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Energy Management in Grid Integrated Microgrid System using Demand Response

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Abstract:- This paper presents an energy management system (EMS) for a grid integrated microgrid with demand response program (DRP) using a farmland fertility algorithm (FFA). A demand response program (DRP) is incorporated with FFA for an EMS. This paper proposes an application of a new metaheuristic algorithm i.e., FFA on incentive based DRP for optimization of the operational and procurement cost and adjusting the load demand of customers during the peak load hours. The technique is applied on IEEE three and ten unit systems integrated with wind and solar system. The proposed FFA algorithm with DRP is compared with the game theory based demand response program (GTBDR), particle swarm optimization (PSO), velocity-controlled particle swarm optimization (VCPSO), and confidence-based velocity controlled particle swarm optimization (CVCPSO). The proposed approach significantly reduces the procurement cost by 45.97% and thus contributes to the microgrid economy. The proposed approach effectively optimizes the targeted objectives by minimization of the operational cost, and electricity trading cost (ETC).

Keywords: *Energy Management, Demand Response Program, Load Curtailment, Customer Incentive, Transaction Cost*

1. Introduction

The electricity demand is constantly increasing due to the growth of the industrial sector, increase in population, and high economic standards of living. Due to several obvious reasons, renewable sources are considered a better alternative to fulfill these increasing demands. However, the increase in penetration of renewable sources is accompanied by intermittency caused by the implementation of several other techniques to get a stable and reliable supply. The increased penetration of intermittent renewable energy resources propels the grid to prepare more reserves to maintain the balance between supply and demand. The increased deployment of renewable sources to the utility grid is subjected to issues of stability and reliability of the system. So the demand response strategy acts as an influential mechanism in providing a consistent and stable supply thereby providing enhanced energy management.

The integrated energy management and DRP provide peak shaving for the grid. The controllable units in the microgrid participate in the response programs based on the peak-time rebate (PTR) and incentive demand-response schemes. Under the incentive and price schemes, the microgrid can interact with the grid actively. With these DRP the microgrid operates at its best. By reducing the grid tie-line power flow during the busiest times, the microgrid offers the grid's peak-shaving service [1]. The dynamic economic load dispatch in

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islanded micro grid was estimated using particle swarm optimization in [2] and it has been found that the responsive loads and renewable power may be curtailed as the substitute to maintain a balance between generation and the load demand. The demand response using PSO has effectively optimized the operational cost, electricity trading cost (ETC) and has maximized the customer's incentive. The complex conjunctional load scheduling in micro grid has been presented in [3] using elephant herding optimization algorithm. The demand response with dynamic pricing concept has been introduced using electric vehicles for optimizing the cost of energy for the customers. The charging and discharging modes of electric vehicles have been used for balancing the plunge and peak shaving of loads respectively.

The zero energy balance based, optimal operation of grid integrated micro grid was explored in [4] to obtain a better efficiency with systematic use of energy resources. It optimizes the usage of fossil fuel and conventional generators for reduced emission with reduced ETC. The optimum load dispatch in islanded mode of micro grid has been achieved in [5] by differing the amount of power interruptibility and by changing the power curtailment maximum limit using the incentive based demand response program. The incentive based demand response program has been offered in [6]-[7] to the customers available for endorsement through load curtailment. These programs enable benefits to customers themselves through incentives and at the same time helps in reducing the fuel and emission cost. These demand response programs as included in energy management of micro grid provides optimization at both the utility and load side of the micro grid. The grid integrated micro grid with demand response program optimally schedules the distributed resources, loads and the transaction power in [8]. The uncertainty of generating resources and forecasted demand are balanced using demand response programs. The demand response program through load curtailment reduces the operational costs and the emission costs of micro grid.

The numerous metaheuristic optimization algorithms, in previous years, have been employed to determine optimal solutions for the ELD problem. These metaheuristic optimization algorithms, though versatile and effective in solving complex problems, are having inherent limitations. One common challenge is their susceptibility to getting trapped in local optima, as they do not always guarantee the identification of the best global optimal solution but may find a solution near the global optimum, hindering the discovery of the global optimum. These algorithms demand significant computational resources, especially for large-scale problems, and their performance can be sensitive to parameter settings. The lack of theoretical guarantees for convergence to the global optimum is another drawback, and handling constraints can be challenging. Additionally, some metaheuristic algorithms may struggle in dynamic environments or exhibit sensitivity to initial solutions.

The limitations of existing metaheuristic optimization algorithms prompted the need for refinement and augmentation to enhance their robustness and applicability across diverse optimization scenarios. In response to this, the developed FFA has demonstrated superior performance as compared with many other well-known metaheuristic methods. The novelty of this work lies in the application of the FFA to address the demand response problem, a domain where this algorithm has not been utilized before. The FFA algorithm excels in terms of convergence accuracy, stability, and speed, showcasing its effectiveness as an optimization tool. This highlights the importance of continuous improvement and innovation in

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algorithmic development to address the challenges posed by the complex optimization problems.

In this paper, a DRP is incorporated for the energy management in the grid integrated micro grid system. The economic scheduling of micro-grid integration with grid system and DRP is a constrained and complex optimization challenge. A nature inspired farmland fertility algorithm (FFA) is applied for solving it. It works on the principle of division of population into regions, depending on the information gathered. It identifies the region of weaker solutions and the corresponding corrective measures for each of them, and thus improves the optimizing ability of the algorithm.

The objective of this research work includes the following points.

1. The load curtailment is employed as a DRP, is utilized to reduce the operational cost, procurement cost of electricity and to reduce the amount of conventional energy consumption.
2. The DRP focuses on optimizing customer incentives and promoting their active engagement in the initiative.
3. The investigation, development and implementation of proposed algorithm for optimizing the cost of dispatch and maximize incentives.

The significant contributions of this research work are as follows.

1. The proposed research work leverages the grid integration topology while diminishing the intermittency of renewable sources.
2. The applied meta-heuristic approach efficiently deals with the tradeoff between demand response and increased dispatch cost, while providing optimal solution for obtaining minimized cost.

The rest of the paper assembly is as follows. The section 2 models the different constituents of the microgrid; section 3 gives the mathematical modeling of incentive based demand response. The section 4 elaborates the proposed FFA algorithm in detail. Further section 5 deals with the problem formulation for microgrids optimum solution, section 6 provides the test cases for the validation of the demand response model. It also discusses about the results obtained with the test cases. The research work is concluded in section 7, followed by the references.

2. Modelling of Grid Connected Microgrid Parameters

The typical structure of grid connected micro grid is shown in Figure 1. It consists of solar photo voltaic supply (SPVS), wind energy conversion system (WECS), diesel generators (DGs) and the electrical load. In the grid connected mode of operation, the electrical power is purchased or sold between the micro grid and the grid. There interconnection facilitates the fulfillment of the load demand in real time. The trading of electrical power accommodates the intermittent behavior of the renewable energy sources. The trading of electrical power depends on the forecasted generation and the load demand. If the micro grid is unable to

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supply the required load demand then power is purchased from the grid, and if the micro grid generation is exceeding the load demand the power is sold to the grid. The mathematical model of various component of microgrid is given as follows:

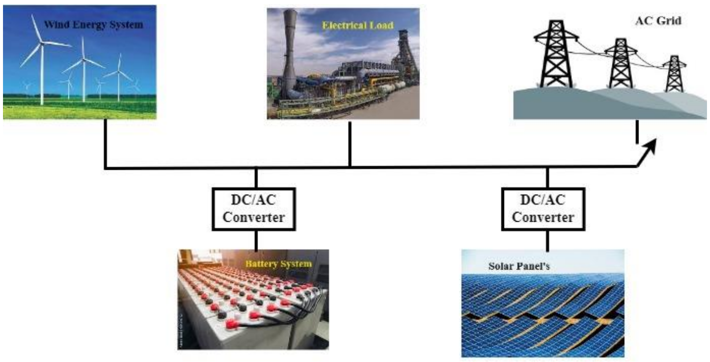

Figure 1 Grid Connected Microgrid Structure

2.1 Solar Photovoltaic Supply System Model

The power generated by solar photovoltaic supply (SPVS) system depends on the irradiation profile of the sun. The power output [9] from SPVS system is given by Equation (1) as,

$$S_{pv} = \eta_{pv} A_{pv} I_{pvt} \quad (1)$$

η_{pv} is the efficiency, A_{pv} is the area of the solar photovoltaic panel system, and I_{pvt} is the incident solar irradiation expressed in (kWh / m^2).

2.2 Wind Energy Conversion System Model

The power generated by wind energy conversion system (WECS) depends on the speed of the wind. The wind speed [9] is given by Equation (2).

$$\frac{V_2}{V_1} = \left[\frac{H_2}{H_1}\right]^{\gamma} \quad (2)$$

V_2 and V_1 are the wind speed at desired and reference height respectively. Further H_2 and H_1 are desired and reference height of a tower respectively. γ is the power law exponent and it varies from 0.14 to 0.25. The W_t is the power output [9] from WECS and is given by Equation (3).

$$W_t = 0.5\, \eta_w \rho_{air} C_p\, A V^3 \quad (3)$$

η_w is the efficiency of the WECS, ρ_{air} is the density of the air, C_p is the wind turbine power coefficient, A is the rotor swept area of wind turbine and V is the velocity of the wind.

2.3 DGs Model

The DGs are installed in micro grid and can be efficiently regulated by the system operator as needed. During the period of low generation from renewable sources and not enough to meet

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the demand the DGs are operated as the subsidiary source of generation to feed the load. The power output of DG [10] follows the quadratic function is given by Equation (4).

$$C_{gi}(P_{i,t}) = a_i P_{i,t}^2 + b_i P_{i,t} \quad (4)$$

C_{gi} is the cost of generation of i[th] generator. $P_{i,t}$ is the power generated by the i[th] generator at time t, a_i and b_i are the cost coefficients of the generators.

2.4 Modeling of Grid

In grid connected mode, the electrical power may be transferred between grid and micro grid, depending on the management of demand-generation. When the micro grid generation meets out the demand and has surplus power then the extra electrical power is sold to the grid. However, during the fall in micro grid generation in supplying the loads, the deficit electrical power is purchased from the grid. It is presumed that the location based marginal prices [11] are adopted for procuring power between micro grid and grids, using a grid tie bus. The total procurement cost [7] for electrical power trading is given by Equation (5).

$$C_{tr}(P_{tr}) = \begin{cases} \gamma_{tr} \times P_{tr} & P_{tr} > 0 \\ 0 & P_{tr} = 0 \\ \gamma_{tr} \times P_{tr} & P_{tr} < 0 \end{cases} \quad (5)$$

$C_{tr}(P_{tr})$ is the ETC, γ_{tr} is the rate of procuring electrical power and P_{tr} is the transferred electrical power. The objective function in grid connected mode [7] for cost minimization of DGs and procurement cost is given by Equation (6).

$$min \sum_{t=1}^{T} \sum_{i=1}^{I} C_{gi}(P_{i,t}) + \sum_{t=1}^{T} C_{tr}(P_{tr}) \quad (6)$$

Equation (6) is subjected to the following constraints represented by Equations (7) – (10).

$$\sum_{i=1}^{I} P_{i,t} + PS_{pv} + PW_t + P_{tr} = P_d - \sum_{j=1}^{J} X_{j,t} \quad (7)$$

$$P_{i,min} \leq P_{i,t} \leq P_{i,max} \quad (8)$$

$$-P_{tr,min} \leq P_{tr,t} \leq P_{tr,max} \quad (9)$$

$$R_{dn,i} \leq P_{i,t+1} - P_{i,t} \leq R_{up,i} \quad (10)$$

The PS_{pv} is the solar power, PW_t is the wind power and P_d is the system load demand.

3. Incentive Based Demand Response Model

The demand response plays an important role in providing costumers a freedom to reduce or shift their usage of electricity from peak periods. This in turn benefits the customers in the form of incentives. The incentive based demand response program is used in proposed grid connected micro grid system. The demand response approach is considered as a second effective method to the existing demand-generation conduct, as it does not focuses on

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expanding or increasing the existing power generation system to meet the load demand. Since it is an incentive based system for the customers and incentivized based on their limit of curtailment. In this demand response model, the customers are categorized on the basis of their readiness for power curtailment. The customers merit function [7] is given by Equation (11).

$$V(\theta, x, y) = y - C(\theta, x) \quad (11)$$

Where θ is the customers category in the range [0, 1], x is the amount of power curtailed in MW by the customers, y is the financial reparation the customers acquires, and the customers will participate in this demand response provided$V \geq 0$. The merit function for the utility [7] is given by Equation (12).

$$U(\theta, \lambda) = \lambda x - y \quad (12)$$

Where λ is the monetary compensation for not supplying electrical power at some location in the grid, and is defined as the cost for interruptible power and is calculated from optimal load flow [12, 13, 14]. The electrical utility aims at maximizing its profit and the objective function [7] is given by Equation (13).

$$\max_{x,y} [\lambda x - y] \quad (13)$$

The customers cost function $C(\theta, x)$ is defined as the amount of cost offered to customers of category θ for reducing the consumption of electrical power by x MW. The mathematical expression [7] of this function is given by Equation (14).

$$C(\theta, x) = k_1 x^2 + k_2 x - k_2 x\theta \quad (14)$$

k_1 , k_2 are the cost coefficients. θ is the customers category decides the willingness of the customers for load curtailment. The customers having $\theta = 1$ is the most willing customers and the customers with $\theta = 0$ is the least willing customers for load curtailment. The customer with greater willingness for load curtailment has the smallest cost and thus has the greatest benefit, and on the contrary the customers with the smaller willingness have the greatest cost and smallest benefit.

The electrical power utility and the customers mutually underwrite an agreement as given in [13-14] is given by Equation (15). According to which y_j is the incentive paid to the customer j, and so the objective function for customers merit is achieved as [7].

$$U_j = y_j - (k_1 x^2 + k_2 x - k_2 x\theta), for\ j = 1\ to\ J \quad (15)$$

The utility merit is given by Equation (16) and the purpose is to maximize the electrical power utility's profit, and is given in Equation (17).

$$U_0 = \sum_{j=1}^{J} \lambda_j x_j - y_j \quad (16)$$

$$max_{x,y} \sum_{j=1}^{J} [\lambda_j x_j - y_j] \quad (17)$$

Equation (17) is subjected to the following constraints represented by Equations (18) and (19).

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$$y_j - (k_1x^2 + k_2x - k_2x\theta) \geq 0,\ for\ j = 1\ to\ J \quad (18)$$
$$y_j - (k_1x^2 + k_2x - k_2x\theta) \geq y_{j-1} - \left(k_1x_{j-1}^2 + k_2x_{j-1} - k_2x_{j-1}\theta_{j-1}\right),\ j = 1\ to\ J) \quad (19)$$

The agreement signed between the electrical power utility and the customers is extended for larger time intervals, for a day in place of an hour. This extended time interval gives more real and budgetary meaning. The finalized mathematical model for the utility merit keeping intact all the necessary constraints and given as follows by Equation (20).

$$\sum_{t=1}^{T}\sum_{j=1}^{J}[\lambda_{j,t}x_{j,t} - y_{j,t}] \quad (20)$$

Equation (20) is subjected to the following constraints represented in Equations from (21) to (24).

$$\sum_{t=1}^{T}[y_{j,t} - \left(k_{1,j}x_{j,t}^2 + k_{2,j}x_{j,t} - k_{2,j}x_{j,t}\theta_j\right)] \geq 0,\ for\ j = 1\ to\ J \quad (21)$$
$$\sum_{t=1}^{T}[y_{j,t} - \left(k_{1,j}x_{j,t}^2 + k_{2,j}x_{j,t} - k_{2,j}x_{j,t}\theta_j\right)] \geq \sum_{t=1}^{T}[y_{j-1,t} - \left(k_{1,j-1}x_{j-1,t}^2 + k_{2,j-1}x_{j-1,t} - k_{2,j-1}x_{j-1,t}\theta_{j-1}\right)],\ for\ j = 2\ to\ J) \quad (22)$$
$$\sum_{t=1}^{T}\sum_{j=1}^{J}y_{j,t} \leq UB_u \quad (23)$$
$$\sum_{t=1}^{T}x_{j,t} \leq CM_j \quad (24)$$

These constraints given in Equation (23) and (24), should satisfy the electrical power utility's total budget (UB_u) and the daily limit of power interruptibility of customer j.

A. Integrated objective function of grid connected microgrid and demand response

In grid connected micro grid system applied with demand response, the objective function is a combination of fuel and ETC minimization and maximization of utility grid demand response merit. The combined mathematical expression for the integrated objective function is given by Equation (25) as.

$$\min w\left[\sum_{t=1}^{T}\sum_{i=1}^{I}C_{gi}(P_{i,t}) + \sum_{t=1}^{T}C_{tr}(P_{tr})\right] + (1-w)\left[\sum_{t=1}^{T}\sum_{j=1}^{J}[y_{j,t} - \lambda_{j,t}x_{j,t}]\right] \quad (25)$$

$$w + (1 - w) = 1 \quad (26)$$

Equation (26) demonstrate w and $1 - w$ are taken as the weights for the objective function given in Equation (25) and both the cost function and the utility merit function are given equal weight age, and w is chosen as 0.5, and the Equation (26) is a mandatory constraint for fulfillment.

4. Proposed Farmland Fertility Algorithm

The FFA is a nature inspired algorithm, and demonstrates the farmer's practice in farmland for improving the soil quality [17]. In this algorithm the farmland is divided into several sections on the basis of soil quality, and so the different sections have different and particular soil quality. The alterations in the quality of soil can be done by adding precise material like fertilizers, manure and other kind of materials. Farmers in proximity of this farmland have knowledge about the sections and the quality of soil. Farmers on their future visits to these farmlands check the soil quality and its fertility and keep a memory of it as local and global memory. In each of their future visit they check the soil fertility and alter the worst section soil quality by mixing it to the best quality soil solution. And the remaining sections are

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mixed with other solutions of the search space. The flow chart of an algorithm is described in the steps given below in Figure 2.

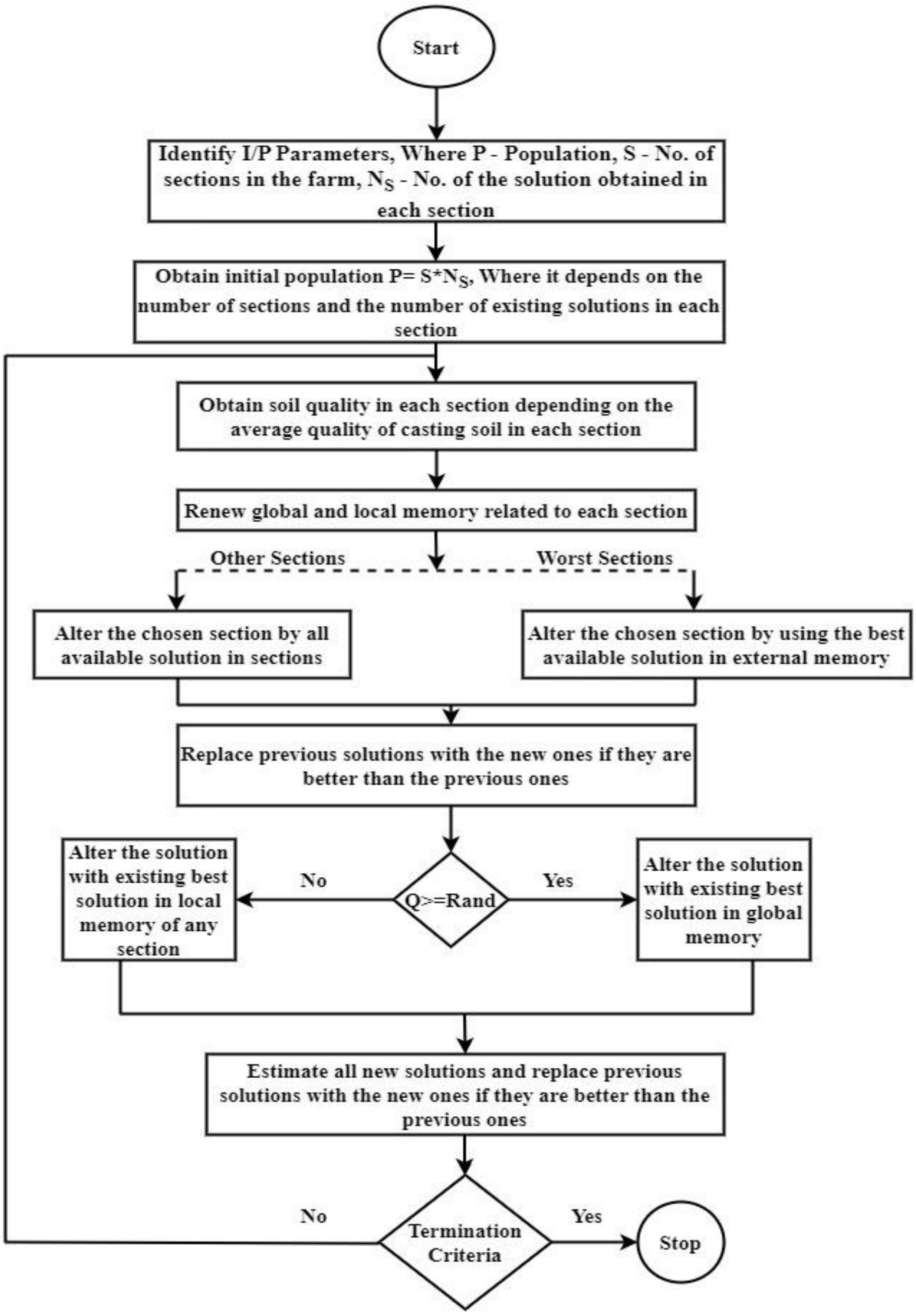

Figure 2 Functional Flow chart of FFA

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5. Problem Formulation for Microgrids Optimum Solution

5.1 Test setup 1

In the test setup 1, the grid integrated microgrid is incorporated with an incentive based demand response framework. The Test setup includes three units of DGs, one unit of WECS, one unit of SPVS and three rural customers. For more accurate authentication of proposed algorithm and energy management, a 24 hours scheduling horizon is considered. The cost coefficient parameters and the operating boundary conditions of the three DGs are given in Table 1.

Table 1 Cost Coefficients of Generators

Sr. No.	A_i	B_i	$P_{i\,min}$	$P_{i\,max}$	$R_{dn,\,i}$	$R_{up,\,i}$
1	0.06	0.5	0	4	3	3
2	0.03	0.25	0	6	5	5
3	0.04	0.3	0	9	8	8

The load demand and the value of power interruptibility of the micro grid for 24 hours period are given in Table 2. The maximum wind and solar power plant ratings are 11 kW and 15 kW respectively, and the maximum power that can be transferred between grid and micro grid is 4 kW. The wind and solar power output data is referenced from [9] and provided in Table 3. To give the test set up a more empirical approach the particulars of solar radiation were obtained from a site field in Harare, Zimbabwe (latitude 17.80 °S) [9]. The particulars of wind speed are obtained at a height of 10 m and at an altitude of 1480 m above the level of sea.

Table 2 Load Demand and the Value of Power Interruptibility

Sr. No.	P_d (kW)	$\lambda_{j,\,t}$ ($)	Sr. No.	P_d (kW)	$\lambda_{j,\,t}$ ($)	Sr. No.	P_d (kW)	$\lambda_{j,\,t}$ ($)
1	31.83	1.57	9	37.53	6.7	17	40.70	6.8
2	31.4	1.40	10	38.33	6.16	18	40.07	6.3
3	31.17	2.20	11	40.03	6.38	19	38.63	5.8
4	31.00	3.76	12	41.17	6.82	20	36.40	4.2
5	31.17	4.50	13	39.67	7.3	21	34.10	3.8
6	32.10	4.70	14	41.70	7.80	22	32.80	3.01
7	32.97	5.04	15	42.10	8.50	23	32.50	2.53
8	34.10	5.35	16	41.67	7.10	24	32.00	1.42

Table 3 Solar and Wind Power Data

Sr. No.	PS_{pv}	PW_t	Sr. No.	PS_{pv}	PW_t	Sr. No.	PS_{pv}	PW_t
1	0	7.56	9	10.56	10.88	17	10.17	8.37
2	0	7.5	10	13.61	11.01	18	7.66	7.61
3	0	8.25	11	14.97	10.94	19	0	6.7
4	0	8.48	12	15	10.68	20	0	5.72
5	0	8.48	13	14.78	10.42	21	0	7.21
6	0	9.42	14	14.59	10.15	22	0	7.75
7	0	9.82	15	13.56	9.67	23	0	7.88
8	7.99	10.32	16	11.83	8.98	24	0	7.69

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In this case the value of power interruptibility, for all the three rural customers is same. The coefficients for customers cost function, customer's type and the daily limit of customer's power consumption is given in Table 4. The microgrid operator is aware of customer's daily limit of interruptible energy (CM_j), it is further used to grade the customers on the basis of their readiness to cut down their electric power usage, θ_j is used to grade the customers. The daily budget limit of the micro grid is given as \$ 500 [9].

Table 4 Customers Parameters

Sr. No.	$k_{1,j}$	$k_{2,j}$	θ_j	CM_j
1	1.079	1.32	0	30
2	1.378	1.63	0.45	35
3	1.847	1.64	0.9	40

5.2 Test setup 2

In the test setup 2, the micro grid is planned to authenticate the suitability of the proposed optimization approach to a larger micro grid system encompassing seven units of DGs, ten units of WECS, ten units of SPVS, and five rural customers [7,15,16]. Tables 5 and 6 provide the details of cost coefficient parameters of the seven conventional generators, the cost coefficient parameters of the customers and the interruptibility limits of five customers respectively.

Table 5 Parameters of DGs

Sr. No.	A_i	B_i	$P_{i\,min}$	$P_{i\,max}$	$R_{dn,i}$	$R_{up,i}$
1	0.0007	23.9	30	150	80	80
2	0.00079	21.62	33	143	60	60
3	0.0048	23.23	27	120	60	60
4	0.10908	19.58	20	80	40	40
5	0.00056	17.87	37	60	40	40
6	0.00951	22.54	25	55	25	25
7	0.00211	16.51	20	30	10	10

Table 6 Customer Parameters and the Interruptibility Limits

Sr. No.	$k_{1,j}$	$k_{2,j}$	θ_j	CM_j
1	1.847	11.64	0	180
2	1.378	11.63	0.1734	230
3	1.079	11.32	0.4828	310
4	0.9124	11.5	0.7208	390
5	1.378	11.63	0.84	440

In this test system, different value of power interruptibility is taken for rural customers, Table 7 and 8 lists the values of power interruptibility of the five customers and the load demand of micro grid for 24 hours.

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Table 7 Value of Power Interruptibility

Sr. No.	$\lambda_{1,t}$ ($)	$\lambda_{2,t}$ ($)	$\lambda_{3,t}$ ($)	$\lambda_{4,t}$ ($)	$\lambda_{5,t}$ ($)	Sr. No.	$\lambda_{1,t}$ ($)	$\lambda_{2,t}$ ($)	$\lambda_{3,t}$ ($)	$\lambda_{4,t}$ ($)	$\lambda_{5,t}$ ($)
1	27.61	28.3	28.79	26.93	27.6	13	47.98	48.58	48.63	47.1	47.93
2	29.41	30.07	30.53	28.79	29.44	14	66.82	67.74	68.07	65.55	66.74
3	28.24	28.87	29.28	27.66	28.33	15	48.5	49.35	49.69	47.41	48.47
4	26.69	28.76	29.28	27.66	28.32	16	49.21	50.28	50.87	49.94	49.19
5	29.01	32.24	32.64	31.2	31.66	17	66.65	69.36	70.29	66.05	67.71
6	33.96	36.67	37.15	35.38	35.99	18	61.49	66.57	67.19	59.69	66.24
7	83.97	89.46	90.65	85.71	87.7	19	56.19	57.67	58.25	54.48	56.53
8	81.1	82.88	83.79	79.06	81.06	20	57.92	59.38	59.98	55.58	57.98
9	110.6	112.93	114.11	107.72	110.44	21	49.16	49.86	50.36	48.31	48.96
10	74.12	75.43	76.09	72.4	73.95	22	54	54.38	54.84	53.46	53.63
11	78.95	80.19	80.65	77.29	78.93	23	34.37	34.67	34.96	33.98	34.21
12	66.85	67.55	67.76	65.75	66.67	24	30.3	30.71	31	29.89	30.2

Table 8 Load Demand on Micro Grid

Sr. No.	P_d (MW)	Sr. No.	P_d (MW)	Sr. No.	P_d (MW)
1	358	9	475	17	527
2	361	10	483	18	507
3	347	11	485	19	426
4	352	12	511	20	394
5	355	13	597	21	348
6	349	14	617	22	341
7	351	15	581	23	352
8	408	16	566	24	356

Table 9 Solar and Wind Power Data

Time in Hrs.	PSpv (MW)	PWt (MW)	Time in Hrs..	PSpv (MW)	PWt (MW)	Time in Hrs.	PSpv (MW)	PWt (MW)
1	0	85	9	130	120	17	170	200
2	0	85	10	180	100	18	160	220
3	0	90	11	210	100	19	70	130
4	0	70	12	215	100	20	0	120
5	0	75	13	205	110	21	0	110
6	0	80	14	195	140	22	0	85
7	0	90	15	190	130	23	0	80
8	70	110	16	190	180	24	0	85

Table 9, gives the hourly forecasted data of solar and wind, and the maximum power output recorded is 210 MW and 220 MW, respectively [15]. The maximum power transfer limit between grid and micro grid is kept to 60 MW.

6. RESULT AND DISCUSSION

The authenticity and suitability of the proposed optimization approach is verified on the two test setups of micro grid as discussed in previous section.

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6.1 Test setup 1

In the test setup 1, equal weightage of w=0.5 is given to both the objective function presented in Equation (25). The optimal output power of DGs and the power transferred between grid and micro grid are shown in Figure 3 and Figure 4 respectively. The curtailed hourly power by the customers is shown in Figure 5 and the total incentive paid to the customers is shown in Figure 6.

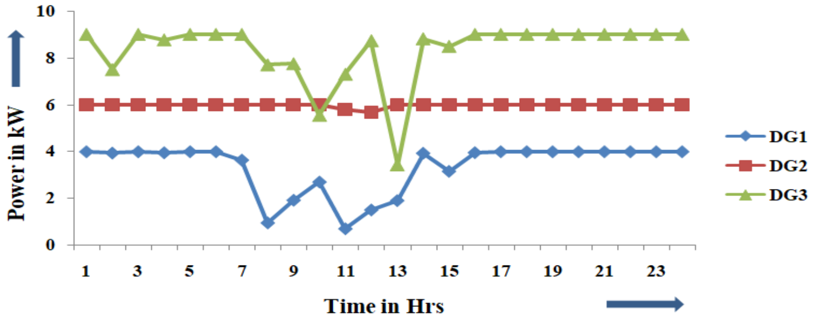

Figure 3 Output Power of DGs

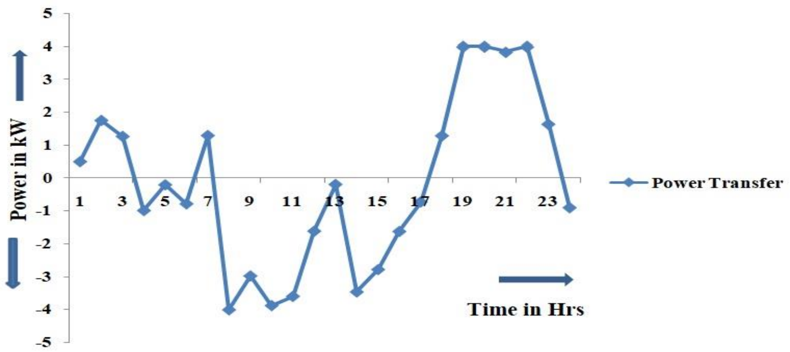

Figure 4 Power Transfer between Grid and Microgrid

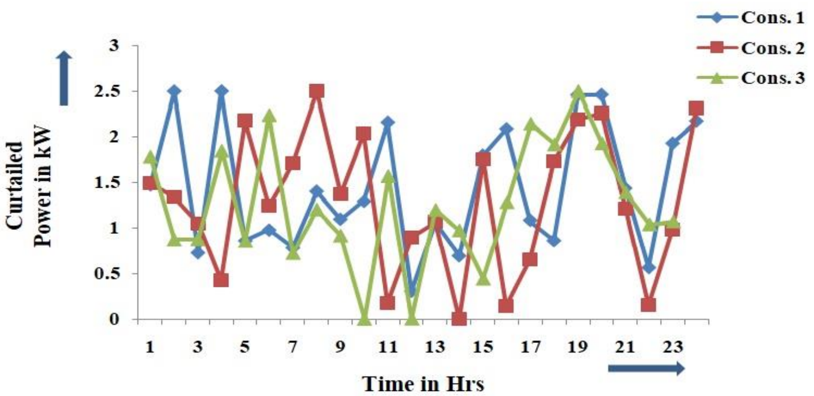

Figure 5 Power Curtailed by 3 consumers

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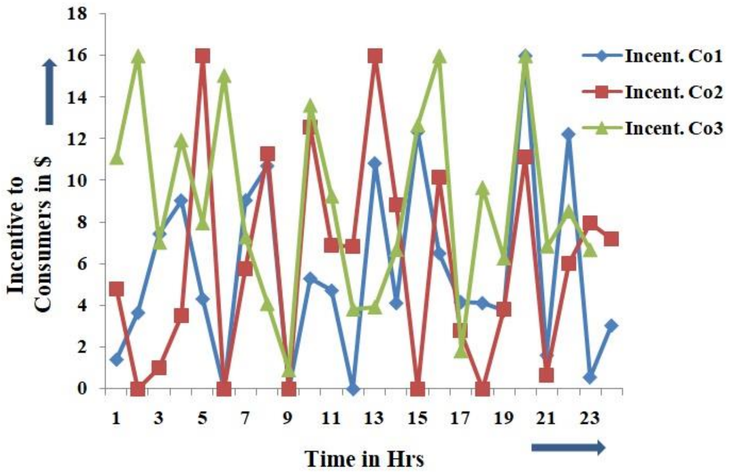

Figure 6 Hourly Consumer's Incentives of 3 Consumers

As shown in the results it is observed that for most of the time when the solar power is not available then the conventional generators are operating at their maximum or near to maximum limit to meet out the electrical requirement. But when the solar power starts to contribute, the conventional generators 1 and 3 reduce their power generation as shown in Figure 1. It is also analyzed that the conventional generators in the micro grid alone are not sufficient to fulfill the load requirement. This now make sense to accommodate the demand response program significantly between grid and micro grid to meet out the load demand. Figure 3 demonstrates the behavior of transferred power when it is negative, power is being sold to the grid and when it is positive, it is purchased from the grid. When the solar and wind power plants are contributing at their rated, the excess available power is sold to the grid system.

The conventional generators have to operate near to their higher operating limit just because the cost of generation is less than the power purchased from the grid. From Figure 4 and Figure 5 it is also known that the customer 3 is getting higher incentive in comparison to customers 1 and 2 as the load curtailed by the customer is more as it is the most willing customer. The load curtailment by customer 1 is less and so the amount of incentive received is also low. The load curtailment and incentive received constraint is also not violated in this test system. The overall processed results, presenting the optimal power output of the conventional generators, procurement cost for transferred power, power transferred between the grid and micro grid, net power curtailed by the customers and optimal incentive received by the customers are given in Table 10.

Table 10 Comparative Analysis of Result for Test Setup 1

Optimization Approach	GTDR[7]	FFA
Aggregated cost of Generated Conventional Power ($)	250	247.81
Procurement Cost for Transferred Power ($)	427	230.69
Incentive paid to customers ($)	371	483.67
Aggregated Customer Energy Curtailed (kWh)	105	96.18
Aggregated amount of Conventional Energy (kWh)	428	423.75
Aggregated Transferred Energy (kWh)	84.5	51.26

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6.2 Test setup 2

The test setup 2 was designed to check the versatility and the multi objective optimizing capability of the proposed optimization algorithm FFA.

The optimal output power of conventional generators and the power transferred between grid and micro grid are shown in Figure 7. The hourly power curtailed by the customers and the total incentive paid to the customers are shown in Figure 8 and Figure 9 respectively.

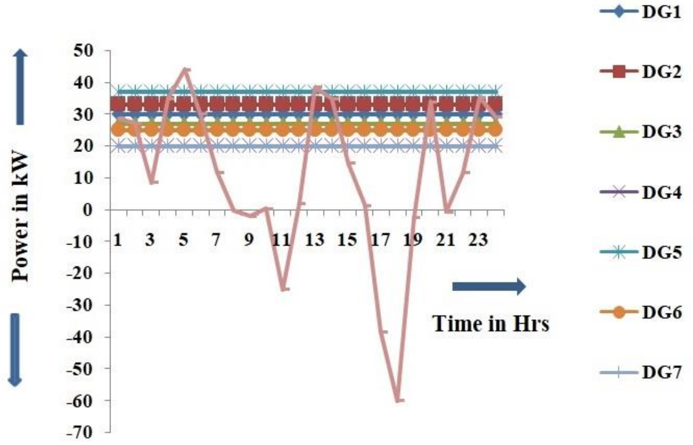

Figure 7 Output Power of DGs and Power Transfer for Test Case II

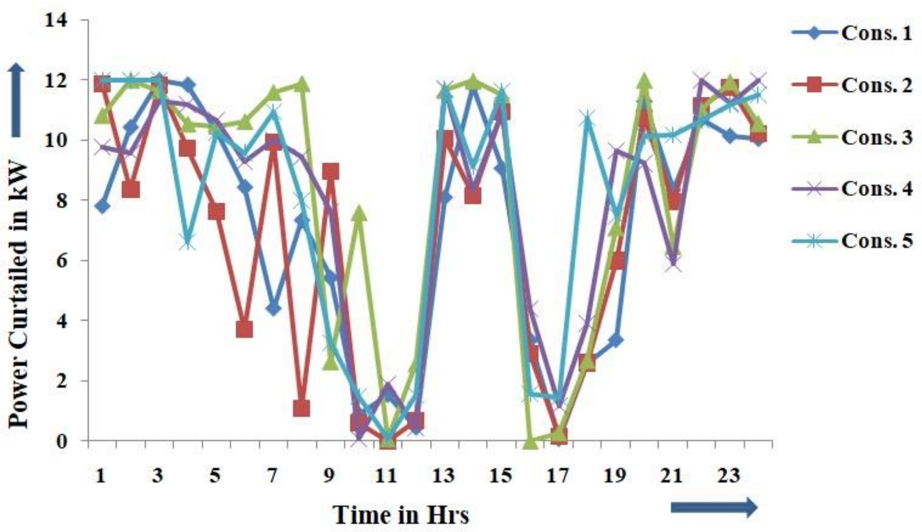

Figure 8 Power Curtailed by 5 Consumers

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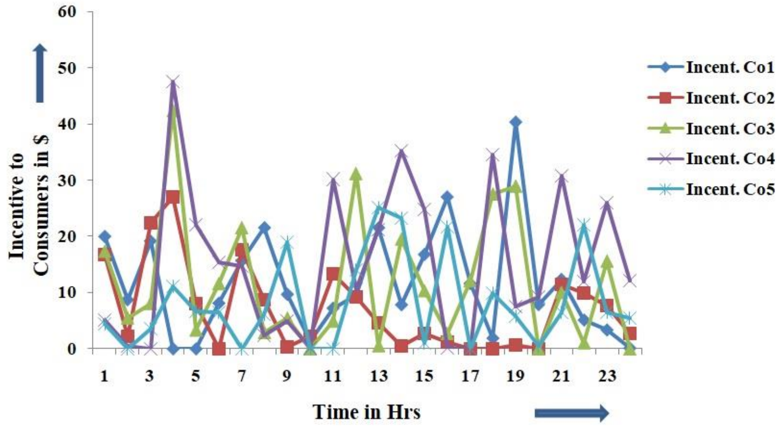

Figure 9 Hourly Consumer's Incentives of 5 Consumers

The comparative of the operating cost of the different optimizing algorithms applied by other researchers and the approach used in this work for the seven conventional generators are given in Table 11. It is observed that applying demand response to the higher bus system has also reduced the peak load demand effectively.

Table 11 Comparative Analysis of Result for Test setup 2

Optimization Approach	PSO[18]	VCPSO[18]	CVCPSO[18]	FFA
Aggregated cost of Power ($)	165,571	165,454	164,001	97,448.06

The optimal operating strategy in test setup II was similar to Test setup 1, as shown in Figure 7 that all the conventional generators are operating on their minimum operating limit. As the high incentives are paid to reduce the load in the peak period, it assures for low operating cost. The demand response strategy also reduces the procurement cost of transferred power and it is $ 3717.43. The customer 4 has effectively contributed for load curtailment and hence is highly incentivized. The total customer's incentive is $ 1297.65. The power generated by the solar and wind plants is quite sufficient to fulfill the load requirement and it is observed that the micro grid has to purchase limited power from grid, rather it sales the power to grid. The results from Test setup 2 also validate the findings of Test setup 1, as they signify that the proposed approach is equally optimizing for larger bus system too.

7. Conclusion

This work demonstrated a multi objective framework for energy management in grid integrated microgrid system using demand response. The analysis was done for two different test cases. In the first test case economic dispatch in grid integrated mode with quadratic DG cost function was used. The results for Test case 1 have shown considerable reduction in procurement cost, energy curtailed cost, and the amount of energy transferred while increasing the amount of incentive paid to the customers. In the Test setup 2 considerable amount of reduction in procurement cost has been obtained. The result also demonstrates and recommend the significant grid integration for reduction of microgrid's operation cost It also explored the application of incentive based demand response program to grid integrated

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micro grid employing metaheuristic algorithm FFA. The operational optimal cost has been obtained between the grid and micro grid, while benefitting the utility and the customers. The proposed approach has effectively optimized the targeted objectives of minimization in both the test cases. The economic dispatch of grid connected micro grid with demand response using FFA has lowered the operational cost, transaction cost and has maximized the customer incentives.

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