A NOVEL APPROACH FOR PEER-TO-PEER EXCHANGE IN MICROGRIDS WITH RESPECT TO CARBON EMISSIONS

Nikolas Spiliopoulos
Newcastle University – UK
n.spiliopoulos2@newcastle.ac.uk

Uma Rajarathnam
Enzen Global – India
uma.r@enzen.com

Damian Giaouris
Newcastle University – UK
damian.giaouris@ncl.ac.uk

Phil Taylor
Newcastle University – UK
phil.taylor@ncl.ac.uk

Neal Wade
Newcastle University – UK
neal.wade@ncl.ac.uk

ABSTRACT

In this paper, a novel methodology is presented in the context of a peer-to-peer (P2P) exchange, with respect to carbon emissions. The methodology includes two steps: 1) the characterization of the users as "energy surplus" or "energy-deficient", and 2) the definition of a zone with dynamic boundaries, in which the P2P exchange is enabled. A graph theory approach is also used, to overcome the flowchart complexity and make the case easily extendable for the future. A case study of a microgrid with 50 users is examined. The results showed that a P2P exchange could provide considerable benefits both for the users and the grid, by achieving significant carbon emissions reduction at the same time.

INTRODUCTION

Modern power systems face significant challenges, due to increasing electricity demand, the ageing of the existing infrastructure and the integration of renewable energy technologies [1]. The reduction of carbon emissions is of particular interest, in the context of a smart grid infrastructure. Microgrids (MGs) are becoming important concepts to integrate DG and energy-storage systems, and are capable of operating autonomously [2]. As the RES penetration increases and the cost of energy storage becomes more competitive, novel energy management strategies are needed in order to allocate the energy in an effective and reliable way.
The concept of smart grid, implies a network where its members have an active role in the daily energy allocation, instead of behaving as passive consumers. In this paper, a novel methodology is presented in the context of peer-to-peer exchange (P2P). Under this concept the users are capable of exchanging energy without depending on energy from the utility grid. For this purpose, a particular zone is considered, which enables the P2P exchange within its boundaries. Zones are sub-regions of the network, which represent particular entities-peers that obey a specific algorithm or technique, under particular criteria [3].
Energy management in the context of P2P exchange has been investigated before. In [4], an energy sharing strategy among smart homes, with appliance scheduling is enabled. The aim is to minimize the cost of electricity bills of the consumers under dynamic pricing. In [5], the authors introduce a conceptual study for open energy systems. A P2P exchange architecture is investigated among three houses, through an external DC busbar. An islanded microgrid is considered. In both studies, a multi-agent system (MAS) approach is selected to model the different entities within the microgrid. A modified simulated annealing triple-optimizer is introduced in [6], in the context of P2P exchange among five neighbouring buildings. The researchers conclude that the suggested method requires significantly less computational time, in comparison to other methods. A different approach of P2P exchange is investigated in [7], as the energy transfer occurs among different microgrids. The authors use a coalitional game theory approach, in order to find the optimum solution (equilibrium). The developed algorithm is computationally very efficient and makes it suitable for a huge number of microgrids and real-time operation techniques.
Zoning methodologies have been introduced in the current literature to enhance operation, control and security of power systems. In [3, 8], zones are introduced in order to improve automatic voltage control methods. The authors highlight the importance of zoning methodologies as they deploy different proximity metrics, clustering criteria and validation indices. In [9], zones with potentially dynamic boundaries for operation and control in future complex systems are investigated. Finally, a geographical zoning methodology is introduced in [10], regarding system security in the context of transmission use-of-tariff (TUoT).
The novelty of this paper, is the investigation of P2P exchange with particular respect to carbon emissions, by considering a dynamic zone in which P2P is enabled. A simple approach is introduced to evaluate the shared benefits between the users and the grid, where all the users are considered as one entity. In this way, complex market models which require auctions and bids among the stakeholders, are avoided, making the methodology practical even for large power systems.

METHODOLOGY

The suggested methodology can be implemented in microgrids, with a particular ToU tariff scheme. It is assumed that the users of the MG have a PV installation and a lithium-ion battery.

An energy management strategy is developed in matlab, where the users charge their batteries during the night (low tariff), and use either the stored energy or the grid during the day (high tariff). The decision making is based on which option costs less. More precisely, if the grid cost is higher than the battery discharging cost, the user uses the battery and vice versa. If one user is able to cover their energy needs, entirely by his battery during the high ToU tariff, they are characterized as an "energy-surplus" user. In contrast, if they need to use the utility grid for at least one timestep during the high tariff, they are characterised as an "energy-deficient" user.

The next step is to check if the "energy-surplus" users could cover the remaining energy of the "energy-deficient" ones, instead of using the utility grid, in the context of a P2P exchange. To what extent the P2P exchange will be put into practice, is dominated by the benefits that this action will have both for the users and the grid. The considered benefits are related to the cost of discharging the batteries of the "energy-surplus" users, instead of using the grid. Additional benefits are examined based on the expected reduction of the CO_2 emissions, based on a given carbon policy for UK in 2020 [11]. In other words, if the cost of discharging the batteries is cheaper than the grid cost, the P2P exchange is enabled. In contrast, the grid covers the remaining energy of the "energy-deficient users", as before. However, the P2P action is not a "black or white" decision, as the remaining energy of some "energy-deficient" users could be covered by their peers and the rest of them by the grid.

A zone is considered, which indicates the area where the P2P exchange is enabled. The minimum area includes the "energy-surplus users", but it can be extended outside the initial MG, as long as benefits are still gained (Figure 1). To simplify the process, a graph theory approach was used, based on [12]. Graph theory, overcomes the complex flowcharts and can be extended easily in future work where more than one MG is considered. Each node represents a group of users, as it is shown in Figure 2. With graph theory, we can zoom-in on Figure 2 and see in detail the energy flows among the users (Figure 3).

The P2P exchange, facilitates an optimum discharging of the "energy-surplus" users' batteries. Priority is given to the "energy deficient" users of the MG. Initially, the zone includes the "energy-surplus" users and one "energy deficient". The optimization runs, and checks if any benefits can be gained. In the case where benefits are gained, the zone starts expanding by adding one more "energy deficient" user at a time. If benefits are still gained, the zone expands to include users outside the MG It is assumed that the grid users don't have either PV panels or batteries installed. The benefits gained are divided equally between the grid and the "energy-surplus" users group. Profits are shared among the users according to the amount of energy each user provides. In this way, complex auctions among the stakeholders are avoided.

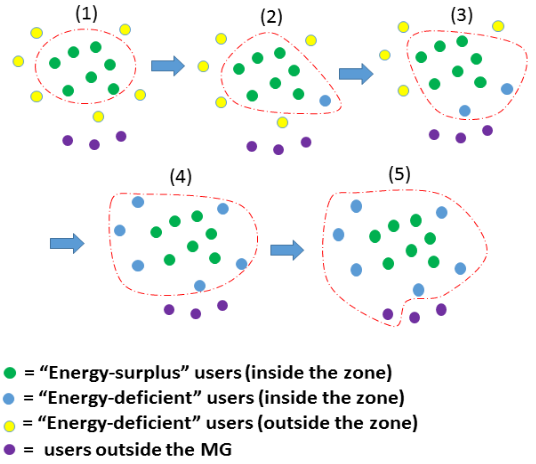

Figure 1: Zone definition.

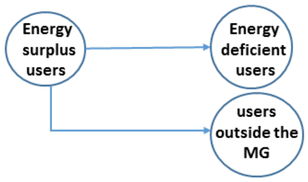

Figure 2: Graph based on graph theory, with 3 nodes and 2 edges.

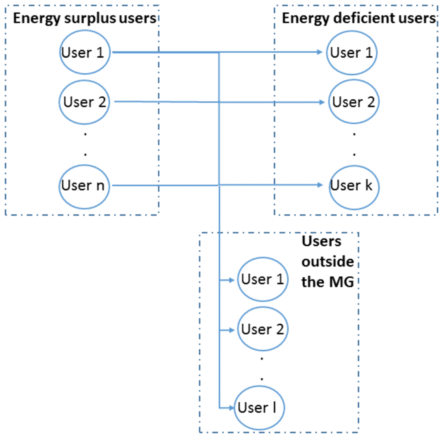

Figure 3: Zoom in on Figure 2, all the energy flows in the context of P2P exchange are shown.

The batteries are 12kWh lithium-ion. The optimization problem is formulated as follows:

Minimize:

$$f = \sum_{i=1}^{n} (C_{\text{charge}(i)} + C_{\text{deg}(i)}) \quad (1)$$

Subject to:

$$SoC_{(i)k+1} - SoC_{(i)k} = I\Delta t \quad (2)$$

$$\sum_{i=1}^{n} I_{(i)} = I_{\text{total}} \quad (3)$$

$$SoC_{\min} \leq SoC_{(i)} \leq SoC_{\max} \quad (4)$$

$$0 \leq I_{(i)} \leq I_{\max} \quad (5)$$

Where, $C_{\text{charge}(i)}$ is the cost for charging the battery i (during the night), and $C_{\text{deg}(i)}$ is the degradation cost during the discharging of battery i. The equations were obtained from [13, 14]. $SoC_{(i)k+1}$ and $SoC_{(i)k}$ are the SoC value of battery i at the moment $k+1$ and k, respectively. The timestep Δt was selected to be 5 minutes. In this case, a SoC window between 10%-90% was selected, thus $SoC_{\min} = 10\%$ and $SoC_{max} = 90\%$. The maximum current was selected to be 4C, which for a given battery of 45Ah will be $I_{\max} = 4 \cdot 45\ A$. As function f is non-linear, fmicon function was used in matlab.

CASE STUDY

A grid-connected MG of 50 users is considered. Each user has a lithium-ion battery of 12kWh and a PV installation of 4kW. A particular Time-of-Use (ToU) tariff scheme is assumed, where the tariff is low during the night (4p/kWh between 22:00-07:00) and high during the day (25p/kWh between 07:00-10:00).

As was already described in the methodology section, the first aim is to characterise each user of the MG as an "energy surplus" or "energy deficient" user. Thus, a simulation model is developed that shows the behaviour of the battery of each user, and the participation of the grid in the demand needs during the day. In Figures 4-5, the SoC, grid cost and the battery cost are presented for an "energy-surplus" and an "energy-deficient" user respectively. As shown in Figure 4, the grid is not used during the high ToU tariff (blue line). On the other hand, in Figure 5 the grid participates to cover the user's needs. In this case, 21 out of 50 users are "energy- surplus" and the remaining ones are "energy-deficient".

Now that the users have been divided in 2groups, the batteries of the "energy-surplus" users are discharged optimally, by expanding the zone gradually by one user each time (Figure 1). In this case benefits are gained until the zone covers all the members of the MG plus 11 users outside the MG. The methodology is applied for one day, as a day ahead schedule based on the expected behaviour of the users.

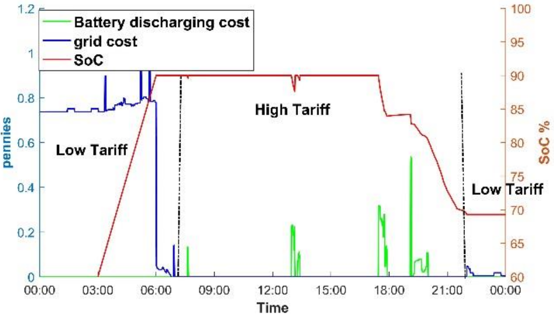

Figure 4: Example of an "energy-surplus" user

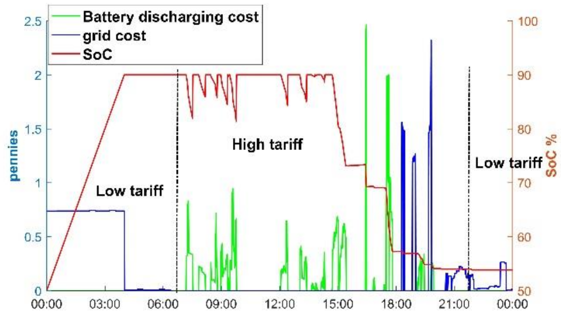

Figure 5: Example of an "energy-deficient" user

At this point, it has to be clarified that each user gives priority to their own energy needs (Figures 4-5). Subsequently, if they are categorized as "energy-surplus" user, they participate in a broader group of "energy-surplus" users which give priority to the members of the MG. If still benefits can be gained (implied that there is still energy in the batteries), the MG provides green energy to extra users outside its boundaries. For that reason, the optimization process uses as initial SoC values, the remaining SoC after each "surplus-user" has fulfilled his own demand. Similarly, the optimization runs separately for the users of the MG, and then the last values of SoC are again used as initial ones, to cover potentially users outside the MG. Finally, the sum of the discharged energy is calculated and subtracted from the initial value as the battery discharging will occur at the same time period (high tariff period).

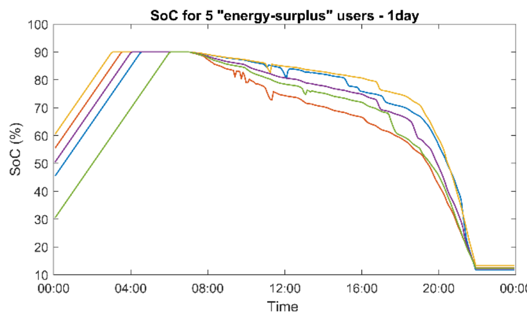

Figure 6: Total SoC profiles of 5 "energy-surplus" users.

The SoC profiles of five "energy-surplus" users are presented in Figure 6 for a whole day. The batteries are charged during the night and then they are used according to the presented methodology. The battery discharging continues until the point where the batteries have almost reached the $SoC_{\min}$ value.

Three different scenarios were examined (Table I) to calculated the benefits gained (Tables II-III).These benefits are dominated by the ToU tariff, the battery cost and the implemented carbon policy. For this case the battery cost is £100/kWh which is expected to be the case, in 2020 [15]. It is assumed that the carbon policy, is the one that UK has adopted for 2020[11]. From the obtained results it can be seen that, although initially it seems more expensive to discharge the batteries, considerable benefits can be gained if carbon emissions are taken into consideration (Tables II-III).

	Description
Scenario 1	P2P exchange occurs only among the members MG (21 "energy-surplus" users & 29 "energy-deficient" users).
Scenario 2	P2P exchange is extended outside the MG and cover the energy needs of 11 extra users (21 "energy-surplus" & 29+11 "energy-deficient" users).
Scenario 3	Same amount of users with Scenario 2. However, a 50% wind penetration is assumed during the night.

Table I: Description of the examined scenarios.

Scenarios	**Grid cost**	**Battery discharging cost**	**Benefits from P2P exchange**
Scenario 1	£ 14.14	£ 15.88	**£ -1.74**
Scenario 2	£ 36.69	£ 41.55	**£ -4.86**
Scenario 3	£ 36.69	£ 41.55	**£- 4.86**

Table II: Benefits only from P2P exchange.

Scenarios	**CO_2 reduction**	**Benefits from CO_2 reduction**	**Total Benefits**
Scenario 1	0.273 tn	£ 8.19	**£ 6.45**
Scenario 2	0.736 tn	£ 22.08	**£ 17.22**
Scenario 3	1.199 tn	£ 35.97	**£ 31.11**

Table III: Total benefits from P2P exchange, including CO_2 emissions.

An interesting feature is the fact that, the CO_2 reduction in "Scenario 2" is almost three times higher in comparison to the "Scenario 1". This happens due to the fact that the 11 extra users outside the MG, have high carbon emission intensity, as it is assumed that they do not have PV panels or batteries installed. The highest benefits are gained in "Scenario 3", as half of the energy that charges the batteries is considered a zero emission source. The presented benefits are daily ones, and are shared between the grid and the "energy-surplus" users.

CONCLUSIONS

A novel methodology regarding P2P exchange is presented. The results showed that considerable benefits can be gained both for the users and the grid, by reducing the CO2 emissions at the same time. The methodology can be extended to multiple MGs and make a feasible case for future energy systems.

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