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Multi-objective Economic Emission Dispatch Optimization Strategy Considering Battery Energy Storage System in Islanded Microgrid

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Abstract— *Economic dispatch (ED) is one of the key problem in power systems. ED tends to minimize the fuel/operating cost by optimal sizing of conventional generators (CG). Greenhouse/toxic gas emission is one of the major problem associated with the CG. Emission dispatch (EMD) deals with the reduction of greenhouse/toxic gas emissions by the optimal output of generators. The multi-objective economic emission dispatch (MOEED) problem has been formulated by considering both fuel cost and emission objectives. The main objective is optimization of fuel cost and environmental emissions from the CG in a compromised way. In this paper, CONOPT solver in General Algebraic modeling system (GAMS) has been proposed to find the the optimal solutions for ED, EMD, and MOEED problems of a microgrid. The microgrid consists of a wind turbine generator (WTG), a photovoltaic (PV) module, three CGs, and a battery energy storage system (BESS) option. The proposed algorithm has been implemented in four case studies, including all energy sources, without WTG, without PV module, and without renewable energy sources (RES). To establish the effectiveness of the proposed algorithm, it has been compared with various algorithms. The comparison result shows that proposed algorithm is more effective, novel, and powerful. Finally, result shows the effectiveness of proposed approach to optimize the objective function for all aforementioned case studies and the CONOPT solver in GAMS outperformed all the approaches in comparison. The impact of BESS on the operating/fuel cost of the microgrid has also been presented for ED. Paradigm is changing in terms of demand response in μG. Demand flexibility (DF) model has also been established with consumers demand variation in optimization process. Result with DF shows the reduction in cost and better management from demand side.*

Keywords— Economic dispatch, Emission dispatch, Energy storage, General algebraic modeling system, Islanded microgrid.

NOMENCLATURE

η	Demand flexibility
μG	Micro-grid
a_g	Cost coefficient
b_g	Cost coefficient
c_g	Cost coefficient
d_g	Emission coefficient
D_t	load demand (MW)
e_g	Emission coefficient
EMD	Emission dispatch (Kghr)
f_g	Emission coefficient
$GAMS$	General Algebraic modeling system
LD_t	Load demand during demand flexibility(MW)
NO_X	Oxides of nitrogen
P_{fg}	Price penalty factor
$P_{g,max}$	Maximum power(MW)
$P_{g,min}$	Minimum power(MW)
$P_{g,t}$	Power generated (MW)
RD_i	Ramp down limit(MW)
RU_i	Ramp up limit(MW)
SO_X	Oxides of sulphur
AC	Annualization coefficient
BESS	Battery energy storage system
CG	Conventional generators
CHP	Combined heat and power
CONOPT	Optimal control for non-linear programming code
DED	Dynamic economic dispatch
DEG	Diesel engine generators
DF	Demand Flexibility
DG	Distributed generator
ED	Economic dispatch
EG	Emission function
ESS	Energy storage system
FC	Fuel cell
GA	Genetic algorithm
IES	Integrated energy system
MGEM	Micro grid energy management
MILP	Mixed integer linear programming
MOEED	Multi-objective Economic emission dispatch
PCC	Point of common coupling
PEMFC	Proton exchange membrane fuel cell
PSO	Particle swarm optimization
PV	Photovoltaic module
r	Interest rate
RES	Renewable energy sources
SED	Static economic dispatch

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SOC	State of charge
TC	Total cost
WOA	Whale optimization algorithm
WTG	Wind turbine generator

1. INTRODUCTION

1.1. Research Motivation

ED is one of the critical problems in power system that needs to be addressed in an efficient manner. ED aims to minimize the generation and transmission cost for the given schedule of load [?]. ED can be categorized into two parts. First is static economic dispatch (SED) and second is dynamic economic dispatch (DED). The SED aims to minimize the cost for a specified time but does not consider the relation of systems at different operating times, whereas DED provides the optimal scheduling of the generating units for different time horizons [?].Constraints like ramp rate constraints, equality constraints, and inequality constraints make the DED problem more complex [?]. In the present paper, the authors have considered and discussed the MOEED and the optimal ED problem as a dynamic problem for the duration of twenty-four hours at an interval of one hour. From several decades, the conventional power system with long transmission network and huge investment exist. With the development of smart grid and microgrid technology which consists of renewable energy sources (RES) and ESS, cost and transmission losses are reduced, and reliability is improved [?]. Mainly unit commitment and economic dispatch are the two main parts of optimal scheduling. Input such as availability of RES, ESS parameters, load demand, DG (distributed generator) parameters, and price for a day ahead market should be known for the economic schedule of DG. Multi-objective economic emission dispatch is the reduction of cost along with the emission of NO_X and SO_X etc. [? ?]. Size selection of DG is essential to consider because they should have enough capacity to supply in case of RESs and ESS supply failure and to supply reserves. Similarly ESS should have enough capacity to charge and discharge according to the peak load requirements.
μG is a better alternative for conventional power plants [?]. μG may be operated in either islanded mode or grid-connected mode [?]. The small distributed generator with ESS are connected with the main grid in grid-connected mode. Distributed generating units may be RES, ESS such as ultra-capacitor or BESS. Generating units are not connected to the main grid and supply a small area in an islanded mode of operation of the μG [?].
When μG is operated in islanded mode, it has excellent advantages like reliability, low emission of pollutants, and low transmission loss. However complexities arise when solving the ED because RESs have some problems of interruptions and randomness, which causes instability in μG and finding the optimal solution. These uncertainties in the RESs make the DED a complex issue. ESS supplies energy in case of supply deficiency and store energy in case of excess supply in smaller grids. In case of load variations, ESS has a great role to manage the interruptions and randomness [?] .The objective of the DED is to optimize the generation cost subject to supply- demand balance constraints and other technical constraints.

1.2. Literature Review

Many approaches have been proposed in recent years for the optimal ED in the μG. Combined economic emission dispatch is discussed, which reduces the cost along with carbon, nitrogen and Sulphur oxides in [? ?]. In [?], optimal ED in μG with energy storage is discussed. In [?], optimal operation of distributed generation is discussed. In [?], optimal dispatch with demand response (DR) has been studied. In [?], the water cycle algorithm application has been discussed with optimal Scheduling of μG with Distributed generation. In [?], ESS capacity optimization for islanded microgrid is considered with combined heat and power (CHP) and electric vehicle scheduling. In [?], optimal scheduling of generators for renewable μG with hydrogen storage systems is studied. In [?], the application of PSO is studied for economic dispatch strategy for distributed generation. A sustainable RES based electricity system is a dream of mankind that has got the attention of several researchers [?]. The operation and design of the integrated energy system (IES) were debated in recent literature [? ? ?]. In [?], a probabilistic energy management scheme is discussed. Energy hubs with a connection of non-dispatchable generators with minimum impact on grid is discussed [?]. Key challenges and technologies of the integrated energy system is discussed in [?] . In multi-objective ED cost of generation and emission level, along with power losses are reduced. The optimal scheduling strategy for virtual power plants is discussed in [?]. In [?], microgrid energy management (MGEM) optimization problem is formulated as mixed-integer linear programming (MILP) and solved in GAMS using CPLEX solver. In [?], time varying PSO is discussed for multi-objective cost and emission dispatch for μG. In [?], an approach based on the WTG and solar PV is proposed. Here a new way is considered for operating energy systems in a μG, suggesting a new mode of consumption and cost, NO_X and SO_X emissions are reduced and another way of energy consumption is discussed. In [?] economic dispatch of μG with CHP and emission cost is presented. ED problem as a part of energy management system and, it is a non-linear problem with some constraints is discussed [? ? ?]. Optimal dispatch of multi- microgrid is presented. Dynamic programming for stochastic economic dispatch in a microgrid is presented in [?]. The optimal economic schedule for a network of microgrids with a hybrid energy storage system using distributed model predictive control is discussed in [?]. Load demand and supply scheduling under uncertainty is discussed in literature [?]. Microgrid with uncertainty is discussed in literature [? ? ? ? ?]. Researchers have discussed price maker trading strategy using virtual bidding [?]. Impact of demand and weather uncertainty has been discussed [?]. Traditional Weight coefficient method is used to solve multi-objective optimization. Different weights are assigned to the cost and emission. Problem is solved according to the priority of cost or emission. Weight coefficient method has some drawbacks like decision maker,s preference can change the solution, no trade-off between two objectives and same objective type etc. [?]. Pareto solution remove this drawback and provides a set of solutions. The trade off solution can be achieved using pareto solution.
In [?] ED in μG with cost function of RES is discussed. PV and WTG forecasting, along with load demand is considered and different credits with renewable and conventional generators is presented. In [?] MOEED using some bio inspired algorithms is presented. In [?] whale optimization algorithm (WOA) technique is compared with some other techniques and shows better results.The major drawback of WOA is less solution speed, low accuracy and provides local solution. Demand response allows an opportunity for consumers to manage the supply-demand balance by shifting or reducing their electricity demand. Demand response allows a consumer to clip peak energy demand in case of high price and valley filling in case of low price. In [?] ED based unit-commitment problem is proposed with demand response and uncertainty. In [? ? ? ? ?] optimal energy management and optimal scheduling in multi-microgrid systems have been proposed on IEEE-33 bus system very effectively. In [?] Multi-objective stochastic programming in microgrids considering environmental emissions have been proposed. In [? ?] Various optimization algorithms and optimal power system operation considering demand response have been discussed.

ESS in grid connected microgrid can play a significant role in modern power system. In the modern electric power systems, ESS provides a vast role to improve stability and reliability. ESS are well utilized for instability due to intermittent nature of RES. Hence ESS is very handy tool for modern power systems. In economic dispatch problems, ESS plays a vital role in balancing demand and supply. ESS can be used as reserve source in optimal economic dispatch. Peak demand may be clipped in an organized way using ESS. Thus, ESS has a crucial role in demand side management (Demand Response). ESS plays a significant role in optimal scheduling of generators to reduce cost.

1.3. The necessity of the research based on challenges in the literature

Several potent multi-objective algorithm such as GA (Genetic Algorithm), PSO (Particle Swarm Optimization), DE (Differential Evolution), NSGA (Non dominated sorting genetic algorithm) ,MOPSO (Multiobjective PSO) and other hybrid optimization techniques have the versatile and attractive performance to solve multi-objective economic emission dispatch problems. Nevertheless, they have limitations like unguided mutation, random number generation, and slow computational speed in GA. Unstable convergence and local optimal solutions are the main limitations of DE. PSO has the limitation of low convergence rate and computational complexity if system size increases. Several meta-heuristic techniques are available in literature but the disadvantage of meta heuristic techniques is the different performance with different problems.
Not much emphasis was given using GAMS to solve this multi-objective economic emission dispatch in μG. The literature gap motivated the authors to study MOEED using GAMS. Keeping in view the above merits and demerits of the various strategies, CONOPT solver in GAMS has been proposed for optimal solution of ED, EMD, and MOEED problem. CONOPT is mainly designed for econometric models and it is very much suitable for economic dispatch problem. CONOPT is a fast method for finding an initial feasible solution.Model where many equations can be solved one by one, CONOPT will take advantage of this property. Paper,s main contribution is to provide an efficient and optimal solution for economic emission dispatch. The impact of BESS has also been considered.

1.4. Novelty and main contribution of the paper

- To propose an optimal ED, EMD, and MOEED analysis of an islanded μG using GAMS.
- A twenty-four-hour optimal ED, EMD, and MOEED analysis is presented.
- Demand in ED and MOEED with minimum-maximum flexibility and result analysis shows the reduction in cost with 20% DF.
- ED with BESS, and optimal charging and discharging schedule of battery is presented.
- The modeling has been done using very powerful and efficient GAMS.
- Results obtained from GAMS have been compared with various algorithms, and it shows better outcomes for all case studies.

1.5. Organization and structure of the paper

Section **??** of this paper is the problem formulation and modeling of μG. Methodology is proposed in Section **??**. Section **??** is the result and discussion part of the paper. Section **??** of this paper is comparative analysis and detailed discussion of simulation results. The paper concludes in Section **??**. Section **??** of this paper is future scope of the proposed work. Section **??** is the appendix that shows the step of proposed algorithm for MOEED, for understanding algorithm steps. The proposed μG consists of three CG i.e DEG, a 30 MW WTG, and a 40 MW PV system.Furthermore, four different case studies have been discussed i.e.considering all sources, without WTG, without PV, and without RES using GAMS.

2. PROBLEM FORMULATION AND MODELING OF μG

2.1. Economic Dispatch

ED is the generation level of each conventional generator, so that the cost of generation is reduced. ED problem is a quadratic constrained problem and it is formulated in (**??**) [**?** **?**]. The objective function minimization strategy is cost of CGs in this case study [**?**], as shown in (**??**) .The problem solution determines the optimal output of generators and hence reduces the cost.

$$C(P_{g,t}) = a_g P_{g,t}^2 + b_g P_{g,t} + c_g \tag{1}$$

where,
$C(P_{g,t})$ represents fuel cost ($hr) of g_{th} CG.
$P_{g,t}$ is power generated by CG.
$a_g(\$MW^2h)$, b_g($MWh) ,and c_g($h) represents the coefficients of cost of g_{th} CG.

The Total Fuel cost function can be formulated as

$$minTC = \sum_{t=1}^{T}\sum_{g=1}^{N} C(P_{g,t}) \tag{2}$$

Economic dispatch is a non-linear constrained problem [**?**].The minimization strategy of objective function has supply ($P_{g,t}$) and demand (D_t) balancing constraint [**?**].

1) *Equality constraint*: This constraint shows the balancing of total generation and total load demand. [**?** **?**]. Transmission losses and maintenance cost have been neglected for simplicity.

$$\sum_{g,t} P_{g,t} = D_t \tag{3}$$

where, D_t represents the load demand for islanded μG.
2) *Inequality constraint*: This constraint shows the limits of CG. CG should lie in between their minimum generation ($P_{g,min}$) and maximum generation level ($P_{g,max}$).

$$P_{g,min} \leq P_{g,t} \leq P_{g,max} \tag{4}$$

Economic dispatch (ED) objective for twenty four hour is to minimize the objective function with three CG.

2.2. Emission Dispatch

The objective function minimization strategy can therefore be formulated as a non-linear equation like that of the cost function. Dynamic emission dispatch optimizes the emission in the dispatch interval of one hour. The optimization problem need to be minimized is formulated as [**?**].

$$E(P_{g,t}) = d_g P_{g,t}^2 + e_g P_{g,t} + f_g \tag{5}$$

where $E(P_{g,t})$ represents the Emission of CG (Kghr).
$P_{g,t}$ is power generated by CG.
$d_g(KgMW^2h)$,e_g(KgMWh) ,andf_g (Kgh) represents the coefficients of emission of g_{th} CG.

The total emission dispatch function reduce total emission over an operating time horizon.

$$minTE = \sum_{t=1}^{T}\sum_{g=1}^{N} E(P_{g,t}) \tag{6}$$

Total emission dispatch should follow the constraint as shown in equations (3-4).

2.3. Multi-objective Economic emission Dispatch

It is combined economic emission dispatch problem, in which multi-objective problem is converted into single objective with the help of price penalty factor [**? ?**] . Price penalty factor for all CGs have been calculated and total objective function C(P) can be formulated easily. Total cost function minimizes both fuel cost and emission. The price penalty factor is the ratio of the fuel cost function to the the emission function ($/kg). Different methods such as max-max, min-min, max-min, min-max, average and common may be used to calculate price penalty factor [**? ?**]. There is no need to calculate pareto optimal front for this converted single objective problem with the help of price penalty factor. Fractional programming is another way to minimize the fuel cost to emission ratio [**? ?**]. In this paper, the price penalty factor [**? ?**] is used in MOEED. The price penalty factor calculation is shown in table 5.

$$C(P) = \sum_{t=1}^{T}\sum_{g=1}^{N}(a_g P_{g,t}^2 + b_g P_{g,t} + c_g) + P_{fg}(d_g P_{g,t}^2 + e_g P_{g,t} + f_g) \tag{7}$$

Where,
P_{fg} is the price penalty factor for g_{th} CG.
d_g,e_g ,and f_g represent the coefficients of emission of g_{th} CG.

2.4. Multi-objective Economic emission Dispatch with RES,s

RES are free from both fuel cost and harmful emissions. But RES,s include installation and maintenance cost and, cost function is calculated as [**? ?**]

$$F(P_{RES}) = P_{RES}(AC.I^P + G^E) \tag{8}$$

Where
P_{RES} is power output of RES.
AC is the annualization coefficient.
I^P is ratio of investment cost to established power ($KW).
G^E is operation and maintenance cost ($KW) [**?**].
Annualization coefficient can be calculated as [**?**].

$$F(P_{RES}) = P_{RES}(AC.I^P + G^E) \tag{9}$$

$$AC = \frac{r}{r-(1+r)^{-N}} \tag{10}$$

Where,
r is the interest rate.
N is the duration of interest in years.

Operation and maintenance cost for renewable WTG and PV is taken as 0.016 ($/Kw) for 20 years at interest rate of 9% [**?**].

I^P for WTG = 1400$/KW
I^P for PV = 5000$/KW

The Cost function of WTG is formulated with all variables.

$$F_{WTG} = 153.3810 \times P_{WTG} \tag{11}$$

Cost function of PV becomes

$$F_{PV} = 547.7483 \times P_{PV} \tag{12}$$

ED with RES,s and CG are combined and calculated [**?**].

$$\sum_{t=1}^{T}\sum_{g=1}^{N}(a_g P_{g,t}^2 + b_g P_{g,t} + c_g) + 153.3810 \times P_{WTG} + 547.7483 \times P_{PV} \tag{13}$$

MOEED with renewable energy sources and conventional generators is converted into single objective problem with the help of price penalty factor [**?**].

$$EED(P) = \sum_{t=1}^{T}\sum_{g=1}^{N}(a_g P_{g,t}^2 + b_g P_{g,t} + c_g) + P_{fg}(d_g P_{g,t}^2 + e_g P_{g,t} + f_g) + 153.3810 \times P_{WTG} + 547.7483 \times P_{PV} \tag{14}$$

Multi-objective economic emission dispatch with RES,s should satisfy the following constraints.

1) *Equality constraint*: This constraint balances total generation and total load demand [**? ?**]. Power generated from CG,s and RES should be equal to total demand.

$$\sum_{g,t} P_{g,t} + P_{RES} = D_t \tag{15}$$

Where, D_t Shows the load demand for islanded μG.
2) *Inequality constraint*: This constraint shows, the limits of RES. RES should lie in between their minimum generation ($P_{RES,min}$) and maximum generation level ($P_{RES,max}$).

$$P_{RES,min} \le P_{RES} \le P_{RES,max} \tag{16}$$

2.5. RES with uncertainty

RES,s uncertainty is one of the main issue in modern power systems. Uncertainty should be handled via stochastic or robust optimization method. RES,s uncertainty is modeled as [**?**]:

$$PV_{unct.}^t = SdPV_{unct.} \times r_1 + PV_{for.}^t \tag{17}$$

$$SdPV_{unct.} = 0.7 \times \sqrt{PV_{for.}^t} \tag{18}$$

$$WTG_{unct.}^t = SdWTG_{unct.} \times r_2 + WTG_{for.}^t \tag{19}$$

$$SdWTG_{unct.} = 0.8 \times \sqrt{WTG_{for.}^t} \tag{20}$$

$SdPV_{unct.}$ is the standard deviation in PV output. r_1 and r_2 are random distribution function with 1 mean and standard deviation zero. $PV_{unct.}^t$ is PV output with uncertainty. $PV_{for.}^t$ is forecasted PV output at time t of the day. $SdWTG_{unct.}$ is the standard deviation in WTG output. $WTG_{unct.}^t$ is WTG output with uncertainty. $WTG_{for.}^t$ is forecasted WTG output at time t of the day.

2.6. ED with demand flexibility constraint

Generally the supply and demand is managed by scheduling from generation side. Demand flexibility is the change of demand by customer to manage generation and demand in an efficient way. Demand response (DR) helps in peak load clipping and filling a valley in demand curve and make demand pattern flat. In this paper demand flexibility is assumed 20%. Demand can vary from 80% to 120%. Demand flexibility is the shifting of load demand from peak hours to off peak hours. Load demand may be fixed or time-shiftable. Time-shiftable demand can be shifted according to convenience. In this paper, this time-shiftable demand is shifted from 80% to 120% and its economic benefits have been discussed. Figure 1 shows, schematic diagram of proposed ED model with demand response flexibility. Demand flexibility (DF) can therefore be mathematically formulated as:

$$DF(\eta) = (1-\eta_{min})LD_t \le D_t \le (1+\eta_{min})LD_t \tag{21}$$

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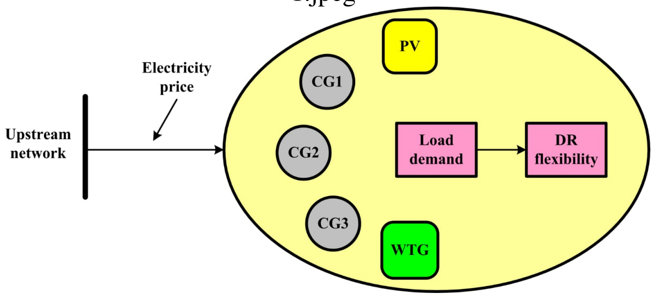

Fig. 1. Schematic diagram of proposed ED model with demand response flexibility

$$\sum_t D_t = \sum_t LD_t \tag{22}$$

where η (Demand Flexibility)= 0% to 20%

Fig. **??** [**?**] shows a general scheme of μG. Distributed generators and loads are connected to the μG. Main grid is connected to a.c microgrid through point of common coupling (PCC). Solar generator is connected to a.c grid through a d.c to a.c converter, which convert solar d.c supply into a.c. WTG is connected through a.c to a.c converter, and converts into desired a.c by microgrid. CGs are also connected through a.c to a.c converter. Battery output is d.c and it is connected to the grid though a d.c to a.c converter. Electric load may be supplied by islanded μG if the PCC is open. It may be supplied in connection with main grid if PCC is closed.

2.7. Economic Dispatch with Energy Storage system

ESS in grid connected microgrid can play a significant role in modern power system. Mathematical modeling of BESS with ED is shown in (**??**)–(**??**) [**?**]. ED with BESS is formulated in (**??**).

$$\min TC = \sum_{g,t} a_g P_{g,t}^2 + b_g P_{g,t} + c_g \tag{23}$$

Variable for TC(Total Cost) minimization are charging, discharging power, SOC and power generated by CG in (**??**).

$P_{g,t}$ = power generated by conventional generators

SOC_t = State of charge at time t.

P_t^{ch} = Charging power of battery

P_t^{dis} = Discharging power of battery

η_{ch} =Charging efficiency

η_{dis} =Discharging efficiency

δ_t=Time interval (1 hour)

P_t^w=Forecasted Wind power

P_t^s= Foretasted solar power

Equation (**??**) shows inequality constraint of conventional generators. Equation (**??**) shows the SOC at time t and shows relation with previous state of charge. Equation (**??**)–(**??**) shows the charging, discharging, and SOC limits. Their min-max limits are specified and objective function should satisfy all the constraints. Equation (**??**) shows the balancing constraint. Battery discharging power is generation and charging power is load. Generation should be equal to demand at every time interval. Equation (**??**) shows equality constraint with RES.

$$P_g^{min} \leq P_{g,t} \leq P_g^{max} \tag{24}$$

$$SOC_t = SOC_{t-1} + (P_t^{ch}\eta_{ch} - \ P_t^{dis}/\eta_{dis})\delta_t \tag{25}$$

$$P_{min}^{ch} \leq P_t^{ch} \leq P_{max}^{ch} \tag{26}$$

$$P_{min}^{dis} \leq P_t^{dis} \leq P_{max}^{dis} \tag{27}$$

$$SOC_{min} \leq SOC_t \leq SOC_{max} \tag{28}$$

$$\sum_{g,t} P_{g,t} + P_t^{dis} = D_t + P_t^{ch} \tag{29}$$

$$\sum_{g,t} P_{g,t} + P_t^{dis} + P_t^w + P_t^s = D_t + P_t^{ch} \tag{30}$$

3. PROPOSED METHODOLOGY

3.1. General Algebraic Modeling system

General Algebraic Modeling system is a tool for optimization and modeling [**?**]. Multi-objective Economic emission dispatch optimization strategy considering battery energy storage system in islanded microgrid is a non-linear problem. Multi-objective Economic emission dispatch optimization is converted into single objective problem with the help of price penalty factor.CONOPT solver is used in GAMS for optimization. Following elements are used for optimization.

1) *Sets*: Sets in the form of index are defined in the initial step. Number of generators and time period of the day sets should be defined. Time period has been defined for a day at an interval of one hour. Generators has been defined with three CG,s, one WTG and one PV module.

2) *Input data*: Input data of CG,s cost coefficients, emission coefficients, minimum and maximum limits of CG,s, load demand, WTG and PV generation has been defined in a tabular form.

3) *Variables*: Variables are the unknown decision sets. Variables are the power output of CG,s, Cost and emission, charging and discharging of storage system and SOC etc. Variables has been optimized using CONOPT solver and level value of variables indicates the optimum value. Marginal value indicates the sensitivity of the variable on objective function.

4) *Equations*: Equation such as Cost function, Emission function, Multi-objective cost and emission function, cost function with BESS and all constraints associated with objective functions has been defined. GAMS equation relates variable and input data. All input data in table are related with variables.

5) *Modeling*: Model is defined as an objective function. Model in the proposed optimization may be cost function, emission function or multiobjective function.

6) *Solver*: Solve statement in GAMS asks to solve proposed model. Different solvers are available in GAMS. CONOPT solver has been used in this problem.

7) *Output*: Output in the proposed study are power output of CG,s, Cost, emission and different parameters of battery. Output may be interfaced with other applications.

Flow chart is shown in Fig. **??**.

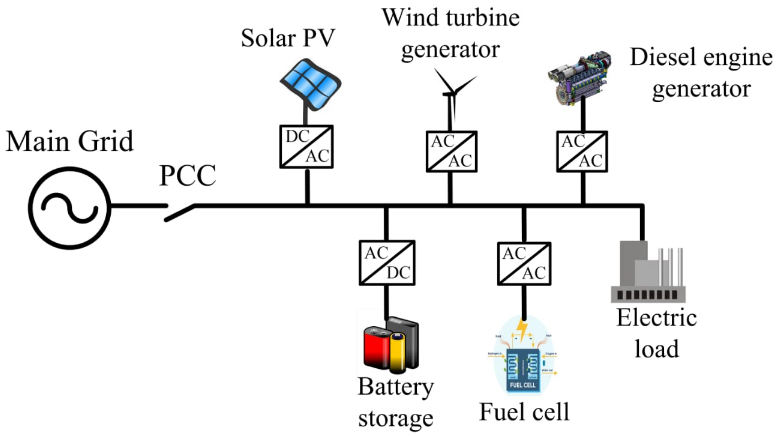

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Fig. 2. General Scheme of Microgrid

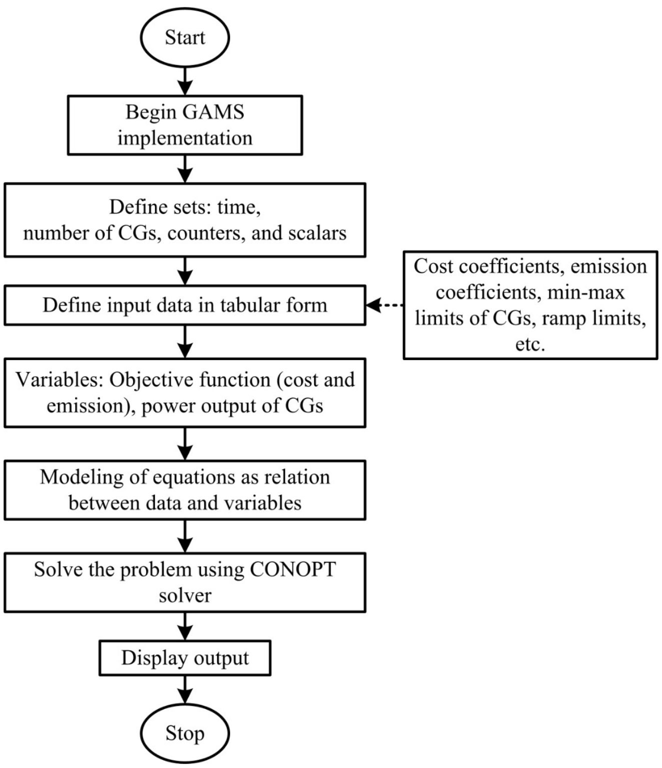

Fig. 3. Flow chart of GAMS

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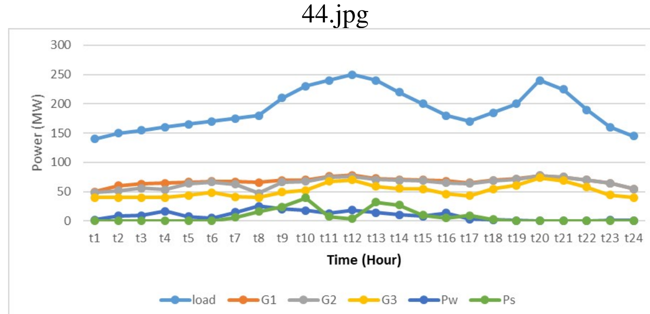

Fig. 4. Optimal output of generators for MOEED for case study 1

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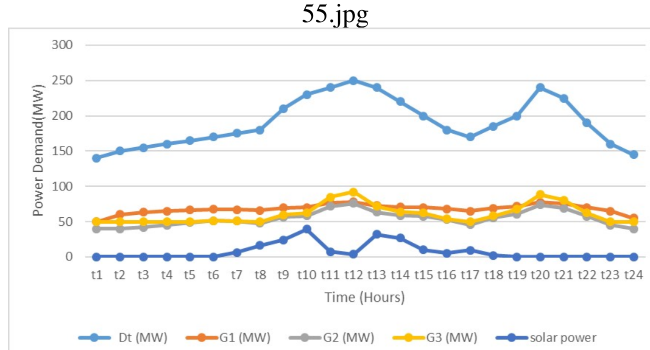

Fig. 5. Optimal output of generators for MOEED for case study 2

4. RESULTS AND DISCUSSION

The Proposed test system is an islanded μG consisting of three CG,s, a WTG of capacity 30 MW and a PV module of capacity 40 MW. While performing the ED, EMD, and MOEED analysis, forecasting of the WTG, PV module, and the load demand have been considered for proposed system [? ?]. All the modeling is done using the CONOPT solver in GAMS (28.1.0) software installed on a personal computer with specifications of intel corei3 processor 2.00 GHz and 4GB RAM. Table 1 shows the data for test system [? ?]. ED, EMD, and MOEED with CG, WTG and PV have been discussed in the results. The twenty-four-hour output of WTG and PV are calculated for various wind speed and solar radiation at a location east coast of USA [?] and are listed in Table 2 along with the hourly load demand of the microgrid. Four different case studies have been discussed to analyze results in MOEED i.e. considering All sources, without WTG, without PV, and without RES. Result obtained has been compared with various techniques for all case studies.

4.1. Case study 1: Considering All Sources

In this scenario, all the sources have been considered for the ED, EMD, and MOEED.The result in table 3 shows the optimal solution of ED following all the constraints.The total cost for ED including all sources, is $299893.3433 with execution time of 8.688 seconds.Emission in this case is 2181.372 kg, with execution time of 8.028 seconds is shown in table 4.Total cost for combined MOEED, including all sources is $ 325355.3401 with an execution time of 12.812 seconds, as shown in table 6. Cost is highest in this case study, but emitted pollutants are least due to RES. Forecasted load demand is 140 MW at first hour of the day. 1.7 MW of load demand has been supplied by non-dispatchable WTG and three CG will share 48.2999 MW, 40 MW and 50 MW respectively.To

Table 1. Data for CGs [?]

CG	$P_{g,min(MW)}$	$P_{g,max(MW)}$	$a_g(\$MW^2h)$	$b_g(\$/MWh)$	$c_g(\$)$	$d_g(KgMW^2h)$	$e_g(Kg/MWh)$	$f_g(Kg)$
G1	37	150	.0024	21	1530	.0105	-1.355	60
G2	40	160	.0029	20.16	992	.008	-.6	45
G3	50	190	.021	20.4	600	.012	-.555	90

Table 2. WTG, PV and Load Demand forecasting of power [? ?]

Time (Hours)	Forecasted load demand (MW)	Forecasted wind Power (MW)	Forecasted PV Power (MW)
1	140	1.700	0.000
2	150	8.500	0.000
3	155	9.270	0.000
4	160	16.66	0.000
5	165	7.220	0.000
6	170	4.910	0.030
7	175	14.66	6.270
8	180	25.56	16.18
9	210	20.58	24.05
10	230	17.85	39.37
11	240	12.80	7.410
12	250	18.65	3.650
13	240	14.35	31.94
14	220	10.35	26.81
15	200	8.260	10.08
16	180	13.71	5.300
17	170	3.440	9.570
18	185	1.870	2.310
19	200	0.750	0.000
20	240	0.170	0.000
21	225	0.150	0.000
22	190	0.310	0.000
23	160	1.070	0.000
24	145	0.580	0.000

Table 3. ED Cost (in \$) comparison of microgrid with various techniques

	All Sources	Without WTG	Without PV	Without Renewable
PSO	299919.4357	272045.2086	204025.1856	176177.9174
SOS	299906.3846	272034.5209	204001.6485	176168.0424
GWO	299896.6562	272033.5531	203988.3084	176167.8827
WOA [?]	299895.7531	272031.0549	203987.5104	176166.5662
GAMS	299893.3433	272029.3841	203984.3098	176165.7890

Table 4. Emission (in Kg) comparison in EMD of microgrid

	All Sources	Without WTG	Without PV	Without Renewable
PSO	2189.6784	2260.4334	2269.4351	2385.7962
SOS	2185.2421	2257.9951	2266.3662	2381.9505
GWO	2184.7448	2256.9551	2265.6551	2380.5190
WOA [?]	2183.9629	2254.2557	2264.9788	2379.4554
GAMS	2181.3721	2252.2174	2261.3145	2377.4217

Table 5. Calculation of price penalty factor for G1,G2 and G3

Penalty factor type	Penalty factor formula	$P_{f1}(\$/kg)$	$P_{f2}(\$/kg)$	$P_{f3}(\$/kg)$
Min-max($P_{fmin-max}$)	$\frac{a_g P_{g,min}^2+b_g P_{g,min}+c_g}{d_g P_{g,max}^2+e_g P_{g,max}+f_g}$	25.15	11.99	4.67

Table 6. Multi-objective EED cost (in $) comparison of microgrid

	All Sources	Without WTG	Without PV	Without Renewable
PSO	325377.3173	297912.8001	230029.0775	202886.6496
SOS	325369.7976	297910.2332	230023.7559	202882.0837
GWO	325368.4448	297908.2971	230020.3064	202882.6042
WOA [?]	325364.4919	297907.5634	230019.0483	202881.7751
GAMS	325355.3401	297899.0148	230012.9407	202873.2391

Table 7. Optimal output of Conventional generators in MOEED with demand for 24 hour using GAMS (All sources)

Time(Hours)	Demand (MW)	G1(MW)	G2(MW)	G3(MW)	WTG (MW)	PV (MW)
1	140	48.2999	40.0000	50.0000	1.700	0.000
2	150	51.4999	40.0000	50.0000	8.500	0.000
3	155	55.7299	40.0000	50.0000	9.270	0.000
4	160	53.3399	40.0000	50.0000	16.66	0.000
5	165	64.1322	43.6478	50.0000	7.220	0.000
6	170	66.3341	48.7258	50.0000	4.910	0.030
7	175	63.0100	41.0599	50.0000	14.66	6.270
8	180	47.2599	40.0000	50.0000	25.56	16.18
9	210	66.4278	48.9421	50.0000	20.58	24.05
10	230	67.7752	52.0492	52.9554	17.85	39.37
11	240	74.4491	67.4404	77.9004	12.80	7.410
12	250	75.5720	70.0302	82.0977	18.65	3.650
13	240	70.7466	58.9018	64.0615	14.35	31.94
14	220	69.2034	55.3429	58.2936	10.35	26.81
15	200	69.0358	54.9566	57.6674	8.260	10.08
16	180	65.1031	45.8868	50.0000	13.71	5.300
17	170	63.8932	43.0967	50.0000	3.440	9.570
18	185	68.9166	54.6816	57.2217	1.870	2.310
19	200	71.5330	60.7156	67.0012	0.750	0.000
20	240	77.2941	74.0015	88.5342	0.170	0.000
21	225	75.1674	69.0971	80.5854	0.150	0.000
22	190	70.1758	57.5856	61.9284	0.310	0.000
23	160	64.4800	44.4499	50.0000	1.070	0.000
24	145	54.4199	40.0000	50.0000	0.580	0.000

Table 8. Optimal output of Conventional generators in MOEED with demand for 24 hour using GAMS (without WTG)

Time(Hours)	Demand (MW)	G1(MW)	G2(MW)	G3(MW)	PV (MW)
1	140	50.0000	40.0000	50.0000	0.000
2	150	60.0000	40.0000	50.0000	0.000
3	155	63.2913	41.7086	50.0000	0.000
4	160	64.8036	45.1963	50.0000	0.000
5	165	66.3159	48.6840	50.0000	0.000
6	170	67.3763	51.1292	51.4644	0.030
7	175	67.2002	50.7233	50.8064	6.270
8	180	65.9590	47.8609	50.0000	16.18
9	210	69.6449	56.3611	59.9438	24.05
10	230	70.3093	57.8934	62.4272	39.37
11	240	76.2662	71.6312	84.6925	7.410
12	250	78.2197	76.1362	91.9940	3.650
13	240	72.7838	63.6000	71.6761	31.94
14	220	70.6727	58.7315	63.7856	26.81
15	200	70.2085	57.6609	62.0505	10.08
16	180	68.0478	52.6779	53.9743	5.300
17	170	64.9337	45.4962	50.0000	9.570
18	185	69.1821	55.2938	58.2140	2.310
19	200	71.6395	60.9611	67.3992	0.000
20	240	77.3182	74.0572	88.6244	0.000
21	225	75.1887	69.1462	80.6650	0.000
22	190	70.2199	57.6871	62.0929	0.000
23	160	64.8036	45.1963	50.0000	0.000
24	145	55.0000	40.0000	50.0000	0.000

Table 9. Optimal output of Conventional generators in MOEED with demand for 24 hour using GAMS (without PV)

Time(Hours)	Demand (MW)	G1(MW)	G2(MW)	G3(MW)	WTG (MW)
1	140	48.2999	40.0000	50.0000	1.700
2	150	51.5000	40.0000	50.0000	8.500
3	155	55.7300	40.0000	50.0000	9.270
4	160	53.3400	40.0000	50.0000	16.66
5	165	64.1322	43.6478	50.0000	7.220
6	170	66.3432	48.7467	50.0000	4.910
7	175	64.9065	45.4334	50.0000	14.66
8	180	62.8195	40.6204	50.0000	25.56
9	210	70.1375	57.4972	61.7851	20.58
10	230	73.3644	64.9391	73.8464	17.85
11	240	75.5010	69.8665	81.8324	12.80
12	250	76.0902	71.2252	84.0345	18.65
13	240	75.2810	69.3590	81.0099	14.35
14	220	73.0095	64.1206	72.5198	10.35
15	200	70.4669	58.2568	63.0162	8.260
16	180	66.7061	49.5837	50.0000	13.71
17	170	66.7877	49.7719	50.0003	3.440
18	185	69.2445	55.4379	58.4475	1.870
19	200	71.5331	60.7156	67.0012	0.750
20	240	77.2941	74.0015	88.5342	0.170
21	225	75.1674	69.0971	80.5854	0.150
22	190	70.1758	57.5856	61.9284	0.310
23	160	64.4800	44.4499	50.0000	1.070
24	145	54.4199	40.0000	50.0000	0.580

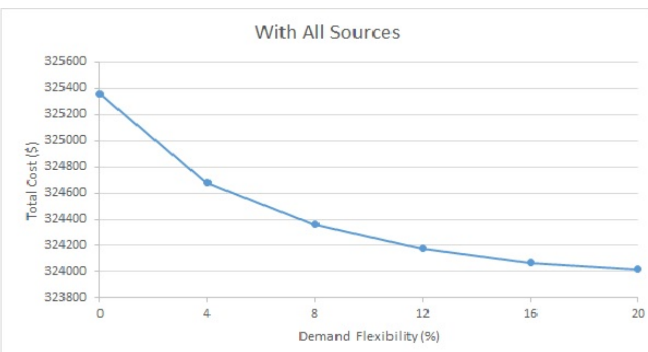

Fig. 6. Demand flexibility versus total cost for MOEED

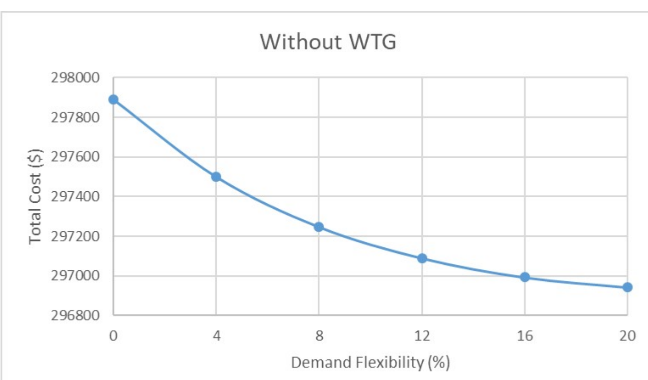

Fig. 7. Demand flexibility versus total cost for MOEED

meet this demand now at this interval of time, PV power is zero and it does not have any power.Now load and generation balance is being maintained, and CG minimum-maximum limit does not violate.The optimal generation of conventional generators is shown in Table 6 at other intervals of time.The difference between load demand and the sum of conventional generators power have been balanced by total renewable power. Load demand is 145 MW at the last time interval. 0.57 MW of load has been shared by WTG. GAMS optimizes the power of three conventional generators at

88.jpg

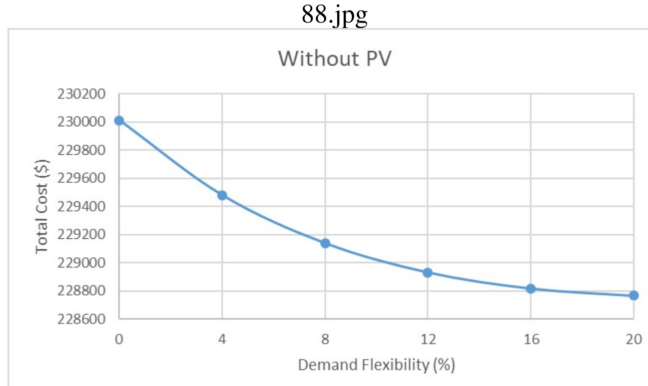

Fig. 8. Demand flexibility versus total cost for MOEED

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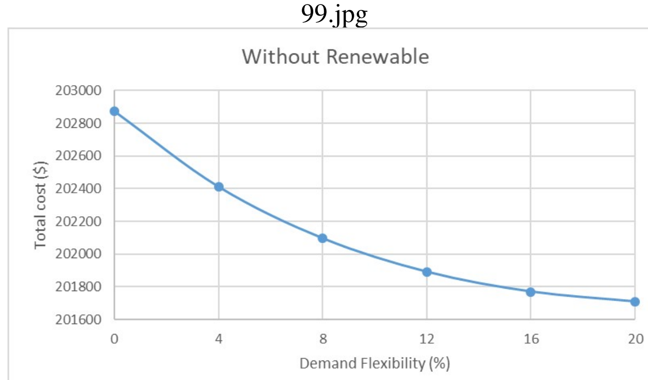

Fig. 9. Demand flexibility versus total cost for MOEED

54.4199 MW, 40 MW, and 50 MW to meet the remaining. A similar optimization procedure has been followed at all other time intervals of demand.ED procedure follows RES first and then the most efficient conventional generator, and so on.Emission in this case study is minimum because both RES have been used, which are free of harmful emissions.Execution time is very less as compared to other techniques. Fig. **??** shows the power output of sen.jpg

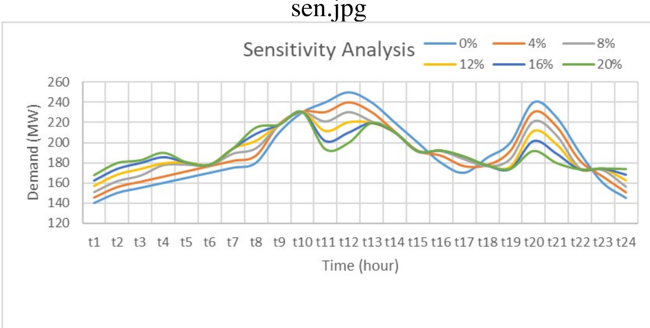

Fig. 10. Sensitivity analysis of demand pattern with different Demand Flexibility

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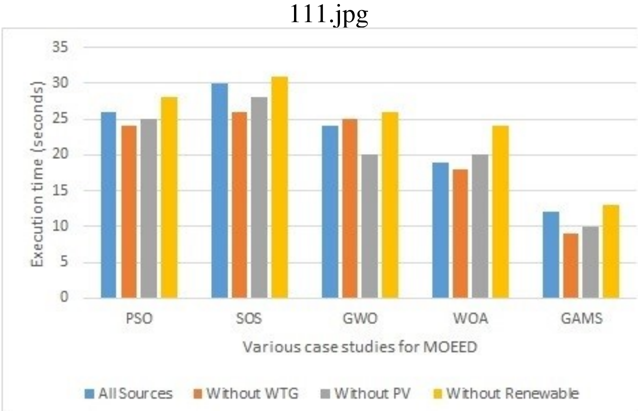

Fig. 11. Execution time of various algorithms for MOEED

Table 10. Optimal output of Conventional generators in MOEED with demand for 24 hour using GAMS (without RES)

Time(Hours)	Demand (MW)	G1(MW)	G2(MW)	G3(MW)
1	140	50.0000	40.0000	50.0000
2	150	60.0000	40.0000	50.0000
3	155	63.2913	41.7086	50.0000
4	160	64.8036	45.1963	50.0000
5	165	66.3159	48.6838	50.0002
6	170	67.3805	51.1390	51.4804
7	175	68.0904	52.7761	54.1334
8	180	68.8002	54.4131	56.7866
9	210	73.0592	64.2351	72.7055
10	230	75.8985	70.7832	83.3181
11	240	77.3182	74.0572	88.6244
12	250	78.7379	77.3312	93.9308
13	240	77.3182	74.0572	88.6244
14	220	74.4789	67.5092	78.0118
15	200	71.6395	60.9611	67.3992
16	180	68.8002	54.4131	56.7866
17	170	67.3805	51.1390	51.4804
18	185	69.5100	56.0501	59.4397
19	200	71.6395	60.9611	67.3992
20	240	77.3182	74.0572	88.6244
21	225	75.1887	69.1462	80.6650
22	190	70.2199	57.6871	62.0929
23	160	64.8036	45.1963	50.0000
24	145	55.0000	40.0000	50.0000

generators and load demand.

4.2. Case study 2: Without WTG

This case studies the ED, EMD, and MOEED problems considering all the sources except WTG. Table 3 shows that the cost without WTG is $ 272029.3841 ,and an execution time is 7.719 seconds. Emission without WTG is 2252.2174 Kg with an execution time of 7.236 seconds, as shown in table 4.The total cost for combined MOEED without WTG is $ 297899.0148 with an execution time of 9.860 seconds, as shown in table 6.The power outputs of generator have been shown in table 7, and all constraints have been satisfied. Emission as compared to case study 1, increases due to wind unavailability. For example, at the 7_{th} time interval, total load demand is 175 MW. PV power available at this interval is 6.27 MW and is being utilized first.168.73 MW is the difference between load demand and generation.This difference has been supplied by three CG. The share of G1, G2, and G3 are 67.2002 MW, 50.7233 MW, and 50.8064 MW respectively. In similar way, other load demands have been satisfied in economic manner for 24 hours. All the constraints have been satisfied during optimization. Emission is higher as compared to case study 1 but lower as compared to case study 3 and 4, because of absence of WTG. Fig. **??** shows the power output of generators and load demand.

4.3. Case study 3: Without PV

All the sources except PV have been considered in this case study. Table 4 shows that cost without solar is $ 203984.3098 and an execution time is 7.266 seconds. Emission without PV is 2261.3145 Kg with an execution time of 7.021 seconds. The total cost for MOEED, including all sources without PV is $ 230012.9407 with an execution time of 9.609 seconds. Power outputs of generator is shown in Table 9 and all the constraints are satisfied. The cost has been reduced but emission increases due to PV power curtailment in this case study. PV power is not available in the early morning (At first five intervals) and during the late night (At last six time intervals). For time interval 1, the load demand is 140 MW.The power extracted from WTG is 1.7 MW. Remaining 138.3 MW of power has been extracted from CG,s.

4.4. Case study 4: Without RES

In this study, all the sources except RES (PV and WTG) have been considered to study the ED, EMD, and MOEED analysis. Cost without RES is $ 176165.7890 with an execution time of 12.906 seconds and every time total power generated by all generators matches with total demand of load. Cost comparison shows the reduction in cost using GAMS. Emission in this case study is 2377.4217 kg with an execution time of 12.121 seconds. MOEED solution shows cost $202873.2391 with time of execution of 13.719 seconds. Emission is maximum without RES,s because of pollution free. At every interval of time, load demand has been balanced by three CG,s satisfying all constraints. At the first interval of time, load demand is 140 MW. This demand has been supplied by three CG and the share of generators is 50 MW, 40 MW, and 50 MW respectively.

4.5. BESS integrated ED without RES

The table 14 shows the parameter of BESS. BESS plays a significant role in ED. Optimal charging and discharging power of BESS, manage supply and demand economically. Battery discharges in peak demand hours, and charges in off-peak demand hours. BESS can act as a reserve source in case of generator outages and emergency conditions. The cost using BESS with conventional generators is $ 176141.5455. Table 13 shows the optimal output of conventional generators, battery charging power, and discharging power.All the constraints have been satisfied, and

Table 11. MOEED sensitivity analysis with demand response flexibility at an interval of 4%

MOEED with DRF	All Sources	Without PV	Without WTG	Without RES
η =4%	324676.657	229480.252	297499.997	202409.871
η =8%	324362.076	229139.177	297247.488	202095.486
η =12%	324176.217	228930.743	297090.057	201891.133
η =16%	324067.525	228815.984	296993.295	201770.269
η =20%	324017.799	228764.465	296942.750	201709.541

optimal output has been obtained. The execution time is 12.949 seconds. The sum of the generation of conventional generators and discharging power of the battery is equal to the sum of load demand and the battery charging power at every time interval. The state of charge of battery is optimized for 24 hour at an interval of one hour.

4.6. BESS integrated ED with RES

The table 15 shows the optimal output of generators with RES. The cost obtained using BESS with RES is $ 167189.7066 and execution time is 7.204 seconds. At first time interval, the total generation of CG is 144.3 MW ,and wind power is 1.7. The load demand is 140 MW and the charging power of the battery is 6.0 MW. Equation (**??**)–(**??**) has been satisfied very well at every interval of time and provides optimal output. All the constraints have been satisfied.

4.7. MOEED with Demand flexibility

Demand flexibility is the change of demand pattern and adjustment of load demand.Table 11 shows the MOEED demand flexibility results at an interval of 4% and has been extended upto 20 %. Table 12 shows the result with demand flexibility for ED. Fig. **??** shows the demand flexibility vs. total cost curve for MOEED considering all sources. Figure 7 shows the demand flexibility vs. total cost curve for MOEED without WTG. Figure 8 shows the demand flexibility vs. total cost curve for MOEED without PV. Figure 9 shows the demand flexibility vs. total cost curve for MOEED without RES.Demand flexibility result shows the reduction in cost and better management from consumer side.

4.8. Sensitivity Analysis

Sensitivity analysis of the proposed algorithm for ED study considering all sources have been presented in this case study. The Cost is the main factor need to be optimized in ED study. The Power output of CG,s is the main fundamental parameter for the cost optimization. Marginal value in the appendix table shows the sensitivity of power output on cost. Marginal zero value in table (16) are not sensitive.It is observed that the marginal value of CG1 at time t1 has a value of 0.010. It means that small change (δ) in power output will increase cost by approximately 0.010 $\times$ δ . The Sensitivity is the main reason for adopting power output of CG1 close to it,s minimum value (37.00) i.e 37.011 at t1. Another sensitivity point is CG1 at t8. It has the marginal value of 0.034. This is the main reason to operate this CG1 at it,s minimum value (37.00) during t8. It means that small change (δ) in power output will increase cost by approximately 0.034 $\times$ δ. Sensitivity analysis with the help of the marginal value may be observed similarly with all other case studies in GAMS.

5. Comparative analysis and detailed discussion of simulation results

5.1. Comparative analysis and discussion of results for ED, EMD, and MOEED

Proposed scheme has been compared with four well developed algorithm i.e particle swarm optimization (PSO), symbiotic organism search (SOS), grey wolf optimizer (GWO), and WOA(Whale optimization algorithm). Cost reduction is the prime objective, without considering emission in ED problem. The table 3 enlists the comparison of the proposed technique with various recently developed algorithms, for ED analysis. The table shows that the cost optimized using the GAMS is much less than other techniques. Time of execution is also very low as compared

Table 12. ED sensitivity analysis with demand flexibility at an interval of 4%

ED with DRF	All Sources	Without PV	Without WTG	Without RES
η= 4%	299829.067	203910.447	271967.932	176089.523
η= 8%	299784.409	203856.218	271924.621	176034.001
η= 12%	299754.572	203820.599	271896.027	175996.132
η =16%	299735.493	203799.944	271877.907	175973.253
η =20%	299725.967	203790.017	271868.136	175961.471

Table 13. Optimal output of Conventional generators in BESS based ED with demand for 24 hour using GAMS Without RES

Time(Hours)	Demand (MW)	P_{th} (MW)	P_t^{ch}	P_t^{dis}	SOC(%)
1	140	146.000	6.000	0.000	53.13
2	150	156.000	6.000	0.000	72.93
3	155	161.000	6.000	0.000	92.73
4	160	162.202	2.202	0.000	100.0
5	165	165.000	0.000	0.000	100.0
6	170	170.000	0.000	0.000	100.0
7	175	175.000	0.000	0.000	100.0
8	180	180.000	0.000	0.000	100.0
9	210	210.000	0.000	0.000	10.00
10	230	224.240	0.000	5.760	79.79
11	240	234.000	0.000	6.000	59.59
12	250	244.000	0.000	6.000	39.39
13	240	234.000	0.000	6.000	19.19
14	220	220.000	0.000	0.000	15.00
15	200	200.000	0.000	0.000	15.00
16	180	185.620	5.620	0.000	35.54
17	170	176.000	6.000	0.000	53.34
18	185	185.624	0.624	0.000	55.40
19	200	200.000	0.000	0.000	55.40
20	240	234.000	0.000	6.000	35.20
21	225	219.000	0.000	6.000	15.00
22	190	190.000	0.000	0.000	15.00
23	160	160.000	0.000	0.000	15.00
24	145	149.040	4.040	0.000	33.33

Table 14. Data for BESS integrated ED

Parameter	value
SOC_o	10 MW
SOC_{max}	30 MW
P_{max}^{dis}	0.2 SOC_{max}
P_{min}^{dis}	0
P_{max}^{ch}	SOC_{max}
P_{min}^{ch}	0
η_c	95%
η_d	90%

Table 15. Optimal output of Conventional generators in BESS based ED with demand for 24 hour using GAMS With RES

Time	Demand (MW)	P_{th} (MW)	P_t^{ch}(MW)	P_t^{dis}(MW)	SOC(%)	P_s(MW)	P_w(MW)
1	140	144.300	6.000	0.000	53.13	0.000	1.700
2	150	146.256	4.756	0.000	68.83	0.000	8.500
3	155	146.259	0.529	0.000	70.57	0.000	09.27
4	160	146.256	2.916	0.000	80.20	0.000	16.66
5	165	157.780	0.000	0.000	80.20	0.000	07.22
6	170	165.060	0.000	0.000	80.20	00.03	4.910
7	175	154.070	0.000	0.000	80.20	06.27	14.66
8	180	144.260	6.000	0.000	100.0	16.18	25.56
9	210	165.370	0.000	0.000	100.0	24.05	20.58
10	230	172.780	0.000	0.000	100.0	39.37	17.85
11	240	213.790	0.000	6.000	79.79	07.41	12.80
12	250	221.700	0.000	6.000	59.59	03.65	18.65
13	240	192.150	0.000	1.560	54.34	31.94	14.35
14	220	182.840	0.000	0.000	54.34	26.81	10.35
15	200	181.660	0.000	0.000	54.34	10.08	08.26
16	180	163.038	2.048	0.000	61.10	05.30	13.71
17	170	162.901	5.911	0.000	80.60	09.57	03.44
18	185	180.820	0.000	0.000	80.60	02.31	01.87
19	200	193.250	0.000	6.000	60.40	00.00	00.75
20	240	233.830	0.000	6.000	40.20	00.00	00.17
21	225	218.850	0.000	6.000	20.00	00.00	00.15
22	190	189.689	0.000	0.000	20.00	00.00	00.31
23	160	158.930	0.000	0.000	20.00	00.00	01.07
24	145	148.460	4.040	0.000	33.33	00.00	00.58

to the other techniques. The table 4 enlists the comparative emission reduction with the proposed technique, for EMD. It is decreasing greenhouse gas emissions, but increasing cost. It is analyzed from results, that removal of emission problem is decreasing cost, but increasing greenhouse gas emission in ED. Reverse is true for main emphasis on emission in EMD. It is decreasing greenhouse gas emissions, but increasing cost. MOEED provides a solution on a compromised basis with the help of price penalty factor. The table 6 enlists the comparative analysis for MOEED. Reduction in cost, emission, and less time of execution for each case study shows the robustness of the proposed algorithm in the GAMS. Generation is equal to load demand at every time interval. The generation level of each plant is within it,s minimum and maximum limits.The execution time is very low as compared to the bio inspired techniques, which is around 20 to 30 seconds. The figure 11 shows the comparative results of MOEED, in terms of execution time for various algorithms.The cost comparison shows that the reduction in cost using the GAMS.The table 7 shows the optimal output of CG with load demand for 24 hours, including all the sources. The table 8 enlists an optimal output of CG with load demand for 24 hours without WTG.The table 9 shows the optimal output of CG with load demand for 24 hour without PV. The table 10 shows the optimal output of CG with load demand for 24 hour using GAMS without RES. Results in table 7, 8, 9, and 10 have been obtained for MOEED. Result shows that, sum of each generating source is equal to the total load demand, at every hour of the day. Every generator is operating with in it,s limit. Results in each scenario have been compared with various algorithms and GAMS optimized the problem with better results and small execution time. All the constraints have been satisfied with optimal output. The figure 4 and 5 shows the graphical results of optimal generator output in MOEED, for case study 1 and 2 respectively. It is concluded from the results in table 7, 8, 9, and 10 that operating cost has been reduced. At every interval of time(one hour of a day), total power generated by all generators is equal to the total load demand. Comparative analysis is shown in table 3, 4, and 6.

5.2. Simulation results with Demand Flexibility

The optimal dispatch of generators for balancing load and generation is a conventional way of scheduling. Paradigm is changing in terms of demand response in μG. The demand response is an another alternative to increasing efficiency and to reduce cost in modern power systems. Demand response flexibility model has also been proposed for extending traditional ED model. Demand is assumed as changing with 20% flexibility with 4% gap. The impact of demand flexibility on operating cost has been analyzed in results. Figure 6, 7, 8, and 9 shows the cost variation with demand flexibility from 0 to 20% with a gap of 4% demand variations for four different case studies, including all energy sources, without WTG, without PV module, and without renewable energy sources respectively. The figures with demand flexibility shows the cost variation with smooth change in demand for MOEED. This is a case study of problem formulation, with demand flexibility to check the results using proposed method. Exponential graph for demand flexibility in every case study shows the robustness of proposed scheme. It is concluded that operating cost is reducing, if demand flexibility option is available for consumer. Major outcome of results obtained from figure 6, 7, 8, and 9 are the gradual decrease in cost with 20% flexibility with a gap of 4%. Figure 10 shows the sensitivity

Table 16. Sensitivity results for ED considering All sources

Time(Hours)	Lower(MW)	Level(MW)	Upper(MW)	Marginal
g1.t1	37.00	37.011	150.00	0.0100
g1.t2	37.00	37.951	150.00	0.0000
g1.t3	37.00	39.375	150.00	0.0000
g1.t4	37.00	38.571	150.00	0.0000
g1.t5	37.00	43.432	150.00	0.0000
g1.t6	37.00	45.883	150.00	0.0000
g1.t7	37.00	42.183	150.00	0.0000
g1.t8	37.00	37.000	150.00	0.0340
g1.t9	37.00	45.987	150.00	0.0000
g1.t10	37.00	48.481	150.00	0.0000
g1.t11	37.00	64.307	150.00	0.0000
g1.t12	37.00	66.970	150.00	0.0000
g1.t13	37.00	55.528	150.00	0.0000
g1.t14	37.00	51.868	150.00	0.0000
g1.t15	37.00	51.471	150.00	0.0000
g1.t16	37.00	44.512	150.00	0.0000
g1.t17	37.00	43.166	150.00	0.0000
g1.t18	37.00	51.188	150.00	0.0000
g1.t19	37.00	57.393	150.00	0.0000
g1.t20	37.00	71.054	150.00	0.0000
g1.t21	37.00	66.011	150.00	0.0000
g1.t22	37.00	54.174	150.00	0.0000
g1.t23	37.00	43.819	150.00	0.0000
g1.t24	37.00	38.934	150.00	0.0000
g2.t1	40.00	44.941	160.00	0.0000
g2.t2	40.00	45.891	160.00	0.0000
g2.t3	40.00	47.069	160.00	0.0000
g2.t4	40.00	46.403	160.00	0.0000
g2.t5	40.00	50.426	160.00	0.0000
g2.t6	40.00	52.455	160.00	0.0000
g2.t7	40.00	49.393	160.00	0.0000
g2.t8	40.00	44.509	160.00	0.0000
g2.t9	40.00	52.541	160.00	0.0000
g2.t10	40.00	54.605	160.00	0.0000
g2.t11	40.00	67.703	160.00	0.0000
g2.t12	40.00	69.906	160.00	0.0000
g2.t13	40.00	60.437	160.00	0.0000
g2.t14	40.00	57.408	160.00	0.0000
g2.t15	40.00	57.079	160.00	0.0000
g2.t16	40.00	51.321	160.00	0.0000
g2.t17	40.00	50.206	160.00	0.0000
g2.t18	40.00	56.845	160.00	0.0000
g2.t19	40.00	61.980	160.00	0.0000
g2.t20	40.00	73.286	160.00	0.0000
g2.t21	40.00	69.112	160.00	0.0000
g2.t22	40.00	59.317	160.00	0.0000
g2.t23	40.00	50.747	160.00	0.0000
g2.t24	40.00	46.704	160.00	0.0000
g3.t1	50.00	56.348	190.00	0.0000
g3.t2	50.00	57.658	190.00	0.0000
g3.t3	50.00	59.286	190.00	0.0000
g3.t4	50.00	58.366	190.00	0.0000
g3.t5	50.00	63.922	190.00	0.0000
g3.t6	50.00	66.723	190.00	0.0000
g3.t7	50.00	62.495	190.00	0.0000
g3.t8	50.00	55.751	190.00	0.0000
g3.t9	50.00	66.842	190.00	0.0000
g3.t10	50.00	69.693	190.00	0.0000
g3.t11	50.00	87.780	190.00	0.0000
g3.t12	50.00	90.823	190.00	0.0000
g3.t13	50.00	77.746	190.00	0.0000
g3.t14	50.00	73.564	190.00	0.0000
g3.t15	50.00	73.110	190.00	0.0000
g3.t16	50.00	65.157	190.00	0.0000
g3.t17	50.00	63.618	190.00	0.0000
g3.t18	50.00	72.786	190.00	0.0000
g3.t19	50.00	79.877	190.00	0.0000
g3.t20	50.00	95.490	190.00	0.0000
g3.t21	50.00	89.727	190.00	0.0000
g3.t22	50.00	76.199	190.00	0.0000
g3.t23	50.00	64.364	190.00	0.0000
g3.t24	50.00	58.782	190.00	0.0000

of demand pattern with 4% change in demand for 24 hours and it shows the change of demand pattern.The table 11 and 12 enlists the MOEED and ED results with demand response flexibility at an interval of 4% respectively. Cost is decreasing with DR flexibility as shown in table 11 and 12. This DR model may be applied for peak demand clipping or valley demand filling with price based optimal scheduling. It is better way of optimal scheduling from consumer side.

5.3. Comparative analysis and discussion of results for ED with BESS

Furthermore, the BESS may be a better option to manage supply and demand. BESS can manage uncertainties of RES by optimal charging and discharging. Uncertainties are not investigated for the proposed test system on μG. A simple model of ED with BESS has been modeled in (**??**)–(**??**). The impact of BESS on operating/fuel cost of the micro-grid for ED problem has also been presented. The table 13 and 15 shows the results of BESS based ED for 24 hours without RES and with RES. The Cost with BESS based ED has been reduced to $ 176141.5455. The Cost without BESS based ED is 176177.9174. It shows the 0.0206 % of improvement in results for case study, without RES. Sensitivity analysis has been provided in table 16. Sensitivity analysis for different case studies may be analyzed, similarly.Results obtained for 24 hours (At an interval of one hour) shows that the sum of the generation of conventional generators and discharging power of the battery is equal to the sum of load demand and the battery charging power at every time interval.

6. Conclusion

In this paper, an optimal ED, EMD, and MOEED analysis of a μG have been presented. The proposed μG consists of three CGs, one WTG, and one PV module along with BESS. Four different case studies have been considered for a comprehensive analysis. The results obtained for twenty-four hours demonstrate the effectiveness of proposed methodology and simultaneously satisfying predefined constraints. Simulation results show optimal economic emission dispatch with optimal operation of WTG, PV, and CGs. Optimal schedule of CGs with WTG and PV integration for twenty-four hours represents the cost reduction and minimization in execution time. Cost reduction in demand flexibility shows the effectiveness of the proposed algorithm. BESS integrated ED shows optimal charging and discharging of battery. Major outcomes of paper are:

- ED, EMD, and MOEED results for an islanded μG using GAMS are compared with various techniques and comparison shows better result with low execution time.
- Demand flexibility result shows the reduction in cost and emission and it shows robustness of algorithm.
- BESS integrated ED shows optimal charging and discharging of battery. It shows 0.0206 % of improvement in results for case study, without RES.
- Percentage Improvement of results have been presented for MOEED as compared with recently proposed WOA. Cost and execution time are the two main indices for comparison analysis. Cost has been reduced by 0.0028%, 0.0028%, 0.0026%, and 0.0042% for four different case studies, including all energy sources, without WTG, without PV module, and without renewable energy sources respectively. Execution time has been reduced by 32.56%, 45.22%, 51.90%, and 42.83% for four different case studies, including all energy sources, without WTG, without PV module, and without renewable energy sources respectively.This improvement is much better as compared to PSO, SOS, and GWO.

7. Future scope of the proposed work

Price based MOEED with price taker and price maker generators may be the better future scope of the proposed work. Proposed work may be extended with grid connected mode and considering transmission losses. Different ESS or RES may be introduced in the problem formulation. Peak demand clipping or valley demand filling concept for a practical problem may be a better future scope of proposed work.This demand pattern change and uncertainty management, using BESS may be a better future scope for a practical problem. Proposed work may be extended on standard IEEE test system of a micro-grid.

8. Appendix

Description of algorithm steps for MOEED considering all sources

CONOPT solver in GAMS software has been installed on a personal computer with specifications of intel corei3 processor 2.00 GHz and 4GB RAM in MS Window 64 bit. Software has been installed using address:
https://www.gams.com/download/
1) Sets description is the first step for initialization of algorithm. Time period from /t1*t24/ and DEGs /g1*g3/ are the sets defined for MOEED.
2) Input data in tabular form is the second step. Table is defined over time period and DEGs. Input data is shown in table 1 and 2.
3) Variable has been defined over the sets in GAMS. Variables in the proposed model are power production of each plant, cost of generation, emission and multi-objective cost and emission.
4) Scalar quantity are cost coefficient of WTG and PV. Constraints with upper and lower limits will be defined and it should not have any index set.
Scalars are the fixed value.
C_w /153.3810/ 'cost coefficients of WTG'
C_s / 547.7483/; 'cost coefficients of PV'
5) Following equations have been modeled in GAMS for MOEED.
Equations.. Cost, Equality, Inequality, Emission, WTG, PV, MOEED cost;
6) All equations mentioned in step 5 will be modeled in this step. It has mainly seven equations. It may be modeled by name of each equation or all.
Model MOEED / all /;
7) Solve statement defines the name of model, type of problem and minimization or maximization of objective function. Any suitable solver may be selected according to the nature of problem. CONOPT solver has been used for proposed model.
Solve MOEED using NLP MIN TC using CONOPT;
This statement indicates that proposed MOEED problem is NLP type, Objective function needs to be minimize is TC (total cost) and

solver used is CONOPT.
8) Output for above mentioned problem are total cost and production level of each plant. Output may be displayed and saved in XSL file.
9) Display statement TC.l and P(g,t).l will display the leveled or optimized value of particular variable. Here, .l represents the actual value of variable. Display (rep,*) and Parameter rep(t,*) statement will display all parameters.
10) Check Solve Summary using MODEL MOEED ALL sources OBJECTIVE cost
TYPE NLP DIRECTION MINIMIZE
SOLVER CONOPT FROM OBJECTIVE cost
**** SOLVER STATUS 1 'Normal Completion'
**** MODEL STATUS 1 'Optimal'
**** OBJECTIVE VALUE '325355.3401'

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