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Using microgrids to improve the grid resilience in the aftermath of extreme events

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ABSTRACT

The adverse effects of extreme events on the grid resulted in growing demands to address grid resilience or provide emergency services. A microgrid, covering small geographical area is less vulnerable to such events. Through its features, such as local generation, optimal load and power scheduling or islanding operation can significantly increase system reliability and resilience. Optimized generation scheduling and energy management models are implemented, by using simplified microgrid component, composite load models, and load prioritization.

Keywords: Microgrids, Grid Resiliency, Energy Management.

I. INTRODUCTION

Maintaining system reliability is a main concern and objective of any utility (Chanda and Srivastava, 2016, Gao et al., 2016). Extreme weather is the main cause of power outages, having significant effects on the electrical infrastructures, with even a greater impact on the power distribution, such as extended outages and significant economic losses, that can lead to large-scale and longer service interruptions, impeding the post-disaster relief efforts, affecting the deployment and operation of the first-response units and recovery operations (Panteli et al., 2016). A microgrid, consisting of distributed energy resources and renewable energy systems (RES) can provide energy to at least critical loads in a sustainable way. A microgrid, a group of generators, energy storage units, interconnected loads with control and management systems can operate in grid connected mode or islanded mode (Belu, 2014a,b). It appears to the grid as a single controllable entity, consuming or supplying power depending upon its total generation and load demand. It is also considered a key smart grid component, allowing the integration of distributed generation (DGs) units and energy storage systems (ESSs) into the power distribution systems and hence removing the need for power system expansion. In order to ensure more reliable, resilient and economical energy supply, energy storage, advanced control, together with energy management and load prioritization, need to be integrated within the MG operation and generation scheduling. The MG ability to operate in islanded mode increases the reliability of the load points. In islanded mode of operation, the loads depend upon the MG local generation. In the case that DGs are unable to supply all of the loads, energy management systems can curtail non-sensitive loads utilizing adaptive control strategies, ensuring that sensitive and critical loads are not interrupted. MGs, isolated from the grid can maintain the supply to critical loads, by optimal generation scheduling. Compared to a power system, a microgrid covers much smaller geographical areas, being less vulnerable to extreme events like hurricanes, blizzards etc.

A power distribution system is resilient if it can anticipate, adapt to, or rapidly recover from a disruptive event, such as natural hazards, extreme weather and human-induced disruptions (Chanda and Srivastava, 2016, Panteli et al., 2016). In this work, electric service restoration is achieved through a decentralized approach where existing or ad-hoc formed microgrids are used to supply loads, targeting the critical loads, through load prioritization and optimal generation scheduling. Optimal generation scheduling and operation models are incorporating proper representations of RES uncertainties, energy reserves, grid availability, load prioritization and demands, in normal and emergency operation modes. Here, we adapted and improved the existing methods to restore electric service to the critical loads in the absence of the grid supply, as well as simplified but accurate MG component models.

II. OPTIMAL GENERATION SCHEDULING

A. Semplified MG Comonent Models

A microgrid has key advantages, in terms of resiliency in its ability to operate in island mode, or to activate and de-activate components, which provides operational flexibility and reduces the vulnerabilities of the centralized generation and long transmission. In islanded operation mode, the loads depend upon the local MG generation (Belu, 2014a, b). In the case when DGs are unable to supply all the loads, MG energy management can voluntarily curtail the non-sensitive and non-critical loads utilizing adaptive strategies, ensuring that the sensitive and critical loads are not interrupted. However, for a real-time MG energy management may be difficult to determine optimal operating points of generation and energy storage to minimize non-critical energy uses to provide longer emergency supply to critical loads. Our analysis is focuses on critical MG components to improve the supply availability in the extreme events, through the optimized use of DER units and load prioritization. The application of the defensive and optimized MG islanding solution is determined by a risk assessment, component weather-dependent failure probabilities and component fragility curves to identify the most vulnerable ones (Hernandez et al. 2016). The islanding operation mode can occur if there is a fault within the upstream network to which the

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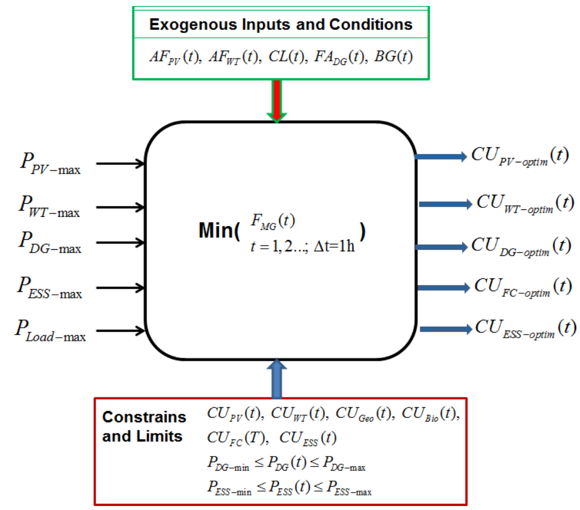
microgrid is connected or by choice. In islanded operation, the supply to the loads within the MG depends upon the generated power of the DG units, energy storage reserves and through the energy management to curtail non-critical loads, based on specific load prioritization algorithms (Amirioun et al., 2018, Wang et al., 2016). The main investigated aspects in our project are: MG generation scheduling, load prioritization, and the development of the MG management and operation system able to monitor the variables that are relevant for operation of the various MG blocks (generated power, weather parameters, energy storage status and load demands).

B. Generation Scheduling Algorithm

Generation scheduling and power flow are formulated as a mixed-integer linear program, and then reformulated as a two-level problem. The first level identifies for each component, the optimal operation and scheduling, while in the second level models the system operations under the worst-case scenarios. Since the optimal scheduling of a MG is a fundamental prerequisite for emphasizing the MG merits, a resiliency-oriented linear programming approach was adopted. The main features of the proposed approach are: develop a two-stage optimization model with real-time network constraints, then an efficient framework for modeling MGs, employing MG simplified components and demand response for mitigating the impact of high-impact, low-probability events. This model exploits optimal energy uses and load prioritization. In islanded operation the optimum power balance is more critical than in grid-connected operation mode. Therefore, reliable energy sources and storage are critical to improve a microgrid operation (Belu, 2014a, b). The rigorous models of the microgrid resources and options, along with prevailing uncertainties are key factors in achieving the desired MG operations in the case of extreme events. MG uncertainties are categorized into: normal operation and contingency-based uncertainties. Therefore, random parameters are represented in the MG scheduling along with their associated probabilities. The proposed approach is flexible and can be extended to any MG types. The framework minimizes the cost function of MG, taking into account the operational constraints. Since the resiliency-oriented MG scheduling models are computationally intensive, the scenarios associated with the uncertain parameters were sensibly reduced for computational tractability. The cost function (TF) which is minimized in order to obtain the minimum MG cost, is expressed by:

$$TF = \min\left\{\Im\left(\sum P_{MG}(t), CU(t), AV_{RES}(t), SOC, \Delta t,\right)\right\} \quad (1)$$

Here, the terms PMG are the maximum available values of the active power that can be generated in the microgrid by the non-dispatchable and dispatchable units, and the available energy of the storage devices. The terms CU(t) are the usage coefficients in relation to the maximum values of the active powers (rated power for generators and maximum capacity for energy storage), in their variation domain [0, 1]. $AV_{RES}(t)$ represents the availability function of RES units, given by input data, e.g. the solar irradiance level or wind availability, from the weather forecasts. The loads are specified based on load profiles for critical, essential, non-critical, or transferable types. Load profiles are modeled by using stochastic models. Decision variables include: generated power by each MG source and storage unit, computed by multiplying its estimated usage coefficient with the rated power at each time step. The optimization energy management and optimal generation scheduling are constrained by the generation and stored energy to meet the specified loads, by solving the MG energy balance equations with specified constrains. The minimization procedures is applied at each time step, over specific time intervals. The input data are: weather forecasts or power predictions, load profiles (load coefficient CL(t)), and reserve estimates, and represented as a black-box of the minimization process, as shown in Fig. 1.



Fig,1. Minimization process representation

MG energy and power balance equations use load forecast or profile, wind velocity and solar radiation data or forecast, energy storage, dispatchable and distributed generation:

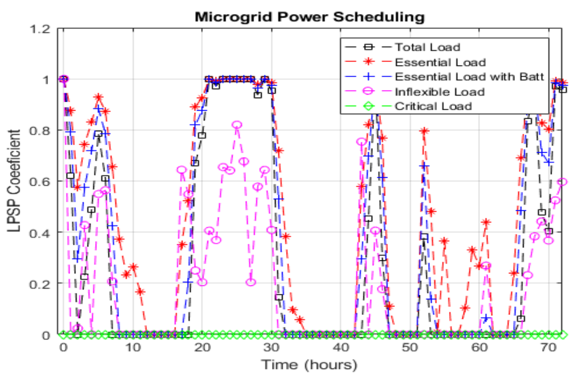
$$P_{MG} = \sum P_L + \sum P_{WT,PV} + \sum P_{DDG} \pm \sum P_{EES} \quad (2)$$

Here, P_{MG} is the microgrid power balance (zero in the islanded operation), P_L is the total load power, $P_{WT,PV}$, P_{DDG} and P_{EES} are the wind turbine and PV, dispatchable DG generated power, and energy storage. By integrating of power equation, over a specific time interval, the energy equation is obtained:

$$E_{MG} = \sum E_L + \sum E_{WT,PV} + \sum E_{DDG} \pm \sum E_{EES} \quad (3)$$

III. RESULTS AND DISCUSSIONS

The optimized energy management and optimal generation scheduling algorithms were calibrated and validated on several MG configurations, unit sizes and for different time intervals, and load profiles and demands. The dynamic composite load models (Raisz and Dan, 2009) are used in our approaches for extend the supply duration. Fig. 2 shows results for a small community microgrid with wind and solar energy units. It consists of a 5 MW maximum load demand, 3 MW installed wind power, 4 MW rated PV power, and 2 MW dispatchable distributed generation. The actual wind velocity and solar radiation data are used. The loss of power supply probability (LPSP), the loss of power supply (LPS) to total demand for a considered period LPSP for various load types and profiles are shown in the upper panel. The graphs are showing that the power for critical loads is continuously supplied. Load prioritization and adjusting the load demand can significantly improve the MG resilience, extending energy supply for essential, critical and most critical loads. The proposed methods calculate the optimal generation scheduling of the distributed non-dispatchable and dispatchable generators and energy storage as per load demand, taking in account power unit constraints, load prioritization and reserve availability at each time step. The generation scheduling is based on the power management strategies discussed above. The optimal generation scheduling and power balance methods were tested on several MG configurations, various load profiles, dispatchable and RES generation scenarios. Besides the testing the optimal scheduling and energy management system algorithms for various MG configurations, using predicted and real wind and solar radiation data, load profiles and fuel reserve scenarios, additional power flow analysis to test the models were conducted using PowerWorld and RTDS simulators.



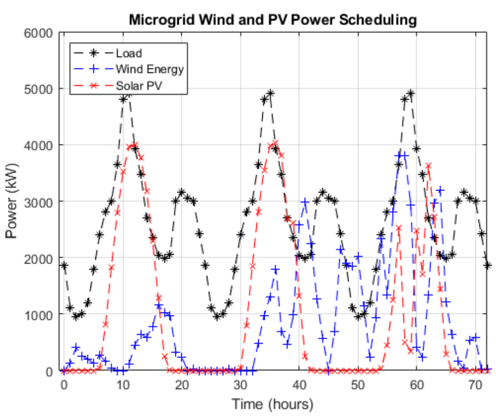


Fig. 2. Community MG: LPSP profile (upper panel), load wind and PV generation (lower panel)

In the case of extreme events, the energy management system finds an appropriate and optimal MG energy schedule, considering available power generation resources, load demand, load prioritization algorithm, and energy storage status. The scheduling models are ensuring the optimal MG operation, reducing its vulnerability and providing extended power supply at least for critical and essential loads. Implemented and validated MG optimal generation scheduling, power management, and load prioritization methods are showing that it is possible an un-interrupted energy supply for critical and essential loads in the case of extreme events. Large-scale embedding of microgrids into power systems offers values for resilience and service restoration. The MG deployment at extended scale has the potential to significantly enhance grid resilience, flexibility, and sustainability, through advanced and intelligent energy management schemes and adaptive islanding. Other MG benefits are: a more reliable electric and improved quality service for microgrid residents, local service helping communities to cope with outages, reduced risks of cascading failure, facilitating the service recovery or even lower energy costs. By dynamically managing local energy generation, energy storage and resources, a microgrid can optimize efficiency, minimize the cost, or maintain system stability.

IV. CONCLUSSIONS AND FUTURE WORK

We developed improved power and energy MG models with limited generation resources to serve critical loads in the case of an extreme event. These models include the DG uncertainties, MG simplified component models, load prioritization, load composite dynamic models, and power management algorithms. MG-assisted critical load service restauration problem is formulated as constrained programs. Models include the maximizing the energy provided to the critical and essential loads weighted by their priority index and minimizing the overall MG energy use. Effects of loads prioritization are studied and evaluated for various MG configurations. Our results are indicating that the reliability is improved and the service is continuously provided to the critical and essential loads in case of load prioritization algorithms are employed, compared with cases when no load prioritization is used.

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