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A Two Stage Increase-Decrease Algorithm To Optimize Distributed Generation In a Virtual Power Plant

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Abstract

A two stage algorithm is proposed in this paper to optimize cost of generation with application to a virtual power plant. First stage of the algorithm presents a methodology to draw a hierarchy for the choice of distributed generators based on the cost of generation. Second stage of the algorithm optimizes generation to minimize cost. An Additive Increase and Multiplicative Decrease algorithm, which is already used for optimization in microgrids is improved further and is presented as Modified Additive Increase Multiplicative Decrease algorithm and is applied in the second stage of the algorithm for optimization. The Modified Additive Increase Multiplicative Decrease algorithm is validated by implementing to schedule generation of distributed generators with intermittent power availability in a Virtual Power Plant in grid connected mode to optimize the cost of generation. The Modified AIMD algorithm is proved to be much more effective than the original AIMD algorithm.

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*Keywords:*Optimizaaation;Generation schedule;Cost of generation;Increase-Decrease algorithm;Virtual power plant

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1. Introduction

Fast dwindling conventional energy sources worldwide is pushing forward the need for harnessing energy from the renewable energy sources (RESs) and distributed generators (DG), paving path for decentralization of generation. The quest to reduce distribution losses in such decentralized generation systems developed the concept

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of small scale generation in the proximity of loads. The operation and control of such distributed systems comprising of small generation units along with local loads fed from them have led to the formation of Virtual Power Plants (VPP). A VPP is a cluster of DG units, loads both controllable and uncontrollable, storage systems and communication, aggregated to mimic a "single virtual generating unit" that can act as a conventional one and capable of being visible or manageable on an individual basis [1]. Autonomous or grid connected mode of operation of a VPP with intermittent generation and demand is quite a demanding task as balancing the generation and demand is essential for the stability of the system. The words VPP and microgrid are used interchangeably in the sections to follow.

The policy shift of governments in many countries towards slowly withdrawing themselves from playing a direct role in energy sector and inviting private parties into active role, augmented by technological advances in operation and control of microgrids for profit maximization are proving attractive for smaller investors. In addition, harnessing energy form RESs is gaining importance due to many reasons like improved efficiencies of PV units, reduced costs of generators, substantial increase in capacities of wind turbines from kW to MW, improved energy storage facilities and attractive subsidies by the governments [2]. These developments enabled even smaller investors to venture in energy sector in the fields of generation and distribution on smaller scales, particularly in microgrids, enforcing a strict competition among them. Offering generation and distribution at lower prices is the key to success in business and is the need of the hour, which requires reduced costs of generation. Of the many methods to reduce the cost of generation, optimum generation scheduling has a major role. Thus the role of optimization of generation is vital in energy market and is prompting a lot of research. Optimization in a VPP is more challenging in view of uncertainty of loads and intermittent power availability from RESs. Deviations between forecasted and real time power availability from solar and wind generators add to the complexity.

Many optimization techniques based on linear programming, fuzzy logic and heuristic search methods etc are developed and are being developed for application in microgrids to different optimization problems. A few applications of optimization techniques in a microgrid operation and control are optimal power flow, load shedding, demand side management, emission reduction, etc. [3]. A heuristic algorithm is used in [4] to optimize the fuel consumption and cost of emission in adjusting generation to demand on-line in a microgrid when connected to grid. A two stage stochastic based algorithm is used in [5] to optimize the size of energy storage facility in different forms of hydrogen, thermal and battery type to balance the generation and demand over 24 hours. A Genetic Algorithm based technique is applied to optimize the energy and power delivery/charging capacity of a battery storage facility in a microgrid to reduce the cost of operation [6]. A modified Bacterial Foraging Algorithm based energy management system is proposed in [7] to optimize the cost of operation of a microgrid having uncertain RESs and energy storage facilities. A Fuzzy logic based energy management system is formulated in [8] to control the charging/discharging of a energy storage system under day ahead generation scheduling in a microgrid with intermittent energy sources. All the methods proposed [3-8] are heuristic search based methods requiring complex computational processes

The present paper proposes a Linear Program based two stage algorithm, to schedule the generation task in a microgrid for optimization of a utility function of interest. The DGs considered are given a priority index based on the function to be optimized in the first stage. A Modified Additive Increase Multiplicative Decrease (MAIMD) algorithm is used in the second stage for generation scheduling among the available DGs.

The original Additive Increase Multiplicative Decrease (AIMD) algorithm, which is a simple linear increase-decrease algorithm, is well adopted and tested for congestion avoidance in communication networks [9, 10]. As a communication network resembles a distribution network in many operational principles, the AIMD algorithm, which is proven effective in communication network, is adopted for solving the problem of optimum generation scheduling in a microgrid environment with intermittent renewable energy sources [11]. This paper identifies a few drawbacks in the AIMD algorithm as applied to microgrids and proposes a few improvements to it to enhance its performance.

2.1 Problem statement

It is assumed that the microgrid considered operates in grid connected mode and always supplies the demand, by drawing grid power if required i.e., at any given time *t* the demand is supplied totally.

$$\sum_{i=1}^{x} S_i(t) = d(t) \tag{1}$$

where S_i is the power available with i^{th} DG, $i=1,.....x$ is the priority number of the DGs in the order of priority, x is the total number of DGs considered in the microgrid, $d\ (t)$ is the demand at time interval t. Eq. (1) offers a choice of DGs to the Energy Management System (EMS) for generation to match the demand at any given time. It also gives the EMS a choice to fix the ratio of how much power that i^{th} DG should generate (S_i) to the total power generation of all DGs ($\sum S_i$) at any given time.
The utility function considered in this paper for optimization is the cost of generation.

$$C\ (t) = \sum_{i=1}^{x} c_i(t)S_i(t) \tag{2}$$

where C is the currency unit, c_i is the cost of energy generation per kWh of the i^{th} generator.

2.2 AIMD algorithm

In AIMD algorithm, the EMS gently increases the power generation of i^{th} DG cumulatively in the additive phase until the generation exceeds the demand. The condition is an indication of a stage where the total generation exceeds the demand. At this stage, the EMS senses excess generation condition and signals the generators to gradually decrease their generation in a multiplicative progression by a constant until a stage is reached when the generation equals demand or until when an accepted error (difference between total generation and demand) is reached. The increment is by an additive constant and decrement is by a multiplicative factor.

Basic AIMD algorithm

```
Initialize the generator and demand
Repeat
$t = t + 1$
if
$\sum_{i=1}^{x} S_i(t) < d(t)$
$S_i(t+1) = \min\ [S_i(t) + \alpha,\ \ S_{imax}(t)], \forall\ i = 1, \ldots\ldots, x$          (Additive Increment phase)
Else
$S_i(t+1) = \max\ [S_i(t) * \beta,\ \ S_{imin}(t)], \forall\ i = 1, \ldots\ldots, x$          (Multiplicative Decrement phase)
end
```

where α is the additive parameter in increment phase and β is multiplicative parameter in the decrement phase. The condition for faster convergence is $0 < \beta < 1$.
Preferably the value of β should be closer to '1' for faster convergence [9]. The quantities S_{imin} and S_{imax} indicate the minimum and maximum power availability of the DGs considered.
The short comings of the AIMD algorithm are discussed in section 2.2. stage II.

Stage II (MAIMD algorithm)

The shortcomings that are observed in the original AIMD algorithm [11] and the modifications proposed in this paper to overcome the shortcomings are as follows

1. The AIMD algorithm considers a single additive parameter α in the increment phase for all the DGs present. This allocates an equal share of allocation of utility function, say power generation, among all the DGs irrespective of their utility value, say cost of generation. This is not economical in view of widely varying utility value of the DGs. As a classical example, the cost of generation per unit of energy varies widely among the wind and PV generators. Scheduling generation among the wind and PV generators on equal basis will not yield the optimized cost of generation. The DGs with lower cost of generation should be allocated more power generation compared to the DGs with higher cost of generation. To achieve this, we propose that different additive parameters α_i shall be used for different DGs in inverse proportion to their cost of generation. This ensures that the cheaper sources are utilized more in comparison to the

costlier sources. Implementation of this modification is required only in the event of classification of DGs in stage 1 and if there is significant difference in utility value of the DGs classified into one group. Different additive parameters may not be required in case of no classification

2. At the end of additive increment phase, if the total allocation to all the DGs exceeds what is required, the original AIMD algorithm [11] implements decrement phase on each of the DGs, which is not fair because the allocation to the higher priority DGs should not be decreased unless the decrement in the lower priority DGs is not sufficient. In other words the allocation to least priority DG should be decreased first , and if there is no chance to decrease its allocation further, then the DG with next higher priority should be decreased. To achieve this we propose that at the end of increment phase, if the total allocation is more than what is required, the decrement phase should be implemented in reverse order of priority index.

Modified AIMD algorithm

```
Initialize the generations
Repeat
 $t = t + 1$
If
 $\sum_{i=1}^{n} S_i(t) < d(t)$

 $S_i(t+1) = \min\ [S_i(t) + \alpha_i,\ S_{imax}(t)], \forall i = 1, \dots\dots, n$        (AI)

 ( $\alpha_i$ is not constant for all the generators and is in inverse proportion to cost of generation of $i^{th}$ unit)
Else
 $S_i(t+1) = \max\ [\beta * S_i(t), S_{imin}(t)], \forall i = n, \dots\dots\dots.1$        (MD)
 ( $i$ is in reverse order)
until end of simulation
```

It is assumed that the EMS has a record of priority indices and implements it. It is also assumed that the increment /decrement signal given by the EMS to the i^{th} generator is received by only that generator.

3. Simulation setup

The utility optimization function considered in this paper is the cost of generation. The cost function can be stated by

$$f\left(S_i(t)\right) = \sum_{i=1}^{x} S_i(t) * c_i\ (t) \tag{3}$$

The optimization problem can be stated as

$$min \sum_{i=1}^{x} f\left(S_i(t)\right)$$
$$s.t. \quad \sum_{i=1}^{x} S_i(t) = d_i(t) \qquad \text{and} \qquad S_{imin}(t) < S_i(t) < S_{imax}(t) \tag{4}$$

For evaluating the performance of the proposed two stage algorithm, a VPP scenario investigated in [7] is considered for optimization of cost of generation. The VPP is considered to have a micro turbine (MT), a wind turbine (WT), a fuel cell (FC) and a solar PV module (PV) of capacities 30 kW, 20 kW, 30 kW and 15 kW respectively in grid connected mode with other details as tabulated in Table 1. The hourly demand and maximum power availabilities (S_{imax}) of the WT and PV generators are as tabulated in Table2. The hourly bidding of energy generation of the different DGs and the hourly cost of energy drawn from grid are as given in Table 3 in Euros per kWh. The load and generation are sampled every hour over a period of 24 hours. The grid power is drawn under

Table 1. Details of DGs

Type of DG	P_{min} (kW)	P_{max} (kW)
MT	6	30
FC	3	30
PV	0	15
WT	0	20

deficit generation.

Since there is no possibility for classification of DGs as each one is of different nature, the DGs are prioritized each hour in stage1 because the cost of generation for each DG is not constant over 24 hours. In stage2 the generations are scheduled among DGs in order of priority using MAIMD. To validate the performance of the proposed two stage algorithm, the original AIMD is also implemented for the same problem.

4. Numerical results

Figure 1 (a) shows that the proposed two stage algorithm effectively schedules generation to match demand. The results of optimal generation scheduling obtained by implementing the proposed two stage algorithm are as tabulated in Table 4 and the results obtained by AIMD are tabulated in Table 5. The hourly costs of generation calculated by AIMD algorithm and the proposed two stage algorithm are consolidated in Figure 1(b). It shows that wherever there is a choice of DGs, i.e., when the total power availability is more than demand, the proposed algorithm schedules generation very economically compared to AIMD algorithm. A detailed comparison of Figure 2 (a) and Figure 2 (b) shows that at each hour, the cheapest source, MT is best exploited in the proposed algorithm as compared to AIMD algorithm. The AIMD algorithm schedules generation among the DGs equally, except for the reason that the minimum power allocation for MT source is 6 kW and that for FC source is 3kW. If the minimum power allocation is made zero, then all the DGs will be scheduled generation equally. On the other hand Table 4 shows that the proposed two stage algorithm is very effective in tapping the cheaper source first and the costlier sources are tapped only when the cheaper sources exhaust. Both the algorithms give same cost when there is no choice of generation possible, i.e., when the demand is more than the total maximum generation. Under these conditions, both the algorithms are using all the sources completely and the additional power required is drawn from grid. This is the reason why both the algorithms are giving same result under this condition. When the VPP operates under excess generation condition, i.e., when the total power available is more than the demand, the AIMD algorithm schedules generation equally among all DGs except for the minimum power to be generated, where as the proposed algorithm schedules generation in priority basis such that the cheaper sources are utilized first and the costlier sources are utilized only when the cheaper sources are completely exhausted.

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Table 2. Hourly demand and the max power availabilities of DGs (kW)

Hour	Demand	WT	PV	Hour	demand	WT	PV
1	52	16.01	0	13	72	11.67	10.7
2	50	16.08	0	14	72	10.15	9.7
3	50	16.16	0	15	76	14.75	8.12
4	51	16.17	0	16	80	16.21	4.95
5	56	17.68	0	17	85	16.14	1.1
6	63	16.17	0	18	88	19.13	0.1
7	70	14.73	0	19	90	17.53	0
8	75	14.56	0.1	20	87	18.95	0
9	76	14.65	0.59	21	78	19.04	0
10	80	13.16	1.98	22	71	19.11	0
11	78	11.67	7.75	23	65	19.93	0
12	74	10.15	9.8	24	56	19.15	0

Table 3 Hourly biddings of energy generation of DGs in Euros per kWh

Hour	MT	FC	PV	WT	P_{grid}	Hour	MT	FC	PV	WT	P_{grid}
1	0.0823	0.1277	0	0.021	0.033	13	0.0885	0.1308	0.0662	0.138	0.215
2	0.0823	0.1277	0	0.017	0.027	14	0.0885	0.1308	0.0654	0.135	0.572
3	0.0831	0.1285	0	0.0125	0.02	15	0.0885	0.138	0.0646	0.132	0.286
4	0.0831	0.129	0	0.011	0.017	16	0.09	0.1315	0.0638	0.114	0.279
5	0.0838	0.1285	0	0.051	0.017	17	0.0908	0.1331	0.0638	0.11	0.086
6	0.0838	0.1292	0	0.085	0.029	18	0.0915	0.1331	0.0662	0.0925	0.059
7	0.0846	0.1292	0	0.091	0.033	19	0.0908	0.1338	0	0.091	0.05
8	0.0854	0.13	0.0646	0.11	0.054	20	0.0885	0.1331	0	0.083	0.061
9	0.0862	0.1308	0.0654	0.14	0.215	21	0.0862	0.1315	0	0.033	0.181
10	0.0862	0.1315	0.0662	0.143	0.572	22	0.0846	0.1308	0	0.025	0.077
11	0.0892	0.1323	0.0669	0.15	0.572	23	0.0838	0.13	0	0.021	0.043
12	0.09	0.1315	0.0677	0.155	0.572	24	0.0831	0.1285	0	0.017	0.037

Table 4. Hourly generation scheduling of DGs and the cost of generation by implementing proposed algorithm

Hour	P_{MT}	P_{FC}	P_{PV}	P_{WT}	P_{Grid}	P_{Total}	Cost (Euro)
1	30	5.992	0	16.01	0	52.002	3.5703
2	30	3.9221	0	16.08	0	50.0021	3.2432
3	30	3.8421	0	16.16	0	50.0021	3.1887
4	30	4.8322	0	16.17	0	51.0022	3.2942
5	30	8.3217	0	17.68	0	56.0017	4.485
6	30	16.8283	0	16.17	0	62.9983	6.0627
7	30	25.2667	0	14.73	0	69.9967	7.1429
8	30	30	0.1	14.56	0.34	75	8.0884
9	30	30	0.59	14.65	0.76	76	8.763
10	30	30	1.98	13.16	4.86	80	11.3239
11	30	30	7.75	10.2513	0	78.0013	8.7012
12	30	30	9.8	4.203	0	74.003	7.9599
13	30	30	10.65	1.3528	0	72.0028	7.4707
14	30	30	9.7	2.3023	0	72.0023	7.5242
15	30	23.1267	8.12	14.75	0	75.9967	8.318
16	30	28.835	4.9	16.21	0	79.945	8.6556
17	30	30	1.1	16.14	7.76	85	9.2299
18	30	30	0.1	19.13	8.77	88	9.0316
19	30	30	0	17.53	12.47	90	8.9567
20	30	30	0	18.95	8.05	87	8.7119
21	30	28.9564	0	19.04	0	77.9964	7.0221
22	30	21.8902	0	19.11	0	71.0002	5.879
23	30	15.0716	0	19.93	0	65.0016	4.8918
24	30	6.852	0	19.15	0	56.002	3.699
				Total cost of generation over 24 hours			165.2139

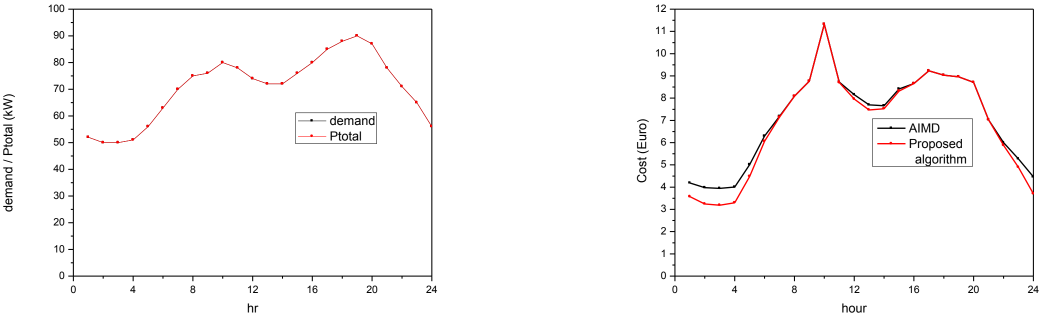

Figure 1 (a) Figure 1 (b)

Figure1. (a) Plot showing the demand and Ptotal generation using proposed two stage algorithm
(b) Plot showing the generation cost computed using AIMD and proposed two stage algorithms.

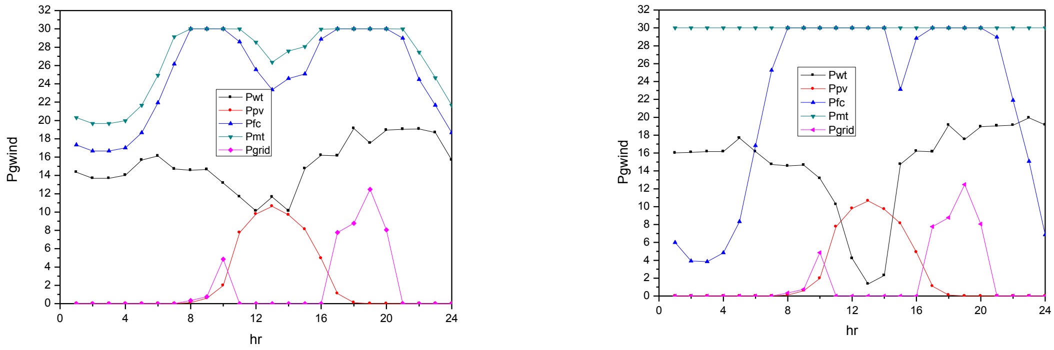

Figure 2 (a) Figure 2(b)

Figure 2. (a) Plot showing generation scheduling using AIMD algorithm
(b). Plot showing generation scheduling using proposed two stage algorithm

The total cost of generation over 24 hours is165.2139 Euros using proposed algorithm as given in Table 4 where as it is 170.7947 Euros, when AIMD algorithm is used as shown in Table5. A net saving of 3.27 % over 24 hours, which is significant, is an endorsement for the effectiveness of the proposed algorithm

5. Conclusion

The advances in profitable utilization of DG and RESs in VPPs along with the liberalised policies of the governments are very promising to the small investors to invest in the energy markets, particularly in generation in small scale. The cost of generation from the different DGs and RESs is different. Profitability increases when the energy is generated at least possible cost. Optimal generation scheduling is one of the methods used for this purpose. This paper has introduced a novel two stage algorithm, which prioritizes the available sources in first stage and uses a modified AIMD algorithm in the second stage for optimization. The effectiveness of the proposed algorithm is tested and validated by using it to optimize the cost of generation in a VPP comprising of DGs and RESs along with the intermittency of load and RESs generation on hourly basis over 24 hours. The proposed algorithm is found to be very effective in reducing the total generation cost considerably over 24 hours, to an extent of 3.27% approximately when implemented in the test case. Reactive power management, sizing of energy storage devices, emission reduction etc are some of the areas, where the proposed algorithm finds application.

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