Optimized energy management control over price-responsive demands

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Abstract. The fair and efficient allocation for all energy management systems is one of the fundamental principles. In order to achieve optimum efficiency, classic allocation strategies aim to optimize the total surplus of customers. This paper proposes the procurement, storage and selling of energy at appropriate times with a new energy management algorithm. Uncertainty is modeled using PSO optimization techniques in relation to both DER production level and the price of energy obtained from / sold to the main grid. The test results show the advantages of the model in energy management performance for a cluster of cost-effective demands.

Keywords. Energy Management System, Renewable Energy Systems, Smart Grid.

1. Introduction
In the last decades, the growth of electricity demand and pollution from the generators has led to an increase in its price. The energy management at demand level has drawn considerable attention under these circumstances. The key goal of energy management is to improve energy efficiency, thereby reducing energy costs and indirectly reducing emission levels [1, 2]. The bidirectional communication infrastructure and decision-making tools provide basic energy management requirements in electrical networks. The development of smart grid technologies [3] will fulfill the first requirement. The creation of the methods for decision-making on requests is a problem under consideration, and this paper is also the principal concern. One of the main concepts in every problem of economic allocation based on the basic principles of the economy is the simultaneous achievement of equity and efficiency. These two criteria must therefore be considered at the same time when allocating energy to requirements. Economics defines equity and efficiency as: Efficiency: Maximum use of social resources is referred to as efficiency [4]. That is to say, whether the allocation of resources for a company’s members maximizes its profit or its total surplus, the allocation will be efficient. Equity: Equity is regarded as equity as a fair share of income generated from the capital of a business by its members. In other words, an allocation is fair and equitable if no member of a company prefers other people's advantages or surplus to himself. If a society's members gain unequal advantages or surpluses from equal wealth (due to their different attributes and characteristics), an attempt to achieve equality decreases the productivity of the society. And it costs the company equally and equitably.

Consequently, absolute equity and productivity in the allocation cannot be accomplished at the same time and, in effect, a trade-off between these two goals should be considered [6]. This challenge is being taken into consideration when describing a community as a collection of requirements under an energy management system and energy as the resource allocated. A new approach to address this problem is proposed in this paper. The proposed energy control system (EMS) is therefore designed in
the following way. Demands provide the EMS responsible for its energy supply with consumption information (levels and marginal utilities). Based on energy price data and demand ranges, the EMS decides on the hourly energy consumption for each requirement and transfers the total energy consumption to energy suppliers in a positive way. Here, two energy sources are therefore considered, namely the main grid and a wind farm. All requests and vendors can be conveyed by EMS.

To address the EMS issue, the aim should be to maximize the utility for the demand clusters (cost reduction), subject to a set of restrictions that shape demand requirements, i.e. minimum day energy consumption, maximum and minimum hourly load levels, load collection and drop ramp limits, energy storage limits and power availability from the main grid and DER. SEES, which is represented using a dc model without loss, covers both the demand and DER.

Linear programming (LP) or nonlinear programming (NLP) can be used to formulate DR optimization problems. Binary decision variables are often used to determine the status (On or Off) of the different consumers and devices, in which case mixed-integer linear (MILP) or mixed-integer nonlinear (MINLP) programming may be used. In reference (7) authors use MILP to optimize DR and schedule the use of renewable energies, batteries and electric vehicles for the residential community grid. A reduction issue of the energy costs purchased from the residential community was overcome in this optimization. Reference [8] uses MILP to achieve minimization of costs in smart micro grid constructions with regard to DR optimization and day-to-day operation. Two different intelligent buildings with 30 and 90 houses are composed of this case study. The optimal schedule of household appliances is identified during the optimization process. Reference [9] is also used to illustrate how strategies such as DR can be suitable in any region, given that the renewable energy is highly penetratable. Reference [10] provides a case in point of NLP for DR optimization, in which the unit engagement problem for a computer grid is resolved. The problem of optimization is the reduction of load and the incentives paid for each interval. Reference [11] gives another example of MINLP, which involves the reduction of gas and grid power purchases by taking various loads into account over time. It decides the optimal day-to-day preparation for energy centers. For an aggregator, the DR specification has been extended to final customers over time. It operates as a service provider and this service provider must be paid for by the DR services. A thermostatically controlled loads aggregation for DR are presented in Reference [12]. In this case, the consumption of air conditioning is regarded as charge. Aggregation services are not limited to applying DR programs, a generalized energy storage aggregation can be found in Reference [13]. The storage of aggregators is used for energy and regulatory activities. It is also possible to incorporate DR services targeting individual users without contracts or service providers [14, 15]. The applications are treated as autonomous since no aggregator is linked to the user. Normally, the user has in his house a device to control the loads if the application is independent. A PV inverter is used in reference [16] while a home energy management system is used in reference [17]. Passive loads (i.e. air conditioning, fridges, laundry maker) and active loads (e.g. DG, ESS, vehicle-to-grid, pv) can be used for the controllable loads. The DR applies to discrete loads in References [19] with only two states: on or off. In recent years, its application in electricity systems has grown, with a focus on artificial intelligence (AI). Metaheuristics is an important part of AI to solve problems with optimization. These techniques have reasonable performance to solve problems with engineering by seeking an almost optimal solution with a reduced calculation load. In problems with a large range of decision variables, metaheuristics can be used and adapted easily to a problem which has many limitations [20]. A photovoltaic, storage, and power network shifting strategy for the optimal functioning of the priced demand response is used in the comparison [18]. The Home Energy Management System implements the optimization algorithm. The PSO algorithm is also used in reference [21]. Other algorithms such as genetic algorithms[22], simulated ringing and differential evolution are often used to solve DR optimization problems[23], taking into account the variation in the price of electricity imposed on us by DSO to reduce consumption. This paper proposes the optimization of the system using the PSO approach to solve the optimization problem and compares the results to a RO topology.
2. Problem Description:
In that case, both the main grid and a stochastic DER (for example a small wind producer), can provide energy demand from the demand cluster. The cluster also has an energy storage system which can be used as necessary. Furthermore, the demand cluster is able to sell electricity in hours with high prices to the main grid. The arrangement between requests and suppliers requires the cluster's EMS to collect suppliers’ hourly details several minutes before power consumption This data and the technical / economic data of the market are used by the EMS to change its hourly energy usage to optimize the maximum utility of the cluster. Following is the specific role of the EMS:
1) In an hour ten minutes before the supply of energy, the main grid submits its price. While the EMS operator has noticed the prices for the initial hours, they are uncertain for the next few hours.
2) The wind producer shall produce the wind power within 10 minutes of delivery. The rates of wind power are estimated for 24 hours a day.
3) EMS specifies the daily electricity and energy usage and quantities supplied by the main grid, the wind turbine and storage unit for each application. The EMS determines the energy fraction that is stored and the energy fraction that is sold to the main grid.
4) Decision-makers and demands (e.g. 5 min. before hour) are aware of the hourly decisions.

3. Problem Description:
The following are the demand response models for the hourly cluster of requests:

\[
\min \left[ \sum e_{t} e_{t}^{2} + \sum w_{t} w_{t}^{2} - \sum \sum u_{t} e_{t} + \sum \sum u_{t} w_{t} + \sum \sum u_{t} e_{t} + \sum \sum u_{t} w_{t} \right]
\]

The objective function is the less complete utility of all requirements for 24 hours. The energy price of the main grid in hour \( t \) is known, but the prices for the next 24-t hours of the day, \( g_{t+1} \) are unknown, and are represented by brackets. The 24-hour wind energy prices are recognized. Notice that the EMS has to purchase all the available wind energy output by taking-or-pay contract. The term referring to the cost of wind power is also an objective term and can be excluded.

3.1. Proposed Algorithm
Given the energy management algorithm in the previous sub-section of the PSO, the following is described:
1) Start \( t=1 \).
2) The energy cost from the central grid shall be sent to the EMS operator for the current hour, e.g. 10 minutes before the hour.
3) The wind generator shall give the wind power to the EMS manager, e.g. 10 minutes before the hour to be generated. Price sensitive demands must submit their present and remaining hours to the EMS dispatcher, e.g. 10 minutes before an hour, their load rates and usefulness.
4) The EMS operator calculates the limit for energy prices and wind production for the 24-t-hours remaining 24-t-days on the basis of historical energy price series from DER’s leading grid and wind power productions. Note that the EMS operator is responsible for the risk associated with the simulation of uncertainty, so that the correct projection techniques are utilized to accurately assess these trust limits.
5) The EMS operator solves the PSO and obtains energy fractions from the main grid, from the wind generator and the storage unit, as well as energy for each individual order, the energy quantity to be stored and the energy quantity to be sold to the principal grid in an hour.
6) The EMS operator informs energy suppliers and demands, e.g. 5 minutes before hour of the optimal decisions made in step 6 above.
7) Update the hour counter \( t \). If <25, go to Step 2. When \( t=25 \) finishes the algorithm for the day and goes on to the next day. Note that in step 5 the EMS incorporates the new hourly information it gets, which updates the confidence limits forecast for the uncertain figures for the rest of the day.

4. Case Study:

4.1. Data
The energy management of 7 criteria is shown in Fig in the 5-bus system. For analysis, 1 is taken into account. Bus 5 includes a wind farm and power storage. Bus 1 connects the main grid. The average power injection from / to the principal grid is 400 MW. Tables I and II respectively contain network data
and technical demand data. In Table II, the last column gives the initial burden for every request. The storage capacity is 200 MWh and the two conversion efficiencies are 90%. The power transferred to the warehouse and the amount of energy stored in the warehouse at the beginning of hour 1 are zero. The total power supplies currently contain 292 Megabytes (MS), 22 Megabytes (MWs), and 0 Megabytes (MWs). Table III provides the data on the minimum hourly demand load. While requirements 1 to 4 are zero in most hourly consumption, requests 5 to 7 are less flexible. The elasticity of demand represents an all-day multi-block utilities feature. Table IV shows the base multi-block utility function. The usefulness for the specifications of 1 to 4 is obtained by increasing the base utility by 0.8, 1.0 and 1.2 respectively in 1-8, 9-16 and 17-24 hours. The basic utilities are multiplied by 1.1, 0.9 and 1.0 in hours 1–8, 9–16, and 17–24, for hourly demand utility 5 to 7.

Figure 1. 5 – Bus Network

| Line | From | To  | Capacity [MW] | Reactance [Ohm] |
|------|------|-----|---------------|-----------------|
| 1    | 1    | 2   | 250           | 0.0341          |
| 2    | 1    | 4   | 150           | 0.0264          |
| 3    | 1    | 5   | 400           | 0.0564          |
| 4    | 2    | 3   | 350           | 0.0249          |
| 5    | 3    | 4   | 240           | 0.0342          |
| 6    | 4    | 5   | 240           | 0.0582          |

Table 2: Least Hourly Demand Level

| Demand | E[day] | D[MS] [MW] | r1[MW/h] | r2[MW/h] | d1.1[MW] |
|--------|--------|------------|-----------|-----------|-----------|
| 1      | 100    | 10         | 6         | 6         | 6         |
| 2      | 100    | 10         | 6         | 6         | 6         |
| 3      | 500    | 70         | 40        | 40        | 30        |
| 4      | 600    | 70         | 45        | 45        | 26        |
| 5      | 1200   | 150        | 100       | 100       | 78        |
| 6      | 1000   | 150        | 90        | 90        | 79        |
| 7      | 1500   | 200        | 110       | 110       | 89        |

Table 3: Technical Data for Demands

| Time | d1.1 [MW] | d2.1 [MW] | d3.1 [MW] | d4.1 [MW] | d5.1 [MW] | d6.1 [MW] | d7.1 [MW] |
|------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 2    | 0         | 0         | 0         | 0         | 0         | 0         | 0         |
| 3    | 0         | 0         | 0         | 0         | 0         | 0         | 0         |
| 4    | 0         | 0         | 0         | 0         | 0         | 0         | 0         |
| 5    | 0         | 0         | 0         | 0         | 0         | 0         | 0         |
| 6    | 0         | 0         | 0         | 0         | 0         | 0         | 0         |
| 7    | 0         | 0         | 0         | 0         | 0         | 0         | 0         |
| 8    | 0         | 0         | 0         | 10        | 20        | 20        |           |
5. Results and Discussion

The demand response problem of the cluster of demands in the following cases is investigated in order to examine the effectiveness of the PSO based EMS:

Without SG: The EMS receives the prices and the wind output in real-time and thus 24 unknown prices / wind outputs without the SG technology. The objective function of this state is the following:

$$\sum_{h=1}^{24} \left[ \min_{\delta} \delta - \sum_{i=1}^{N} u_{i,h}(e_{i,h}) \right] + \beta T + \sum_{n=1}^{24} \gamma_n$$

In SG: real-time prices and wind production via SG technology are available. The proposed algorithm is considered for the use of this information. The results are shown in numbers. 2 and 3, representing, respectively, for the case and for non-SG the fractions of energy supplied by / from the main grid and supplied by the producer of wind. Figure 4, on the other hand, shows the energy transferred to the storage unit and the energy supplied from the storage unit.

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|   | 0 | 0 | 0 | 0 | 10 | 20 | 20 | 10 | 20 | 20 | 10 | 20 | 20 |
|---|---|---|---|---|----|----|----|----|----|----|----|----|----|
| 9 | 0 | 0 | 0 | 0 | 10 | 20 | 20 | 10 | 20 | 20 | 10 | 20 | 20 |
| 10| 0 | 0 | 0 | 0 | 10 | 20 | 20 | 10 | 20 | 20 | 10 | 20 | 20 |
| 11| 0 | 0 | 0 | 0 | 10 | 20 | 20 | 10 | 20 | 20 | 10 | 20 | 20 |
| 12| 0 | 0 | 0 | 0 | 10 | 20 | 20 | 10 | 20 | 20 | 10 | 20 | 20 |
| 13| 0 | 0 | 0 | 0 | 10 | 20 | 20 | 10 | 20 | 20 | 10 | 20 | 20 |
| 14| 0 | 0 | 0 | 0 | 10 | 20 | 20 | 10 | 20 | 20 | 10 | 20 | 20 |
| 15| 0 | 0 | 0 | 0 | 10 | 20 | 20 | 10 | 20 | 20 | 10 | 20 | 20 |
| 16| 0 | 0 | 0 | 0 | 10 | 20 | 20 | 10 | 20 | 20 | 10 | 20 | 20 |
| 17| 1 | 1 | 2 | 2 | 20 | 40 | 40 | 20 | 40 | 40 | 20 | 40 | 40 |
| 18| 1 | 1 | 2 | 2 | 20 | 40 | 40 | 20 | 40 | 40 | 20 | 40 | 40 |
| 19| 1 | 1 | 2 | 2 | 20 | 40 | 40 | 20 | 40 | 40 | 20 | 40 | 40 |
| 20| 1 | 1 | 2 | 2 | 20 | 40 | 40 | 20 | 40 | 40 | 20 | 40 | 40 |
| 21| 1 | 1 | 2 | 2 | 20 | 40 | 40 | 20 | 40 | 40 | 20 | 40 | 40 |
| 22| 1 | 1 | 2 | 2 | 20 | 40 | 40 | 20 | 40 | 40 | 20 | 40 | 40 |
| 23| 1 | 1 | 2 | 2 | 20 | 40 | 40 | 20 | 40 | 40 | 20 | 40 | 40 |
| 24| 1 | 1 | 2 | 2 | 20 | 40 | 40 | 20 | 40 | 40 | 20 | 40 | 40 |
| 25| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
Figure 4. (a) Power Transported to the Storing Part

Figure 4. (b) Power Transported from the Storing Part

Table 4: Real Information and Prediction Boundaries of Energy Cost

| Time (h) | Actual [$/MWh] | Lower bound [$/MWh] [RO method] | Upper bound [$/MWh] [RO method] | Lower bound [$/MWh] [PSO method] | Upper bound [$/MWh] [PSO method] |
|---------|----------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| 1       | 47.45          | 42.93                           | 61.52                           | 45.62                           | 60.94                           |
| 2       | 48.39          | 37.31                           | 61.75                           | 43.46                           | 60.11                           |
| 3       | 45.28          | 31.63                           | 56.45                           | 39.63                           | 55.43                           |
| 4       | 46.38          | 30.17                           | 53.28                           | 42.15                           | 50.12                           |
| 5       | 48.72          | 30.12                           | 54.63                           | 46.15                           | 53.72                           |
| 6       | 50.71          | 31.6                            | 62.9                            | 45.45                           | 60.72                           |
| 7       | 60.01          | 37.71                           | 65.46                           | 40.71                           | 63.62                           |
| 8       | 60.52          | 34.09                           | 70.66                           | 37.26                           | 68.23                           |
| 9       | 60.56          | 37.15                           | 73.51                           | 49.23                           | 69.51                           |
| 10      | 60.48          | 34.53                           | 72.27                           | 52.63                           | 70.32                           |
| 11      | 60             | 37.25                           | 74.93                           | 55.23                           | 71.23                           |
| 12      | 60             | 37.44                           | 75.51                           | 54.23                           | 72.23                           |
| 13      | 59.46          | 37.46                           | 75.67                           | 51.23                           | 75.68                           |
| 14      | 59.18          | 35.64                           | 74.94                           | 54.16                           | 70.23                           |
| 15      | 57.05          | 35.05                           | 74.15                           | 49.63                           | 73.15                           |
| 16      | 57.93          | 36.31                           | 75.46                           | 48.63                           | 72.31                           |
| 17      | 73.76          | 53.82                           | 92.86                           | 65.89                           | 91.00                           |
| 18      | 87.55          | 69.96                           | 107.98                          | 75.62                           | 108.23                          |
| 19      | 79.77          | 64.2                            | 105.68                          | 65.29                           | 103.23                          |
| 20      | 70.3           | 56.89                           | 99.07                           | 61.23                           | 98.05                           |
| 21      | 61.16          | 46.16                           | 86.16                           | 51.23                           | 95.63                           |
| 22      | 59.87          | 40.85                           | 80.73                           | 52.36                           | 79.23                           |
| 23      | 54.36          | 32.29                           | 71.65                           | 42.56                           | 69.23                           |
| 24      | 51.97          | 32.12                           | 70.49                           | 40.25                           | 68.53                           |
Note that the main grid energy prices, as stated in Table 4, range from hrs 17 to 20 above the demands of the services. Therefore, in all cases, the strong model leads to a small amount of energy being acquired from the main grid and even to energy being sold within several hours to the main grid. The demand cluster utilizes the energy in the storage facility during these hours. The storage facility makes it possible for the cluster of demands to store energy in hours when the main grid prices are small and to use energy in hours when the major grid prices are high. On the other hand, the energy prices of the major grid are lower in hours 1 to 6 than those of demand. The robust model thus leads to energy acquisition from the main grid as much as possible. The main difference between the amount of energy consumption in the two cases, with and without SG, lies on the fact that in the case without SG, the EMS schedules the energy consumption at the beginning of the day, while in the case with SG, the EMS takes advantages of bidirectional communication to reschedule the energy consumption and to adapt it to the actual energy price and the actual wind power production hour by hour. With the SG technology, wind energy is used in its entirety and only about 75% of the total usable wind energy is used without SG.

6. Conclusion
Detailed digital simulations predict a flexibles management mechanism even under uncertainty with PSO-based optimization techniques. Similarly, contact in two ways often offers an efficient response to requests. The study concludes that the topology proposed focuses on the efficient use of energy from resource sources. The micro grid with hybrid optimization technology can be expanded to boost the EMS for the future.

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