Economic Feasibility of a Power Delivery System in Indian Scenario by Modified Differential Evolution

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Abstract

This paper depicts an optimal power allocation strategy pertaining to the economic consideration of the frame work of a typical urban Indian microgrid power delivery scheme. A heuristic method has been modified and implemented in generating optimal power. Two case studies have been done for computing minimum cost of the microgrid power delivery system through optimal power operation. In the first case, the consumers operate individually with optimal supply of power obtained from the Distributed Energy Resources (DERs), The second case deals with the optimal operation of consumers' with DERs forming a microgrid. In each case, the analyses have also been done for two types of seasonal load demand incorporating summer and winter months. A reduction of 13% and 16% cost has been obtained in microgrid power delivery system to than that of separately operating consumers' system for both summer and winter season respectively. Moreover, a comparative study portrayed more or less improved outcome by modified differential evolution with that of linear programming method, as applied to different cases for the problem mentioned in [17].

Keywords: Distributed Energy Resources, Microgrid based power delivery system, Modified Differential Evolution.

1. Introduction

Nowadays, the electricity generation systems are emerging with upcoming renewable DERs, various topologies and novel controlling techniques. With the growing awareness of economic power production this shift moves electricity supply away from highly centralized universal service towards more dispersed system, generally known as Distributed Energy Resources. These include heterogeneous qualities of sources belonging to conventional and non-conventional energy generation category. In relation to competent exploitation of natural resources, efforts have been made to stimulate development of sustainable energy sources, such as solar photo-voltaic systems, windturbines, combined heat-power, fuel cells etc. as distributed energy systems (DERs). Number of works related to the design intends and functions of DERs are available in literature [1–5].

The conventional power delivery systems are now facing trouble in many aspects with its big units and complicated operation. Hence, these centralized power systems have resulted in an expensive system with increasing load requirement. Consequently, new notion of electric power technology has been started by clustering small distributed energy resources close to the load points operating independently forming an autonomous system. This kind of power delivering network is known as microgrid system. Considering the effective distribution of energy, studies on the improvement of microgrid systems have been made by many research groups [6-9]. On the other hand, several designs of distributed network have been made to ensure proper network operation [10]. Jiang and Douglas proposed an integration of DERs into the grid which includes both AC and DC connections [11]. Outalov et. al. depicted an adaptive microgrid system, which comprised of low medium voltage distribution systems with a concept of integrated DERs [12]. To achieve energy efficiency, special attention has been paid [14] on distribution networks with DGs [13] and active voltage level management of combined heat and power (CHP) system. A new approach to incorporate distributed generation along with controlled sources has been developed and presented by Eminoglu. et al [15]. Dolan et al [16] proposed a microgrid framework of an island distribution network by incorporating various sizes of energy storage system (ESS). Several researchers worked on technical aspects of microgrid, but the economic analysis have not been dealt with much standardization.

Economic analysis of DER in connection to microgrid is sparse. Optimal operation of DERs by the implementation of linear programming pertaining to total cost has been performed by Zoka et al [17]. On the other hand, a pricing mechanism reflecting a lower cost allocation of distributed generators based on certain game theory has been presented by Bhaskar et.al [18]. These two works are quite interesting. Since, the real time problems are too complicated to model numerically, standard analytical methods, as stated in [17, 18] sometime fails to consider the mixed nature of these types of problems. Moreover, for these types of problems, soft computing techniques may be proved efficient but these types of works are rarely available in the literature.

Nowadays, a new soft computing technique called Differential Evolution (DE) technique has been found performing remarkably well in mixed complex problems of many dimensions [19-24]. Regardless of initial parameter values, DE helps to attain the actual global solution. DE is advantageous over other soft computing techniques in terms of its fast convergence characteristics through fewer control parameters, outperforms other soft computing methods.

DE shows a potential approach in solving optimization problem within short computational time. However, economic problems including optimal power generations from DERs in microgrid have not been evaluated by this technique.The major shortcoming of Differential Evolutionary algorithm is its premature convergence to some local optima which results in the deterioration of the performance with the growth of dimensionality of the search space. Hence by regulating different control parameters of DE an effort has been made to develop better convergence speed and thereby good performance. The new controlling strategy is called as modified DE which is developed and applied in the present problem.

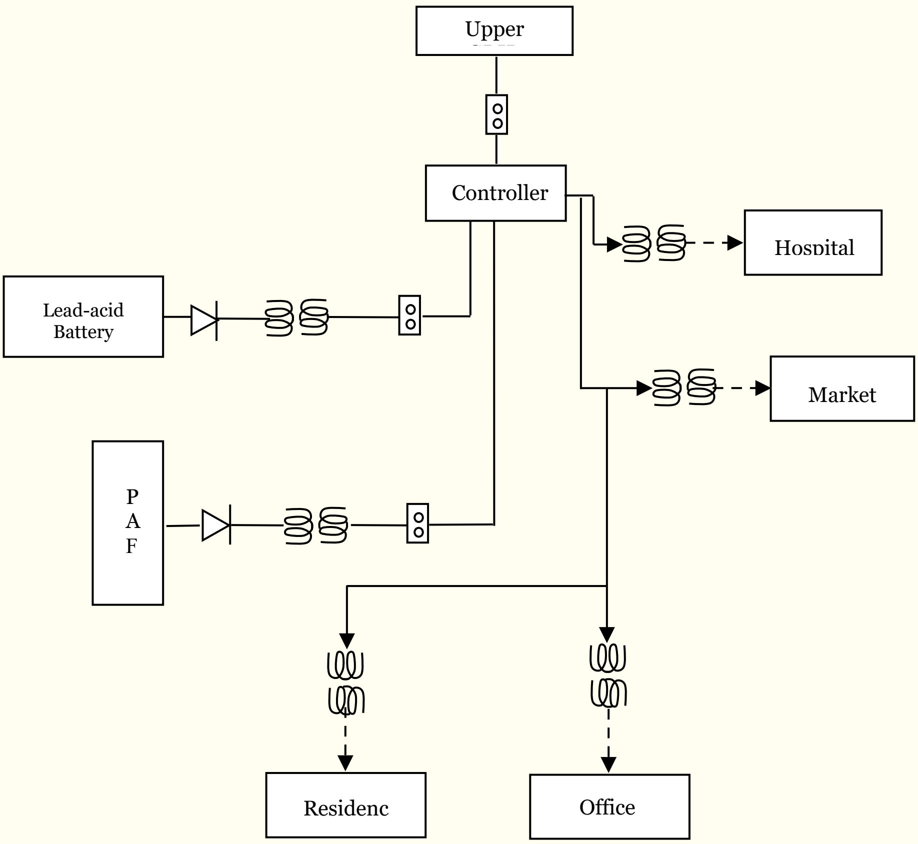
Indian cases are considered because of the huge amount of demand supply gap in power generation and be short of real data for the real time operation of microgrid systems. Again, it is observed that to cope up with this shortfall in power generation, many a times small microgrids are formed in markets or localities which in most of the cases are dependent on diesel driven sets. This obviously have adverse impact on environment. In this study, energy storage system and fuel cells are considered as DERs to supply power in a small given Indian locality. Power generating sources from wind and solar energy are not considered as DER because they are dependent on climatic conditions, which generally vary from season to season and place to place. Apart from DERs, a provision of electricity contract with utility has been considered. The economic estimation of power delivery framework has been done considering both separately operating consumers' system and consumers altogether forming a microgrid system. These two types of consumer operation have been studied under summer and winter loads for an Indian context. The consumers considered here are residence, office, hospital, and market.

2. Problem Formulation

The present system consists of fuel cells and energy storage system as the DERs for the microgrid power delivery system. Nowadays, Phosphoric Acid Fuel Cells (PAFC) is one of the commercially accessible fuel cells, having a capacity of 50 KW to 11 MW [25, 26]. The advantage of fuel cell includes operation with almost negligible losses allied with low temperature combustion in mechanical–to–electrical conversion procedure. Thus, they are found to overcome the problems in related losses which occurs in almost every conventional electrical power producing systems. Among other types of fuel cells, PAFCs are the most advanced types which can be used for on-site power generations in residential complex, schools, hospitals, and hotels, as quality power services [27 28]. Fuel and siting flexibility, along with low chemical and thermal emissions, and high efficiency, and modularity of PAFC provide evidence as an excellent part-load performer over conventional power equipment. Usually, the battery energy storage system (BESS) plays a key role in meeting the power demand during peak load hours, and thereby causing reliability and economic benefits. Hence, a battery (bt) is provided during peak loads by discharging its stored energy. With high efficiency and low storage cost, lead acid battery find their application as most suitable one in the decentralized power systems [29].An attempt has been made to meet power demand of four types of consumers, in a small locality of India by considering PAFC and a lead acid battery.

In the present work, an economic assessment of two types of power distributing system, namely consumers separately operating type and many consumers altogether forming a microgrid system with DERs have been portrayed through optimal operation of DERs by the appliance of modified DE Algorithm. The total cost defined as the objective function of this problem has been considered as the summation of initial cost, microgrid construction cost, installation cost of DERs, running cost of DERs and the utility cost from/to grid. The initial cost corresponds to the base capital of DERs, while the working cost gives the operational cost of DERs. The cost related to microgrid construction has been defined as the microgrid cost. The electricity charge in contract with utility is the utility cost. Here the microgrid is designed, installed, and controlled according to theconsumers' economic point of view, as shown in Fig. 1.

2.1. Objective Functions



The objective function is presented as the total cost as given in equations (1).

Figure 1: Microgrid Test System in a small Indian locality

$$C=C_I+C_{cm}+C_U+C_R \qquad (1)$$

where, C_I, C_u, $C_{cm,}$ and $C_R$are the installation cost, utility cost, microgrid constructing cost, and the running cost respectively. These costs are expressed as given below;

$$C_I=\sum_{cons=1}^{n}\left[x.ic_{DG}\left(cons\right)+y.ic_{bt}\left(cons\right)+I_{DG}.ic_{DG}+I_{bt}.ic_{bt}\right] \qquad (2)$$

Where, $ic_{DG}$and ic_{bt} are the installation costs of DG and *bt* respectively.x and y are the factors multiplied with the initial capital costs of DG and btrespectively, to determine the total annual depreciation expenses of DGand battery system.I_{DG} and I_{bt} are the acceptable rate of return on the initial investment provided by funding organization. Sinking fund methodare used to calculate these factorsas shown below

$$x,y = \frac{d_r^{Lft_{x,y}}}{(1+d_r)^{Lft_{x,y}} - 1} \quad (3)$$

Where, Lftis the life time of DERs, and $d_r$is the rate of depreciation
The microgrid cost has been stated as

$$C_{Cm} = aC_b + bC_{tfm} + eC_{dl} + fC_c + I_b C_b + I_{tfm} C_{tfm} + I_{dl} C_{dl} + I_c C_c \quad (4)$$

Where $C_{tfm,}C_b$, C_{dl},$C_c$are the initial costs of the transformer, circuit breaker, distribution line and controller respectively. The interest rates on initial investment on circuit breaker, transformer areI_b, $I_{tfm,}$ respectively, while that of distribution line and controller are I_{dl}, I_c respectively. The product of initial cost and interest rates provides the annual return on the capital baseof every component as shown in equation (4).
To calculate the annual depreciation values of circuit breaker/change-over switch, transformer, distribution line and controller, the respective multiplying factors are determined through sinking fund method as shown in equation (5)

$$a,b,e,f = \frac{d_r^{Lft_{a,b,e,f}}}{(1+d_r)^{Lft_{a,b,e,f}}} \quad (5)$$

Where,*a*, *b*, *e* and *f*are the multiplying factors for circuit breaker/change-over switch, transformer, distribution line and controller respectively.
The price related with the conventional grid, in purchasing and selling electricity for Nods number of days per season, has been shown below in equation (6);

$$C_U = \sum_{cons=1}^{n} \sum_{ss=1}^{m} Nod_s \sum_{hr=1}^{t} \{e_p P_{Op}(ss,hr,cons) - e_s P_{Osl}(ss,hr,cons)\} + 12e_b\{\max P_{Op}(cons)\} \quad (6)$$

where, the power purchased and sold rates are e_p and e_s respectively; while the base charge for contract of electricity with the conventional grid is $\boldsymbol{e_b}$. The base charge of electricity for contracting with the utility is and represents the

The total running cost is given as,

$$C_R = \sum_{cons=1}^{n} \sum_{ss=1}^{m} Nod_s \sum_{hr=1}^{t} \{P_{ODG}(ss,hr,cons)O_{DG} + P_{Obt}(ss,hr,cons)O_{bt}\} \quad (7)$$

Where, P_{ODG} and O_{DG} are power generated and operating cost of DG; while $P_{Obt}$and $O_{bt}$are the power generation and running cost of battery.

2.2. Constraining Functions

Optimal power generation of DERs has been considered as the mainconstraining function, in resulting to minimum annual cost, the as defined in (8)

$$\sum_{cons=1}^{n} P_{ODe}(ss,hr,cons) = P_{ODG}(ss,hr,cons) + P_{Obt}(ss,hr,cons) + P_{Op}(ss,hr,cons) - P_{sl}(ss,hr,cons) \quad (8)$$

Where; P_{ODe} is the total load of n different consumers. P_{DG} and P_{bt} are power outputs from the distributed generator and battery respectively. P_{op} and P_{sl} are the powers purchased and sold, according to the contract with the utility. The equation describes that the total power generations from different DERs along with purchasing and selling the power from upper grid must balance the required load demand of different consumers.

The other side constrains are as follows;

$$0 \le P_{ODG}(hr,cons) \le IC_{DG}(cons) \quad (9)$$

$$0 \le P_{Obt}(hr,cons) \le IC_{Obt}(cons) \quad (10)$$

$$0 \le P_{ODG}, P_{Obt}, P_{Op}, P_{sl}, IC_{DG}, IC_{bt} \quad (11)$$

Where equations (9) and (10) give us the maximum and minimum range of power generation from distributed generator and battery respectively. Equation (11) shows the positive constraint of all the variables.

3. Proposed Algorithm: Modified Differential Evolution

Among other soft computing methods, DE involves simple technical steps resulting in a highly efficient technique for multi constrained optimization problem. The probabilistic operation of DE, through which solution vectors are updated [30] includes the following steps:

I. Initially, *x* encoded elements are randomly chosen for *j* individual variables forming population size of N_P.of as initial solution vector. For each *x* in N_P a mutant vector v_{ij} is formed by the formula given as

$$v_{ij} = x_{r1} + MF(x_{r2} - x_{r3}) \quad (12)$$

where *r1*, *r2*, and *r3* are three mutually distinct randomly drawn indices from (1,…i.,..N_P), and also distinct from*i*, and *MF* is the mutation factor.

II. Next, the crossover operation is done considering every elements of the mutated variables, v_{ij}.. A trial vector u_{ij} is generated and then for each component of vector, a random number is drawn which lies between u [0,1]. Crossover ratio (CR), performs as a cut off function, in the crossover operation as given by (14), where the population numberand the number of variables in objective function is given as*i* and *j* respectively.

$$\text{If rand } j <= CR, u_{ij} = v_{ij}, \text{else } u_{ij} = x_{ij} \quad (13)$$

III. Finally, depending on the value of fitness function, the new matrix replaces, the original vector matrix in the selection procedure.

IV. At the end, in the final step, when the result converges to a required optimal value, while meeting all the constraint ranges; consequently, the number of iterations or generations stops.

An effort has been made to attain an improved solution through the implementation of modified DE. A modified DE algorithm is adopted where different mutation operators are implemented to generate more number of off springs for every solution. The mutation operator calculates the off springs considering the information of best solution along with the neighborhood solution, thus increasing the probability of generating better solutions.An improved variant of DE has been presented in [31] where, a balance between exploration and exploitation was made to increase the probability of generating better off springs. Moreover, through proper sampling within the feasible region global optima can be achieved. The approach of this method has been based on two modifications to the original DE. This modified mutant operand is given as

$$u_{i,j} = x_{r3,j} + F_{\alpha}\left(x_{best,j} - x_{r2,j}\right) + F_{\beta}\left(x_{i,j} - x_{r1,j}\right) \quad (14)$$

The influence of the parent and best solution is shown as F_{β} and F_{α}s respectively.

4. Formulation of Proposed Algorithm

The economic evaluation has been performed considering the above mentioned objective functions through the application of modified DE. The following steps are shown below as;

Step I

Let

$$\begin{bmatrix} P^{ps}_{O_1 DG} \\ P^{ps}_{O_2 DG} \\ P^{ps}_{O_3 DG} \\ . \\ . \\ . \\ P^{ps}_{O_{24} DG} \end{bmatrix} \text{ and } \begin{bmatrix} P^{ps}_{O_1 bt} \\ P^{ps}_{O_2 bt} \\ P^{ps}_{O_3 bt} \\ . \\ . \\ . \\ P^{ps}_{O_{24} bt} \end{bmatrix}$$

be the trial matrices of power output, which is generated from DG and battery respectively. These matrices pertain to power demand over 24 hours over a day, and a population size of ps. The number of rows in the population size which relates to the number of variables present in the objective function. Moreover, the power generations are subjected to the electric supply-demand balancing constraint, according to Eq (8).

Step II

Based on the objective functions, more than one variables have been constructed within each element of the trial matrix. Accordingly, the size of the population vector has also been modified.

Step III

Three sets of matrices are chosen randomly, from population pool matrix[28].

$$X = x_{r3} + F_{\alpha}\left(x_{best} - x_{r2}\right) + F_{\beta}\left(x_{i} - x_{r1}\right) \quad (15)$$

The above equation is used to compute new encoded individuals forming the mutant vector. $[x_1, x_2, x_3, \ldots\ldots\ldots\ldots x_{ps}]$ and $[X_1, X_2, X_3, \ldots. X_{ps}]$ are the set of elements constituting original and mutated vector. The range of mutation facors, i.e. $F_{\alpha}$and F_{β} are assumed to lie within 0.7to 0.9 and 0.1 to 0.3 respectively [27].

A defined rule has been used for the probabilistic study; which includes three randomly chosen rows, with a random pick leaving one different row at every pick time. The study resulted a value of 0.8 for F_{α} and 0.1 for F_{β}.

Step IV

Next, the crossover operation is executed by considering a certain probabilistic ratio, known as crossover ratio, with a value 0.9; which generally ranges from 0 to 1[24]. Further, random values corresponding to each variable have been compared with CR, and better solutions are chosen for next operation.

Step V

In the selection step, fitness values are first computed for both original and mutated solutions[32, 33]. Then, both the values are compared according to the objective function, and the better solution is saved for the next step. the modified matrix, constituting both mutated and original elements are given below as;

$$\begin{bmatrix} X_1 \\ x_2 \\ x_3 \\ X_4 \\ . \\ . \\ x_{ps-1} \\ X_{ps} \end{bmatrix}$$

Step VI

The above four steps are repeated, unless all the vectors forming the population pool perform all the operations, such as random selection, mutation and crossover processes.

Step VII

After every iteration, the better values of the variables constituting the objective function are constrained through the given ranges. This iterative method continues in search of further better results and finally concludes when the solution to objective function reaches to an optimized minimum value satisfying all the problem constraints.

5. Input Parameters

The microgrid power delivery system, considered the following input parameters, regarding the DERs and loads, for cost estimation through modified differential evolution algorithm.

Typical load variation of all the consumers individually as well as forming a microgrid in an Indian scenario is shown in is given in Fig 2, Fig 3 and Fig 4 respectively.

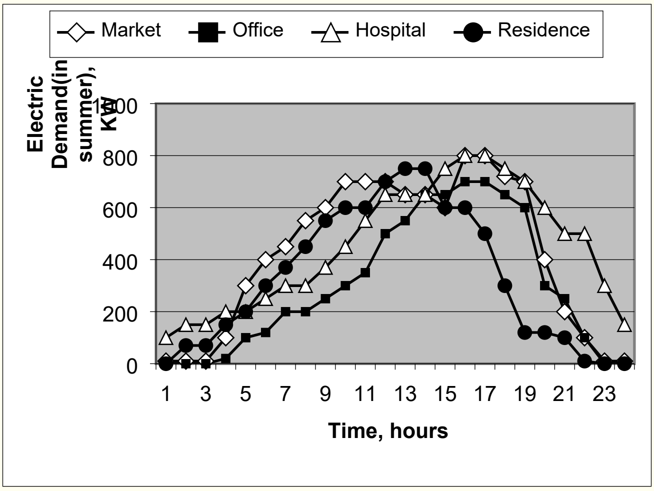


Figure 2: Load demand of different types of consumer in Indian summer season

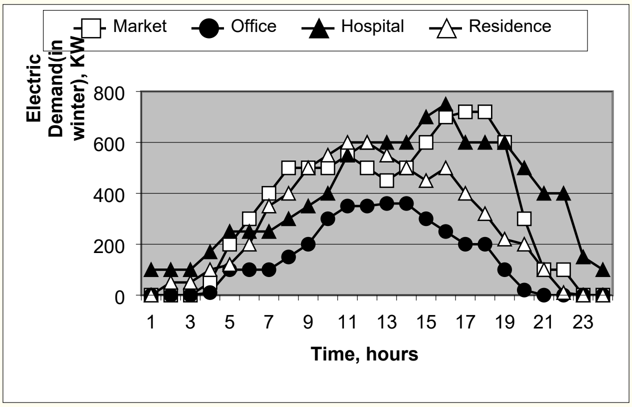


Figure 3: Load demand of different types of consumer in Indian winter season

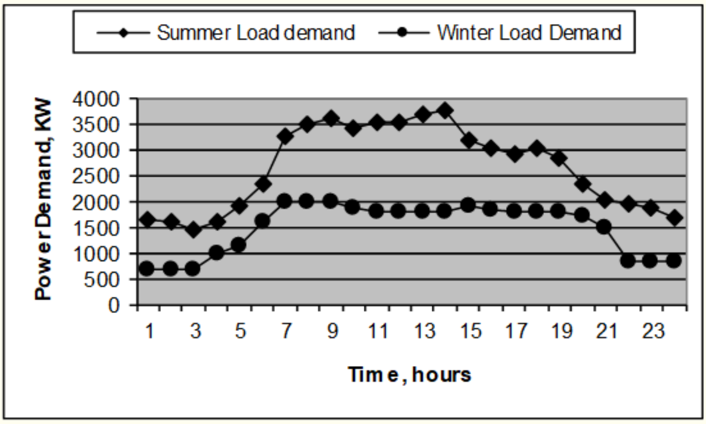


Figure 4: Load demand of a microgrid formed in a specific Indian context

The load profiles represent a residential campus of an academic institution in a city of India. The expenses which include the constructional cost of microgrid are given below in table 1. For a total load of 2.5 MW, a huge amount of current transmission will cause an enormous loss and might get damaged. So, to have a reliable and safe transmission of power a step-up transformer has been installed at the generation site. Similarly, at the consumers' end a step-down transformer has been set up., Moreover a controller is fixed at the junction point of grid and DERs, i.e. PAFC, battery; which senses the required load demand, and decides the optimal choice of the above power resources. Further, two circuit breakers and one change over switch were also installed for this function. Some approximated charges in contract with the grids has been shown in table 2. PAFC are normally configured in a single stack or four stack modules consisting of number of cells in vertical arrangement with an inverter. The total cost of PAFC is classified into two portions as construction cost given as per KW of electrical capacity and running cost as per KWh. The main cost of BESS per power includes the cost of power conversion device, net present value of cost of battery. While the running cost constitute only the price of charging battery, which is generally very negligible compared to the main cost. The equipment required for forming and running microgrid power network are shown in table 3. [29, 34-36].

Table 1. Constructional cost of Microgrid

Equipment required for Microgrid	Cost (Rs)	Lifetime (years)
Switches	8,37,000	6
Communication Line	12,44,000	20
Controller	20,000	30
Transformer(s)	28,00,000	15

Table 2. Electricity Charges

Typeofpower	Base Rate (Rs/KVA)	Electricity Charges(Rs/kWh)	
		Summer	Winter
CP	200	6.30	2.68

Table 3. Costs related to the DERs

Distributed Generator (Fuel Cell)	
Operation Cost	10(Rs/kWh)
Initial cost	253000(Rs/KW)
Lifetime	6(years)
Battery System	
Operation Cost	6(Rs/kWh)
Charging time	8(hrs)
Efficiency of Charge/discharge cycle	72-78(%)
Initial Cost	120555(Rs/KW)
Lifetime	20(years)

Consumers' individual operation forms a separate installation of DGs for every consumer. Depending upon the maximum demand of each consumer, installed capacity of DG and BESS are decided, and so its initial cost varies negligibly from the data given in table 3. Though these powers distributing systems are a less complicated one from that of microgrid system, but they still comprise of transformers, switch, distribution cables and a controller.

6. Results

6.1. Cost Analyses

The present works evaluated minimum cost of power delivery system through optimal power generation from DERs, for a specific Indian load demand. A modified DE technique has been implemented, for the economic estimation considering two case studies, which are as follows

I. Each consumer operates individually, by making a separate service with conventional grid beside optimal operation of DERs. As, no microgrid system has been formed; so, the microgrid construction cost is excluded from the total cost of consumer which defines the objective function in (1).
II. All the consumers together with the DERs forms the microgrid

Here, both the cases have been analyzed based on summer and winter season loads. The minimum price of energy has been calculated through optimized power generation from consumers' view point. DERs are optimally installed depending upon the daily variation of power demand for different types of consumers.

In case I, consumers' individual operation forms a separate installation of DGs, apart from the power distributing system, while in case II, the microgrid construction involves a single site generation by DERs depending on the total load demand, although a more complicated transmission and distribution system is required for providing electricity to all the consumers simultaneously.

The results showed that the variation of optimized power lies within the range of consumer load demands to bound on the generation of unnecessary power, pertaining to a cost effectual power system. This optimal power operation resulted in both negative and positive power deviations over a day. Less power generation has been in displayed as positive power deviation; while indication of negative power deviation refers to generation of more in the cost analysis, these negative and positive power deviations generally used and compensated by selling and purchasing in contract with grid respectively. Apart from the economic aspect, this decentralized energy resources provide a reliable power to the different consumers. More or less similar pattern of optimal power operation over a day are obtained for both individual and microgrid operation of consumers. The results showed that, the average power deviation occurred more in individual operation with respect to that of microgrid. This can be explained as, the peak demands of some consumers come under the bases demand of other individuals, which is generally supplied by installed capacity. The total computed cost on annual basis of all the consumers for case I and case II, during summer and winter seasons are given in table 4 and table 5 respectively.

Table 4. Electricity Costs for Case I

Consumers (season)	Total Cost (INR)	Electricity pricing per KWh
Hospital (Summer)	3.3368×10^6	26.04
Hospital (Winter)	3.0364×10^6	25.83
Office (Summer)	2.1946×10^6	23.98
Office (Winter)	1.9382×10^6	22.37
Residence (Summer)	3.0426×10^6	23.35
Residence (Winter)	2.7900×10^6	21.76
Market (Summer)	2.1328×10^6	23.30
Market (Winter)	2.2676×10^6	20.65

Table 5. Electricity Cost for CaseII

Consumers (season)	Total Cost(INR)
Microgrid (Summer)	9.437×10^6
Microgrid (Winter)	8.884×10^6

Table 4 depicts the individual optimal operation of all the four consumers resulting to a total cost ofRs 1,07,06800 in summer, and Rs 1,00,32200 in winter. A cost reduction of about 6.3% occurred in the winter season to that of summer. Hence, from the above observations it can be inferred that the consumers optimally installing DERs in winter is little more economical to that in summer. This is mainly due to the more load demand by the consumers in summer for Indian context, and hence the running cost along with back up energy cost enhances slightly with respect to that of winter. Here, the installed average capacities of DERs have been set same for all the consumers, by considering the peak demand among all the consumers. In summer, the average utilized capacities by hospital, office, market and residence are 450 KW, 350 KW, 405 KW, 425 KW of DG respectively. While 225 KW, 175 KW, 200 KW, and 212KW of average capacities of battery are consumed by hospital, office, market and residence respectively. From the above consumed capacities of the batteries it can be concluded that lead acid battery has been effectively used in addition to peak load shaving. Here, the entire consumers contract an average capacity of 68 KW from utility in the Indian summer.For estimating the energy pricing mainly by the non-conventional sources, the contracted capacities from utility are used only for extreme shortage of power generation. The optimal power operation in winter results in average consumed capacities from DG as 350 KW, 400 KW, 300 KW, and 400 KW by hospital, office, market and residence respectively. On the other hand, hospital, office, market, residence uses 175 KW, 200 KW, 150 KW and 150 KW respectively from battery. Mainly due to the difference of load demand for winter and summer seasons in an Indian scenario, the total cost in winter becomes cheaper with that in summer.

Table 5 represents case II, resulting to Rs94,37000 in summer season and Rs 88,84010 in winter season. Hence, it can be concluded that all the consumers' altogether forming a microgrid achieves a better economic result to that obtained from the consumers operating individually. During summer the total cost reduction occurred about

11.85%, while in winter 11.4% of cost has been reduced. Thus, it has been inferred that, energy can be met efficiently in a cheaper rate by forming a microgrid power delivery system, operating with both DERs and conventional grid.

6.2. Comparative Studies

A relative study has been performed in computing total annual cost of power delivery system by the application of modified differential evolution and linear programming method [17]. Four cases of power delivering frame as shown in [17] have been considered in for the present study. These are as follows;

1. Every consumer operates individually with the grid, without optimal operation of DERs.
2. Each consumer undergoes optimal operation of DERs along with grid, without forming amicrogrid
3. All the consumers together form a microgrid, by optimal operation of DERs, without contracting power from grid.
4. All the loads operate together along with utility grid, by forming a microgrid, through optimal power generation by DERs.

The results obtained for case 1 and case 2 as computed by two techniques are compared and given below in table 6 and table 7 respectively,

Table 6. Compared Results of Case 1

ConsumerType	Total Cost(JPY)	
	Linear ProgrammingMethod [17]	ModifiedDifferentialEvolutionAlgorithm
Hotel	483,140,00	347,980,00
Office	519,600,00	347,740,00
Hospital	423,900,00	305,970,00
Factory	279,150,00	204,700,00
SportCenter	593,050,00	467,000,00
Groceryshop	375,210,00	303,390,00

Table 7. Compared Results of Case 2

ConsumerType	Total Cost(JPY)	
	Linear ProgrammingMethod [17]	ModifiedDifferential Evolution Algorithm
Hotel	445,060,00	328,570,00
Office	522,660,00	392,970,00
Hospital	395,820,00	292,300,00
Factory	252,140,00	215,690,00
SportCenter	556,310,00	427,190,00
Groceryshop	369,140,00	270,560,00

Table 8 portrays the relative study of computing methods for cases 3 and 4.

Table 8. Computed Results of Case 3 and Case4

Total Cost (10^2 ×JPY)	LinearProgramming Method [17]	ModifiedDifferential Evolution Algorithm
Total Cost For CaseIII	2,51,4140	1,92,5520
Total Cost For Case IV	2,51,2490	1,86,3400

The relative picture states that, for all the cases, application of modified Differential evolution arrived with a better result over both the linear programming. The consumers' costs relating to optimal distribution system, by the application of modified differential evolution algorithm have been found much less in comparison with those obtained by linear programming method [17]. In case I, modified DE reduces the cost about 19% to 30% from that of linear programming method. The reduction in cost for case II varies around 14 to 26 % from that using linear programming. Cases III and IV, provides a cost reduction of about 7 to 17 %, and 10 to 25% respectively. In this study, the economic evaluation of six types of consumers', namely hotel, sport-center, office, hospital, factory and grocery shop show that both microgrid and individual consumer system gives better result with the application of modified differential evolution algorithm. Moreover, the microgrid system appears to be economically better one than that of separately operating consumers' system by the application of both the methods. Though the stated method in [17], i.e. the linear programming method is comparatively easy to implement and can be expressed by simple linear functions, but it fails to consider the heterogeneity of different consumer load profile. Thus, the evolutionary approach in these economic analyses proves much more effective. In comparison with other methods, the main advantage of differential evolution consists in its simplicity. As the efficiency of the search for global minimum is very much sensitive to the control parameters, modified differential algorithm generates a better result by the setting its self-adaptive control parameters. So, the implementation of modified differential algorithm provides significantly better results.

8. Conclusion

The present work proposed an economic estimation of two different frame works of energy delivery system in an Indian context, through optimal operation of DERs. In future this type of energy delivery system may prove to be a better option for small Indian locality. Moreover, the work also depicts and analyzes a comparative picture of energy economy for both stand–alone microgrid system and separately operating consumers' system. The relative pictures for all the cases as mentioned in [17], regarding the cost optimization of power-delivery system represents that modified DE method yields a better result to that provided by the linear programming method. This can be attributed to the fact that adaptive nature of modified differential algorithm can accommodate to the changes of dynamic environment, in respect to that with hard computing techniques.

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