SIMULATION OF DEMAND RESPONSE STRATEGY FOR MICROGRID SYSTEM

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Abstract— Microgrid is an effective means to integrate distributed generation (DG) resource. However, uncertain renewable DG such as wind turbine and photovoltaic outputs and load demands can introduce tremendous difficulties for energy management in microgrids. To mitigate such difficulties, price-based demand response (PBDR) can adjust the loads to adapt to the renewables. On the other hand, dispatchable DG such as micro-turbines can coordinate with the PBDR to further manage the power balance and achieve economic benefits. In this paper a two-stage robust microgrid coordination strategy is proposed: a PBDR is scheduled a day ahead and micro-turbine outputs are modified hourly. A two-stage robust optimization model is pro-posed to address the coordination problem with guaranteed robustness against the uncertainties of renewable DG and load demands. Simulation results show PBDR and multiple DG units can coordinate effectively to accommodate the renewable and demand uncertainties while maximizing the microgrid benefits.

Keywords—DG, DRM, PBDR, Microgrid ,etc.

I. INTRODUCTION

Modern power systems are penetrated with growing distributed generation (DG), including the utility owned middle scale DG units and individually owned units. DG has a high degree of flexibility and provides several technical and economic benefits such as reduction of energy losses, enhancement of power quality, and enhancement of system stability and reduction of network maintenance costs. In general, DG can be classified into two groups according to controllability of its generation resources, i.e. dispatchable and non-dispatchable. Dispatchable DG has cost-effective operation and good reliability due to its enough and certain energy resources, such as micro-turbines, fuel cells, etc. On the other hand, the non-dispatchable DG generally has eco-friendly advantages and sustainable development incentives, such as wind turbines and solar photovoltaics (PVs). In practice, these two types of DG can work together to achieve over-all economic profits, system reliability and environmental benefits simultaneously. For the energy management problem, demand response has already been applied to reshape the load profile. [1]

Microgrids are relatively small-scale power systems that include electrical loads (any device that consumes electric power, e.g., refrigerators, industrial machines, etc.), DERs. A microgrid can operate as a single system (*island* mode) or it can be connected to a utility grid (*grid-connected* mode). Due to introduction of Information and Communications Technologies (ICT) to microgrids, a two-way communication of energy data between producers and consumers is made possible. Hence, informed decisions can be taken based on the information gathered on microgrid components. [7] Modern power systems are penetrated with growing distributed generation (DG), including the utility owned middle scale DG units and individually owned units. DG has a high degree of flexibility and provides several technical and economic benefits such as reduction of energy losses, enhancement of power quality, and enhancement of system stability and reduction of network maintenance costs. [8]
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II. MOTIVATION OF RESEARCH

Utilities have long wanted to flatten the load curve in an effort to reduce the production costs and lighten the power system stresses. This has led to different price based and incentive based DR schemes that encourage customers to alter their power consumption patterns in such a way that the social welfare is maximized. In this section, a review of some of the current research works on DR is presented while retaining the focus on incentive and price based DR. The researchers propose a profit based utility driven DLC arguing that a cost minimization approach results in revenue loss since it does not include customer rate structure. The number of customers to be controlled under the DLC program is considered a decision variable based on price, payback ratio and load pattern. In this research, the customer rate structure via Time-of-Use (TOU) prices is included within the cost minimization objective to capture the response of the customers. [8]

In the present study, a neural network learning technique has been employed to model the controllable load of the customer. Application of a control signal by the Microgrid Operator (MGO) to reduce the effective demand of individual customers has been proposed. This control will be particularly useful from the perspective of an isolated microgrid where neither energy markets nor Independent System Operator (ISO) exist to regulate the real time prices. Rather, a simpler control of the load is desired. Principles of utility-customer interface, as mentioned in the earlier works, have been envisaged while modelling the optimal DR framework in this work.[10]

Research Problems:

- Constant Power Generation (24*7 Electricity Generation)
- Solar Radiation and Temperature is variable in Solar PV, and wind speed is variable in Wind Power Plant
- Energy storage system with effective Energy management control
- Hybrid operation of Multiple RES (Renewable Energy Sources) and Power Management is important
- Demand Response with Hourly generation scheduling is also important.

Research Objectives:

- Importance of Renewable Energy sources mainly Solar PV and Wind
- Development of standalone Hybrid system of Solar PV and wind with energy back up system.
- Matlab Simulation of PDRM based Microgrid System using RES.
- Implementation of Price based Demand Response Management for Proposed system.

III. MICROGRID

Definition of Microgrid:-

A microgrid is a group of interconnected loads and DERs within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and that connects and disconnects from such grid to enable it to operate in both *grid-connected* (a microgrid supplies or draws power to/from a utility grid) or *island* mode (a microgrid is disconnected from a utility grid). Based on this definition, a microgrid is characterized by the following three distinct features:-

• DERs installations must have clearly defined boundaries, i.e., they should be bounded to only one microgrid,
• Total power generations need to exceed peak demands so that it could be disconnected from a utility grid, i.e., it can be in *island* mode, and
• It must contain computer systems that monitor, control and balance energy demand, supply and storage in response to changing energy needs.

Hence, these characteristics show that a microgrid is a small-scale power system with ability of self-healing when there is power interruption in a utility grid. In the following sections, we first present architecture of *industrial* microgrid where energy demand includes industrial loads (e.g., manufacturing processes).

Microgrid Architecture

An architecture of a microgrid is shown in Figure 3.1. The main microgrid components include solar PV panels, wind turbines, ESSs, loads (industrial loads in our case), energy spot markets, and a microgrid controller. Through a **P**oint of **C**ommon **C**oupling (PCC) circuit breaker, it is possible to connect or disconnect the microgrid from the utility grid. Under normal conditions, the microgrid is connected to the utility grid for the purpose of energy transactions. However, when there is fault (e.g., power outage, low power quality, etc.) in the utility grid, the PCC disconnects the microgrid to be an autonomous system, i.e., it is in *island* mode. In this case, local generations in the microgrid should support the loads of the microgrid.

Control and management of microgrids can be established in centralized or distributed manner. As shown in Figure 3.1, centralized control mechanism relies on a central controller and it coordinates the DERs in terms of energy generation scheduling and protection from over-current due to short circuits.

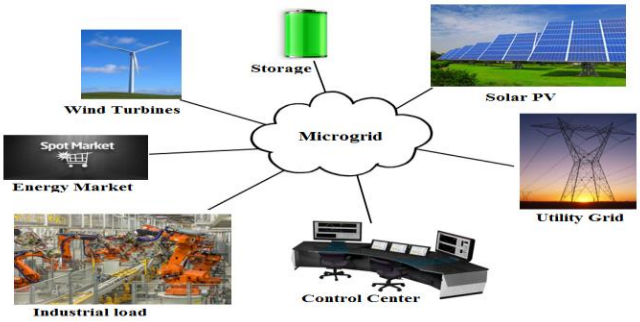


Figure 3.1 – Architecture of a microgrid

For global optimality, the centralized control manner can have the advantage of high Efficiency. Decentralized control and operation could be useful in case where distributed control is required (e.g., in remote areas). In such areas, communication network between the DERs and the central controller can be interrupted due to geographical distance or unreliable network connections.

Models of Wind, Solar and Storage

This section discusses models of basic microgrid components such as wind turbines, solar PV panels and ESSs.

Wind power

Wind turbines generate electrical power by extracting kinetic energy from air flow using rotors and blades (refer to Figure 3.2.1). If the turbines are installed in locations with strong and sustainable winds, the generated power could be of a significant amount to meet some energy demands.

A typical wind turbine is characterized by its *power curve* as shown in Figure 3.2.2. The power curve relates wind power to wind speed. The power *Pwind* (W) extracted from wind speed is proportional to the density of the air, the rotor area, and the cube of the wind speed as:

$$P_{wind} = \frac{\rho}{2} * A_w * c_p(\lambda_w, \theta) * v^3$$

……………………….. (3.1)

Where

- ρ is air density (*kg/m*3),
- *Cp* is performance or power coefficient,
- λw is ratio *vt/vw* (ratio between blade tip speed *vt*(*m/s*) and wind speed at hub height upstream the rotor *vw*(*m/s*)),
- θ is angle of the blade chord to the plane of rotation (or pitch angle), and
- *Aw* is area covered by rotor of wind turbine (*m*2).

IV. DEMAND RESPONSE MANAGEMENT

Demand Response and Micro grids

DR programs have costs associated with them and the participation of both the MGO and customers are of utmost importance. A DR program can be subjected to different manifestations to achieve its end objective while retaining the user specifications. DR in its simplest form can have two different alternatives. In the first case, customers reduce their consumption during peak load hours according to an established agreement with the MGO which yields benefits to both the entities. This voluntary reduction in consumption by the customer can reduce the energy costs but may result in increased inconvenience and discomfort to the customers. The second alternative is to shift the load to off-peak hours from the peak hours. In this case, the customer reduces its consumption during peak hours driven by high prices and consumes electricity during lower price hours. This pattern of response does not alter the total energy consumption of the customer but only changes the load pattern. This is beneficial in terms of operational reliability and reduced dispatch costs from the MGO's perspective and decreased payments by the end user. Different alternatives of the DR program can be outlined as shown below:

Incentive Based Programs

- Conventional
- Direct Load Control
- Interruptible Load Management
- Market Based Approaches
- Capacity Market
- Ancillary Service Market
- Demand Side Bidding
- Emergency DR

Price Based DR

- Time-of-Use pricing
- Critical Peak Pricing
- Real Time Pricing

DR initiatives are finding increased participation among the utilities and end users. In FERC's annual report on 'Assessment of Demand Response and Advances metering' [1]; developments in DR, Advanced Metering Infrastructure (AMI) and smart grid standards have been highlighted and their potential in energy management have been documented. One interesting outcome of the report is shown in Figure. 4.1. The figure shows an increase in the peak reduction potential across all customer classes over a span of six years. The report estimates total peak reduction potential of 55,980 MW across all regions of NERC. The quantum of resources that can be used for energy management suggests the significance of DR in today's grid operation especially during the summer months. To better reflect the system performance and the effect of DR, the present work considers the summer months for system modelling. Smart grids have felicitated the induction of DG resources like PV panels and fuel cells, the presence of which has divided the power system into smaller islands thereby reducing the losses and improving the sustainability. This has resulted in what is called smart microgrids. A formal definition of microgrids has been presented by the U.S. department of Energy in which states that "A microgrid is an integrated energy system consisting of interconnected loads and DERs, which as an integrated system, can operate in parallel with the grid or in an intentional island mode."

The essential building blocks and the components of microgrids are better illustrated by Figure. 4.1. Isolated microgrids have been particularly useful in areas where connection to the main grid is restrictive or financially infeasible. In the isolated mode, the system is self-reliant wherein the responsive system load is satisfied by the locally available generation.

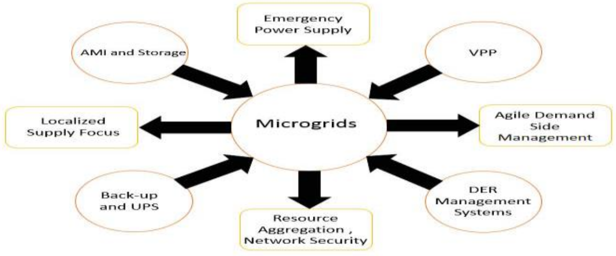


Figure 4.1: Microgrids and their constituents

Microgrid Operations Model

Overall Framework for Optimal DR

The total energy consumption of a residence though small, can provide a major initiative in load following and DR, when aggregated. From the MGO's perspective, a good model can provide the MGO with an accurate estimate of the demand and help manage its generation resources optimally. In the proposed DR framework, an interface between the residential customers and the MGO is presented. A closed loop optimal DR framework has been depicted in Figure. 4.2 Where individual load profiles of residential customers are estimated and the evaluated aggregated demand of the microgrid is presented to the MGO controller. The MGO can use this aggregated demand and issue a control signal through its energy management system.

The proposed framework for optimal DR comprises three main modules (Figure. 4.2), namely, Load Profile Estimator (LPE), Load Profile Aggregator (LPA) and the Microgrid Energy Management System (MEMS). A cost minimization based optimal operations scheduling of the microgrid is performed by the MEMS unit, and an optimal control signal *Pmax* is determined, which is fed back to the LPE at the customer side. This *Pmax* signal, along with the temperature and TOU price data is used to estimate the optimal demand profile. Based on this optimal demand, the MEMS determines the least cost optimal generation schedule of all generation resources in the microgrid system. Thus, a DR scheme in the context of microgrids with a simple control has been proposed while retaining its robustness. The overall architecture of the proposed optimal DR framework is shown in Figure. 4.2.

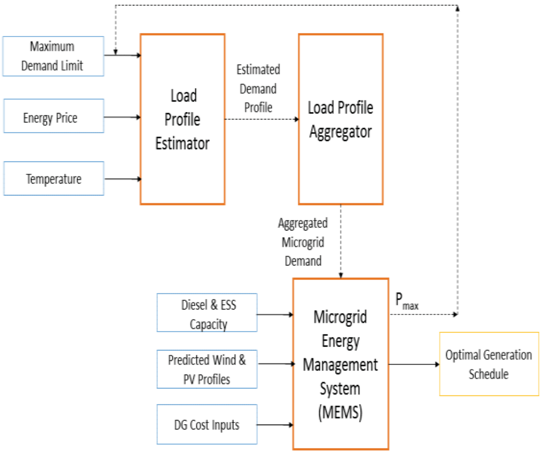
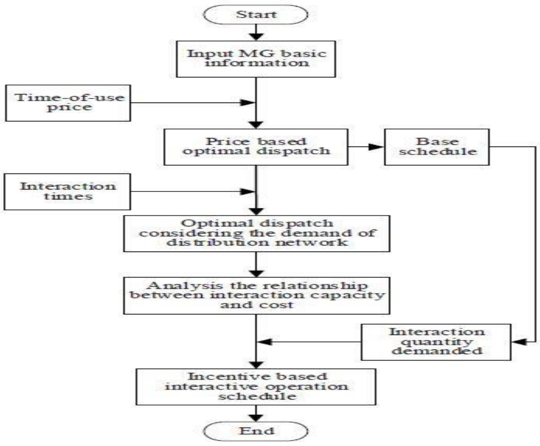


Figure 4.2: Proposed architecture of the optimal DR framework

V. SIMULATION AND RESULT DISCUSSION

Simulation of DRM based Microgrid System



This paper aims to coordinate the PBDR and dispatchable DG for robust and optimal operation of a microgrid. Specifically, a two-stage robust coordination strategy of the day-ahead demand response and the dispatchable DG is proposed against the uncertainties of the non-dispatchable DG and the load demands. In the first stage, a day-ahead PBDR is optimized and scheduled for 24 hours with day-ahead predicted non-dispatchable DG outputs and demands.

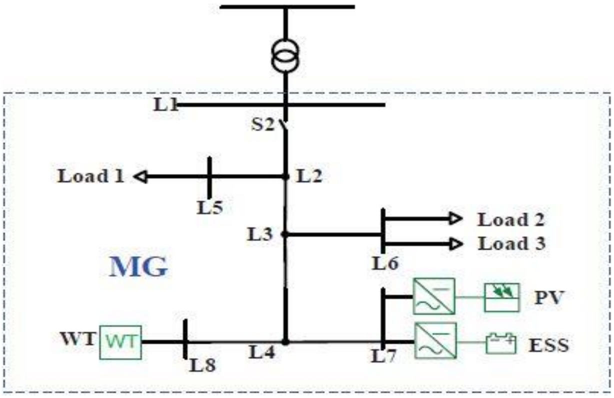


Fig 5.2- Structure of Proposed System

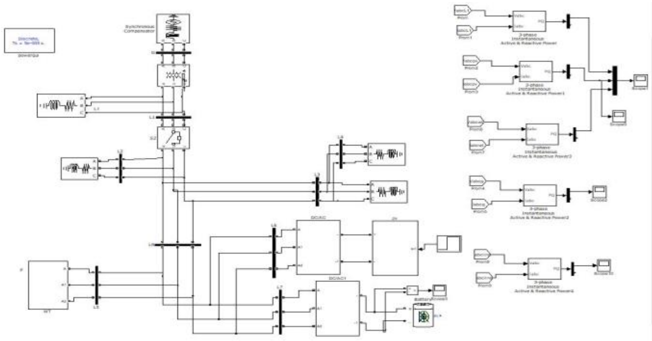
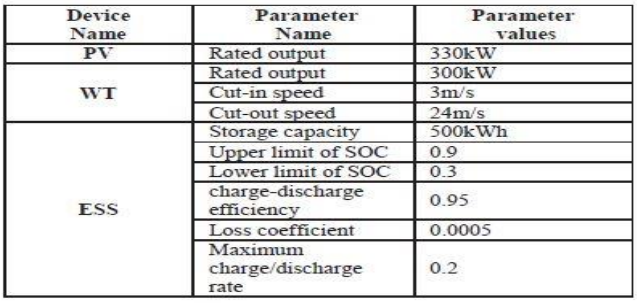


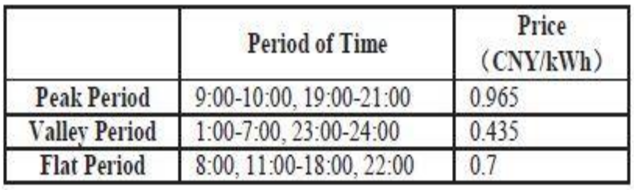
Fig 5.3- Simulation of Proposed System

A two-stage robust optimization model is pro-posed to address the coordination problem with guaranteed robustness against the uncertainties of renewable DG and load demands. Simulation results show PBDR and multiple DG units can coordinate effectively to accommodate the renewable and demand uncertainties while maximizing the microgrid benefits**.**



Device Name	Parameter Name	Parameter values
PV	Rated output	330kW
WT	Rated output	300kW
	Cut-in speed	3m/s
	Cut-out speed	24m/s
ESS	Storage capacity	500kWh
	Upper limit of SOC	0.9
	Lower limit of SOC	0.3
	charge-discharge efficiency	0.95
	Loss coefficient	0.0005
	Maximum charge/discharge rate	0.2

Table 5.1-System Parameters of Microgrid



	Period of Time	Price (CNY/kWh)
Peak Period	9:00-10:00, 19:00-21:00	0.965
Valley Period	1:00-7:00, 23:00-24:00	0.435
Flat Period	8:00, 11:00-18:00, 22:00	0.7

Table 5.2-Time of Use Price

It is important to indicate that other levels can also be considered according to practical data, and they do not affect the implementation of the proposed coordination strategy.

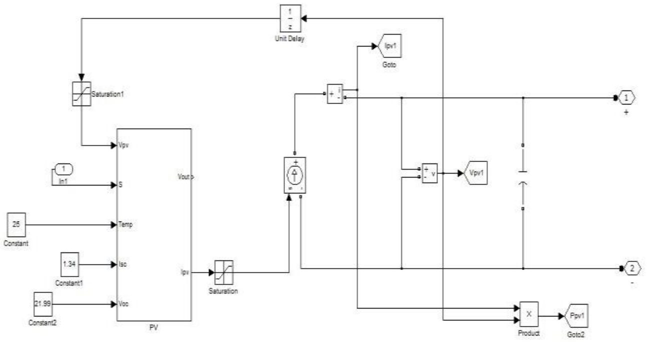


Fig 5.4- Matlab Simulation of Solar PV System

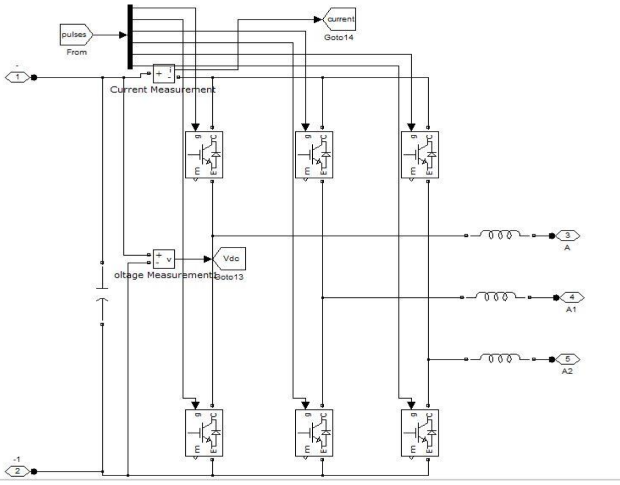


Fig 5.5- Inverter for Solar PV output

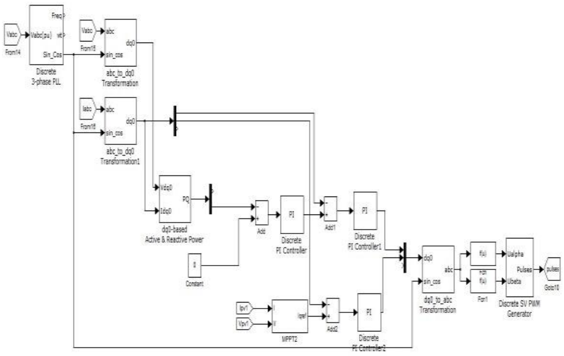


Fig 5.6-Inverter Pulse controller for Solar PV system

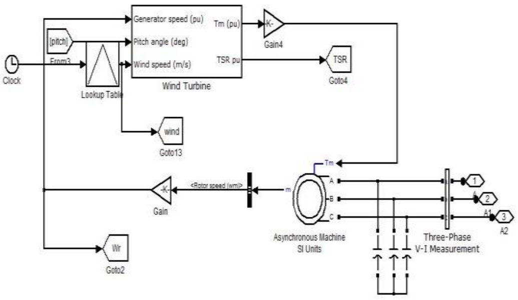


Fig 5.7- Matlab Model of Wind Power Plant

Simulation Results

The proposed strategy is tested on the IEEE 9- bus radial distribution system which has been modified to a microgrid and its data can be obtained from. All the demands in this system are assumed to be price-responsive. The data for wind turbine, PV and micro-turbine locations, sizes and operation and maintenance costs are given in Table 5.1. Performance of the pro-posed strategy with the second stage implemented, compared with a conventional single-stage PBDR and micro-turbine coordination strategy.

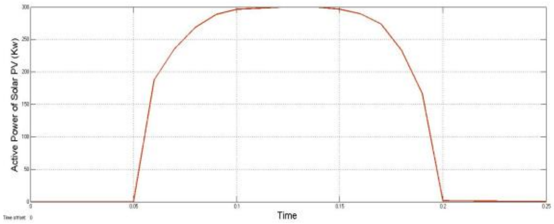


Fig 5.8- Solar PV Output Power (KW)

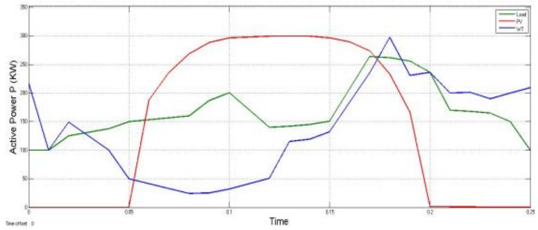


Fig 5.9-Input Information of Microgrid (Active Power of PV, wind and Load Demand)

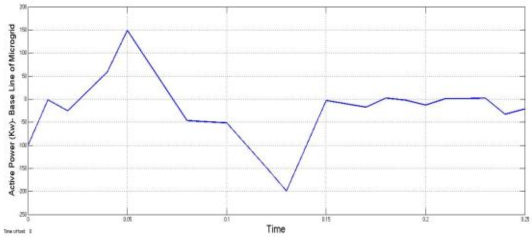


Fig 5.10-Base Line of Microgrid

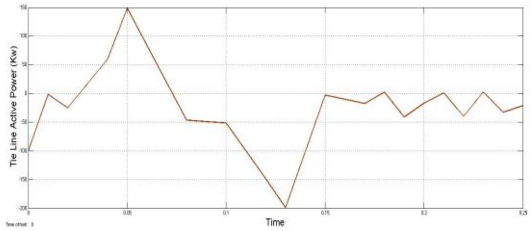


Fig 5.11-Tie Line Active Power (KW)

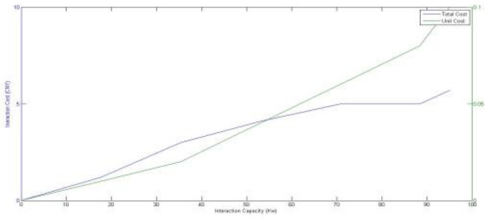


Fig 5.12-Interaction Capacity (KW)

The microgrid of RES output is the total output of the four units in the system. At the hours of 2:00, 3:00, 11:00, 14:00 and 15:00, the energy generated by the renewable DG is sufficient, so the microgrid sells energy to the main grid and the micro-turbines do not generate energy. On the other hand, the micro-turbines generate high energy between 8:00 and 9:00 when the wind energy and the solar energy is low and between 17:00 and 21:00 when the solar energy is low and the demands are high. The micro-turbines generate sufficient energy so that the microgrid does not buy energy from the main grid. It indicates that the energy generated by all the DG with the micro-turbine output adjustment is sufficient for the demands which are reshaped by the day-ahead PBDR. It can be concluded that the second stage hourly micro-turbine generation adjustment can coordinate with the first stage day-ahead PBDR efficiently and robustly.

VI. CONCLUSION

The Proposed an interaction operation strategy for microgrid successfully implemented using Price based Demand Response system. The demand and generation of electricity is coordinated using interaction strategy for microgrid with Renewable Energy Sources. In the proposed microgrid coordination strategy, the overall economic benefits are optimized with the day-ahead 24-hour PBDR price levels and the hourly micro-turbine operation, and the customer bills, demand energy quantity and voltage regulation are considered to guarantee the customer benefits. To ensure the optimization results are robust against the uncertain wind turbine outputs, PV outputs and load demands, and price cost results shows the successful implementation of proposed system in Matlab Simulink.

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