Resilient Microgrid Management Solution

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Abstract

Growing number of distributed generation and energy storage system installation has introduced new challenges and opportunities for reliable and efficient operation of power grids across the globe. The evolution of smart grid has resulted in the emergence of self-contained energy ecosystems called microgrids as an aggregation of distributed generations, energy storage systems, and loads.
One critical value microgrid brings to the grid is resilience, which means the capability to anticipate risks, limit their impacts, and bounce-back rapidly to maintain desired services through survival, adaptability and evolution in the face of consistently changing environment. NEC Labs America has developed a management solution for microgrids which can work in both grid-tied and grid-disconnected modes while reducing cost of operation and improving resiliency from disasters, system failures and other unforeseen events. This solution also supports the integration of renewable generation and demand fluctuations when the microgrid is connected to the grid.

Keywords
energy management, microgrid, renewable integration, resiliency

1. Introduction

A microgrid is the aggregation of loads, distributed generation resources, and energy storage devices (**Fig. 1**). During operation, a microgrid is counted as an independent entity in a power system which can exchange power, information, and control signals with other microgrids and the min grid.

Introducing microgrids into a power system has several benefits in terms of its operation. Some of these benefits include supporting the integration of renewable generation in the grid, reducing the cost of supplying electricity, isolating critical elements of the power grid and supporting them during outages, and participating in electricity markets to offer different services to the grid. According to a new report from Navigant Research, worldwide vendor revenue from microgrids will grow from $4.3 billion in 2013 to $19.9 billion in 2020, in the base scenario.

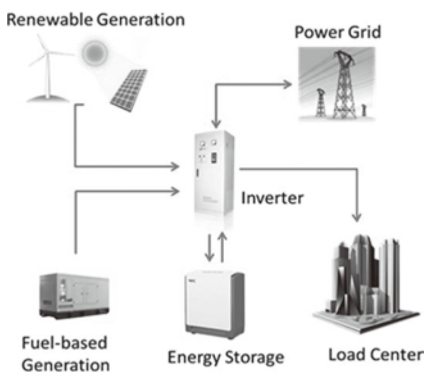

Fig. 1 Microgrid structure.

To operate a microgrid efficiently, there are two tasks that should be accomplished by a management solution: 1) optimizing the microgrids performance by defining long term control strategies based on the application; 2) operating and controlling the microgrid in real time and satisfying all operational constraints. Furthermore, it is important to model and limit degradation of energy storage units to extend their life due to their high capital cost.

To achieve these objectives, NEC Labs America has developed a management solution for microgrids. This management solution consists of two main layers: Energy Management System (EMS) and Resilience Controller

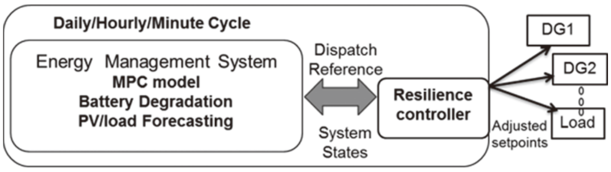

Fig. 2 NEC microgrid solution layout.

which continuously exchange information with each other (**Fig. 2**).

2. Energy Management System (EMS)

Energy management problem deals with economic scheduling of various devices within a microgrid to supply its electrical demand in both grid-tied and grid-disconnected modes of operation. This problem could be challenging due to the issues associated with operation of different devices. These issues include intermittent and uncontrollable nature of many types of renewable sources, load variations in time, different grid power tariffs, planned and unplanned outages, distributed energy resources' (DERs) efficiency characteristics, energy storage degradation, and availability of different options to balance the electric supply and demand. EMS is one of the key business values of the solution since it directly affects the daily operational cost of a microgrid. EMS consists of operation models for microgrid devices including their cost model and operational constraints such as predicted generation of renewables and dynamic load prepared by forecasting module, dynamic tariff structure, deterministic and stochastic grid power outages, efficiency-based cost model for DERs, battery amp-hour based cost model and degradation model. In addition, the interaction between devices within the microgrid network is considered through the overall supply-demand balance model. The above-mentioned models are integrated into the framework of an economic scheduling (ES) problem. The modular architecture of EMS results in a flexible and generic structure. In this structure, any new device could be added to the network without any microgrid remodeling. Also, any failed device can be removed from the EMS model until it could be setup again. Last but not least, the modular structure could create more revenue by delivering additional services to the regional power system such as ancillary services, demand response, and peak load shaving.

To handle the uncertainty in renewable generation and load profiles, Model predictive control (MPC) technique is employed in EMS. MPC is a class of control methodologies which use a model to project the behavior of system. It also measures the actual values of forecasted data and dynamically revises the predicted profiles. Model-based closed-loop control makes this the best suitable agile approach for EMS problem.

2.1 Battery Degradation Model

As chemical storage devices, original energy capacity and power capability of battery deteriorates over the course of its lifetime. The deterioration of battery energy capacity and power capability is affected by several environmental and operational factors.

Since batteries are one of the most expensive entities in microgrids, it is crucial to operate them in a way which maximizes its economic lifetime. To do so, first we have developed an accurate battery degradation model integrating both cycling and calendar aging in a single framework for Li-Ion batteries. Neural network and statistical techniques with deep understanding of battery operation in power systems are utilized to build an accurate degradation model. This model integrates cycling and calendar aging and selects appropriate input parameters. Ultimately, the degradation model is integrated with the microgrid EMS to observe and limit battery degradation and modify battery setpoints generated by the EMS to achieve certain battery lifetime. This feature and its integration into EMS is the first of its kind.

2.2 Forecasting Models

The solution includes forecasting as an enabling piece of technology. Forecasts of renewable generation and load are required due to the uncertainty of these variables. Our forecasting technology is based on time series methods and can include exogenous inputs such as temperature and other variables. The forecasting technology is computationally very light in terms of memory and processing requirements. This is because of the unique manner in which the inputs are used in the forecasting process based on expert knowledge about physics of underlying system and relationships among different system parameters. The forecasts are repeated at every time step of the EMS by incorporating the most recent data of load and renewable generation. This feature also improves the accuracy and enables improved cost performance from the EMS. The forecasting technology can also be applied outside the energy management and optimization functions to improve reliability and to assess potential market participation areas.

3. Resilience Controller

One critical value microgrid brings into a power system is resilience, which refers to the capability of the grid to anticipate risks, limit their impacts, and bounce-back rapidly to maintain desired services through survival, adaptability and evolution in the face of consistently changing environment. Since microgrid is a smaller and localized version of the traditional grid with distributed energy resources (DERs), a microgrid controller has to deal with all the challenges a traditional power system have, and additional challenges including the intermittency of renewables and the switching between grid-tied and grid-disconnected operation modes.

The microgrid resilience controller is designed to manage all challenges related to the resilient operation of system as discussed above. Microgrid resilience controller provides a multitude of functionalities for both grid-connected and grid-disconnected microgrid systems. Specifically, the following functions are provided: 1) Automatic generation control, 2) Reactive power management, 3) Equipment state/failure identification, 4) Fluctuation stabilization, 5) Islanding microgrid during emergency or maintenance, 6) Reconnecting microgrid to main grid.

Usually EMS schedules the power outputs for distributed generators (DGs) on a daily/hourly/minute cycle, based on forecasted renewable generation and load profiles. The resilience controller runs every few seconds to take care of disturbances happening during the microgrid operation. If everything goes perfectly as expected, the resilience controller commands all DGs to exactly follow the power references set by EMS. If disturbance occurs or there is change in the renewable generation/load, the resilience controller will make adjustments to the setpoints of all distributed generators. If a generator fails, the resilience controller will identify it and feedback this information to EMS for updated dispatch references. The main technology used in the resilience controller is the dynamic droop control, which keeps adjusting the droop control coefficients on all DGs based on real-time system operating conditions.

As the resilience controller is managing the resilience aspects of the microgrid, it needs to cooperate with EMS so that they work together as integral pieces of a unified microgrid management solution.

4. Technology Validation

Since it is expensive and time-consuming to setup a hardware testbed for technology validation, we have developed a Real-Time Simulation Platform to validate the developed Microgrid Management Solution, as shown in **Fig. 3**.

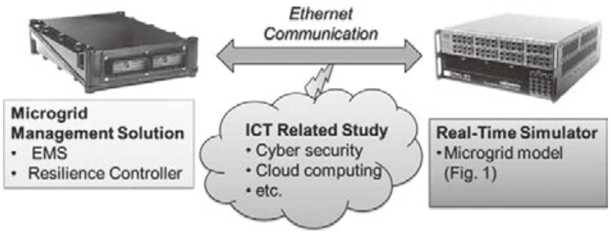

Fig. 3 Microgrid solution technology validation.

In the Real-Time Simulation Platform, the Microgrid is modeled in the real-time simulator from Opal-RT Technologies, Inc., while the Microgrid Management Solution is implemented in a controller. The information exchange between the controller and the Microgrid is through TCP/IP. The platform is able to create different resilience events with millisecond-level accuracy, so the performance of the Microgrid Management solution can be tested.

This validation approach shortens the development cycle since the controller can be tested before the hardware is ready, and can lower development cost by avoiding possible damages to the hardware. With the capability to integrate both communication network and power network, the implementation of Information and Communications Technologies (ICT) in power industry can also be studied based on this platform.

5. Conclusion

In this paper, we have described the Resilient Microgrid Management Solution which has been developed at NEC Labs America. This solution incorporates the main customer requirements in microgrid markets. Among these requirements are electricity cost reduction and renewable energy utilization which are achieved in the EMS layer of the management solution. Resilience is another important factor in microgrid's domain which is addressed in the controller layer of this solution. Combination of several unique enabling technologies in NEC microgrid management solution has provided an opportunity to play an active role in microgrid market at different regions of the world.

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* Ethernet is a registered trademark of Xerox Corporation.

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Vol.10 No.2
April 2016

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