DEMAND RESPONSE IMPLEMENTATION IN MICROGRID OPERATION

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Abstract: In recent years, the popularity of Microgrid has increased because of renewable sources. The integration of renewable sources such as solar, wind creates some difficult challenges in Microgrid operation due to their unpredictability. Demand Response Program (DRP) along with Energy Storage Systems results in reliable Microgrid operation. Therefore, in this work an optimization model is formulated considering demand response program. The Optimization problem is formulated as mixed integer linear programming problem to minimize the Microgrid operation costs. For case study an 11-bus grid-connected Microgrid is considered and solved using GAMS software. Simulation is performed without and with DRP. The outcomes verify the efficiency of the proposed model.

Index Terms- Microgrid, Energy Storage, Demand Response Program, Operating Cost.

I. INTRODUCTION

Recently use of Distributed Generations such as solar, wind, microturbines has increased in power systems to meet the increased electricity demand. Besides their advantages they pose some difficult challenge in the secure operation of power system. The solution of this problem is the cause of evolvement of Microgrid [1]. Microgrid is a tiny sized power system including Distributed Generations, Storage systems, Controllable loads, and a control unit [2]. These Microgrids generally operate in grid connected mode and in case of emergency they can operate independently. An overview of the Microgrid was given in [3-5]. Microgrid topic has got attention from many researchers [6].

Power generation from renewable sources (Solar & wind) depend upon solar irradiation and wind speed, so they are variable in power generation. Battery Energy Storage System are generally used in Microgrid, it stores energy when generation is higher or releases stored energy when load is higher [7]. Another remedy is to implement Demand Response Program (DRP) in Microgrid operation [8]. Demand Response Program is defined as the change in the electricity usage by the end-term users from their normal consumption pattern in response to the change in electricity prices over time or incentive given them to reduce electricity use when the market price is high [9-10]. DRP reduces the peak demand thereby reducing the operation cost [11-12]. Due to unpredictable renewable generation scheduling of microgrid should be done more precisely for the safe and secure operation. Scheduling of microgrid in stand-alone mode is performed in [13-17], whereas scheduling for grid-connected microgrid is performed in [17-21].

Scheduling of Microgrid is done using deterministic model in [17-18]. To minimize the operation cost and power losses stochastic scheduling of grid connected microgrid is done in [19] considering the battery degradation cost. Homer software is used for sizing and energy management in [20]. Differential Evolution Algorithm is used in [21] for scheduling of wind-turbine based DC microgrid considering the battery ageing.

In this paper, an energy management model for Microgrid is presented. Multi-objective optimization model is formulated to minimize the operating cost and carbon emission from Microgrid. Mixed integer linear programming is used to formulate the problem and then solved in GAMS environment which gives the result in very short time in comparison to other tools.

II OPTIMIZATION MODEL

In this paper, operation management problem of Microgrid considering environmental concern is formulated as multi-objective optimization problem. Two objectives which are total operating cost and pollution emission are conflicting and are minimized at same time subjected to system constraints.

A Objective Functions

Objective 1: Minimization of operating cost

Operating cost of Microgrid includes fuel cost of all generating sources, their start-up/shut-down costs, cost of energy exchanged with the utility grid.

$$\text{Min F} = \sum_{t=1}^{T}\{\sum_{i=1}^{n_g}[P_{gi}(t)B_{gi}(t)u_i(t) + S_{gi}(u_i(t) - u_i(t-1))] + \sum_{j=1}^{es} P_{esj}(t)B_{esj}(t)u_j(t) + P_{grid}(t)B_{grid}(t)\} \quad (1)$$

Where T is Operating horizon, n_g - no. of generating units, n_{es} - no. of energy storage units, u_i- States of unit i , P_{gi}- Power output of generating unit i, P_{esj} - Power output of energy storage, P_{grid}- Power exchange with the utility grid, B_{gi} - Generating units' bid, B_{esj}- Energy storage systems' bid, B_{grid} - Utility grid' bid, S_{gi} - Start-up / Shut down costs of i^{th} generating unit.

B Constraints

Load balance. For the power system operation to be reliable generation must satisfy the load.

$$\sum_{i=1}^{n_g} P_{gi}(t) + \sum_{j=1}^{es} P_{esj}(t) + P_{grid}(t) = P_{L,DRP}(t) \quad (2)$$

Power generation limit.

$$P_{gi,min}(t) \leq P_{gi} \leq P_{gi,,max}(t) \quad (3)$$

$$P_{esj,\,min}(t) \leq P_{esj}(t) \leq P_{esj,max}(t) \quad (4)$$

$$P_{grid,\,min}(t) \leq P_{grid} \leq P_{grid,max}(t) \quad (5)$$

Battery limits. State of charge of energy storage at any instant t is given as

$$SOC(t) = SOC(t-1) + P_c(t)\eta_c - P_d(t)/\eta_d \quad (6)$$

$$SOC_{\min}(t) \leq SOC(t) \leq SOC_{max}(t) \quad (7)$$

$$P_c(t) \leq P_{c,max} \quad (8)$$

$$P_d(t) \leq P_{d,max} \quad (9)$$

Total load after implementing demand response program is given by

$$P_{L,DRP}(t) = P_L(t) \cdot \{1 + E(t,t) \cdot \frac{[P(t) - P_0(t) + A(t)]}{P_0(t)} + \sum_{\substack{t'=1 \\ t' \neq t}}^{24} E(t,t') \cdot \frac{[P(t') - P_0(t') + A(t')]}{P_0(t')}\} \quad (10)$$

P_L is the demand before applying DRP. The second term in the given equation is due to self-elasticity and third term is due to cross elasticity. This paper considers the demand response under the time-of-use. In TOU there is no incentive A(t) given.

III. SIMULATION & RESULTS

For case-study an 11-bus Microgrid consisting Micro-turbine, Fuel-cell, Wind-turbine, Photo-voltaic and battery is considered which is connected to the utility grid. Technical limits of generating sources are given in Table 1. The price offers of different generating sources, their start-up costs are given in Table 2.

Table 1: Installed Generating Sources

S. No.	Power Sources	Min Power (MW)	Max Power (MW)
1	MT	6	30
2	FC	3	30
3	WT	0	15
4	PV	0	25
5	Battery	-30	30
6	Utility Grid	-30	30

A battery of 30KWh capacity is used with minimum charge/discharge rate of 15Kw. Initial state of charge of battery is assumed as 20KWh. Charging/Discharging efficiency of battery is taken as 95%. The total demand of the Microgrid is 1684KWh for a single day with the peak demand of 90KWh. Fig. 1 depicts the estimated load. The predicted power output of renewable sources is given in Table 3. Technical data of all sources are taken from Ref. [23]. To examine the impact of battery and fuel cell on the Microgrid operation the 'on' state is taken knowingly for these sources. Since Microgrid is operating in grid-connected mode utility state is on for all time. The cross elasticity of load is given in Table 4. Based on load curve low load period is 1-8, off-peak period is 22-24 and peak period is 9-21.

Table 2: Bids and Pollutants of generating sources

Power Source	Bids	Start-up/Shutdown Cost (€ct/kWh)
MT	0.457	0.96
FC	0.294	1.65
WT	1.073	0
Solar	2.584	0
Bat	0.38	0
Utility	-	0

Table 3: Forecasted Power Output of Renewable Generating Sources

Hour	WT	PV	Hour	WT	PV
1	1.79	0	13	3.92	24
2	1.79	0	14	2.37	21
3	1.79	0	15	1.79	7.88
4	1.79	0	16	1.31	4.23
5	1.79	0	17	1.79	0.55
6	0.915	0	18	1.79	0
7	1.79	0	19	1.31	0
8	1.31	0.2	20	1.79	0
9	1.79	3.7	21	1.31	0
10	3.09	7.53	22	1.31	0
11	8.775	10.45	23	0.915	0
12	10.41	11.9	24	0.615	0

Table 4: Self & Cross Elasticity

	Low load	Off-peak load	Peak load
Low load	-0.10	0.032	0.024
Off-peak load	0.032	-0.10	0.02
Peak load	0.024	0.02	-0.10

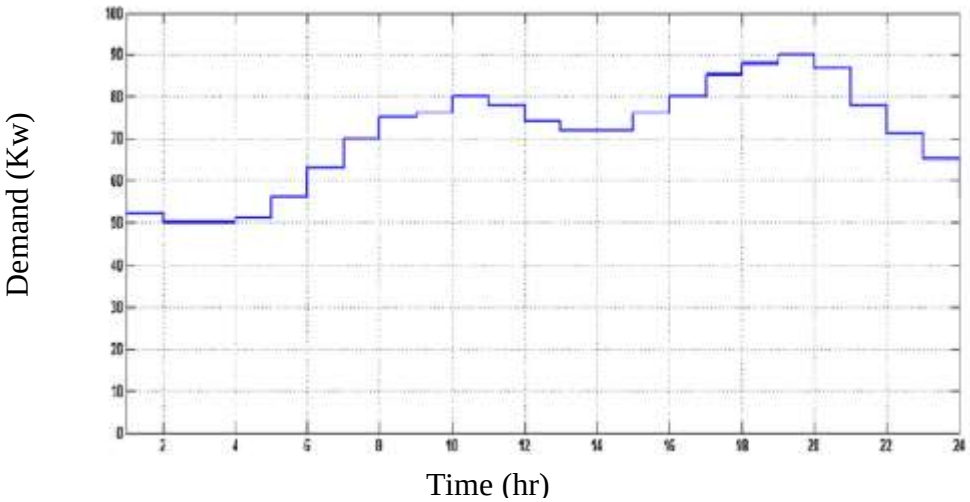

Fig (1) Demand of Microgrid

Considered a case where all units are operating within their power limits including utility grid. Then simulation is performed under without and with DRP

A Without DRP: In this case operating cost and emission both are optimized simultaneously without considering DRP. The operating cost under this case is determined as 26,541 cents.

Table 5 shows the optimal power dispatch among the generating units and power exchange with utility grid. As visible from fig.3 during the initial hours when utility prices are lower, Microgrid operator provides the needed load from the grid instead of using local generation and during these hours battery also get charged.

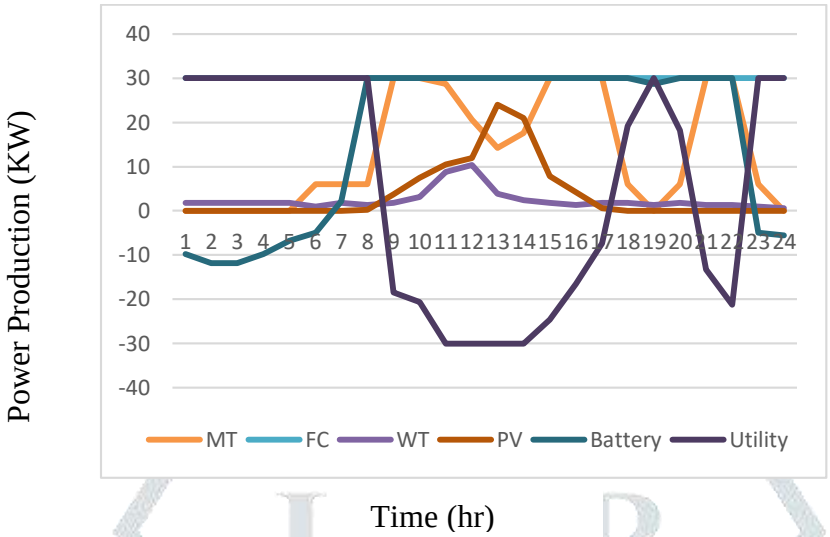

Fig (2) Power Output of generating units and power exchange with utility grid without DRP

When utility grid price is higher than the generating cost of rest units, operator provides demand from these local generating units and sell the extra energy to the grid. During these hours battery gets discharged and micro turbine operates at their maximum limits.

B With DRP: In this case optimization is done with TOU-DRP. In this DRP, three different electricity rates are decided, the tariff for low, off-peak, and peak load are taken as 30, 50 and 400 cents/kWh respectively. The operating cost is obtained as 24,177 cents.

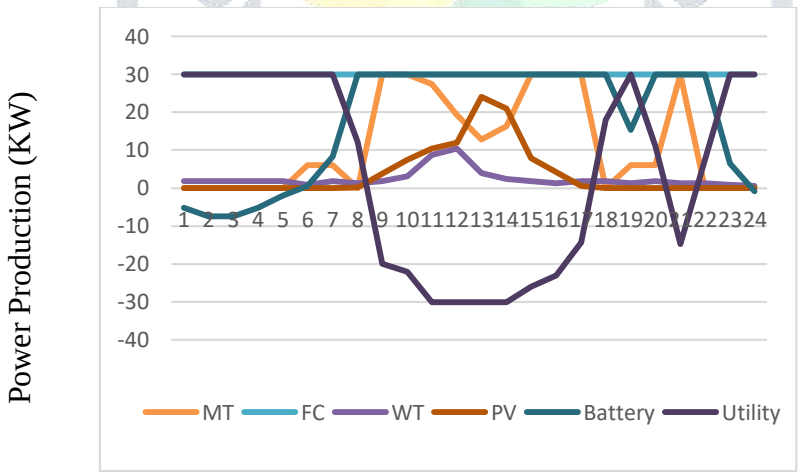

Fig (3) Power Output of generating units and power exchange with utility grid with DRP

Simulation results with DRP are shown in Fig. 4, 5 and table 6. As seen from fig. 5 without DRP demand during 9-21 period is higher with a peak of 90 kWh, but with the use of DRP, demand during this period is reduced and the curtailed demand is shifted to low load period. Thus, DRP helps in load-levelling. It was also found that Micro-turbine remains off for more periods as compared to without DRP which helps to reduce operating cost.

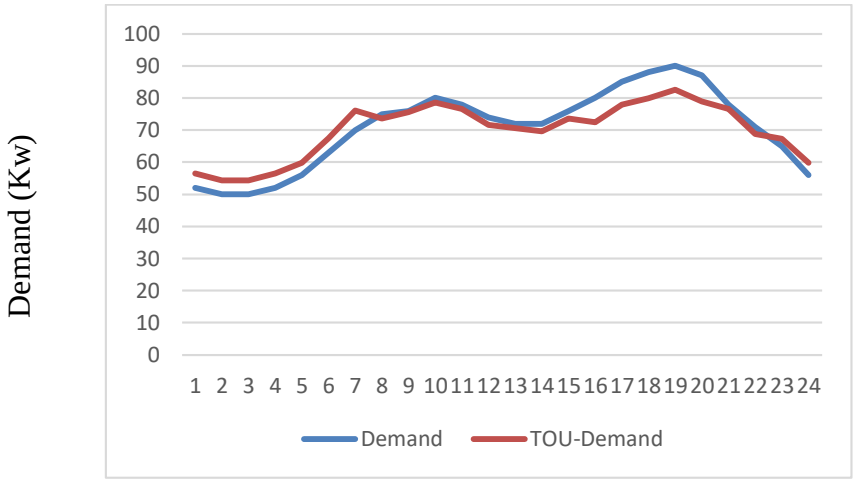

Fig (4) Microgrid load without and with DRP

IV. CONCLUSION

The presented paper performs an energy management of grid connected Microgrid. The power production from generating units and grid is optimally scheduled while implementing DRP. The objective is to minimize operating costs of Microgrid for a period of 24-hr using GAMS software. From the optimization results, it can be confirmed that in comparison to no DRP, the operating costs is reduced by 8.91% when DRP is implemented in Microgrid operation.

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