# Energy Management of Interconnected Microgrids; A Generalized Extreme Learning Machine Probabilistic Forecasting and Internet of Things Approach

Morteza Dabbaghjamanesh, *Student Member, IEEE*, Shahab Mehraeen, *Member, IEEE*

***Abstract*—Based on the IEEE 1547.4 standard, decomposition of the grid into interconnected microgrids (MGs) can enhance the system operation and reliability significantly. However, effective energy management and security of the network is more challenging with interconnected microgrids. This paper proposes a new stochastic framework for optimal energy/power management of the interconnected MGs based on the Internet of Things (IoT) approach. Since distribution feeder sensors should send/receive data to/from microgrid central controller (MGCC), an IoT-based management of single/multiple MGs is much safer unlike in physical communication. Internet-based interactions can potentially increase the network security and privacy. Next, a newly probabilistic forecasting framework is proposed using the Generalized Extreme Learning Machine (GELM) to model the uncertain parameters associated with the problem such as hourly load demands, and renewable energy output powers. The demand response including the shift-able and curtailable loads are considered. Finally, the proposed problem is formulated as a Mixed Integer Linear Programming (MILP) optimization problem and is tested on three interconnected MGs including two residential MGs and one hospital MG to demonstrate the high efficiency and performance of the proposed method.**

## I. Introduction

INTEGRATION of the loads and Distributed Energy Resources (DERs) in a small electric network is known as the microgrid (MG). MGs are currently drawing a great deal of attention, in comparison with the large power grids, due to advantages such as self-healing ability, closeness to the consumer, higher reliability and resiliency, and lower transmission and operation costs. In spite of many advantages, there exist some challenges in the MG energy/power management and stability.

In the conventional power system, Distribution System Operator (DSO) is responsible for power management among the network players. However, in the modern power grids, the DSO and MGs can have different owners with different roles and policies. Meanwhile, due to the interconnected network, any change in an individual MG can affect the entire grid [1]. Although based on the IEEE-1547.4 standard [2], the decomposition of the grid into the interconnected sub-MGs can potentially improve the system operation and reliability; however, communication limitations between the interconnected MGs can arise due to privacy and security concerns. Thus, a system-level coordinator is vital to achieve effective power management for the interconnected MGs [3].

The energy/power management single MG connected to conventional grid has been studied in many literatures where the DSO is responsible for entire system management. For instance, in [4], effective energy management of the multi-period islanded MG has been investigated. Authors utilized a Mixed-Integer Linear Programming (MILP) formulation and employed the bender decomposition technique [4] to coordinate the MG with the main grid. A two-layer dispatch framework is suggested in [5-8] to address the economic dispatch of the MG. The authors consider the spinning reserve to assure the MG operation. In [9], the marker-based MG is studied where the MG is in correlation with the DSO market. The MG energy/power management considering Renewable Energy Sources (RESs) is explored in [10], [11] where the authors use storage units to overcome uncertainties in non-dispatchable generation units.

Although the energy management of single MG has been widely discussed, the impact of the interconnectivity within a system of the interconnected MGs is not well discussed. The mismatch control of the multi-agent interconnected MGs has been examined in [12] and [13] where power interchange is controlled between areas in order to satisfy demand/generation of the areas. The interconnected MGs energy/power management under load uncertainty is studied in [14]. An effective power dispatch of interconnected MGs has been explored in [16] under uncertainties in generation and demand. In [15], a bi-level optimization technique is proposed for the energy management of the interconnected MGs where a central generation unit acts as an upper level unit whereas the lower level comprises DERs and power deficit is compensated by the upper-level unit. A robust optimization technique (worst-case scenario) is investigated in [17] for the optimal energy management of renewable-based distributed MGs. In [18], a decentralized energy management technique is proposed for the interconnected MGs based on Alternating Direction Method of Multipliers (ADMM) method. Authors modeled uncertainties related with RESs and load demand using Monto Carlo Simulation (MCS) followed by the scenario reduction method.

In this paper, a new framework is established for the interconnected MGs based on the Internet of Things (IoT). The IoT is activated in an extremely dynamic environment with a large number of devices that will be connected to the Internet, along with the extensive distribution and heterogeneity of the available resources. In comparison with other techniques, the IoT method has a lot of significant advantages such as less computational burden (due to the fast data processing) [19], more security and privacy [20], easily extendible and more practical network (due to its applications in the smart cities) [21]. Hence, compared to the existing literature, the main contributions of this research can be summarized as follows:

- Develop an optimization framework for interconnected MGs based on the IoT approach. The primary objective is to minimize the operation cost of the network and automate system while satisfying all the security and operational constraints associated with the problem,
- Develop a thorough mathematical model for effective energy/power management for the interconnected MGs. The proposed formulation includes centralized processing with no exchange of information between the interconnected MGs, and
- Develop a stochastic framework according to the Generalized Extreme Learning Machine (GELM) method for modeling the uncertain parameters such as hourly load demand and renewable energy output power.

## REFERENCES


[1] Z. Wang, B. Chen, J. Wang, M. Begovic, and C. Chen, “Coordinated energy management of interconnected microgrids in distribution systems,” IEEE Trans. Smart Grid, vol. 6, no. 1, pp. 45–53, Jan. 2015.

[2] IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems, IEEE Standard1547.4, 2011, pp. 1–54.

[3] Z. Wang, B. Chen, J. Wang, J. Kim, and M. Begovic, “Robust optimization based optimal DG placement in microgrids,” IEEE Trans. Smart Grid, vol. 5, no. 5, pp. 2173–2182, Sep. 2014.

[4] A. Khodaei, “Microgrid optimal scheduling with multi-period islanding constraints,” IEEE Trans. Power Syst., vol. 29, no. 3, pp. 1383–1392, May 2014.5] Q. Jiang, M. Xue, and G. Geng, “Energy management of microgrid in grid-connected and stand-alone modes,” IEEE Trans. Power Syst.,vol. 28, no. 3, pp. 3380–3389, Aug. 2013.

[6] W. Su and J. Wang, “Energy management systems in microgrid operations,” Elect. J., vol. 25, no. 8, pp. 45–60, Oct. 2012.

[7] W. Su, J. Wang, and J. Roh, “Stochastic energy scheduling in microgrids with intermittent renewable energy resources,” IEEE Trans. Smart Grid, vol. 5, no. 4, pp. 1876–1883, Jul. 2014.

[8] C. Moreira, F. Resende, and J. P. Lopes, “Using low voltage microgrids for service restoration,” IEEE Trans. Power Syst., vol. 22, no. 1, pp. 395–403, Feb. 2007.

[9] S. Parhizi; A. Khodaei; M. Shahidehpour, "Market-based vs. Price-based Microgrid Optimal Scheduling," in IEEE Transactions on Smart Grid , vol.PP, no.99, pp.1-1

[10] T. A. Nguyen and M. L. Crow, "Stochastic Optimization of Renewable-Based Microgrid Operation Incorporating Battery Operating Cost," in IEEE Transactions on Power Systems, vol. 31, no. 3,

[11] C. Zhang; Y. Xu; Z. Y. Dong; J. Ma, "Robust Operation of Microgrids via Two-Stage Coordinated Energy Storage and Direct Load Control," in IEEE Transactions on Power Systems , vol.PP, no.99, pp.1-1

[12] H. S. V. S. Kumar Nunna and S. Doolla, “Multiagent-based distributed energy resource management for intelligent microgrids,” IEEE Trans. Ind. Electron., vol. 60, no. 4, pp. 1678–1687, Apr. 2013.

[13] H. S. V. S. Kumar Nunna and S. Doolla, “Demand response in smart distribution system with multiple microgrids,” IEEE Trans. Smart Grid, vol. 3, no. 4, pp. 1641–1649, Dec. 2012.

[14] M. Fathi and H. Bevrani, “Adaptive energy consumption scheduling for connected microgrids under demand uncertainty,” IEEE Trans. Power Del., vol. 28, no. 3, pp. 1576–1583, Jul. 2013.

[15] G. E. Asimakopoulou, A. L. Dimeas, and N. D. Hatziargyriou, “Leader follower strategies for energy management of multi-microgrids,” IEEE Trans. Smart Grid, vol. 4, no. 4, pp. 1909–1916, Dec. 2013.

[16] N. Nikmehr and S. Najafi Ravadanegh, “Optimal power dispatch of multimicrogrids at future smart distribution grids,” IEEE Trans. Smart Grid, vol. 6, no. 4, pp. 1648–1657, Jul. 2015.

[17] Y. Zhang, N. Gatsis, and G. B. Giannakis, “Robust energy management for microgrids with high-penetration renewables,” IEEE Trans. Sustain. Energy, vol. 4, no. 4, pp. 944–953, Oct. 2013.

[18] Z. Wang, B. Chen, J. Wang, and J. Kim, “Decentralized energy management system for interconnected microgrids in grid-connected and islanded modes,” IEEE Trans. Smart Grid, vol. 7, no. 2, pp. 1097–1105, Mar. 2015.

[19] Yi, Meng, Qingkui Chen, and Neal N. Xiong. "An Effective Massive Sensor Network Data Access Scheme Based on Topology Control for the Internet of Things." Sensors 16, no. 11 (2016): 1846.

[20] J. H. Lee and H. Kim, "Security and Privacy Challenges in the Internet of Things [Security and Privacy Matters]," in *IEEE Consumer Electronics Magazine*, vol. 6, no. 3, pp. 134-136, July 2017.

[21] W. Ejaz, M. Naeem, A. Shahid, A. Anpalagan and M. Jo, "Efficient Energy Management for the Internet of Things in Smart Cities," in *IEEE Communications Magazine*, vol. 55, no. 1, pp. 84-91.