints of the system are satisfied.

To achieve these objectives, the active participation of consumers in total load demand profile improvement is increasingly seen politically desirable, especially any voluntary RLD program taking $\lambda_{t,e}^{MCP}$ and $\lambda_{t,h}^{MCP}$ into consideration. For this implementation, *ABC-2 unit* is developed to shift load demand from time period t to sometime before and/or after time t. It can be a way to induce lower electricity consumption at times of high MCP, during peak electricity demand, in a cost-effective manner or when system reliability is jeopardized.

On the other hand, a certain RLD amount income is verified by *ABC-2 unit* in period t, shifted from other periods. At the end, in period t, considering the consumption shifting (incoming: RLD+/outgoing: RLD-) and the consumption reduction, the final consumption can be lower or higher than the initially expected demand depending on the objective. It is important to keep in mind that the total consumption can be dropped to less than the initially expected demand. This case will occur if the appliance electricity consumption cannot be shifted from other periods to this period.

In essence, the proposed MSSP-ABC algorithm with the novel RLD criterion consisting of *ABC-1* and *ABC-2 units* will be found to be reliable, efficient and cost-effective.

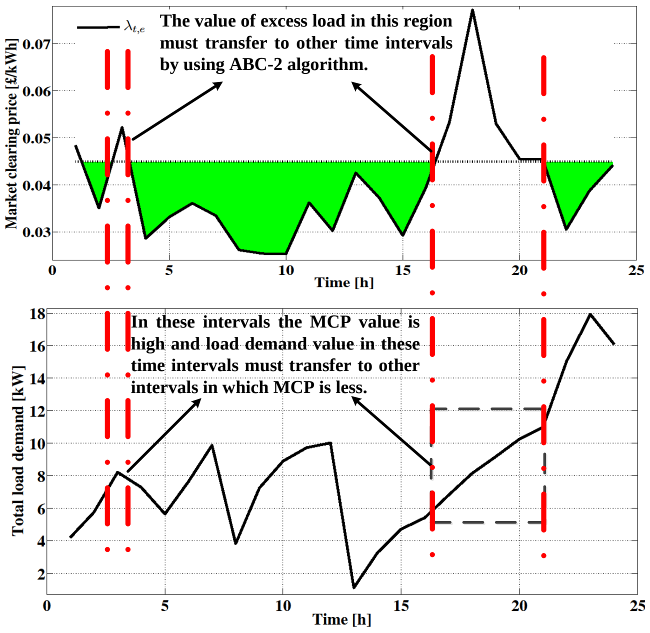


Figure 3: Method of demand side management based on MCP in the *ABC-2 unit*

2.4. *MCP unit*

In this unit, the MCP is calculated based on the schedules obtained from *ABC-1* and *ABC-2 units* and the supply and demand bids submitted by the participants using forward market with double-side auction [35–38]. Supply and demand bids as well as optimal schedules of the participants are the parameters given to the *MCP unit*. The forward market aggregates supply and demand in the merit order as price-quantity pairs. The quantities are the optimal schedules obtained from *ABC-1* and *ABC-2 units*, and the prices are the supply and demand bids submitted by the participants. As expected, the aggregated supply and demand quantity-price are monotonically increasing and decreasing step-wise curves, respectively. Then, the MCP will be the point of aggregated supply and demand curves intersection. Subsequently, the value of the payoff function for each participant can be computed using the *MCP unit*.

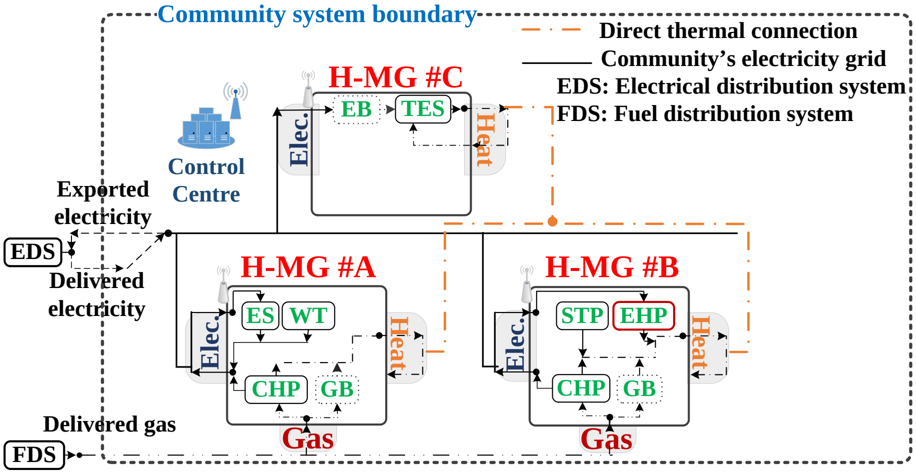


Figure 4: schematic of the system under study

3. Problem formulation

To illustrate how the proposed method works, it is applied to a case study for the multiple H-MG depicted in Figure 4. As shown in this figure, multiple H-MG comprises three different H-MGs A, B and C with various dispatchable/non-dispatchable DER resources. As observed in this figure, the resources storing electrical/thermal power are included in A and B for storing provided excess electrical/thermal power. At the beginning of the planning horizon, each H-MG decides whether to operate individually or in coalition with other H-MGs, and determines the selling price offered to the consumers to be used during the planning horizon. After fixing the H-MGs operation status as individual (i.e. {A},{B},{C}&{UG}) or coalitional (i.e. {AB},{AC},{BC} which are double coalition and {ABC} which is a triple coalition) and the buying/selling prices, each H-MG decides the amount of energy purchased/sold in the pool to/from other H-MGs to supply the demand of all its consumers during each period (e.g. one hour) over along the planning horizon (e.g. 24 hours). All other information about the capacity of equipment installed in each H-MG are presented in [10] in detail and therefore not repeated in this paper. At first, the objective functions for the case study are described and then the main results of applying the proposed algorithm are presented and discussed.

3.1. Objective functions

The objective functions defined in both *ABC-1* and *ABC-2 units* are based on decision making problem related to maximizing solitary profit of each H-MG in independent working conditions or the profit resulting from their participation in coalitional cooperation among each other. With this difference that the value of the profit resulting from the participation of the consumers in the RLD program has been included in the objective function of problem *ABC-2 unit*. In the following paragraphs, the mathematical model of the discussed problem has been presented in this paper.

An multi-stage decision-making problem with the defined objective functions in both *ABC-1* and *ABC-2 units* is employed in MSSP-ABC algorithm. This problem is constrained by a collection of market clearing problems representing pool trading, and its individual objective functions corresponding to profit maximization. To reach this aim, an MSSP-ABC algorithm is developed to include additional profit for the players who are involved in a deregulated power market environment. In this direction, the mathematical model represents the equilibrium of a pool-based market taking into account the outcomes on the spot market based on expected profit maximization for H-MGs; and the anticipation of the upstream grid or H-MGs for achieving success and earning more profit under collation formation. The demand is considered exogenous but supply bids and the power generation of DERs are obtained as endogenous variables of the model. The optimization problem of this model seeks maximum profit for H-MGs considering coalition formation between them and contains H-MGs, DERs and RLD scheduling constraints, when the day-ahead energy market [39] can be cleared under different operating conditions to deal with profit maximization problems of all H-MGs. The proposed structure provides a procedure to derive the optimal offering strategy of all players including H-MGs, DERs of them and upstream grid. In this direction, an H-MG can decide about its level of involvement in the future pool markets as well as the selling/buying price offered to/from other H-MGs with the goal of maximizing the expected profit. The mathematical formulation of the optimization problem is presented as follows.

3.1.1. Objective function in ABC-1 unit

Different scenarios which have been considered for defining objective functions are as follows:

- **Profit resulting from H-MG *i* under individual operation**

$$\mathbf{Profit}^{i}|_{\forall i} = \mathbf{max} \sum_{t=1}^{24} \left(\begin{array}{l} \sum\limits_{\forall k \longmapsto i} (P_{t,e}^{k,i} \times \pi_{t,e}^{k,i} + P_{t,h}^{k,i} \times \pi_{t,h}^{k,i}) \\ + \sum\limits_{\forall j \neq i} \left(\begin{array}{l} P_{t,e}^{i-,j} \times \pi_{t,e}^{i-,j} + P_{t,h}^{i-,j} \times \pi_{t,h}^{i-,j} \\ -(P_{t,e}^{i+,j} \times \pi_{t,e}^{i+,j} + P_{t,h}^{i+,j} \times \pi_{t,h}^{i+,j}) \end{array} \right) \\ + P_{t,e}^{UG+,i} \times \pi_{t,e}^{UG+,i} - P_{t,e}^{UG\text{-},i} \times \pi_{t,e}^{UG\text{-},i} \end{array} \right) \times \Delta t \\ - \sum_{\forall k \longmapsto i} FU_{t}^{k,i} \times \pi^{ng} \qquad (1)$$

The first right side term of Eq. 1 states the income value resulting from the production of electrical/thermal powers produced by the DER k existing in H-MG *i*. The right side term section is equivalent to the value of paid cost for supplying the fuel required by thermal resources. Section three states the income from selling electrical/thermal powers sold to other H-MGs minus the cost of buying electrical/thermal powers from other H-MGs for the completion of its function of the power required in the H-MG *i*. The last term of the equation shows the value of electrical power bought from the upstream grid for supplying the H-MG *i* load demand.

- **Profit resulting from H-MG *i* and H-MG j (j≠i) considering coalition formation between them**

$$\sum_{\forall t} \mathbf{Profit} = \sum_{\forall t} \mathrm{Profit}^{i} @ \sum_{\forall t} \mathrm{Profit}^{j}, \quad \forall j \neq i \qquad (2)$$

- **Profit resulting from upstream grid**

$$\mathbf{Profit}^{UG} = \sum_{\forall i,t} (P_{t,e}^{UG+,i} \times \pi_{t,e}^{UG+,i} - P_{t,e}^{UG\text{-},i} \times \pi_{t,e}^{UG\text{-},i}) \qquad (3)$$

3.1.2. Objective function in ABC-2 unit

The objective functions defined in this part of simulation problem are exactly similar to objective functions defined for *ABC-1 unit* with this difference that profit value resulting from the consumer′s participation in RLD program must also be considered. Because of this, the following expression must be added to all the Eqs. 1-3:

- **Profit resulting from RLD program**

$$\textbf{Profit}_t^{RLD} = P_t^{RLD+,i} \times \pi_t^{RLD+,i} - P_t^{RLD\text{-},i} \times \pi_t^{RLD\text{-},i} \tag{4}$$

3.2. Technical and economic constraints

- **Supply bids**

$$\underline{\pi}_{e/h}^{k,i} \leqslant \pi_{t,e/h}^{k,i} \leqslant \overline{\pi}_{e/h}^{k,i} \tag{5}$$

where $\underline{\pi}_{e/h}^{k,i}$ and $\overline{\pi}_{e/h}^{k,i}$ are respectively the minimum and maximum offer of the electrical/thermal price in the i^{th} H-MG. $\overline{\pi}_e^{k,i}$ can be considered the equivalent of the value of predicting electrical MCP of the day before implementing uncertainty. $\underline{\pi}_e^{k,i}$ can be considered zero for renewable resources and for resources which consume fuel, can be estimated by calculating electrical marginal cost value (MC_e) of the desired resource. MC_e for fuel consuming resource is calculated from the following equation:

$$MC_{t,e}^{k,i} = \frac{P_{t,e}^{k,i}}{\zeta_e^{k,i}} \times \pi^{ng} \tag{6}$$

Also, $\underline{\pi}_h^{k,i}$ can be considered the equivalent of thermal marginal cost value (MC_h) and can be calculated by

$$MC_{t,h}^{k,i} = \frac{P_{t,h}^{k,i}}{\zeta_h^{k,i}} \times \pi^{ng} \tag{7}$$

- **ES and TES constraints** [26]

For modelling ES and TES constraints such as stored energy limitations, maximum power charge/discharge limitations and power equilibrium have been considered.

$$\underline{P}_e^{ES} \leqslant P_{t,e}^{ES,i} \leqslant \overline{P}_e^{ES} \tag{8}$$

$$\underline{SOC}^{ES} \leqslant SOC_t^{ES,i} \leqslant \overline{SOC}^{ES} \tag{9}$$

$$SOC_t^{ES,i} = SOC_{t-1}^{ES,i} + \frac{P_{t,e}^{ES,i}}{\overline{P}_e^{ES}} \tag{10}$$

$$SOC_{t=1}^{ES,i} = SOC_{INI}^{ES} \tag{11}$$

$$\underline{P}_h^{TES} \leqslant P_{t,h}^{TES,i} \leqslant \overline{P}_h^{TES} \tag{12}$$

$$\underline{\mathrm{SOC}}^{\mathrm{TES}} \leqslant \mathrm{SOC}_t^{\mathrm{TES},i} \leqslant \overline{\mathrm{SOC}}^{\mathrm{TES}} \tag{13}$$

$$\mathrm{SOC}_t^{\mathrm{TES},i} = \mathrm{SOC}_{t-1}^{\mathrm{TES},i} + \frac{P_{t,h}^{\mathrm{TES},i}}{\overline{P}_h^{\mathrm{TES}}} \tag{14}$$

$$\mathrm{SOC}_{t=1}^{\mathrm{TES},i} = \mathrm{SOC}_{\mathrm{INI}}^{\mathrm{TES}} \tag{15}$$

- **CHP constraints** [40]

$$\underline{P}_e^{\mathrm{CHP},i} \leqslant P_{t,e}^{\mathrm{CHP},i} \leqslant \overline{P}_e^{\mathrm{CHP},i} \tag{16}$$

$$P_{t,e}^{\mathrm{CHP},i} = \mathrm{FU}_t^{\mathrm{CHP},i} \times \zeta_{t,e}^1 + X_t^{\mathrm{CHP},i} \times \zeta_{t,e}^2 \tag{17}$$

$$P_{t,h}^{\mathrm{CHP},i} = \mathrm{FU}_t^{\mathrm{CHP},i} \times \zeta_{t,h}^1 + X_t^{\mathrm{CHP},i} \times \zeta_{t,h}^2 \tag{18}$$

where the coefficients $\zeta_{t,e}^1$ and $\zeta_{t,e}^2$ can be determined as $f(\underline{P}_e^{\mathrm{CHP},i}, \overline{P}_e^{\mathrm{CHP},i}, \zeta_{t,e})$ and $\zeta_{t,h}^1$ and $\zeta_{t,h}^2$ can be calculated as $f(\underline{P}_h^{\mathrm{CHP},i}, \overline{P}_h^{\mathrm{CHP},i}, \zeta_{t,h})$ from interpolation of manufacturers' curves of efficiency with respect to loading level and considering the full load electrical efficiency (i.e. $\zeta_{t,e}$) and thermal efficiency (i.e. $\zeta_{t,h}$).

- **EHP constraints** [26]

$$P_{t,h}^{\mathrm{EHP},i} = P_{t,e}^{\mathrm{EHP},i} \times \mathrm{COP}_t \tag{19}$$

where COP_t is coefficient of performance.

$$0 \leqslant P_{t,h}^{\mathrm{EHP},i} \leqslant \overline{P}_h^{\mathrm{EHP}} \tag{20}$$

- **GB constraints** [26]

$$0 \leqslant P_{t,h}^{\mathrm{GB},i} \leqslant \overline{P}_h^{\mathrm{GB}} \tag{21}$$

$$P_{t,h}^{\mathrm{GB},i} = \zeta_h^{\mathrm{GB},i} \times \mathrm{FU}_t^{\mathrm{GB},i} \tag{22}$$

- **STP constraints** [26]

$$P_{t,h}^{\mathrm{STP},i} = S \cdot G_t^{\star}(\eta_0) - \frac{a_1(\mathrm{Tem}_t^c - \mathrm{Tem}_t^a)}{G_t^{\star}} - \frac{a_2(\mathrm{Tem}_t^c - \mathrm{Tem}_t^a)^2}{G_t^{\star}} \tag{23}$$

where S is the collector surface area (corresponding to efficiency parameter) (m^2), $G^{\star}$ is the solar radiation ($\frac{kW}{m^2}$). a_1 and a_2 are the first order and second order thermal loss coefficients ($\frac{kWm^2}{k^0}$), Tem_t^c is the collector mean temperature, η_0 is the ambient temperature and is the zero thermal loss efficiency.

- **WT constraints**

$$0 \leqslant P^{WT,i}_{t,e} \leqslant \overline{P}^{WT,i} \tag{24}$$

- **Upstream grid constraints** [10]

$$0 \leqslant P^{UG+}_{t,e} \leqslant \kappa \times \sum_{\forall i} P^{UG+,i}_{t,e} \tag{25}$$

$$0 \leqslant P^{UG-}_{t,e} \leqslant \kappa \times \sum_{\forall i} P^{UG-,i}_{t,e} \tag{26}$$

where κ is part of excess/ shortage power required by the H-MG *i* or upstream grid.

- **Electrical/thermal power balance in H-MG *i***

$$\begin{aligned} &P^{D,i}_{t,e} + P^{ES+,i}_{t,e} + P^{EHP,i}_{t,e} + P^{EB,i}_{t,e} + \sum_{\forall j \neq i} P^{i+,j}_{t,e} \\ &+P^{UG-,i}_{t,e} = \sum_{\forall j \neq i} P^{i-,j}_{t,e} + P^{UG+,i}_{t,e} + P^{CHP,i}_{t,e} + P^{WT,i}_{t,e} \end{aligned} \tag{27}$$

$$\begin{aligned} &P^{D,i}_{t,h} + P^{TES+,i}_{t,h} + \sum_{\forall j \neq i} P^{i+,j}_{t,h} = \sum_{\forall j \neq i} P^{i-,j}_{t,h} + \\ &P^{CHP,i}_{t,h} + P^{GB,i}_{t,h} + P^{EHP,i}_{t,h} + P^{EB,i}_{t,h} + P^{TES-,i}_{t,h} \end{aligned} \tag{28}$$

- **Electrical/thermal power balance in multiple H-MG**

$$\begin{aligned} &\sum_{\forall i} (P^{D,i}_{t,e} + P^{ES+,i}_{t,e} + P^{EHP,i}_{t,e} + P^{EB,i}_{t,e} + P^{UG-,i}_{t,e}) \\ &= P^{CHP,i}_{t,e} + P^{WT,i}_{t,e} \end{aligned} \tag{29}$$

$$\begin{aligned} &\sum_{\forall i} (P^{D,i}_{t,h} + P^{TES+,i}_{t,h}) = \\ &\sum_{\forall i} (P^{CHP,i}_{t,h} + P^{GB,i}_{t,h} + P^{EHP,i}_{t,h} + P^{EB,i}_{t,h} + P^{TES-,i}_{t,h}) \end{aligned} \tag{30}$$

- **RLD constraint**

$$P'^{D,i}_{t,e} = \tilde{P}^{D,i}_{t,e} + P^{RLD+,i}_{t,e} - P^{RLD-,i}_{t,e}, \quad \forall P'^{D,i}_{t,e} > 0 \tag{31}$$

$$P^{RLD-,i}_{t,e} \leqslant \alpha \times \tilde{P}^{D,i}_{t,e},\ P^{RLD+,i}_{t,e} \leqslant \beta \times \tilde{P}^{D,i}_{t,e} \tag{32}$$

$$\sum_{\forall i,t} P^{RLD+,i}_{t,e} = \sum_{\forall i,t} P^{RLD-,i}_{t,e} \tag{33}$$

4. Result and discussion

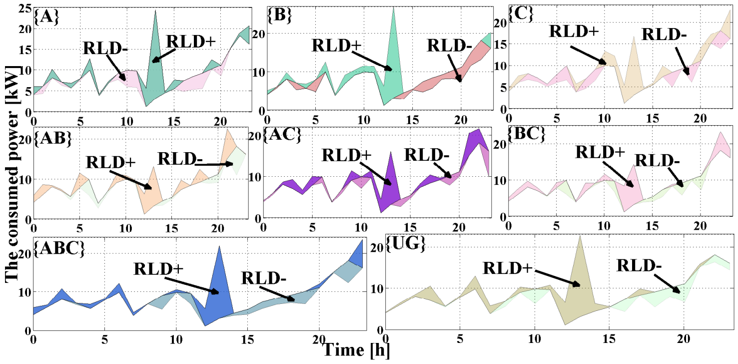
This section presents an illustrative scenario to which the proposed MSSP-ABC algorithm has been applied under the possibility of individual operation and coalition formation of distributed H-MGs. The H-MGs schedule performed by a control centre which maximizes their own profit under individual operation or coalition formation, taking into account the resources′ constraints for each period.

For demand side, the power consumption profile of each H-MG under different scenarios are shown in Figure 5(a) where the consumption load demand profiles are completely different in H-MG *A* during planning period under each scenario. There are foreseeable conditions in which could be possible that RLD+ might exist in one scenario while RLD- can occur under another scenario during the same time interval around the daily peak consumption periods. For each RLD+ or RLD- event, the control centre has previously established the consumption reduction and shifting available in each consumption cluster, according to the chosen objective function (i.e. individual operation or coalition formation). It is also considered to allocate or maybe distribute the corresponding profit to each H-MG and upstream grid under different scenarios. The maximum consumption and shifting capacity can also be seen, so one can have an idea on how much consumption shifting could be additionally scheduled. As shown in Figure 5(a), the maximum value of RLD+ is achieved at 13:00 o′clock because of the severe impact of purchasing power from upstream grid when MCP is cheap as shown in Figure 5(a). Under this condition, in addition to earning higher profit associated with DER resources in H-MG *A*, consumers in this H-MG have been increasingly getting benefited from having a role relating to RLD program during daily operation of the network. From Figure 5(a), the total amount of RLD+ consumption is seen to be more than 43% of the total amount of RLD- under all scenarios. In addition, its maximum value is about 53% while the scenario {AC} could have taken place during 24 hours of operation as seen in Figure 5(a). In this scenario, the necessary power needed to supply the consumers in H-MG *C* can be met by the DER resources existing in H-MG *A*. The excess generation in H-MG *A* can also be spent for feeding RLD+ in that or selling to the upstream grid.

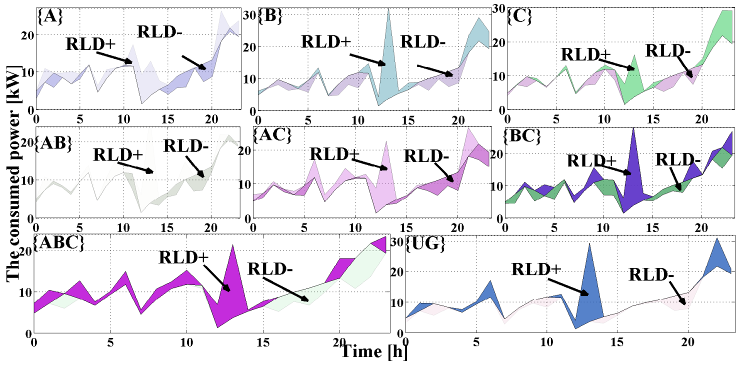
The increase of RLD+ and RLD- in the H-MG *B* along the 24h of the day is almost the same (about 41%), however, the maximum value of the difference between RLD+ and RLD- is about 51% when scenario {C} has occurred, because, in this scenario, the purchasing power from upstream grid by H-MGs B and C has increased significantly. While this is true for all scenarios, except for {UG} which shows a reduction around 21% relative to {C} as seen in Figure 5(b) and 5(c). In this case, the load is shifted from time periods when higher prices are expected, for instance the end of the day, to time periods with lower expected prices, e.g. night and some afternoon time periods. Thereby, when H-MGs tried to exchange power with each other while upstream grid is responding to hourly prices scheduling, *ABC-2 unit* has also performed at the same time to reduce more the peak load demand and flattens the total aggregated load curve of all H-MGs as seen from Figure 5(b). Another feature of the effective coalition formation is also the management of energy balance, for scenarios where a limited and/or restricted electrical power is purchased from the upstream grid. For instance, as it can be seen in Figure 5(a), shifting a part of consumption to the night hours when prices are more favourable for H-MG *A* and B coalition formation leads to the reduction of RLD+ value relative to RLD- (around 37%), although trend is reversed in H-MG *C* as seen in Figure 5(c) which shows the capability of the proposed algorithm to regulate energy balance feature under coalition formation processes.

Analyzing load demand daily operation profiles provides insight into understanding market behaviour of each H-MG, interactions between different H-MGs under different scenarios of individual operation and coalition formation, and also the arising flexibility. This is another key aspect/feature that are now about to explain market conditions and load demand correlations change throughout the day-ahead operation so the real value of flexible systems needs to be obtained by performing multiple H-MG operation analysis. This also enables the consideration for a distributed profit scenario for each H-MG under different conditions, and monitor the maximum consumption and shifting capacity.

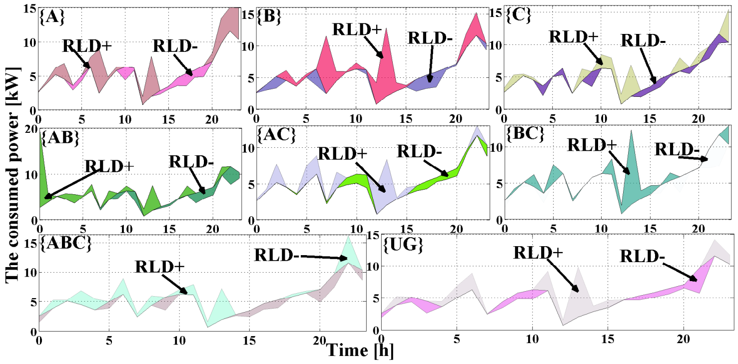
In the above, the values of $\lambda_{t,e}^{\mathrm{MCP}}$ and $\lambda_{t,e}^{\prime\mathrm{MCP}}$ obtained by *ABC-1* and *ABC-2 units* are



(a) H-MG *A*



(b) H-MG *B*



(c) H-MG *C*

Figure 5: Load profile of H-MG *A*, B and C under individual or coalition inter-operating conditions

compared to address inter-operability between multiple-coalition in H-MGs. The demand side strategy applied in *ABC-2 unit* has had a significant effect in reducing the MCP value in all of the time intervals. As can be observed in Figure 6, that $\lambda_{t,e}^{MCP}$ value is higher than $\lambda_{t,e}^{\prime MCP}$ in more than 96% of time intervals when H-MGs operate independently without coalition. In particular, the difference between them under {AB} and {ABC} scenarios has respectively reached 79% and 92% of time intervals; considering that it has undergone even more intense reduction under {UG} scenario up to 33% of time intervals than any other scenario.

The maximum and minimum values of MCPs have also had significant reduction in all the possible scenarios as seen in Figure 6. This is while the maximum value of $\lambda_{t,e}^{\prime MCP}$ unlike $\lambda_{t,e}^{MCP}$ is reached to a value between 4% to 28% of its initial value in all the possible scenarios. In addition, the minimum value of $\lambda_{t,e}^{\prime MCP}$ has shown more reduction relative to $\lambda_{t,e}^{MCP}$ (between 17% and 96%) in all the possible scenarios. The double coalition formation among H-MGs undoubtedly had considerable effect in lowering the maximum values of MCP especially with respect to the case that H-MGs are allowed to work more independently. This is while the maximum value of MCP is negligibly increased under triple (grand) coalition, i.e. {ABC}, but its minimum value is significantly reduced under this scenario. This shows that grand coalition among H-MGs is a critical decision criterion which needs to be carefully idealized at all the times. For instance, comparison of values in Figs. 5 and 6 shows that when MCP has its maximum value under all scenarios, MSSP-ABC algorithm has tried to motivate the customers shift their energy demand to off-peak period when MCP is lower, and when it is more convenient for the H-MG to distribute electricity. The minimum values of $\lambda_{t,e}^{MCP}$ and $\lambda_{t,e}^{\prime MCP}$ have occurred at the early hours of the day (except {AB}) and at the end of the day in all possible scenarios, respectively. The values of $\lambda_{t,h}^{MCP}$ and $\lambda_{t,h}^{\prime MCP}$ obtained by *ABC-1* and *ABC-2 units* are compared in Figure 7 to address inter-operability between multiple-coalition in H-MGs.

The comparison of the profit profiles earned by each H-MG and upstream grid under different scenarios are shown in Figure 8. As observed, H-MG *A* has achieved its highest profit in an individual operation (i.e. {A}) and gained less profit under scenarios {AB} and {AC}, about 30% and 41%, respectively. This highlights that

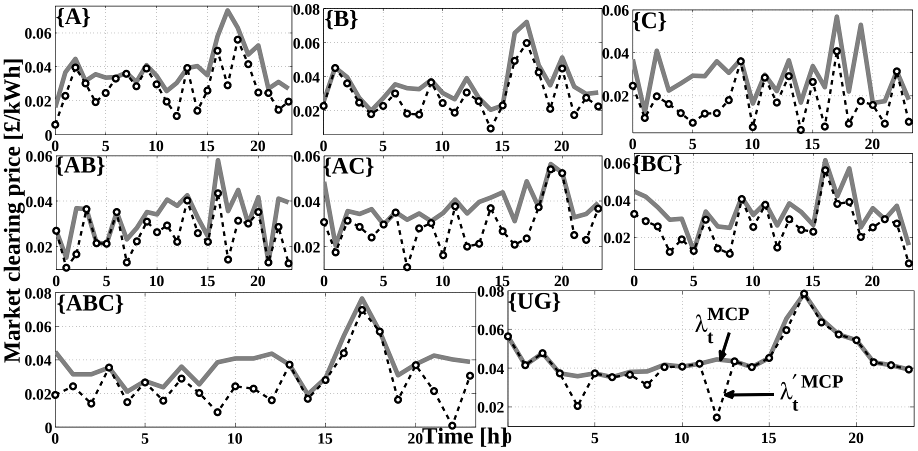


Figure 6: Electrical MCPs for mutual inter-operability schemes or independent function

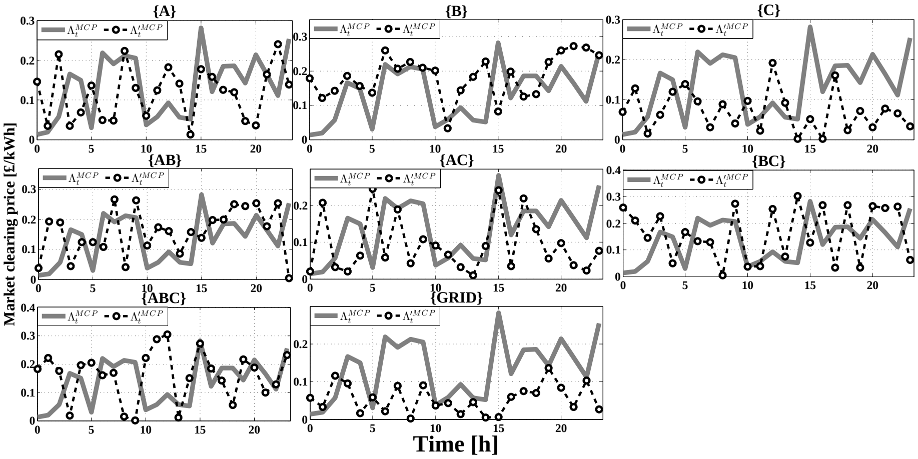


Figure 7: Thermal MCPs for mutual inter-operability schemes or independent function

even the sum of the profits of H-MGs A and B is reduced by 26% under {AB}, because, forming the coalition {AB} not only has decreased the profit of each one of H-MGs A and B, but also has reduced the obtained total profit. This is while the value of MCP in more than 58% of the time intervals is significantly reduced relative to the scenarios in which the H-MGs A and B operate as inter-operable parts. In fact, interoperability of the H-MGs is offered by the Proposed MSSP-ABC algorithm where the excess energy of one H-MG can be stored or momentarily consumed in another H-MG. On the other hand, although {AB} has had negative effect over the profit obtained from H-MGs A and B, it has had positive effect over the MCP value. In grand coalition schemes, similar conditions have occurred and a 57% decrease in the value of total profit has been obtained from forming coalition. However, in 50% of time intervals, the value of MCP in {ABC} is less than its value in the scenarios when H-MGs operate, independently. Regarding {BC} and {AC}, these results can also be reversed. It means that the total profit from {AC} and {BC} has respectively increased by 40% and 60% relative to the H-MGs operating completely independent. This is while the values of MCP after forming coalitions {AC} and {BC} have respectively reduced for about 46% and 58% of time intervals, relative to the H-MGs independent operation. In other words, forming coalition would not only increase the participation rate of H-MG owners and consumers in the deregulated market, but can also be considered to smooth the fluctuation of load demands. It is important to mention that the profit obtained from forming coalition by upstream grid has become less than the H-MGs in an individual operation which requires optimization for inter-operable routines. This means that during coalition formation among H-MGs, they have bought less power from the upstream grid and they have supplied their needed power from their partners as much as possible.

5. CONCLUSION

In this paper, an optimal, autonomous, and distributed bidding-based energy optimization scheduling algorithm is proposed in order to maximize the profit and energy balancing efficiency of H-MGs under residential loads, in specific when mul-

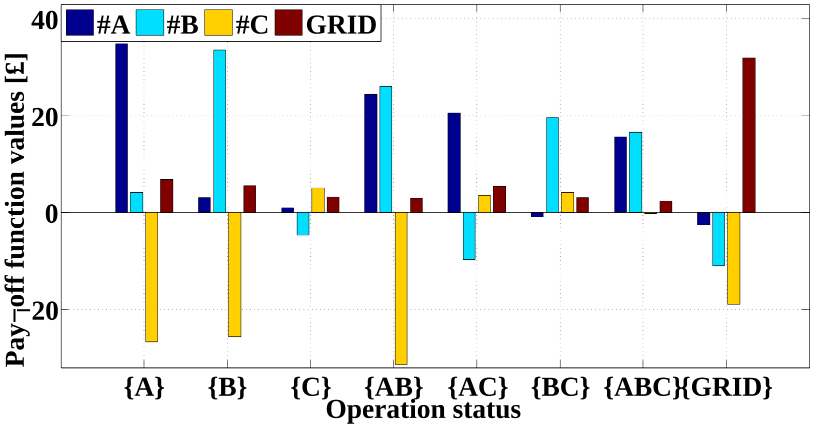


Figure 8: Obtained profit profiles by H-MGs and upstream grid under solitary or coalitional H-MGs

tiple H-MGs are trying to share their DER energy resources to create a reliable supply of sustainable energy. Unlike most of the previous strategies that focus solely on the interactions between the utility companies and conventional buildings, the basis of the proposed design is the interactions among the H-MG to help increase their overall energy efficiency infrastructure, to reduce the energy costs as well as to improve the profit of both supplier and buyer. The proposed algorithm uses interactive H-MGs communication which maximizes profits either operated separately or in a group. In order to encourage H-MGs to behave in a way consistent with the group′s interests, (i.e., inter-operatible coalition formation) a smart pricing tariff should be implemented such that the interactions among the H-MGs automatically lead to an optimal load profile with optimal DER scheduling and/or lower MCP. Some of the proposed algorithm advantages are:

1) to selectively identify within multiple H-MGs not only the amount of their energy consumption at each hour of the day, but also the portion of the energy desired to obtain from each available energy resource under individual operation or as coalition formation. 2) to facilitate influencing energy consumption levels in each H-MG through coalition formation. This support can be accomplished by introducing impetus energy cost functions. These energy cost functions depends on not only the energy production by DERs inside each H-MG, but also on the amount

of MCP, the energy consumption, and the energy production by other H-MGs in the multiple H-MG systems.

Interoperability of the H-MGs is offered by the proposed market structure where the excess energy of one H-MG can be stored in their ES/TES or momentarily consumed/sold in another H-MG/ upstream grid when MCP is relatively high or during coalition formation. In essence, it is proposed that MSSP-ABC algorithm is effective in reducing the peak demand and the value of MCP while simultaneously contributing to gain a greater profit under coalition formation, in comparison with individual operation of H-MG. The reduction is achieved in peak demand which depends on the load participation in RLD operation during peak hours, the appropriate value of MCP and the profit earned by H-MG under individual operation or as coalition formation which is globally implementable for a range of energy management, optimization and trading applications in smart multiple H-MGs. The presented architecture and simulation results confirmed the applicability of the proposed algorithm to power management and trading in smart multiple H-MGs.

In future work, the authors are planning to improve market operation by integrating the possibility of coalition formation among consumers. Additionally, physical constraints of the network, such as voltage at different locations and power flow through lines, will be formulated as an optimal power flow problem.

6. Acknowledgments

The authors acknowledge the fruitful discussions on H-MG interoperability with Prof. Jovica Milanovic from School of Electrical and Electronic Engineering, University of Manchester, Ferranti Building, M13 9PL Manchester, UK. This work was partly funded by European Union's Horizon 2020 research and innovation programme (NobelGrid project) under the grant agreement # 646184.

Credence. US-Ireland Research and Development Partnership Program (centre to centre), funded by Science Foundation Ireland (SFI) and The National Science Foundation (NSF) under the grant number 16/US-C2C/3290.

This work has been supported by the Danish Energy Technology Development and Demonstration Program (EUDP) through the Sino-Danish Project “Microgrid Technology Research and Demonstration" (meter.et.aau.dk) and also by the International Science & Technology Cooperation Program of China, project Number: 2014DFG62610.

[1] G. Goodall, A. Hering, A. Newman, Characterizing solutions in optimal microgrid procurement and dispatch strategies, Applied Energy 201 (2017) 1–19.

[2] N. Nikmehr, S. Najafi-Ravadanegh, A. Khodaei, Probabilistic optimal scheduling of networked microgrids considering time-based demand response programs under uncertainty, Applied Energy 198 (2017) 267–79.

[3] M. Marzband, N. Parhizi, J. Adabi, Optimal energy management for stand-alone microgrids based on multi-period imperialist competition algorithm considering uncertainties: experimental validation, International Transactions on Electrical Energy Systems, 30 (1) (2015) 122–31.

[4] M. H. Amrollahi, S. M. T. Bathaee, Techno-economic optimization of hybrid photovoltaic/wind generation together with energy storage system in a stand-alone micro-grid subjected to demand response, Applied Energy 202 (2017) 66–77.

[5] V. Lešić, A. Martinčević, M. Vašak, Modular energy cost optimization for buildings with integrated microgrid, Applied Energy 197 (2017) 14–28.

[6] A. Anvari-Moghaddam, A. Rahimi-Kian, M. S. Mirian, J. M. Guerrero, A multi-agent based energy management solution for integrated buildings and microgrid system, Applied Energy 203 (2017) 41–56.

[7] K. Kok, S. Widergren, A society of devices: Integrating intelligent distributed resources with transactive energy, IEEE Power and Energy Magazine 14 (3) (2016) 34–45.

[8] D. Forfia, M. Knight, R. Melton, The view from the top of the mountain: Building a community of practice with the gridwise transactive energy framework, IEEE Power and Energy Magazine 14 (3) (2016) 25–33.

[9] F. Rahimi, A. Ipakchi, F. Fletcher, The changing electrical landscape: End-to-end power system operation under the transactive energy paradigm, IEEE Power and Energy Magazine 14 (3) (2016) 52–62.

[10] M. Marzband, N. Parhizi, M. Savaghebi, J. Guerrero, Distributed smart decision-making for a multimicrogrid system based on a hierarchical interactive architecture, IEEE Transactions on Energy Conversion, 31 (2) (2016) 637–48.

[11] M. Marzband, A. Sumper, Implementation of an optimal energy management within islanded microgrid, International Conference on Renewable Energies and Power Quality (ICREPQ), Cordoba, Spain, 2014.

[12] M. Marzband, A. Sumper, M. Chindriş, B. Tomoiagă, Energy management system of hybrid microgrid with energy storage, *The International Word Energy System Conference (WESC)*, Suceava, Romania, 2012.

[13] M. Marzband, A. Sumper, O. Gomis-Bellmunt, P. Pezzini, M. Chindris, Frequency control of isolated wind and diesel hybrid microgrid power system by using fuzzy logic controllers and PID controllers, in: Electrical Power Quality and Utilisation (EPQU), 2011 11th International Conference on, 2011, pp. 1–6.

[14] F. Farzan, M. A. Jafari, R. Masiello, Y. Lu, Toward optimal day-ahead scheduling and operation control of microgrids under uncertainty, IEEE Transactions on Smart Grid 6 (2) (2015) 499–07.

[15] Y. Zong, D. Kullmann, A. Thavlov, O. Gehrke, H. Bindner, Application of model predictive control for active load management in a distributed power system with high wind penetration, IEEE Transactions on Smart Grid 3 (2) (2012) 1055–62.

[16] J. Valinejad, M. Marzband, M. F. Akorede, T. Barforoshi, M. Jovanović, Generation expansion planning in electricity market considering uncertainty in load

demand and presence of strategic GENCOs, Electric Power Systems Research 152 (2017) 92–104.

[17] M. Marzband, M. Javadi, S. A. Pourmousavi, G. Lightbody, An advanced retail electricity market for active distribution systems and home microgrid interoperability based on game theory, Electric Power Systems Research 157 (2018) 187–99.

[18] E. Stephens, D. Smith, A. Mahanti, Game theoretic model predictive control for distributed energy demand-side management, IEEE Transactions on Smart Grid 6 (3) (2015) 1394–02.

[19] N. Kinhekar, N. Padhy, F. Li, H. Gupta, Utility oriented demand side management using smart AC and micro DC grid cooperative, IEEE Transactions on Power Systems PP (99) (2015) 1–10.

[20] J. Ma, J. Deng, L. Song, Z. Han, Incentive mechanism for demand side management in smart grid using auction, IEEE Transactions on Smart Grid 5 (3) (2014) 1379–88.

[21] T. Luo, M. Dolan, E. Davidson, G. Ault, Assessment of a new constraint satisfaction-based hybrid distributed control technique for power flow management in distribution networks with generation and demand response, IEEE Transactions on Smart Grid 6 (1) (2015) 271–78.

[22] J. M. Zolezzi, H. Rudnick, Transmission cost allocation by cooperative games and coalition formation, IEEE Transactions on Power Systems 17 (4) (2002) 1008–15.

[23] F. Kamyab, M. Amini, S. Sheykhha, M. Hasanpour, M. M. Jalali, Demand response program in smart grid using supply function bidding mechanism, IEEE Transactions on Smart Grid 7 (3) (2016) 1277–84.

[24] E. Nekouei, T. Alpcan, D. Chattopadhyay, Game-theoretic frameworks for demand response in electricity markets, IEEE Transactions on Smart Grid 6 (2) (2015) 748–58.

[25] H. M. Soliman, A. Leon-Garcia, Game-theoretic demand-side management with storage devices for the future smart grid, IEEE Transactions on Smart Grid 5 (3) (2014) 1475–85.

[26] M. Marzband, Experimental validation of optimal real-time energy management system for microgrids, Phd thesis, Departament d'Enginyeria Elèctrica, EU d'Enginyeria Tècnica Industrial de Barcelona, Universitat Politècnica de Catalunya (2013).

[27] M. Marzband, H. Alavi, S. S. Ghazimirsaeid, H. Uppal, T. Fernando, Optimal energy management system based on stochastic approach for a home microgrid with integrated responsive load demand and energy storage, Sustainable Cities and Society, 28 (2017) 256–64.

[28] M. Marzband, R. R. Ardeshiri, M. Moafi, H. Uppal, Distributed generation for economic benefit maximization through coalition formation based game theory concept, International Transactions on Electrical Energy Systems, (2017) 1–16.

[29] M. Marzband, S. S. Ghazimirsaeid, H. Uppal, T. Fernando, A real-time evaluation of energy management systems for smart hybrid home microgrids, Electric Power Systems Research, 143 (2017) 624–33.

[30] M. Marzband, M. Javadi, J. L. Domínguez-García, M. M. Moghaddam, Non-cooperative game theory based energy management systems for energy district in the retail market considering DER uncertainties, IET Generation, Transmission & Distribution, 10 (2016) 2999–3009.

[31] M. Marzband, M. Javadi, J. L. Domínguez-García, M. M. Moghaddam, Non-cooperative game theory based energy management systems for energy district in the retail market considering DER uncertainties, IET Generation, Transmission & Distribution, 10 (12) (2016) 2999–3009.

[32] M. Marzband, A. Sumper, J. L. Domínguez-García, R. Gumara-Ferret, Experimental validation of a real time energy management system for microgrids in

islanded mode using a local day-ahead electricity market and MINLP, Energy Conversion and Management 76 (0) (2013) 314–22.

[33] M. Marzband, E. Yousefnejad, A. Sumper, J. L. Domínguez-García, Real time experimental implementation of optimum energy management system in standalone microgrid by using multi-layer ant colony optimization, International Journal of Electrical Power & Energy Systems, 75 (2016) 265–74.

[34] M. Marzband, A. Sumper, A. Ruiz-Álvarez, J. L. Domínguez-García, B. Tomoiagă, Experimental evaluation of a real time energy management system for stand-alone microgrids in day-ahead markets, Applied Energy 106 (0) (2013) 365–76.

[35] E. Allen, M. D. Ilic, Price-Based Commitment Decisions in the Electricity Market, Springer Science & Business Media, 1999.

[36] M. Marzband, M. M. Moghaddam, M. F. Akorede, G. Khomeyrani, Adaptive load shedding scheme for frequency stability enhancement in microgrids, Electric Power Systems Research, (2016) 1–11.

[37] M. Marzband, F. Azarinejadian, M. Savaghebi, J. M. Guerrero, An optimal energy management system for islanded microgrids based on multiperiod artificial bee colony combined with markov chain, IEEE systems journal, PP (99) (2015) 1–11.

[38] M. Marzband, M. Ghadimi, A. Sumper, J. L. Domínguez-García, Experimental validation of a real-time energy management system using multi-period gravitational search algorithm for microgrids in islanded mode, Applied Energy, 128 (0) (2014) 164–74.

[39] G. Liu, Y. Xu, K. Tomsovic, Bidding strategy for microgrid in day-ahead market based on hybrid stochastic/robust optimization, IEEE Transactions on Smart Grid 7 (1) (2016) 227–37.

[40] B. Jiang, Y. Fei, Smart home in smart microgrid: A cost-effective energy ecosystem with intelligent hierarchical agents, IEEE Transactions on Smart Grid 6 (1) (2015) 3–13.