MULTI-OBJECTIVE DISPATCH OF DISTRIBUTED GENERATIONS IN A GRID-CONNECTED MICRO-GRID CONSIDERING DEMAND RESPONSE ACTIONS

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ABSTRACT

In this paper, a novel Smart Energy Management System (SMES) architecture is proposed to solve the multi-objective dispatch of distributed generation problem in a Micro-Grid with different technologies and new concepts such as demand response action. The multi-objective optimization problem is formulated as a constrained mixed integer nonlinear problem in which a set of Pareto optimal solutions will be obtained through the simultaneous optimization of operating cost and the net emission inside the Micro-Grid. The findings indicate that the optimal dispatch of units together with incorporating demand side bidding actions can reduce energy prices for the consumers or increased revenues for the aggregators.

INTRODUCTION

In recent years, the growing consumption of fossil fuel, poor energy efficiency and environmental issues have been a significant concern for many modern societies, utilities and researchers [1,2]. In Order to address these issues suitably, alternative energy resources (e.g. wind, biomass, solar, hydro and etc.) in forms of distributed generations (DGs) can be used effectively [3]. These technologies have become more widespread mainly due to needs for better reliability, higher power quality, more flexibility, less cost and smaller environmental footprints. Although, high penetration of DGs into the grid environment will bring new challenges for the safe and efficient system operation, these issues can be well addressed by Micro-Grids (MG) which are low-voltage (LV) distribution networks comprising various distributed generators, storage devices and controllable loads that can operate either interconnected or isolated from the main distribution grid as a controlled entity [1,4].

The MG integrates various energy resources such as photovoltaic solar cells, batteries, fuel cells, combined heat and power (CHP) systems, micro-turbines and diesel engines to serve different types of loads[5]. Moreover, the MG can exchange energy with the utility based on decisions made by the Smart Energy Management System (SEMS) considering environmental and technical issues as well as operation and maintenance cost of MG as competitive objectives.

Recently, it has become the main concern for many societies to implement SEMSs for optimal operation of their electricity grids with minimum energy costs, energy consumptions and pollutant emissions [6,7]. Although, different unit commitment scheduling problems have been proposed and solved beforehand, they all have complexity and lack of comprehension.

This paper presents a novel SEMS architecture to optimize the operation of a typical Micro-Grid considering its total cost of operation and the net emission as two important objectives. Since the problem is formulated as a nonlinear constraint multi-objective optimization problem and the objectives are impossible to minimize at a time, SEMS uses a multi-objective optimization algorithm named as Fuzzy Weighted Sum Method (FWSM). The developed optimization algorithm is applied to the test system and the simulation results are achieved, thereafter. Finally, optimal dispatch of distributed generators is obtained for the best compromised solution.

SMART ENERGY MANAGEMENT SYSTEM

An advanced smart energy management system has many functions, including: demand side management , enhanced monitoring of system assets, control and optimization of consumers' appliances, greater control of energy services, better integration of distributed energy on macro and micro scales, cost minimization for both suppliers and consumers.

In this paper, the proposed architecture of a SEMS includes three main parts named as Data Acquisition agent (DAQ), Data Processing unit (DP) and Optimizer. The DAQ agent includes some advanced metering infrastructures (AMI) to collect data from suppliers and consumers. In this part, the metering data is sent via Multi-Media Communication (MMC) mediums such as fiber-optics to supervisory controller. The DP unit serves as as interconnection between DAQ agent and the optimizaer, collecting and organizing the data before transmission to the last part. Similarly, the optimizer determines the most efficient way to execute an action after considering many factors related to the objects referenced and the conditions specified in the query.

It’s noteworthy that for the safe and secure operation of a typical MG, there is a strong need for accurate estimation of some stochastic parameters such as meteorological conditions, load levels and spot market price tariffs in a day ahead. This task is also done suitably in DP unit where different approaches are utilized to find unknown patterns and predict the mentioned stochastic parameters.

PROBLEM FORMULATION

The multi-objective dispatch of a MG with different resource technologies is defined as a problem to allocate optimal power generation set points as well as suitable ON or OFF states to DG units in a sense that several objectives are optimized simultaneously while satisfying several equality and inequality constraints.

In this paper, the proposed MG includes various DG sources such as microturbine (MT), photovoltaic (PV), wind turbine (WT), diesel generator (D), fuel cell (FC) and battery (Bat.). Likewise, the objective functions of the proposed SEMS are the total cost of the MG and the net emission inside the grid that must be minimized over a 24-hour horizon for a day ahead.

The total cost function stated in Eq. (1) includes the following terms: bids from DG units, MG operation cost, start-up/shut-down cost, energy storage cost, and costs belongs to demand response programs.

$$\begin{aligned}&Min\ \ TotalCost(P)\\&=\sum_{t=1}^{T}\{\sum_{i=1}^{L}[u_i(t)P_{Gi}(t)B_{Gi}(t)+S_{Gi}\left|u_i(t)-u_i(t-1)\right|]\\&+\sum_{j=1}^{M}[u_j(t)P_{essj}(t)B_{essj}(t)]+u_{Buy}(t)P_{Grid}(t)B_{Grid\_Buy}(t)\\&-u_{Sell}(t)P_{Grid}(t)B_{Grid\_Sell}(t)+P_{DR}(t)B_{DR}(t)\}\end{aligned}\tag{1}$$

where, T is the total number of hours, L and M are the total number of generators and storage units, $u_i(t)$ and $u_j(t)$ are status of ith DG and jth storage, $u_{Buy}(t)$ ($u_{Sell}(t)$) is the status of power exchange between the MG and the utility, $P_{Gi}(t)$,$P_{essj}(t)$ and $P_{Grid}(t)$ are the power production of ith DG, jth storage and grid respectively , $P_{DR}(t)$ is the amount of power contributed in demand response programs, S_{Gi} is start-up/shutdown cost, $B_{Gi}(t)$ and $B_{essj}(t)$ are the bids of ith DG and jth storage, $B_{Grid\_Buy}(t)$ and $B_{Grid\_Sell}(t)$ are the bids of grid for selling (buying) power to (from) the MG, $B_{DR}(t)$ is the cost of contribution in demand response programs and $P_{Demand}(t)$ is the amount of load at hour t.

In a similar manner, the emission function that includes the amount of emission produced by DGs, storage units and the grid, is formulated as follow:

$$\begin{aligned}&Min\ \ TotalEmission(P)\\&=\sum_{t=1}^{T}\{\sum_{i=1}^{L}[u_i(t)P_{Gi}(t)E_{Gi}(t)]+\sum_{j=1}^{M}[u_j(t)P_{essj}(t)E_{essj}(t)]\\&+u_{Buy}(t)P_{Grid}(t)E_{Grid}(t)\}\end{aligned}\tag{2}$$

where $E_{Gi}(t)$ and $E_{essj}(t)$ are gas emission production of ith DG and jth storage, $E_{Grid\_Buy}(t)$ is gas emission production of the macro-grid at hour t.

The problem constraints can be also described as follows:

Power supply balance

$$\begin{aligned}&\sum_{i=1}^{L}P_{Gi}(t)+\sum_{j=1}^{M}P_{essj}(t)+u_{Buy}(t)P_{Grid}(t)-u_{Sell}(t)P_{Grid}(t)=P_{Demand}(t)\\&-u_{Curtail}(t)P_{curtail}(t)-u_{diff\_\mathrm{Re}q}(t)P_{diff}(t)+u_{diff\_non\mathrm{Re}q}(t)P_{diff}(t)\end{aligned}\tag{3}$$

where, $P_{curtail}(t)$ and $P_{diff}(t)$ are amounts of curtailed and deferred loads, $u_{diff\_Req}(t)$ / $u_{diff\_nonreq}(t)$ are status of deferrable loads when they contribute in demand response program at hour *t*.

Status of buy/sell , from/to the grid

$$u_{Buy}(t)+u_{Sell}(t)\le 1\tag{4}$$

Battery control

$$\begin{aligned}&Q_j(t)=Q_j(t-1)-\frac{1}{\eta_{Dj}}u_{Dj}(t)P_{essj}(t)+\eta_{Cj}u_{Cj}(t)P_{essj}(t)\\&u_{Dj}(t)+u_{Cj}(t)\le 1\\&Q_{\min}\le Q_j(t)\le Q_{\max}\\&Q_j(1)=Q_e\end{aligned}\tag{6}$$

where, $Q_j(t)$ is the state of charge, u_{Cj} (t)/$u_{Dj}(t)$ is status of charge/discharge for the jth storage device at hour t, η_{Dj} or η_{Cj} is discharging/ charging efficiency of jth storage and Q_e is initial state of charge.

The first equation illustrates charging/discharging process and the second one show that these two processes cannot occur simultaneously at any time.

Demand response constraint

$$\begin{aligned}&P_{curtail,\min}(t)\le P_{curtail}(t)\le P_{curtail,\max}(t)\\&P_{diff,\min}(t)\le P_{diff}(t)\le P_{diff,\max}(t)\\&\sum_{t=1}^{T}\left\{u_{diff\_\mathrm{Re}q}(t)P_{diff}(t)-u_{diff\_non\mathrm{Re}q}(t)P_{diff}(t)\right\}=0\end{aligned}\tag{7}$$

In a MG, the loads are classified into three major categories named as critical, curtailable and deferrable. The critical loads such as lighting have high priorities and cannot be shed. Oppositely, curtailable loads such as HVAC are the ones that can be interrupted upon the request from system operator. Likewise, deferrable loads such as washing machine can be deferred from peak times to off-peak times.

MULTI-OBJECTIVE OPTIMIZATION

In a multi-objective optimization problem, a set of optimal solutions known as Pareto-optimal are introduced instead of a best solution with regard to all objectives. Generally, in a multi-objective optimization problem there are different objective functions required to be optimized simultaneously considering a set of equality and inequality constraints. In a FWSM, The non-dominated solutions store in a finite-size repository based on a fuzzy-based clustering approach. In this regard, each objective function is evaluated with a fuzzy membership function, as follows [7-8]:

$$\mu_{fi}(X) = \begin{cases} 1 \;, & f_i(X) \le f_i^{\min} \\ 0 \;, & f_i(X) \ge f_i^{\max} \\ \dfrac{f_i^{\max} - f_i(X)}{f_i^{\max} - f_i^{\min}} \;, & f_i^{\min} \le f_i(X) \le f_i^{\max} \end{cases} \qquad (8)$$

where, f_i^{min} and f_i^{max} are the lower and upper bounds of i^{th} objective function, respectively. In the proposed algorithm, the values of f_i^{min} and f_i^{max} are evaluated by optimizing each objective function separately. In the next step, the normalized membership value is calculated for each element inside the repository, as follows:

$$N\mu(j) = \frac{\sum_{k=1}^{n} \omega_k \times \mu_{fk}(X_j)}{\sum_{j=1}^{m} \sum_{k=1}^{n} \omega_k \times \mu_{fk}(X_j)} \qquad (9)$$

where, m is the number of non-dominated solutions, ω_k is the weight factor for k^{th} objective function. The decision making is done by normalized membership value.

CASE STUDY

In this paper a low voltage (L.V) MG has been considered as a test system in which primary feeders amed as residential, commercial and industrial, ake power from the distribution substation to the load areas by way of subfeeders and lateral-branch circuits. The load within the MG is equal to the total energy demand of 1705 kWh for a typical day [5]. As shown in Fig.1, the proposed MG consists of various DG resources such as micro turbine, diesel generator, photovoltaic, wind turbine, Fuel cell and battery. The bid coefficients of DGs are shown in Table I. It is also assumed that 2% of all loads can be shifted and 5% of residential loads can be curtailed in a demand response program. The bids from deferrable loads are 6.9 and 69 Ect per kWh for high and low priority ones respectively, while these bids are equal to 13.8 and 138 Ect per kWh for the curtailable loads, respectively [5].

TABLE I
BID COEFFICIENTS OF DG SOURCES [5]

Type	ai(Ect/kWh)	bi(Ect/h)	Start-up/Shut-down cost (Ect)
MT	4.37	85.06	9
PAFC	2.84	255.18	16
D	3	20	0
PV	54.84	0	0
WT	10.63	0	0
Bat	0	4.43	0

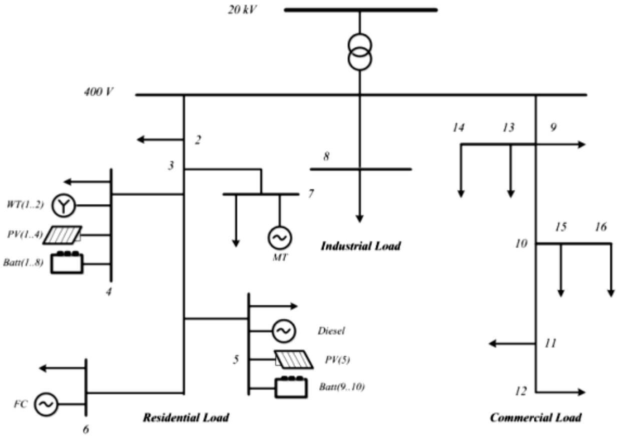

Fig.1.LV network case study [5]

NUMERICAL RESULT

In this section of the work, the proposed method is applied to the test system and the multi-objective scheduling problem is solved by a CPLEX Solver in GAMS environment. The SEMS is also fed by the MG technical information and forecasted values (e.g. wind speed and solar radiation) as input data. The Pareto-optimal set for cost vs. emission objectives obtained by Fuzzy Weighted Sum Method (FWSM) is shown in Fig.2.

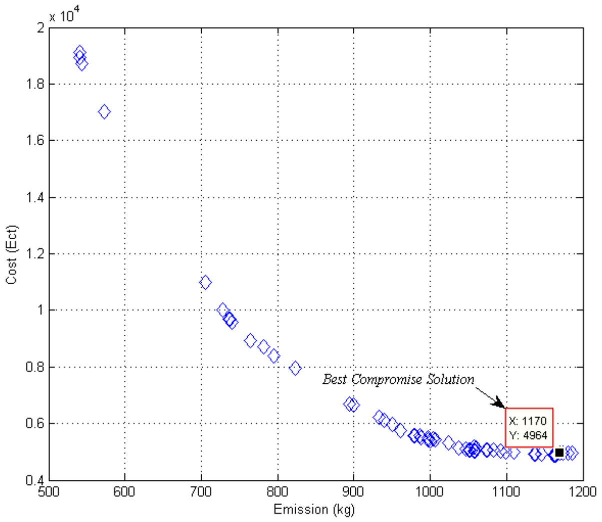

Fig.2. Pareto optimal fronts of emission and cost

Fig.3 shows the optimal dispatch of DGs in a grid-connected mode considering both objectives. It’s observed that in the first hours of the day a large portion of the load is supplied by the utility through the Point of Common Coupling (PCC) because the utility bids are lower in comparison with those of others. Due to growth of demand and bids of utility during the next hours of the day, DGs increase their output powers according to priority in lower cost and emission correspondingly. It should be also noted that the charging process of the battery is done at the first hours of the day when the prices are low but the discharge action is postponed to the midday when the load curve reaches peak values. In a similar manner, Fig.4 shows that curtailable loads can be curtailed in midday (from 9 to 16) upon the SEMS request to mitigate both cost of operation and emission. Besides, deferrable loads have the ability to join effectively in demand response programs and bring about less cost and emission as well.

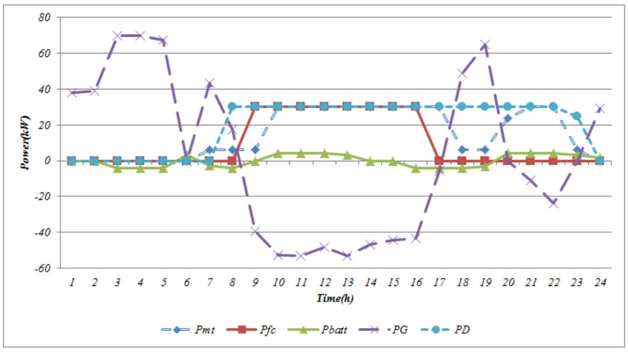

Fig.3. Optimal dispatch of units and grid

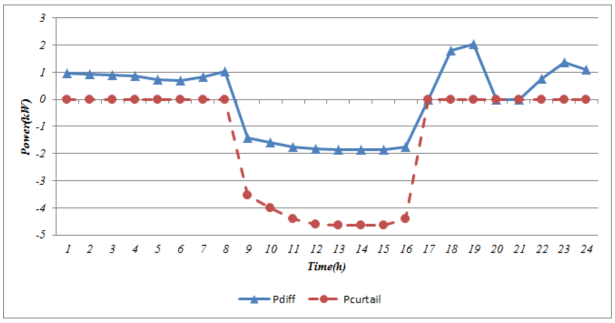

Fig.4. Participation of loads in demand response program

CONCLUSION

In this paper a novel SMES architecture was proposed to solve the multi-objective power dispatch of a Micro-Grid with different resource technologies and demand response. The case studies results showed the applicability of the proposed multi-objective optimization model for a micro-grid considering environmental-economic objectives in operations. The simulation results also confirmed that incorporating demand side bidding actions could reduce energy prices for the consumers and/or increased the revenues of the aggregators in micro-grids.

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