New Advances in Power System Distributed Operations with Multi Microgrids

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BRIDGESOURCE Utilities Solutions

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In collaboration with thought leadership from *BridgeSource Utilities Solutions* (BSUS), and in conjunction with the *Energy Systems Research Laboratory* under my own guidance at *Florida International University* (FIU), we are committed to the creation of a series of Whitepapers which provide insightful perspective on perplexing issues facing the United States Electric Utilities Operational Transformation.

Power systems have continuously varying electrical system infrastructures with load and source variables that dynamically change with operating conditions. These variables include the energy storage state of charge and efficiency as well load level and priority of the connected components that dynamically change based on time and demand requirements. Distributed energy resources (DERs) with coordinated management and interactive support have proven to benefit electricity customers in terms of resilience and dependability [1]. But the rising use of DERs in grids also brings forth unheard-of difficulties, like coordination and stability problems [2]. Power electronic devices often connect DERs to other parts, such as FACTS, energy storage systems, new loads, and HVDC links with the power system. The increasing penetration of power electronic components will drastically diminish grid inertia, making the utility grid very susceptible to disturbances and endangering the stability of the power system [3]-[4]. This is true even though they enable ultra-fast grid control and load adjustments. Disturbances in the grid may cause a significant number of DERs or microgrids to disconnect briefly when the penetration level of DERs and microgrids is high. This may seriously threaten the stability and security of the bulk power system. Unfortunately, such problems have not been addressed by existing technologies.

Due to a rise in severe weather occurrences that cause protracted outages, more significant regulatory requirements for higher reliability and resilience levels, and expanding penetrations of distributed energy resources (DERs), the electric power distribution system is faced with unprecedented problems [5]. This highlights the necessity for an advanced operational platform that can accommodate cutting-edge applications to control distribution system operations, particularly under abnormal conditions. Utility companies typically use a Distribution Management System (DMS) to execute the FLISR's functions in conjunction with a number of other subsystems. Unfortunately, a standard DMS cannot properly use the interactions between the subsystems for grid operation. By combining activities across various subsystems to facilitate the creation of sophisticated grid management applications, an ADMS addresses the drawbacks of a conventional DMS. In essence, an ADMS enables the integration of new applications that can easily access data from numerous systems, such as Distributed Energy Resource Management Systems (DERMS), Supervisory Control and Data Acquisition (SCADA), It also enables Outage Management Systems (OMS), and Advanced Metering Infrastructure, but not limited to (AMI) [6]-[8].

To meet this need, advanced distribution management systems (ADMS) have recently made advancements, and new applications have been created to guarantee dependable, resilient, and cost-effective distribution grid operations. Fault Location, Isolation, and Service Restoration (FLISR) is one such crucial application that is currently being used by most utility companies and offered by the majority of ADMS suppliers [9], [11]. The conventional FLISR application needs to be upgraded in light of incorporating DERs, microgrids, and smart switches that can be used to reconfigure and purposefully island portions of the distribution networks. More studies are required to make model-based FLISR applicable for large-scale imbalanced power distribution systems with various reconfiguration options. In addition, a thorough proof-of-concept evaluation of sophisticated applications benefits the industry, and ease of integration into the ADMS environment is necessary before utility companies can embrace them, as shown in Fig. 1.

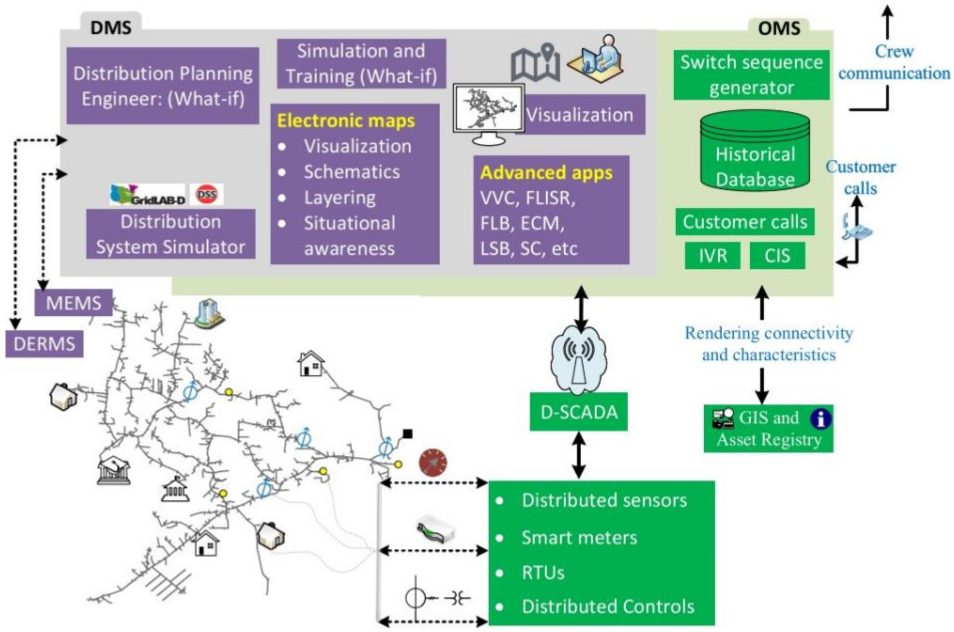

Figure 1: Advanced Distribution Management System ADMS [8]

Impact of Advanced Distribution Management System (ADMS) on the Power System Operation

The expansion of distributed renewable and nonrenewable energy resource installations, increasing utility-scale energy storage, hybrid electric vehicle use, and demand response presents the electric distribution system with unprecedented prospects and difficulties. Utilities, end users, manufacturers, and other distribution system actors actively redefine the utility operational model as new technologies emerge. Utility systems could previously operate primarily in isolation, but with the intricate coordination and integration required for these distributed resources, they now face a systems integration issue. A microgrid is one possible method for merging these technologies, a group of interconnected loads and distributed energy resources within well-defined electrical boundaries that operate as a single controllable entity concerning the grid. A microgrid can connect and disconnect from the grid, allowing it to function in grid-connected and island mode. A microgrid can also provide auxiliary services to the main distribution grid or utility, such as voltage support and regulation. This is a functionality that a standard end-user system cannot offer. Furthermore, utilizing distributed energy resources (DERs), storage devices, and responsive loads, a microgrid not only supplies energy but also improves local reliability, decreases emissions, and contributes to a cheaper cost for energy delivery. A microgrid can also enhance power quality by sustaining voltage and reducing voltage dips within the microgrid.

The advanced distribution management system (ADMS) is based on the DMS - a decision support system utilized by distribution operators and field operating employees for coordinated and efficient monitoring and control of the electric distribution system - but includes additional functionality. The ADMS combines energy efficiency, demand response, and distributed resource technologies to enable grid operators to make more informed decisions about operating the distribution system more efficiently, reliably, and affordably. Like a microgrid, this system allows electric distribution utilities to combine distributed energy resources, demand response, energy storage systems, and electric vehicles.

Utilizing ADMS has the enormous benefit of combining numerous systems into one system. This potent data acquisition and supervisory control technology unite devices under smart grid management. And this is what the ESRL testbed infrastructure will provide through multiple features, such as SCADA infrastructure that operate and monitor laboratory systems and provide research, training, and a platform to test proposed systems.

Integrating multi-microgrid systems to ensure reliable and resilient operation of the power grid.

Various issues including 1) the incorporation of renewable energy sources, 2) generation uncertainty, 3) power quality issues, and 4) angular and voltage stability, will need to be addressed. The application of multi-Microgrid systems has become a crucial solution to ensure the stability and reliability of the electric grid. The approach to be applied performs at both local and global optimization levels. Each energy management system at the MG level uses all resources available (PV, Wind, ESS) to satisfy local demand through local optimization and only transmits surplus energy data signals to the MMG level. In this level, the MMG central center can deliver the power needed if there is any increase in external load in the grid. As a result, they are keeping the frequency and the voltage stable and at the desirable level.

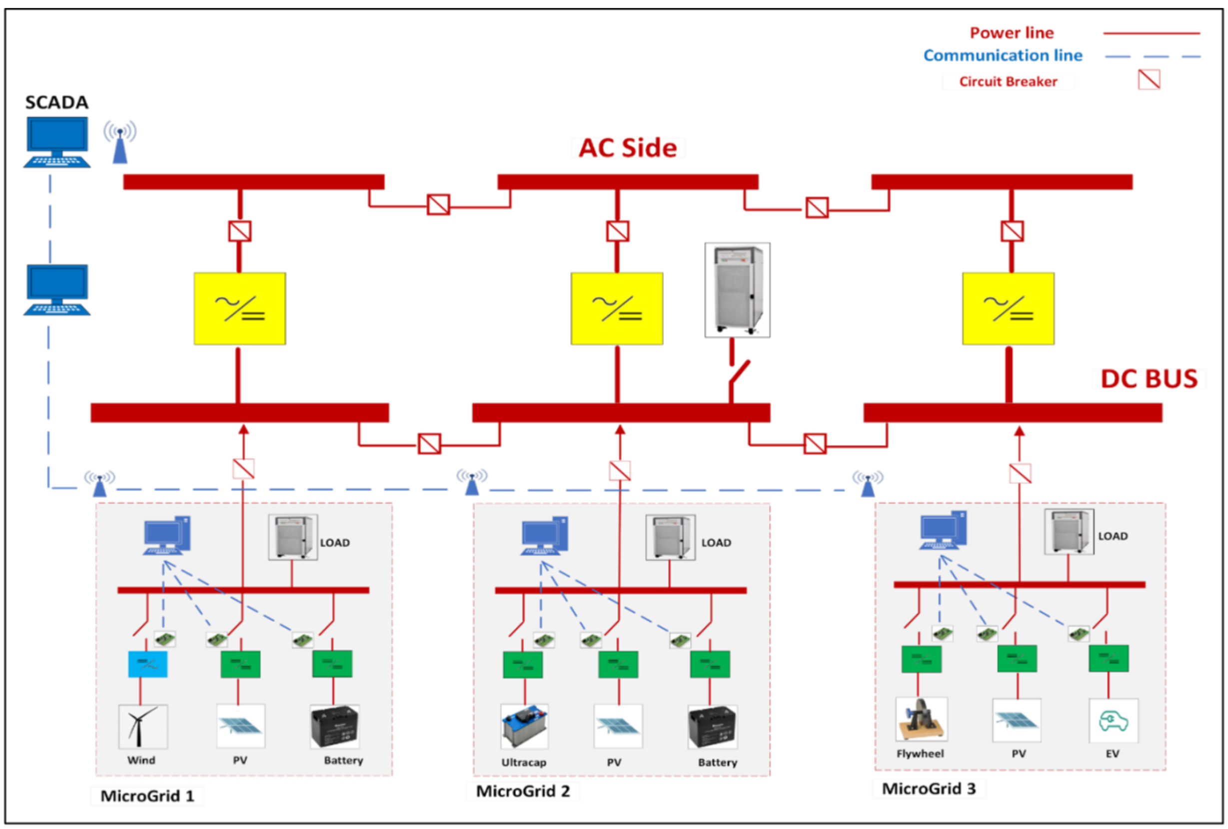

Figure 2: Microgrid structures and the suggested energy management model

Utilizing EVs in grid Voltage/VAR compensation

Advanced management systems are crucial to controlling this aggregated power efficiently to meet the load demand in normal and abnormal operating conditions. These renewable energy resources could be in one location, such as the Roscoe wind farm in Texas and the Solar Star in California, or segregated, as with the private PV small systems at homes. The high penetration of these intermittent-in-nature renewable energy resources (RERs) must be attached to energy storage systems (ESSs) to stabilize the power system network. One of the feasible approaches is to use electric vehicles (EVs) as energy storage or demand response tools to deal with the variation in renewable energy generation. However, the high penetration of EVs and RERs would stress the existing infrastructure of distribution networks and cause several challenges, such as voltage and frequency regulation issues. For instance, during peak power generation by the RES, insufficient load problems could cause overvoltage problems. On the contrary, high penetration levels of electric vehicle charging stations will increase demand on the grid, consequently resulting in Undervoltage issues.

Overvoltage and Undervoltage issues can arise simultaneously in multi-feeder distribution networks due to the stochastic nature of renewable energy and the demand for EV charging. As a result, voltage management becomes difficult, and traditional voltage control devices, including on-load tap changers (OLTCs), may experience quick wear and tear due to prolonged use. Thus, smart charging strategies and the vehicle-to-grid concept were recently utilized in regulating the distributed network voltage and grid ancillary services. There are two ways to use the EVs as energy storage devices: one as an active power support to the power grid during peak hours and for V2G charging stations in the parking lots; however, this could cause degradation in the battery's lifetime. The second is a form of reactive power compensation, which has no degradation effect on the battery besides supporting the grid voltage. To achieve this, advanced distributed management systems (ADMS) are mandated. The EVs' information, such as their reactive power margin, state of energy, and positions, are gathered promptly through a communication layer by the system operators (SOs) in each charging station and sent to a higher master control center (MCC) as shown in Figure 1. Based on these data, reactive power dispatch and load forecasting studies will be done at the MCC, and the decisions will be sent back to the SOs to determine the charging or discharging power for each EV.

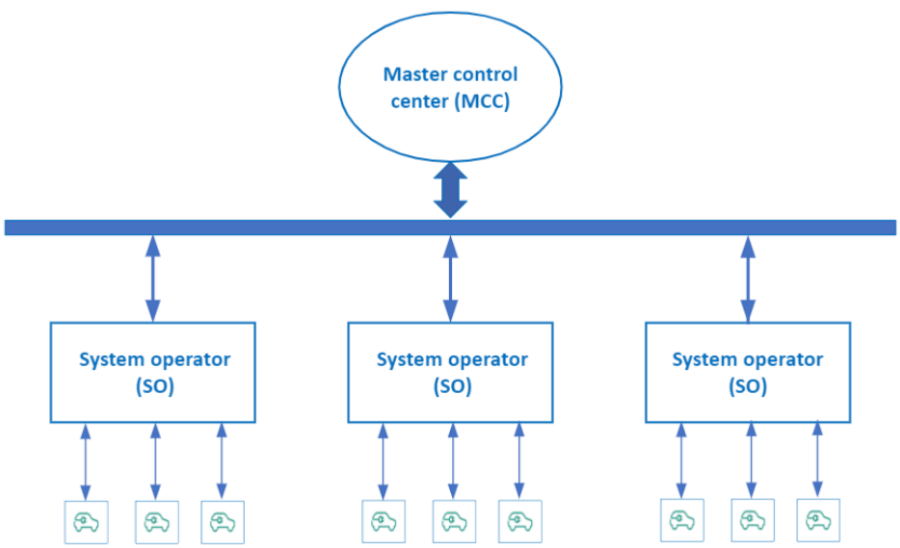

Figure 3: Voltage/VAR control structure for EVs

Inverter-based resources in distributed generation and bulk power supply

The introduction of microgrids improves reliability and resilience, increases the use of renewable sources, and reduces the cost of distributed energy resource (DER) equipment in conventional power systems. While inverter-based resources (IBRs) can be either grid-following or grid-forming, in some cases of IBR, inverters energize an entire microgrid. In grid-following mode, the utility controls the regulation of voltage and frequency. In grid-forming operation, however, inverters regulate voltage and frequency at their interconnection point. Compared with the conventional power system, IBRs show different behavior under fault conditions. To elaborate, as a result of the fault current properties of IBRs, IBRs create a substantial difference in the fault current profile between grid-connected and microgrid-islanded modes and between IBR-dominant or rotating machine-dominant configurations. At the distribution system level, IBRs pose several protection challenges, for instance, sympathetic tripping, coordination loss, protection blinding, and failed auto reclosing, but they do not exhibit conventional system's short circuit behavior, including transient, sub-transient, and steady-state responses.

Grid-connected inverters, having an H-bridge topology, are commonly connected to the grid via a transformer that gives galvanic isolation. Moreover, the inverter side of the transformer is ungrounded while the grid side is grounded. Although this arrangement protects the inverter, fails to "see" the importance of the zero-sequence current during asymmetric faults. The solution to this problem could be replacing conventional H-bridge topology with a neutral-point-clamped (NPC) topology. Although NPCs are more complex circuit and control-wise, with primary and secondary grounded transformers, they can "see" and respond to zero-sequence voltages from the grid side. Moreover, traditional distribution protection schemes that heavily depend on fuses and reclosers are not expected to work well in IBR-sourced microgrids.

Most inverters used in IBRs utilize current limit techniques to protect semiconductor switches. As a result, the inverter current shows a very short transient, fewer than two 60 Hz cycles. Then it returns to a steady-state fault current that is typically around 1.1–1.5 pu of the inverter's current rating during a fault condition. To mitigate this problem, inverters can be manufactured to increase the magnitude and duration of the fault current. Although this may be promising, it potentially increases the size, complexity, and cost, which will also harm microgrid dynamics. Another solution to this problem is Undervoltage relaying, which does not require a communication layer. Although Undervoltage relaying readily indicates the existence of a fault, it does not work well in identifying the fault's location. With a communication layer and a high degree of accuracy, a differential protection method can be utilized, and it is typically implemented in the form of a fault location, isolation, and service restoration (FLISR) system, mostly in distribution systems. Alongside the communication network, expensive FLISR requires breakers, relays, and associated transducers at both ends of every protected zone.

Furthermore, utilizing wideband gap power semiconductor devices in high-frequency multilevel inverter converter topology may bring a power-dense solution where a higher switching frequency permits the use of smaller components in the low-pass filter. That extracts the 60-Hz component from the switched waveform, and higher-voltage operation can lead to greater operating efficiency through reduced resistive losses. Having said that a combinational adaptive protection method may be utilized for the utmost performance under various fault conditions in an advanced distribution management system (ADMS). Adaptive protection is a real-time system that can modify protective actions according to changes in the system's condition having treads of grid-following and grid-forming modes. To elaborate further, this method can connect bidirectional power-sharing between AC and DC systems. It can change the protection scheme and settings during mode changes from grid-connected to islanded operation with updated short circuit current values depending on whether the grid is available to provide higher fault current levels.

Overall, interconnected inverter-based resources significantly impact a traditional power system's power generation, transmission, distribution, and consumer sectors. Moreover, it is considered to be the future, and according to North American Reliability Corporation (NERC), "The IEEE P2800 team has an aggressive schedule to complete this standard due to the gravity of its importance for North America, and it is striving for approval and adoption by end of 2021. In the meantime, utilities should make sure that their interconnection requirements are sufficiently clear to ensure reliable operation and performance of inverter-based resources connecting the bulk power supply (BPS)." Above all, it can certainly state that with more microgrids in power system architecture, inverters could potentially perform islanded operations and interact with one another for active and reactive power share even in a catastrophic power failure.

Finally, Energy Systems Research Lab (ESRL) of Florida International University (FIU), with its state-of-the-art smart grid test bed, has been conducting numerous federally funded research projects related to electrical energy systems on land, in space, and at sea for the last 20 years. This kind of research space, coupled with expert scientists and researchers, keeps modernizing itself to comply with future energy system requirements. Regarding IBRs, three microgrids having IBRs, such as solar photovoltaics, wind energy conversion system (WECS), and energy storage systems (ESS), researchers research to develop novel circuit to system-level components, architecture, and algorithms. With ESRLs in-house circuit, converter, control, protection, and system-level research and development facility, the researchers keep upgrading conventional converters with novel converter topologies and incorporating communication for security and protection networks. The novel control, security, and protection algorithm ESRL produces ensure its place ahead of time.

References:

[1] Z. Bie, P. Zhang, G. Li, B. Hua, M. Meehan and X. Wang, "Reliability Evaluation of Active Distribution Systems Including Microgrids," in IEEE Transactions on Power Systems, vol. 27, no. 4, pp. 2342-2350, Nov. 2012, doi: 10.1109/TPWRS.2012.2202695.

[2] S. Bahramirad et al., "Guest Editorial: Special Section on Asset Management in Smart Grid," in IEEE Transactions on Smart Grid, vol. 6, no. 2, pp. 953-954, March 2015, doi: 10.1109/TSG.2015.2394053.

[3] Y. Li, Peng Zhang, Lingyu Ren and T. Orekan, "A Geršgorin theory for robust microgrid stability analysis," 2016 IEEE Power and Energy Society General Meeting (PESGM), Boston, MA, USA, 2016, pp. 1-5, doi: 10.1109/PESGM.2016.7741211.

[4] A. Saint-Pierre and P. Mancarella, "Active Distribution System Management: A Dual-Horizon Scheduling Framework for DSO/TSO Interface Under Uncertainty," in IEEE Transactions on Smart Grid, vol. 8, no. 5, pp. 2186-2197, Sept. 2017, doi: 10.1109/TSG.2016.2518084.

[5] U.S. Department of Energy Feb Voices of Experience: Insights, Into Advanced Distribution Management Systems. Accessed: May 2020. [Online]. Available: https://www.smartgrid.gov/ADMS.html

[6] A. Dubey, A. Bose, M. Liu, and L. N. Ochoa, ''Paving the way for advanced distribution management systems applications: Making the most of models and data,'' IEEE Power Energy Mag., vol. 18, no. 1, pp. 63–75, Jan. 2020.

[7] S. Vadari, Electric System Operations: Evolving to the Modern Grid. Norwood, MA, USA: Artech House, 2020.

[8] S. Poudel, P. Sharma, A. Dubey and K. P. Schneider, "Advanced FLISR With Intentional Islanding Operations in an ADMS Environment Using GridAPPS-D," in IEEE Access, vol. 8, pp. 113766-113778, 2020, doi: 10.1109/ACCESS.2020.3003325.

[9] S. Department of Energy. (Aug. 2016). Advanced Distribution Management System (ADMS) Program. [Online]. Available: https://www. smartgrid.gov/files/ADMS_MYPP_20160824_DRAFT.pdf

[10] A. Dubey, A. Bose, M. Liu, and L. N. Ochoa, ''Paving the way for advanced distribution management systems applications: Making the most of models and data,'' IEEE Power Energy Mag., vol. 18, no. 1, pp. 63–75, Jan. 2020.

[11] Y. Li, P. Zhang, M. Althoff and M. Yue, "Distributed Formal Analysis for Power Networks With Deep Integration of Distributed Energy Resources," in IEEE Transactions on Power Systems, vol. 34, no. 6, pp. 5147-5156, Nov. 2019, doi: 10.1109/TPWRS