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# Demand side management in a smart micro-grid in the presence of renewable generation and demand response

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A B S T R A C T

In this study, a stochastic programming model is proposed to optimize the performance of a smart micro-grid in a short term to minimize operating costs and emissions with renewable sources. In order to achieve an accurate model, the use of a probability density function to predict the wind speed and solar irradiance is proposed. On the other hand, in order to resolve the power produced from the wind and the solar renewable uncertainty of sources, the use of demand response programs with the participation of residential, commercial and industrial consumers is proposed. In this paper, we recommend the use of incentive-based payments as price offer packages in order to implement demand response programs. Results of the simulation are considered in three different cases for the optimization of operational costs and emissions with/without the involvement of demand response. The multi-objective particle swarm optimization method is utilized to solve this problem. In order to validate the proposed model, it is employed on a sample smart micro-grid, and the obtained numerical results clearly indicate the impact of demand side management on reducing the effect of uncertainty induced by the predicted power generation using wind turbines and solar cells.



## 1. Introduction

Future distribution systems will certainly face the increased penetration of wind and solar renewable sources, which have an intermittent natural behavior. This may endanger the security of the system operation [1,2]. In order to implement advanced planning for Distributed Energy Resources (DERs) to ensure the economic and safe operation of these systems, and Advanced Measuring Infrastructure (AMI) is necessary [3–5]. AMI establishes a bidirectional telecommunication between customers and electricity companies to provide readability, monitoring, and remote control of meters; data collection and transmission to electricity companies; processing and analysis of information, as well as the implementation of energy consumption management in an attempt to ensure the reliability of the system and to guarantee the creation of a balance between supply and demand [6–8].

To manage and control a smart microgrid, the structure of the AMI system generally includes:

- Smart meters with Power Line Carrier (PLC) communications installed at the customer premises. The smart meter of medium and large customers using General Packet Radio Service (GPRS) could be directly connected to the utility.
- To manage all smart meter measured data from each installation, Data Concentrators (DC) are installed in the proximity of 20 kV/400 V distribution transformers. Data concentrators integrate PLC communications that exchange information with smart meters and communicate with central.
- Meter Data Management Systems (MDMSs) are mainly Meter Data Management & Repository (MDM/R) systems in which the received unprocessed data are collected from all meters or sensors then processed in order to deliver the required data to distributed system operator and application systems.

One of the main drawbacks in the management of renewable resources, including wind and solar energies, is the issue of uncertainty in their behavior, such that before the use of solar and wind energy and other renewable energies in power system,

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**Nomenclature**

| | |
|---|---|
| r | total number of residential consumers |
| c | total number of commercial consumers |
| i | total number of industrial consumers |
| $\eta$ | efficiency of the PV system |
| Si | solar irradiance(kW/m$^2$) |
| $Pr_s$ | probability of scenarios |
| $\alpha_w$ | scale parameter Weibull distribution |
| $\beta_w$ | shape parameter Weibull distribution |
| $V_{wind}$ | wind speed(m/s) |
| $V_m$ | average wind speed |
| $P_R$ | rated power of the wind turbine |
| $V_{ci}$ | cut-in speed of the wind turbine |
| $V_r$ | rated speed of the wind turbine |
| $V_{co}$ | cut-in speed of the wind turbine |
| $f_v(V_{wind})$ | wind speed probability density function |
| $F_v(V_{wind})$ | wind speed distribution function |
| $P_w(V_{wind})$ | power output of WECS(kW) |
| $f_{P_w}(P_w)$ | probability density function for the power output of WECS |
| $f_{P_{PV}}(si)$ | solar irradiance probability density function |
| $F_{P_{PV}}(si)$ | solar irradiance distribution function |
| $P_{PV}(si)$ | power output of PVS |
| $P_h$ | power output of HSWPS |
| $f_h(P_h)$ | probability density function for the power output of HSWPS |
| RC(r,t) | amount of load reduction planned by each residential consumer in period $t$ |
| CC(c,t) | amount of load reduction planned by each commercial consumer in period $t$ |
| IC(i,t) | amount of load reduction planned by each industrial consumer in period $t$ |
| $RC_t^{max}$ | maximum load reduction proposed by each residential consumer in period $t$ |
| $CC_t^{max}$ | maximum load reduction proposed by each commercial consumer in period $t$ |
| $IC_t^{max}$ | maximum load reduction proposed by each industrial consumer in period $t$ |
| $\zeta_{r,t}$ | amount of incentive payment to each residential consumer in period $t$ |
| $\zeta_{c,t}$ | amount of incentive payment to each commercial consumer in period $t$ |
| $\zeta_{i,t}$ | amount of incentive payment to each industrial consumer in period $t$ |
| $F^{Cost}$ | total expected cost |
| $F^{Emission}$ | total emissions |
| COC(t) | certain operational cost function |
| UOC(t) | uncertain operational cost function |
| $P_i(t)$ | output power $i$th unit in period $t$ |
| $\pi_i(t)$ | offered price $i$th unit in period $t$ |
| $I_i(t)$ | on and off status of the $i$th DG in period $t$ |
| $SU_i(t)$ | start up or shut down cost of the $i$th DG in period $t$ |
| $RC_i^{DG}(t)$ | reserve costs of the $i$th DG in period $t$ |
| $RC_j^{DR}(t)$ | demand response program coats of the $j$ th load in period $t$ |
| $P_{Grid}(t)$ | active power bought/sold from/to the utility in period $t$ |
| $\pi_{Grid}(t)$ | offered price bought/sold from/to the utility in period $t$ |
| $C_{i,s}^{DG}(t)$ | running cost of the $i$th DG unit at the $t$ th period in the $s$th scenario |
| $C_{j,s}^{DR}(t)$ | the cost caused by load reduction by the $j$ th DRPs during the $t$ th period in the $s$th scenario |
| $ENS_{n,s}(t)$ | amount of involuntarily load shedding in period $t$ and scenario $s$ |
| $Emi_{DG}(t)$ | average pollution of DG units |
| $Emi_{Grid}(t)$ | average pollution of Grid |
| $CO_{2,i}(t)$ | carbon dioxide pollutants of $i$th DG unit in period $t$ (kg/MWh) |
| $SO_{2,i}(t)$ | sulfur dioxide pollutants of $i$th DG unit in period $t$ (kg/MWh) |
| $NO_{x,i}(t)$ | nitrogen oxide pollutants of $i$th DG unit in period $t$ (kg/MWh) |
| $P_{Demand_{t,s}}$ | load consumption in period $t$ and scenario $s$ |
| $P_{DR,s}(t)$ | active power participated in DPRs |
| $R_{DG}(i,t)$ | scheduled spinning reserve provided by DG I in period t |
| $P_{DG}(i,t,s)$ | active output power of DG I in period t and scenario s |
| $P_{DG,i}^{min}$ | minimum output power limit of DG i |
| $P_{DG,i}^{max}$ | maximum output power limit of DG i |
| $W_{ess}(t)$ | battery energy storage at time $t$ |
| $\eta_{charge}(\eta_{discharge})$ | charge(discharge) efficiency of the battery |

*List of abbreviations*

| | |
|---|---|
| PDF | Probability Density Function |
| CDF | Cumulative Distribution Function |
| DRP | Demand Response Program |
| DSM | Demand Side Management |
| DER | Distributed Energy Resource |
| AMI | Advanced Metering Infrastructure |
| DR | Demand Response |
| PSO | Particle Swarm Optimization |
| MOPSO | Multi-Objective Particle Swarm Optimization |
| WES | Wind Energy System |
| PLC | Power Line Carrier |
| DC | Data Concentrators |
| MDM/R | Meter Data Management & Repository |
| PVS | Photovoltaic System |
| PVS | Photovoltaic System |
| HSWPS | Hybrid Solar-Wind Power System |
| DG | Distribution Generation |
| VOLL | Value of Lost Load |
| EENS | Expected Energy Not Served |
| MT | Micro-Turbine |
| WT | Wind Turbine |
| PV | Photovoltaic |
| FC | Fuel Cell |
| PCC | Point of Common Coupling |
| GPRS | General Packet Radio Service |
| MDMS | Meter Data Management System |

network operators have always used storage services to manage production shortages and to create a balance between production and consumption. Today, with the advent of renewable energies, such as wind and solar energy, and the lack of certainty in their production potential, the need to provide storage and find a solution to resolve this uncertainty is felt more than ever. One of these solutions is the use of Demand Response Programs (DRPs) [9,10].

Recently, significant studies have been conducted for better implementation of demand side management programs and