UNIVERSITY OF TECHNOLOGY SYDNEY

Managing Unbalanced Distribution Grid with Distributed Renewable Energy Sources and Electrical Vehicles

by Md Rabiul Islam

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Certificate of Original Authorship

I, Md Rabiul Islam declare that this thesis, is submitted in fulfillment of the requirements for the award of Doctor of Philosophy, in the School of Computer Science, Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Publications and Conference Contributions

The following publications are part of the thesis.

Peer-reviewed international journal publications

[1] M. R. Islam, H. Lu, M. J. Hossain, and Li. Li, "Mitigating unbalance using distributed network reconfiguration techniques in distributed power generation grids with services for electric vehicles: A review," Journal of Cleaner Production, vol. 239, p. 117932, December 2019. **(Published)**

[2] M. R. Islam, H. Lu, J. Hossain, M. R. Islam, and L. Li, "Multi-objective optimization technique for mitigating unbalance and improving voltage considering higher penetration of electric vehicles and distributed generation," IEEE Systems Journal, vol. 14, issue 3, pp. 3676-3686, September 2020. **(Published)**

[3] M. R. Islam, H. Lu, M. R. Islam, J. Hossain, and L. Li, "An IoT- based decision support tool for improving the performance of smart grids connected with distributed energy sources and electric vehicles," IEEE Transactions on Industry Applications, vol. 56, issue 4, pp. 4552- 4562, April 2020. **(Published)**

[4] M. R. Islam, H. Lu, J. Hossain, and L. Li, "An Optimal Coordination of Electric Vehicles and Distributed Generators for Voltage Unbalance and Neutral Current Compensation," IEEE Transactions on Industry Applications, vol. 57, issue 1, pp. 1069- 1080, November 2020. **(Published)**

[5] M. R. Islam, H. Lu, M. R. Islam, J. Hossain, and L. Li, "Coordinating Electric Vehicles and Distributed Energy Sources Constrained by Users Travel Commitment," IEEE Transactions on Industrial Informatics, Early Access, November 2021 **(Published)**

Peer-reviewed international scientific conference publications

[6] M. R. Islam, H. Y. Lu, M. J. Hossain, and L. Li, "Improving power quality of distributed PV-EV distribution grid by mitigating unbalance," in 2019 IEEE International Conference on Industrial Technology (ICIT), Melbourne, Australia, Feb-2019, pp. 643-648. **(Published)**

[7] M. R. Islam, H. Lu, G. Fang, L. Li, and M. J. Hossain, "Optimal dispatch of electrical vehicle and pv power to improve the power quality of an unbalanced distribution grid," in 2019 International Conference on High Performance Big Data

and Intelligent Systems (HPBD&IS), Shenzhen, China, May 2019, pp. 258-263. **(Published)**

[8] M. R. Islam, H. Y. Lu, M. J. Hossain, and L. Li, "A comparison of performance of GA, PSO and DE algorithms for dynamic phase reconfiguration technology of a smart grid," in 2019 IEEE Congress on Evolutionary Computation (CEC), Wellington, June 2019, pp. 858-865. **(Published)**

[9] M. R. Islam, H. Y. Lu, M. J. Hossain, and L. Li, "Compensating neutral current, voltage unbalance and improving voltage of an unbalanced distribution grid connected with ev and renewable energy sources," in 2019 22nd International Conference on Electrical Machines and Systems (ICEMS), Harbin, China, August 2019, pp. 1-5. **(Published)**

[10] M. R. Islam, Lu Haiyan, M. J. Hossain, Li Li "Reducing Neutral Current of a higher EV Penetrated Unbalanced Distribution Grid", Dec 10 – 12, 2019, 9th International Conference on Power and Energy Systems, Perth, Australia, December 2019, pp. 1-5. **(Published)**

[11] M. R. Islam, Lu Haiyan, M. J. Hossain, Li Li "Multi-objective Dynamic Phase re-configuration Technique to Mitigate the Unbalance Due to Penetration of Electric Vehicles", Dec 10 – 12, 2019, 9th International Conference on Power and Energy Systems, Perth, Australia, December 2019, pp. 1-5. **(Published)**

Abstract

With the intensifying efforts to combat climate change by reducing greenhouse gases, there is an increasing trend to use electric vehicles (EVs) and renewable energy sources (RES). With the increasing penetration level of RES and EVs in low voltage distribution grids, the unbalance of distribution grids has a significant negative impact and is therefore a critical issue. This thesis addresses this issue by suggesting several effective ways to mitigate grid unbalance.

Firstly, this thesis proposes a new index, the imbalance factor, to represent the degree of imbalance among phases in a distribution grid. A higher value of this imbalance factor means that one phase has more EVs connected compared to the other two phases. Using this factor, the impacts of the uncoordinated integration of EVs among phases at different levels of phase imbalance were investigated. The results show that the degree of voltage unbalance and the neutral current are higher when the imbalance factor increases, thus, this imbalance factor is confirmed as an effective index of unbalance of a distribution grid.

Secondly, this thesis proposes an improved control method for utilizing the resources from distribution network operators (DNOs) and PV owners to minimize the voltage unbalance factor and the neutral current by solving a multi-objective optimization problem. The control method jointly controls phases at the nodes and PVs in phases to mitigate grid unbalance without coordinating EVs, changing total demand, and the total generation of a distribution grid. This control method eliminates the communication and the computation complexity caused by EV coordination. The efficacy of this method is evidenced by the superior performance of a simulated Australian distribution grid.

Thirdly, this thesis proposes a novel approach for eliminating grid unbalance, which is a novel hierarchical control strategy for optimal coordination of EVs. This control strategy consists of two kinds of controllers arranged in a hierarchical structure, with the central controller at the top layer and the local controllers at the bottom layer. An improved EV converter is also designed and implemented for the local controller to compensate for the neutral current. The central controller coordinates EVs at the selected sensitive nodes by considering the capability of local controllers after jointly coordinating phases at each node

and PV dispatch. EV coordination at the sensitive nodes not only reduces communication and computation complexity, but also convenient for EV users.

Lastly, this thesis proposes an improved control strategy to mitigate grid unbalance and manage demand-generation by maximizing RES and minimizing EV charging cost, considering the individual EV user's hardware characteristics and ensuring that each EV's required driving distance can be achieved. Compared with methods using a central controller only, which need to account for all of the information, this new control method uses a local controller in each EV to reduce the communication overhead in gathering information and decrease the computational load. This local controller processes data related to each EV user's hardware characteristics and their driving needs and only sends the EV's charging priority and required energy to the central controller. The central controller then uses this information, about the energy tariff from the retailer, and the present grid performance to tune the EV's charging or discharging power. This new control method is implemented in a simulation of an Australian LV distribution grid. The simulation results show that this method not only reduces the neutral current and voltage imbalance, it also maximizes the use of RES and ensures that the EV travel commitment can be met.

In summary, this thesis successfully addresses the issue of LV distribution grid unbalance due to the high level of penetration of RES and EVs by proposing a suite of three control methods. These methods mitigate and/or eliminate grid unbalance while maximizing the use of RES in a LV distribution grid for the convenience of EV users.

Keywords: voltage unbalance; neutral current; travel requirement; PV re-phasing; EV coordination; optimal dispatch; mitigating unbalance.

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Nomenclature

Global abbreviations used in this thesis:

Fig.	Figure
PV	Photovoltaic
DG	Distributed Generations
RES	Renewable Energy Sources
LV	Low Voltage
EV	Electric Vehicle
WT	Wind Turbine
DNO	Distribution Network Operator
NGV	Neutral to ground
3P4W	Three-phase four-wire
DNR	Distribution Network Reconfiguration
LBI	Load Balancing Index
PUI	Phase Unbalance Index
VUF	Voltage Unbalance Index
CUF	Current Unbalance Index
LVUR	Line Voltage Unbalance Rate
PVUR	Phase Voltage Unbalance Rate
DFR	Distribution Feeder Reconfiguration
SCADA	Supervisory Control and Data Acquisition
OPDGA	Optimal Distributed Generation Allocation
APF	Active Power Filter
VSI	Voltage Source Inverter

CSI	Current Source Inverter
BES	Battery Energy Storage
SOC	State of Charge
RE	Renewable Energy
DVR	Dynamic Voltage Restorer
D-STATCOM	Distribution Static Compensator
SPOC	Service Point of Connection
DOD	Depth of Discharge
IoT	Internet of Things
MQQT	Message Queuing and elementary transport
ULF	Unbalanced Load Flow
PCC	Point of Common Coupling
SPWM	Sinusoidal Pulse Width Modulation
UMC	User Managed Charging
ARCM	Average Rate Charging Method