ORIGINAL ARTICLE

Automated Dispatch of Wind Power on Microgrid for Voltage Regulation

Nithin S.[1]*, Vijith K.[1], Rajinikandh C.[1], and Sasi K Kottayil[1]

[1]Department of Electrical and Electronics Engineering, Amrita School of Engineering, Coimbatore Amrita Vishwa Vidyapeetham, Amrita University, India.

(**Received** 8 August 2018; **Accepted** 5 October 2018; **Published on line** 1 September 2019)

*Corresponding author: s_nithin@cb.amrita.edu

DOI: 10.5875/ausmt.v9i3.1912

Abstract: The variability of wind power generation adversely affects the grid conditions and the utilities find it challenging to accommodate variations in the injected wind power. To resolve this issue utilities impose curtailment of wind power generation. Demand side management (DSM) strategies have gained popularity among utilities in recent years. An advanced Demand Response (DR) scheme known as Demand Dispatch (DD) enable utilities to reshape demand curve to closely follow generation. An automated DD strategy is proposed as a solution to the issues related to high penetration of wind turbine generators (WTG) on micro grid. It basically balances the WTG power injection with real time controlled dispatchable loads. DD adopts smart communication for real time data collection as well as for dispatchable load management. A field implementation of DD in maintaining voltage stability in a DC microgrid with micro-WTG (m-WTG) is studied. The experiment results presented validate the scheme.

Keywords: Microgrid; wind electric generator; real time data communication; demand dispatch

Introduction

Environmental degradation and depletion of fossil fuels enhanced the development of renewable energy (RE) systems. Though environmentally benign, RE sources in general and wind power in particular is varying in nature and uncontrollable too. Fluctuating wind power penetration on electric power grid has adverse effects such as voltage fluctuation and frequency excursion on the grid [1-2]. Such irregularities challenge generation scheduling and make system operation complex. When power evacuation from wind farms becomes difficult, utilities are forced to curtail wind power generation [3-4]. Yet there is a need to accommodate higher RE penetration on power grids in order to mitigate the dual challenge of climate change on one side and power demand on the other. For example, the intended nationally determined contribution (INDC) of India demands capacity addition of wind power plants [6] by more than 100% in five years from 2017. Energy storage based schemes have been proposed by researchers to compensate the variability in wind power generation [2, 6-8]. Electric Vehicles were identified by a few researchers as a promising medium for distributed energy storage [9-13]. But large number of distributed energy storage systems increases the system cost, yet the operational complexity is not reduced too.

In 2008 Federal Electricity Regulatory Commission (FERC) introduced demand response (DR) [14], through which customers on electric utilities would voluntarily participate in load reduction. DR programs are a big success in reducing peak power demand [14], but it cannot guarantee absorption of excess generation when required. In such scenario an advanced version of DR called demand dispatch (DD) [13, 15] could be useful. Consumer load that can change their consumption pattern, upon request from utility is called Dispatchable Load (DL). DD makes use of DLs and information and communication technology (ICT) in reshaping the demand curve. The utility need to aggregate and precisely control such loads for effective DD operation. DD offers full capabilities of demand side management (DSM), with which the utility can control DLs to exactly match a varying RE generation. DLs could be in the range of a few kilo Watts to Mega Watts and their response time could be from a few milliseconds to seconds [15]. The utility has to aggregate the scattered DLs and connect or disconnect these in synchronism with the wind power injection so as to nullify the effect of the latter. Bulk energy storage units like battery banks and pumped hydro systems too can actively participate in DD as DLs. The advancements in Smart Grid (SG) technology [16-18] facilitate the real time bi-directional communication needed for DD. The study presented in this paper finds DD as a promising solution for handling the fluctuations in power generation under high wind penetration.

This paper reports an investigation on DD, for voltage control in an autonomous DC microgrid solely powered by wind. This is a real time on-field study that uses a micro Wind Turbine Generator (m-WTG) installed on roof top and is powered by natural wind. The on-field study considered operating conditions naturally prevailed at the time of investigation.

Proposed DD Strategy

Electric power utilities primarily depend on Demand aggregators in identifying loads that are capable of flexible operation. Consumers can enroll their loads for DD operation and will benefit with incentives. The communication infrastructure offered by smart grid along with Internet of Things (IoT) will aid in direct control of such loads. Flexible loads such as Electric Vehicle (EV), battery storage units, water pumps, room heaters, HVAC, adaptive lighting systems etc. are few examples of such loads. The charging and discharging of EVs and battery storage systems could be controlled to have flexible demand in the grid. It is not necessary for water heaters, room heaters and HVAC units to be switched off completely; instead their consumption could be varied (reduced/ increased) moderately. In case of DD large number of such loads are aggregated and precisely controlled in real-time without sacrificing the comfort needs of consumers. The DD strategy proposed here assumes that utility have identified and prioritized such loads.

A DC microgrid consisting of a m-WTG is considered for the study. The m-WTG, installed in the roof top Renewable Energy laboratory of Amrita School of Engineering, Coimbatore, has a power rating of 100W at a wind speed of 10m/s. The microgrid is to operate in islanded mode, delivering power to the local loads. It has a battery support to serve DC loads at a nominal voltage of 12 V. DC microgrid is given in Figure 1.

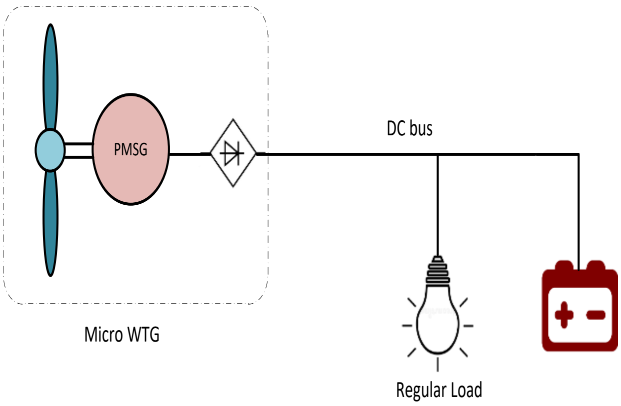

Figure 1. DC microgrid considered for the study.

The task assigned to DD here is to regulate the voltage of the DC microgrid within permissible limits. + 7.5% and – 5% have been assumed as the maximum permissible voltage regulation; it means a range from 11.4 V to 12.9 V, represented as V_L and V_H respectively.
Implementation of DD requires real time synchronized measurements on the microgrid. Real Time Data Collection Unit (RTDCU) [19] developed in this laboratory is custom made for measurements on microgrids. The RTDCU is capable of simultaneously sampling DC voltage, current and then computes power consumption. The RTDCUs are time synchronized with the help of a common triggering pulse and these monitor the m-WTG generation, bus voltage, local demand and change in demand during DD. RTDCUs are equipped with ZigBee to communicate these measurements to a centralized processing unit where decisions are taken. Figure 2 depicts the DD strategy on DC microgrid and Figure 3. shows the RTDCU developed. The regular demand on the microgrid is 20W.

Nithin S. had his under graduate and post graduate degrees in Electrical Engineering and Embedded systems respectively. He is working as an Assistant professor in the Department of Electrical & Electronics Engineering at Amrita Vishwa Vidyapeetham, Coimbatore. His areas of interest include Smart Grid, Demand Side Management and embedded systems design.
Email: s_nithin@cb.amrita.edu

Vijith K. had his under graduate and post graduate degrees in Electrical Engineering and Power Electronics respectively. He is working as an Assistant professor in the Department of Electrical & Electronics Engineering at Amrita Vishwa Vidyapeetham, Coimbatore. His areas of interest include distributed generation and power electronics for smart grid applications.
Email: k_vijith@cb.amrita.edu

Rajinikandh C. had his under graduate degree in Electrical Engineering. He is working as a Lab Assistant in the Renewable energy laboratory under Department of Electrical & Electronics Engineering at Amrita Vishwa Vidyapeetham, Coimbatore. His areas of interest include wind forecasting, electrical machines and power electronics.
Email: c_rajinikandh@cb.amrita.edu

Sasi K Kottayil had his basic and post graduate degrees in Electrical Engineering, in 1980 (REC Calicut) and 1984 (College of Engineering Trivandrum) respectively, and doctoral degree on *Utility Scale Wind Electricity Generation* in 2000 (Jadavpur University. He is working as Professor in the Department of Electrical & Electronics Engineering at Amrita Vishwa Vidyapeetham, Coimbatore, India since 2004. *Renewable Energy Conversions* and *Electrical Energy Conservation and Management* are the areas of his interest.
Email: kk_sasi@cb.amrita.edu

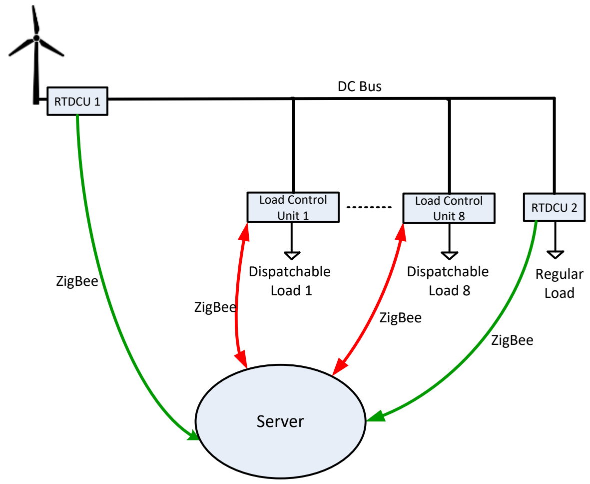

Figure 2. DD strategy on microgrid.

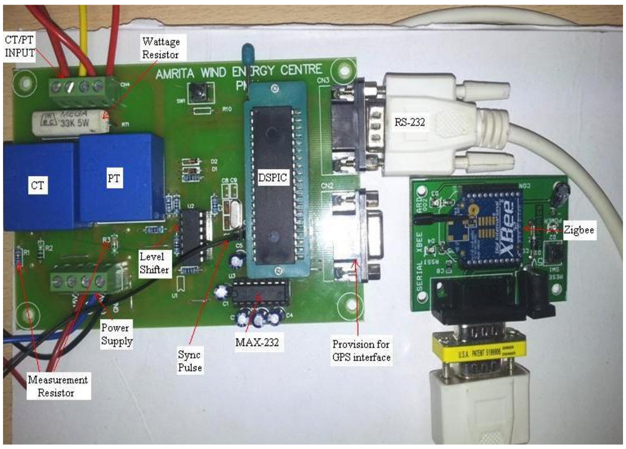

Figure 3. RTDCU developed.

Each DL is connected to the microgrid through a Load Control Unit (LCU). The LCU is equipped with a ZigBee transceiver and a microcontroller to interpret the data and control signals. LCU is capable of power measurement as well. The schematic of LCU is given in Figure 4.

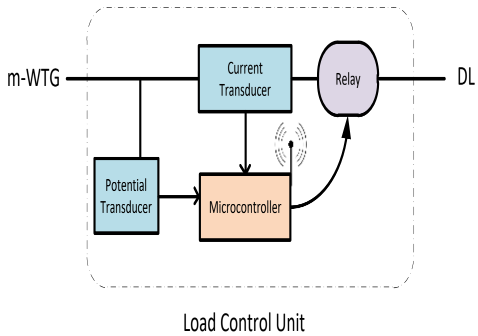

Figure 4. Schematic of LCU.

DD Deployment and Performance

The grid voltage and wind power injection are monitored in real time and DLs are controlled to regulate the grid voltage. The priority of DLs are pre-assigned for the task. A total of 8 DLs are considered for the implementation of DD on the DC microgrid. The power rating of DLs varies from 1W to 5W. The technical specifications of the m-WTG are given in Appendix. Table 1. presents the priority of DLs. The DD algorithm is depicted in Figure 5.

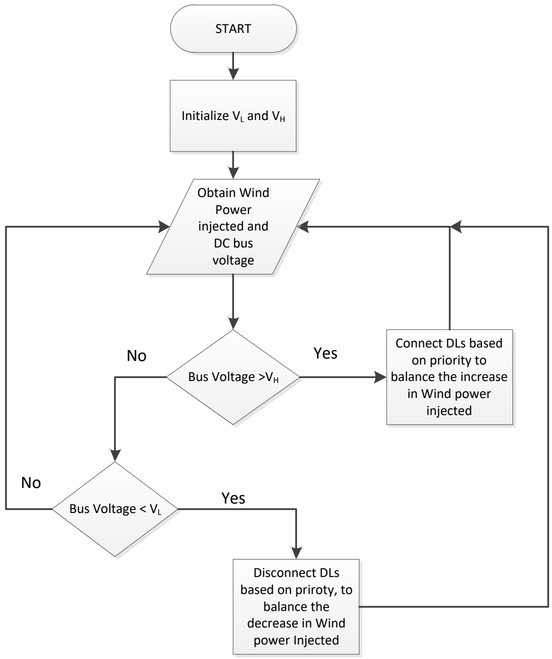

Figure 5. Flow chart of DD.

Table 1. Priority assignment of DLs.

S.No	Power rating (W)	Priority assigned
1	1	1
2	1	3
3	2	1
4	2	2
5	2	3
6	2	3
7	5	5
8	5	3

The varying wind speed measured and recorded at the site chosen for the study (Amrita campus, Coimbatore) is presented in Figure 5. The test period is a little more than 90 minutes. The variation in wind reflected in power injection by the m-WTG and that led to voltage fluctuation in the DC microgrid. Figure 6. depicts these voltage fluctuations during the same period of test. As seen, there are violations of voltage constraint at many instants during the period of observation.

DD has then been deployed to alleviate the voltage fluctuation in the microgrid. Load addition/removal during DD operation is depicted in Figure 7 shows the record of power consumption on the microgrid; the consumption is matched to the real time generation by connection and disconnection of deferrable loads as

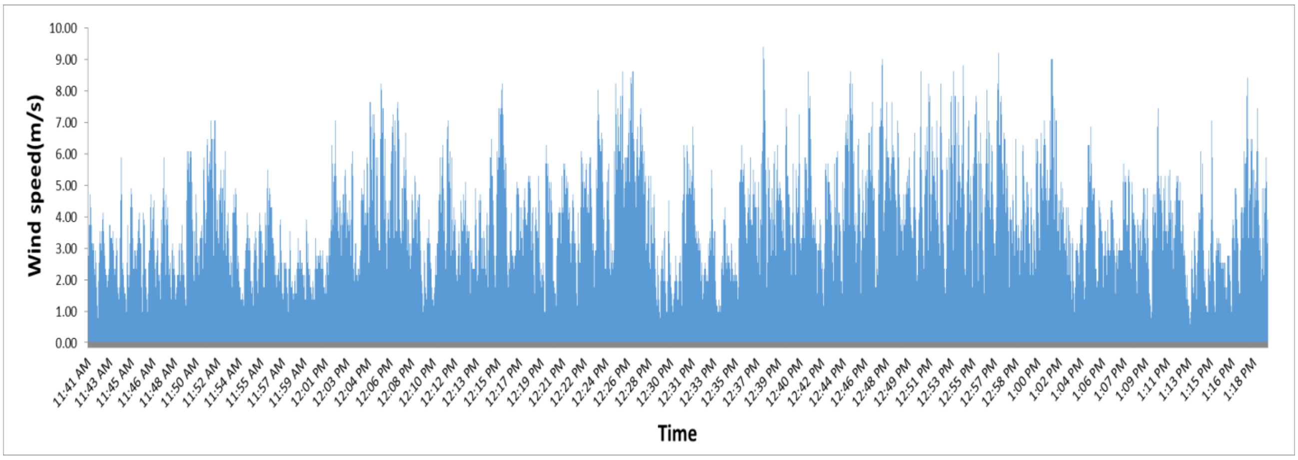

Figure 5. Wind speed recorded (every 1 second) in the month of June 2018 at site.

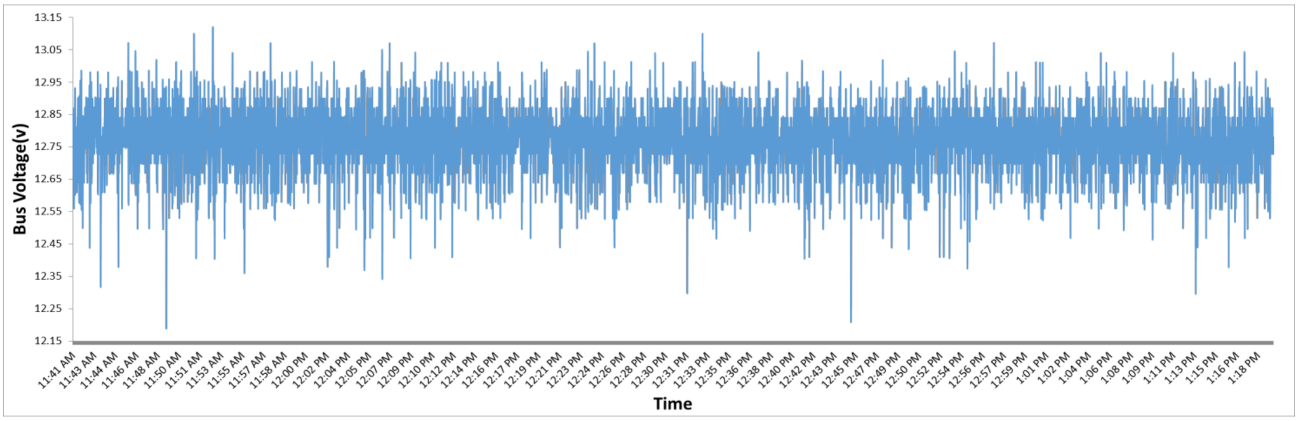

Figure 6. Voltage fluctuations during wind power injection.

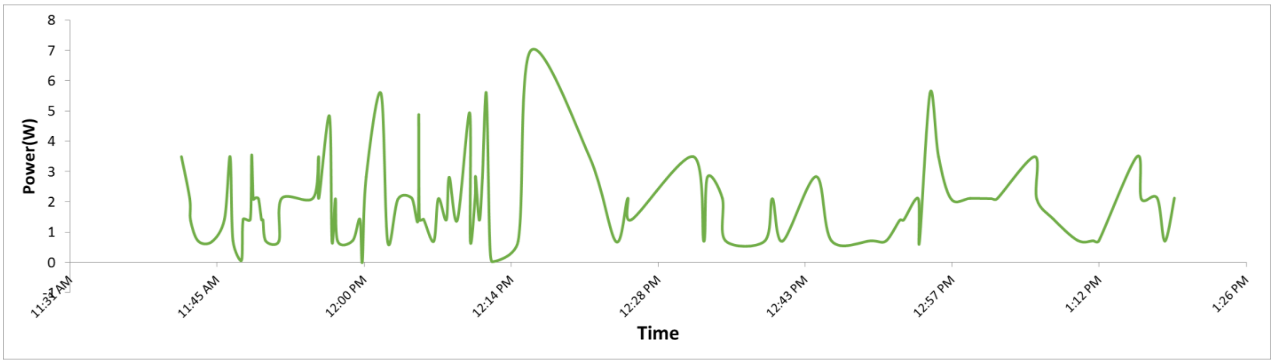

Figure 7. DLs added during DD to maintain bus voltage.

decided by the DD algorithm and implemented through LCU. The rise in Figure 7 is the addition of DLs and fall is the removal of DLs. The profile of grid voltage with DD is shown in Figure 8; obviously, the voltage is maintained within the permissible range.

Conclusion

The operational constraints of a conventional power system to accommodate high RE penetration can be mitigated to a large extent in the smart grid environment. A DD scheme can be viewed as a case where DSM is directly linked with distributed generation and executed in real time using smart grid communication systems. The DD scheme proposed here continuously monitors the amount of power injected by wind and DLs are individually connected or disconnected such that the total power consumption by all connected DLs matches the power injection by the wind in real time.

Advanced Metering Infrastructure (AMI) together with Wide Area Measurement System (WAMS) offers the communication backbone needed for DD operations [18].

The Smart Meter (SM) at consumer premises will act as a gateway for DD and the associated LCU will connect or disconnect individual loads upon request

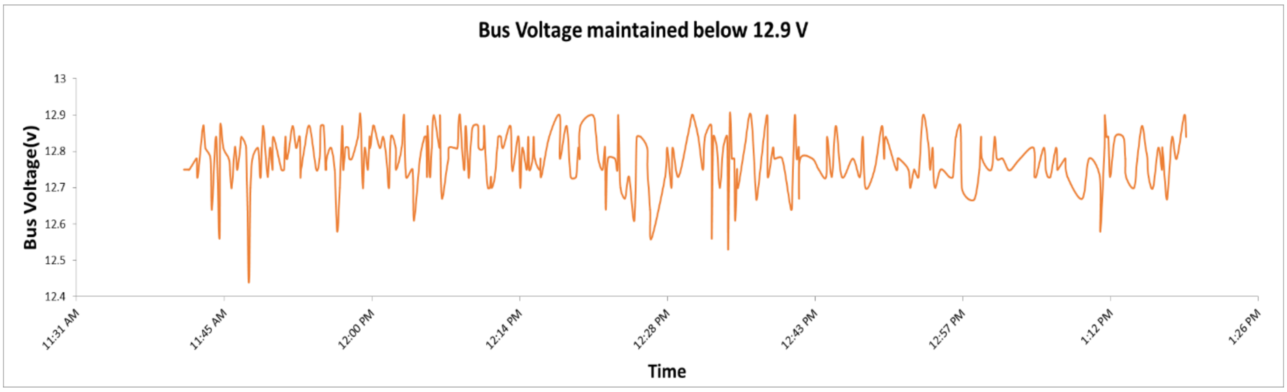

Figure 8. Bus voltage with DD.

from utility.

Appendix

1. micro Wind Turbine Generator(m-WTG)
   PMSG-100W, 24V, Cut-in wind speed - 3m/s

References

[1] Z. Bie, G. Li, H. Liu, and X. Wang, "Studies on voltage fluctuation in the integration of wind power plants using probabilistic load flow," in proceeding of *2008 IEEE Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century*, Pittsburgh, July 20-24, 2008.
doi: 10.1109/PES.2008.4596131

[2] G. Pepermans, J. Driesen, D. Haeseldonckx, R. Belmans, and W. D'haeseleer, "Distributed generation: definition, benefits and issues," *Energy Policy*, vol. 33, no. 6, pp. 787-798, 2005.
doi: 10.1016/j.enpol.2003.10.004

[3] Luo, Guo-liang, Yan-ling Li, Wen-jun Tang, and Xiao Wei, "Wind curtailment of China's wind power operation: Evolution, causes and solutions," *Renewable and Sustainable Energy Reviews*, vol. 53, pp. 1190-1201, 2016.
doi: 10.1016/j.rser.2015.09.075

[4] Cai, Guowei, and Kong, Lingguo, "Techno-economic analysis of wind curtailment/hydrogen production/fuel cell vehicle system with high wind penetration in China." *CSEE Journal of Power and Energy Systems*, vol. 3, no. 1, pp. 44-52, 2017.
doi: 10.17775/CSEEJPES.2017.0007

[5] "India's Intended Nationally Determined Contribution: Working Towards Climate Justice," United Nations Framework Convention on Climate Change, Submission by India.

[6] D.L. Yao, S.S. Choi, K.J. Tseng, and T.T. Lie, "A Statistical Approach to the Design of a Dispatchable Wind Power-Battery Energy Storage System," *IEEE Transactions on Energy Conversion*, vol. 24, no. 4, pp. 916-925, 2009.
doi: 10.1109/TEC.2009.2025331

[7] N.W. Miller, R.S. Zrebiec, R.W. Delmerico, and G. Hunt, "Battery energy storage systems for electric utility, industrial and commercial applications," in proceeding of *Proceedings of 11th Annual Battery Conference on Applications and Advances*, Long Beach, Jan. 9-12, 1996.
doi: 10.1109/BCAA.1996.485001

[8] Q. Li, S. S. Choi, Y. Yuan, and D. L. Yao, "On the Determination of Battery Energy Storage Capacity and Short-Term Power Dispatch of a Wind Farm," *IEEE Transactions on Sustainable Energy*, vol. 2, no. 2, pp. 148–158, 2011.
doi: 10.1109/TSTE.2010.2095434

[9] Shuang Gao, K. T. Chau, Chunhua Liu, Diyun Wu, and C. C. Chan, "Integrated Energy Management of Plug-in Electric Vehicles in Power Grid With Renewables," *IEEE Transactions on Vehicular Technology*, vol. 63, no. 7, pp. 3019–3027, 2014.
doi: 10.1109/TVT.2014.2316153

[10] Junhao Lin, Ka-Cheong Leung, Victor O. K. Li, "Optimal Scheduling with Vehicle-to-Grid Regulation Service," *IEEE Internet of Things Journal*, vol. 1, no. 6, pp. 556–569, 2014.
doi: 10.1109/JIOT.2014.2361911

[11] Qilong Huang, Qing-Shan Jia, and Xiaohong Guan, "Robust Scheduling of EV Charging Load with Uncertain Wind Power Integration," *IEEE Transactions on Smart Grid*, vol. 9, no. 2, pp. 1043-1054, 2016.
doi: 10.1109/TSG.2016.2574799

[12] J. Pahasa and I. Ngamroo, "Coordinated Control of Wind Turbine Blade Pitch Angle and PHEVs Using MPCs for Load Frequency Control of Microgrid," *IEEE Systems Journal*, vol. 10, no. 1, pp. 97–105, 2016.
doi: 10.1109/JSYST.2014.2313810

[13] Keith Dodrill, "Demand Dispatch—Intelligent Demand for a More Efficient Grid," 2011.

[14] Federal Energy Regulatory Commission, Assessment

of demand response and advanced metering: staff report, 2006.

[15] A. Brooks, E. Lu, D. Reicher, C. Spirakis, and B. Weihl, "Demand dispatch," *IEEE Power and Energy Magazine*, vol. 8, no. 3, pp. 20–29, 2010. doi: 10.1109/MPE.2010.936349

[16] S. Massoud Amin and B. F. Wollenberg. "Toward a smart grid: Power delivery for the 21st century," *IEEE Power and Energy Magazine*, vol. 3, no. 5, pp. 34–41, 2005. doi: 10.1109/MPAE.2005.1507024

[17] A. Mao, J. Yu, and Z. Guo, "PMU placement and data processing in WAMS that complements SCADA," in proceeding of *IEEE Power Engineering Society General Meeting, 2005*, San Francisco, June 16, 2005. doi: 10.1109/PES.2005.1489223

[18] Vehbi C. Gungor, Dilan Sahin, Taskin Kocak, Salih Ergut, Concettina Buccella, Carlo Cecati, and Gerhard P. Hancke, "Smart grid technologies: Communication technologies and standards," *IEEE Transactions on Industrial Informatics*, vol. 7, no. 4, pp. 529–539, 2011. doi: 10.1109/TII.2011.2166794

[19] Nithin S., Sivraj P., Sasi K. K., and Robert Lagerstöm, "Development of a real time data collection unit for distribution network in a smart grid environment," in proceeding of *2014 POWER AND ENERGY SYSTEMS: TOWARDS SUSTAINABLE ENERGY*, Bangalore, March 13-15, 2014. doi: 10.1109/PESTSE.2014.6805323