Microgrid Simulation Analysis of Critical Loads: Distribution Planning for Nonhomogenous EV Distributions

George Nail
Klipshe School of Electrical and Computer Engineering
New Mexico State University
Las Cruces, USA
grnail@nmsu.edu

Olga Lavrova
Klipshe School of Electrical and Computer Engineering
New Mexico State University
Las Cruces, USA
olavrova@nmsu.edu

Jamal Mamkhezri
Department of Economics, Applied Statistics & International Business
New Mexico State University
Las Cruces, USA
jamalm@nmsu.edu

Nataraj Pragallapati
Klipshe School of Electrical and Computer Engineering
New Mexico State University
Las Cruces, USA
nataraj@nmsu.edu

2021 IEEE International Electric Machines & Drives Conference (IEMDC) | 978-1-6654-0510-2/21/$31.00 ©2021 IEEE | DOI: 10.1109/IEMDC47953.2021.9449554

***Abstract*— In the last several decades, public interest for electric vehicles (EVs) and research initiatives for smart AC and DC microgrids have increased substantially. Although EVs can yield benefits to their use, they also present new demand and new business models for a changing power grid. Some of the challenges include stochastic demand profiles from EVs, unplanned load growth by rapid EV adoption, and potential frequency (harmonics) and voltage disturbances due to uncoordinated charging. In order to properly account for any of these problems, an accurate and validated model for EV distributions in a power grid must be established. This model (or several models) may then be used for economic and technical analyses. This paper supplies insight into the impact that EVs play in effecting critical loads in a system, and develops a theoretical model to further support a hardware in-the-loop (HIL) real time simulation of modelling and analysis of a distribution feeder with distributed energy resources (DERs) and EVs based on existing data compiled.**

Keywords—distributed energy resources (DERs), electric vehicles (EVs), hardware in-the-loop (HIL), microgrids, distribution planning, reliability, resiliency, power systems, variable loads, real-time simulation, power grid modeling, economic data, critical loads

I. Introduction

With a changing power grid moving towards a future of smart microgrids, there has been much debate of centralized vs. decentralized control schemes, AC vs. DC microgrids, communication and protocol variations, battery limitations, renewable energy penetration impact and composition of DERs to a microgrid [1]. Beyond control schemes [2] and protection protocols is a growing necessity to properly address stochastic loads and generation components that will integrate to form tomorrow's power grid [2]. To completely describe stochastic model formulation, we need to address renewable energy, energy storage, and electric vehicles simultaneously. Additionally, for electric vehicles, issues of charging methods [3][4], harmonic and transient impacts, inverter interfacing [5], voltage sags, power quality [6], privacy of the customer, and cyber-security measures should be analyzed [7].

Similar to the makings of a benchmark testbed for microgrid configurations [8], the proper model to learn the impacts of EVs are currently being developed. The probabilistic nature of EVs have prompted a push in research towards appropriately estimating the load produced by stochastic charging and discharging by EVs and the impact EVs have on a distribution system for planning and reliability purposes [9][10][11][12]. In one paper, the IEEE 13-bus test feeder is used to analyze, in a standard fashion, critical grid stability with various scenarios of EVs [11]. In several papers, Monte Carlo simulations are formulated involving a range of EV makes to more adequately determine the most likely driving distances and locations of EVs in a region [9][10][12]. The first of these papers also includes the sensitivities in a mobility distribution assessment of "socio-geographical" influences on the location of EVs [10]. This first reference paper most adequately accounts for a wide range of EV models, as well as data backing a distribution of EVs in a model [10]. This analysis outlines how one may then determine the approximate load produced by a nonhomogeneous EV generation, shown critical to know as in another paper in which similar probabilistic determinations for an EV load were found [13].

As just overviewed, some approaches to studying EVs construct too general a scope whereas others too specific. A more nuanced model, analysis, and EV distribution is necessary to founding a greater understanding of system protection and distribution planning. This paper will, in an effort to establish a proper model and aid the research community in understanding EV impacts on the grid, evaluate a microgrid-like distribution system, assert a slight region specific EV distribution, and provide critical load impact analyses based on those EVs.

II. Overview of Our Methods

In this paper, we seek to produce several studies for the impact of nonhomogeneous EV distributions on the critical loads of microgrids and microgrid feeders of different types – residential and commercial. This distribution will consist of a representation of generalized compiled data supplied by the U.S. Department of Energy's Alternative Fuels Data Center on EV fleet loads. This data may be then used in several case studies to evaluate EVs and their impact on

This work was partially supported by the NSF Grants \#OIA-1757207 (NM EPSCoR), HRD-1345232, HRD-1914635 and funding from the Electric Utility Management Program (EUMP) at the New Mexico State University.

distribution planning regarding critical load impacts for a residential based load distribution feeder study, a commercial based load distribution feeder study, and a full substation service territory consisting of mixed loads study. To conduct this study, the service territory of a large substation supplying New Mexico State University (NMSU) is used to construct each case study. NMSU's electricity is supplied by one primary substation and assisted by two much smaller substations that aid in providing energy for variable and non-critical loads (i.e. football stadium). NMSU also hosts an on-campus central generation station as a supplemental energy source to the primary substation. By eliminating the central plant and smaller substations that are integrated with voided loads, we may easily design a research space that emulates a microgrid using NMSU's current grid architecture. We are supplied with a one-line diagram of the NMSU electrical system but cannot, unfortunately, provide this data and information in this paper. This one-line diagram, as well as data files for several buildings on campus supply us with the energy consumption of each of the six feeders from the campus substation and some individual building energy consumption information. By compiling this load information with some general assumptions for interpreting the limited information we have from the one-line diagram, we can construct to a MATLAB Simulink model of the NMSU distribution grid.

Something to note about this system is that it is parsed into a 25 kV (23.9 kV) and 5 kV (4.16 kV) regime type system. The campus facility's team is gradually transitioning the whole campus system to a 25 kV system. However, because of this shift and the way that transformers in this one-line diagram designed, much of the 5 kV system is lumped as single loads and then connected to parent 25 kV transformer units. In doing so, this simplification of the system does affect the redundant design of the system, making each of our distribution feeders radially modeled. This adjustment should still justify a generalization of most distribution feeders. A residential feeder and commercial feeder for individual study may then be studied as individual partitions from the larger substation service territory. Of course, there are parts of the 5 kV loads in this system that are connected to another substation. In our attempts to control for the impacts on distribution planning on a single substation service territory, the simplification of lumped loads and selection of independent feeders (feeders only directly connected to a single substation) supports the prudency and resiliency in this simplification for these case studies. In summation these method provide three distribution system case studies, one residential feeder (feeder 1), one commercial feeder (feeder 6), and one whole service territory set of six distribution feeders, backed by real building load data and one-line diagrams from campus facilities of the NMSU grid.

With these models, we can then assign critical loads to various parts of our systems based on recommendations by campus facilities and knowledge of the system's dependencies for each of these assigned critical loads. Our critical loads can be defined as loads that cannot be afforded to be lost in the case of a system blackout or line fault. Similar critical loads in everyday distribution infrastructure would include health clinics, emergency services buildings, care facilities, and some government buildings just to name a few.

The construction of this model is in the interest of NMSU as a method for justifying future renewable energy installations as well as future study capabilities for the power research group at NMSU. By constructing this NMSU distribution model, a data-backed distribution system may be simulated in a synergistic fashion with DERs. Several buildings, including the electrical engineering building, at NMSU have rooftop solar that can be used in the future for HIL modeling the integration of EVs and DERs together.

Finally, an analysis of the impact on critical loads will be conducted in MATLAB Simulink as well as other policy and technical design suggestions [14][15]. This work is intended to be used in future HIL simulations with OPAL-RT with the same model for similar analyses considering the absence of hard data from the actual distribution systems to simulate. We hope to observe in this study to what scale EVs detrimentally physically impede the reliability performance of a distribution feeder off a substation service territory and to what scale EVs adoption accelerates that physical implication based on regional data. Discussion of these implications will play a role in economic policy and current market considerations made by utilities. This model will be useful for the planning of an electric utility for large system demands due to charging and/or distributed energy storage for peak shaving utilizing electric vehicles in a microgrid setting.

A. *Theory for developing EV Distribution*

Regarding the distribution of EVs, different assumptions for the placement of EVs must be made for our models for each type of model. Since we do not possess qualitative data available for current EV plug-in stations on campus as they relate to the lumped loads selected, generalizations must be adopted. For our residential and commercial EV distributions, however, we may be able to adapt data regarding the City of Las Cruces' per county EV adoption for scale and the rooftop solar information by zip code of the Las Cruces service territory for a sense of EV placement in the model. This specificity yields a proportionate number of vehicles registered in the collected data for that zip code as well as a data-backed value of the number of rooftop solar consumers that exist in that given zip code. An assumption in this paper is that those who adopt rooftop solar are also those who are most likely to adopt EVs. These numbers will then be divided in accordance with the socio-economic data supplied and possibly applied by exploiting past Monte Carlo techniques from other papers [9][10][12].

B. *Adaptation of EV data to New Mexico State University (NMSU) System*

After having produced an adequate distribution of EVs from very broad data supplied for the City of Las Cruces data, this EV distribution will be adapted as variable battery sources similar but not identical to the buildings in our model. First, however, the existing model will be partitioned into identified critical loads, residential loads, and commercial. Selecting EV injections with be applied randomly and individually in the single-phase residential model and randomly but lumped in the commercial model. Once EV injection points in the model are defined, these values will be scaled to match that of current adoption of EVs in the city (including NMSU campus adoption). After EV injection assignment and scaling for EV penetration, we may then change the EV charging types using different assumptions provided in the computation of EV loading using the DOE's Alternative Fuels Data Center on EV fleet loads. Current estimates to extreme adoption stipulations simulated against existing infrastructure can be used to measure loading pressures critical transformers and thereby lead to considerations in future design. In doing so, we can recommend suggestions in considering reliability and resiliency for these types of changing systems.

C. *MATLAB Simulink Model and Overview of Study*

It's important to point out that this paper and later, provided results, thesis is intended to aid in constructing tools and methods for studying EVs. Past models are too specific to the study area and others are too broad. This work is made in hopes of supplying the power group at NMSU with tools to conduct HIL studies with DERs and future EV adoption and to add to add a nuanced method of realism and generalization for analyzing variable loads like EVs within an adaptable context for designing distribution systems around the globe.

III. Expected Data and Results

The results to be drawn from the model above will include a summary of the model created and methodology proposed for making similar models like it. Included will be an overview of the voltage sag impact of our studied distribution of EVs on critical loads and the system. This will then develop into a discussion of whether this difference matters when compared against comparable models with different distributions. MATLAB Simulink data will be discussed as well as the macro (possibly tabulated) information regarding the final model's load profiles and considerations for critical loads, if permitted to release this information (possibly bounded by non-discloser agreements (NDAs)).

IV. Conclusions and Future Work

The conclusions we expect to draw are that some form of updated infrastructure (specifically transformers) evaluation regularly take place for utilities, automated metering infrastructure (AMI) be put in place to monitor reliability threatening, greater considerations for greater variable line loading at the distribution level in planning be accounted for, and that similar analyses of rapid EV adoption take place in other regions of the country for validation. Certainly, at New Mexico State University, this model will be used in additional real-time simulations to facilitate power electronic, reliability metrics, cyber-security, and economic policy implications utilizing a model that considers nonhomogeneous EV distributions and their behavioural irregularities. Furthermore, work will be done with these created models for looking at microgrid integration of DERs using HIL with OPAL-RT with emphases in system protection. Future studies may also include that of studying harmonics with EV charging in scale. Entities interested in this type of research include other research universities and institutions involved with IEEE, governmental research arms including NSF funding this work, and companies interested in using realistic simulations for product development and proof of concept in solar, electric vehicles, and battery circle.

Acknowledgment

This work was partially supported by the NSF Grants \#OIA-1757207 (NM EPSCoR), HRD-1345232, HRD-1914635 and funding from the Electric Utility Management Program (EUMP) at the New Mexico State University.

References

[1] C. Liu, K. T. Chau, D. Wu and S. Gao, "Opportunities and Challenges of Vehicle-to-Home, Vehicle-to-Vehicle, and Vehicle-to-Grid Technologies," in Proceedings of the IEEE, vol. 101, no. 11, pp. 2409-2427, Nov. 2013.

[2] M. F. Zia, E. Elbouchikhi, M. Benbouzid, Microgrids energy management systems: A critical review on methods, solutions, and prospects, Applied Energy, Volume 222, 2018, Pages 1033-1055, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2018.04.103.

[3] X. Huang, Y. Fu, J. Zhang, K. He, H. Cheng and H. Zhang, "The Impact of Electric Vehicle Development on Grid Load Power and Electricity Consumption," 2019 12th International Conference on Intelligent Computation Technology and Automation (ICICTA), Xiangtan, China, 2019, pp. 158-16.

[4] D. Niculae, M. Iordache, M. Stanculescu, M. L. Bobaru and S. Deleanu, "A Review of Electric Vehicles Charging Technologies Stationary and Dynamic," 2019 11th International Symposium on Advanced Topics in Electrical Engineering (ATEE), Bucharest, Romania, 2019, pp. 1-4.

[5] W. Choi, W. Lee and B. Sarlioglu, "Reactive power compensation of grid-connected inverter in vehicle-to-grid application to mitigate balanced grid voltage sag," 2016 IEEE Power and Energy Society General Meeting (PESGM), Boston, MA, 2016, pp. 1-5.

[6] A. Cai, Y. Yu, L. Xu, Y. Niu and J. Yan, "Review on reactive power compensation of electric vehicle charging piles," 2019 22nd International Conference on Electrical Machines and Systems (ICEMS), Harbin, China, 2019, pp. 1-4.

[7] A. K. Karmaker, S. Roy and M. R. Ahmed, "Analysis of the Impact of Electric Vehicle Charging Station on Power Quality Issues," 2019 International Conference on Electrical, Computer and Communication Engineering (ECCE), Cox'sBazar, Bangladesh, 2019, pp. 1-6.

[8] M. N. Alam, S. Chakrabarti and X. Liang, "A Benchmark Test System for Networked Microgrids," in IEEE Transactions on Industrial Informatics, vol. 16, no. 10, pp. 6217-6230, Oct. 2020, doi: 10.1109/TII.2020.2976893

[9] S. Huang and D. Infield, "Monte Carlo modelling for domestic car use patterns in United Kingdom," 2014 International Conference on Connected Vehicles and Expo (ICCVE), Vienna, 2014, pp. 68-73.

[10] S. Barghi-Nia and F. Sirois, "Development of stochastic models for assessing the impact of Electric Vehicles in distribution grids," 2015 IEEE Power & Energy Society General Meeting, Denver, CO, 2015, pp. 1-5, doi: 10.1109/PESGM.2015.7286166

[11] V. Vita and P. Koumides, "Electric Vehicles and Distribution Networks: Analysis on Vehicle to Grid and Renewable Energy Sources Integration," 2019 11th Electrical Engineering Faculty Conference (BulEF), Varna, Bulgaria, 2019, pp. 1-4.

[12] J. Li et al., "Sequential model of the grid load structure with electric vehicle load," 2016 China International Conference on Electricity Distribution (CICED), Xi'an, 2016, pp. 1-4.\

[13] F. Chen, Z. Chen, H. Dong, Z. Yin, Y. Wang and J. Liu, "Research on the Influence of Electric Vehicle Multi-Factor Charging Load on a Regional Power Grid," 2018 10th International Conference on Measuring Technology and Mechatronics Automation (ICMTMA), Changsha, 2018, pp. 163-166.

[14] B. Arellano, S. Sena, S. Abdollahy, O. Lavrova, S. Stratton and J. Hawkins, "Analysis of electric vehicle impacts in New Mexico urban utility distribution infrastructure," 2013 IEEE Transportation Electrification Conference and Expo (ITEC), Detroit, MI, 2013, pp. 1-6.

[15] G. Stoeckl, R. Witzmann and J. Eckstein, "Analyzing the capacity of low voltage grids for electric vehicles," 2011 IEEE Electrical Power and Energy Conference, Winnipeg, MB, 2011, pp. 415-420..

[16] O. Marcincin, Z. Medvec and P. Moldrik, "The impact of electric vehicles on distribution network," 2017 18th International Scientific Conference on Electric Power Engineering (EPE), Kouty nad Desnou, 2017, pp. 1-5.

[17] J. Lei, Z. Xiaoying, Z. Labao and W. Kun, "Coordinated scheduling of electric vehicles and wind power generation considering vehicle to grid mode," 2017 IEEE Transportation Electrification Conference and Expo, Asia-Pacific (ITEC Asia-Pacific), Harbin, 2017, pp. 1-5.

[18] Augustine, S., Reno, M. J., Brahma, S. M., & Lavrova, O. (2020). Fault Current Control and Protection in a Standalone DC Microgrid Using Adaptive Droop and Current Derivative. IEEE Journal of Emerging and Selected Topics in Power Electronics.

[19] Quiroz, J. E., Reno, M. J., Lavrova, O., & Byrne, R. H. (2017, April). “Communication requirements for hierarchical control of volt-VAr function for steady-state voltage”. In 2017 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT) (pp. 1-5). IEEE.

[20] N. Pragallapati, S. J. Ranade and O. Lavrova, "Cyber Physical Implementation of Improved Distributed Secondary Control of DC Microgrid," 2021 1st International Conference on Power Electronics and Energy (ICPEE), Bhubaneswar, India, 2021, pp. 1-5, doi: 10.1109/ICPEE50452.2021.9358705.