An under voltage-frequency load shedding method for emergency condition of microgrids.

Sarchami O, Shafiee Q, and Bevrani H

Published (to be published) in:1st IEEE Conf. on New Research Achievements in Electrical and Computer Engineering (CBCONF), Tehran, Iran

(Expected) publication date: 2016

An Under Voltage-Frequency Load Shedding Method for Emergency Condition of Microgrids

Omid Sarchami, Qobad Shafiee and Hassan Bevrani
Department of Electrical and Computer Engineering
University of Kurdistan
Sanandaj, Kurdistan, Iran
Emails: Omidsyt@gmail.com; q.shafiee@uok.ac.ir, bevrani@uok.ac.ir

Abstract—Maintaining balance between generations and loads is an essential issue in power electronic-interfaced microgrids. Furthermore, due to inherent changing of operation mode from grid-connected to islanded, the risk of placing the microgrid in emergency condition is increased. Therefore, it is vital to recognize the emergency condition and implement an efficient approach, accordingly. This paper introduces a new algorithm for under voltage-frequency load shedding in AC microgrids. The proposed algorithm uses the system frequency, rate of change of the frequency, and voltage standard deviation parameters to identifying emergency condition properly at the right time and decrease the amount of load shedding to the least. The effectiveness of the proposed approach is evaluated through a typical microgrid test system.

Index Terms- **Emergency control, load shedding, microgrids, frequency index, voltage index.**

I. INTRODUCTION

Literature review shows that recent blackouts occurred due to various forms of instabilities [1]. Socio-economic impact of blackouts are so destructive, therefore review their causes and predict an appropriate approach for the future, is the only remedy [2]. Different forms of instability have been presented. For instance, under frequency load shedding (UFLS) and under voltage load shedding (UVLS) to avoid frequency and voltage instabilities [3], [4]. However, instabilities do not generally happen in specific pure form, being weakness of these methods. At UFLS of conventional power system, there is no fear for load shedding, because the whole system may collapse for a particular load [5].

Recently, several modern emergency control methodologies such as wide area measurement system (WAMS)-based emergency control, Simultaneous voltage and frequency-based load shedding, and wave propagation-based emergency control have been investigated [6].

Microgrid (MG) is a small scale power system formed at distribution level to improve the efficiency, reliability, and expandability of large power system. Using renewable energies resources in these small-scale systems helps to reduce global warming and to speed up entering the power industry in the deregulated environments [7].

The most essential needs in an electrical network are the balance between generation and load, and also an acceptable voltage and frequency range. In MGs, and in grid-connected mode, this issue is not challengeable because the main grid acts as reference bus. Therefore, main grid is responsible to compensate deficit between generation and consumption. In this mode of operation, the reference values are determined by main grid [8], [9]. The best place to do load shedding is where the voltage at the instant of fault clearance increases. Once voltage is in an acceptable range, load shedding is not necessary; otherwise, the voltage drop determines the amount of load shedding [10].

It is demonstrated that in MGs the frequency changes with normal load changes tends to be much higher than bulk power system, e.g., using low droop coefficient may lead to large variations in frequency [11].

Using rate of change of the frequency (RCOF) increases the sensitivity of MG to emergency conditions so it may improve emergency condition detection. On the other hand, it can be used to detect source of disturbance, and to estimate the power imbalance [12].

Studying real time voltage stability based on reactive power reserve and voltage stability margin, is investigated in [13]. Coordinating emergency voltage and reactive power control using local online measurement is presented in [14]. Lack of reactive power causes a drop in the system voltage. The voltage drop causes overloading the line and as a result, relays are activated [15].

Due to numerous contingencies in the power grids, using only voltage or frequency for load shedding is not sufficient to capture all post contingency conditions. The requirement of considering both system frequency and voltage indices in emergency control is shown in [16], [17]. Reactive power, demonstrates its importance in the 14th August 2003 blackout, which caused the collapse of the interconnected power system of the Midwest and Northeast of United States and Canada [18], [19]. In [20], reactive power is directly used into the reactive power load shedding together with active power load shedding, to address the voltage stability issue.

During recovery after islanding, some loads that were disconnected by load shedding should be reconnected again. In order to avoid large frequency deviations during the load restoration, it was assumed that it is possible to define a certain number of steps for load restoration. This number of steps can be changed in accordance to the percentage of load shedding [4], [21].

In this paper, a new load-shedding algorithm is proposed to improve the stability of MGs in emergency conditions. The proposed algorithm uses both voltage and frequency indices to provide an intelligent load shedding. Furthermore, the impact of reactive power on emergency conditions is studied. As a result, it is recommended using voltage standard deviation for load shedding. Simulation results are provided to evaluate the effectiveness of the proposed approach.

The rest of this paper is organized as follows. Section II describes the emergency control. The power deficit calculation is illustrated in Section III. The proposed algorithm for load shedding is introduced in Section IV. Section V includes case studies and results. Section VI concludes the paper.

II. Emergency Control

Due to uncertainty in the nature of distributed generations (DGs) as well as some contingencies, the MG may turn into islanded mode and its returning to its original shape is a significant process. In the MGs, the emergency conditions are remarkably increased in comparison to traditional power system. Thus, a reliable design of an algorithm for maintaining stability in these conditions is essential. To achieve this, measuring appropriate parameters, recognizing emergency conditions and also managing an appropriate emergency control procedure are vital [22]. In the connected mode, imbalance power between generation and loads will be compensated by the main grid. In the case of occurring severe disturbances in the system, the MG turns into islanded mode to avoid the probable collapse. Once the MG turns into islanded mode, the local loads must be supplied. However, it is not possible to supply all the MG loads because of generation constraints in economic, planning and generation constraint. Hence, load shedding will be inevitable. Generally, load shedding procedure includes the amount of loads to be shed, the number of load shedding steps, the amount of shed load in each step, the location of load shedding and the time delays between the steps [4].

The static and dynamic load shedding can be done. In the static load shedding, the load shedding steps are constant, while in dynamic load shedding, the dynamic characteristic of the system determine the steps. Usually, the slow dynamic components can be ignored in emergency control analysis and design [9]. To avoid unnecessary load shedding, rate of change of frequency (ROCOF) is normally recommended [12].

The islanded operating conditions occurs when a portion of the utility system becomes electrically isolated from the remaining part of the power system (because of disturbances maintenance. The electrical islanding conditions should not be continued for a long time, unless the aggregated active and reactive DG generation closely matches the load demand [11]. Load shedding under one parameter (voltage or frequency) does not have high reliability and increases the possibility of over load shedding [16], [23]. In UFLS, the impact of voltage variation on the frequency deviation is usually ignored and vice versa for UVLS. In practice, where these two parameters are dependent to each other, under voltage-frequency load shedding (UV-FLS) will be useful [16].

III. Power Deficit Calculation

Most recent researches generally use only the system's voltage or frequency. The outages in power system as a serious problem can be occurred due to various forms of voltage or frequency instability or either both. It is shown that the active and reactive powers affect the system frequency in under-frequency load shedding [24], [25], [26]. Although load shedding is essential for MGs under overload conditions, differences between these small-scale systems and conventional power systems must be taken into account. In such a systems, determination of the system inertia and the amount of load that to be removed is not straightforward. According to the swing equation for synchronous generators we have [23]

$$\Delta P_m(t) - \Delta P_L(t) = \Delta P_D(t) = 2H\frac{d\Delta f(t)}{dt} + D\Delta f(t) \qquad (1)$$

or using Laplace transformation we can obtain

$$\Delta f(s) = \frac{1}{2Hs + D}[\Delta P_m(s) - \Delta P_L(s)] \qquad (2)$$

where, Δf, ΔP_m, D, ΔP_D and ΔP_L are frequency deviation, mechanical power change, load damping coefficient, load generation imbalance proportional to the total load change and system load change, respectively. The magnitude of power deficit after disturbance is calculated as

$$\Delta P_D(t) = 2H\frac{d\Delta f(t)}{dt} \qquad (3)$$

Assuming no speed governing at $t=0^+s$ (i.e., $\Delta P_m = 0$), using (1), one can write

$$\Delta f(s) = \frac{-\Delta P_L(s)}{2Hs + D} \qquad (4)$$

The above equation formulates frequency deviation caused by load changing. The power deficit is classified in a specific load shedding table based on the load and its priority. In the mentioned table, the load shedding can be classified within different steps in terms of size and type [4], [27].

IV. Proposed Algorithm

According to a load shedding table, load shedding steps must be produced for the given case study. In general, the proposed algorithm can be summarized in the following steps (see Fig. 1).

- *Step 1*: Measuring voltage standard deviation (SDV_{mes}) and comparing with the voltage threshold (V_{th}) to make a decision.
- *Step 2*: Measuring frequency (f_{mes}) and ROCOF (Δf_{mes}), and comparing both of them with their thresholds ($f_{thr}, \Delta f_{thr}$), to make a decision. Once dismissing limits occurs, it checks out the time K_1 to see if it is over or not. Time K_1 is used to avoid unnecessary load shedding since the voltage may change due to the reasons other than faults.
- *Step 3*: If last steps dismiss their limit, calculate loads for the required load shedding.
- *Step 4*: Applying delay K_2; it is required to see the effect of load shedding.
- *Step 5*: Checking whether load shedding is still required. If load shedding still needed, algorithm goes back to Step 1, otherwise the algorithm is ended.

The thresholds and delays at each step in the proposed algorithm are determined according to sensitivity and the dynamic characteristics of the MG. As mentioned above, the purpose of this paper is to design an effective algorithm for emergency conditions of MGs. As will be shown later, the voltage standard deviation parameter is used to better identifying emergency conditions and prevent the system from possible collapses.

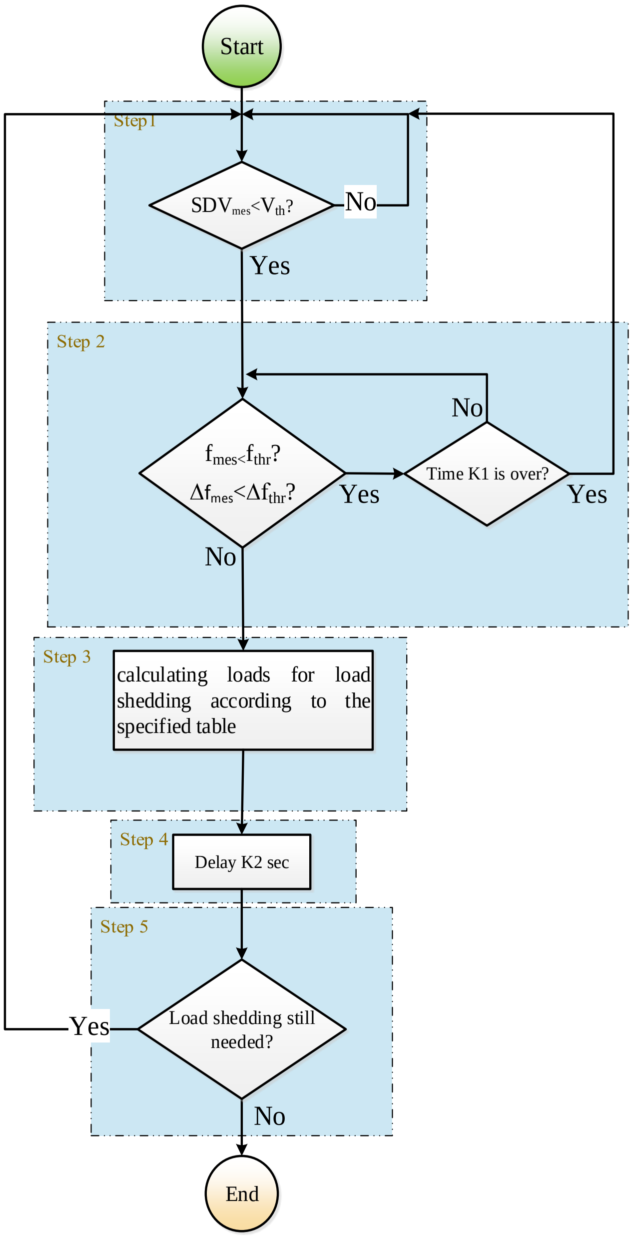


Fig. 1: Flow chart of the proposed load shedding algorithm

V. Simulation Results

A MG test system has been considered to evaluate the effectiveness of the proposed method. As shown in Fig. 2, the underlying MG includes three diesel generators and one DFIG unit supplying six load blocks (each load block include several loads but for simplicity all loads are shown in one block). DGs and their local loads are in 480v and through Transformers (480v/25kv) and lines (with Z1 parameter as shown in Table I and for more information see [28]) in 25kv are connected to each other. The electrical parameters of system are provided in Table I. It is assumed that the MG system turns to the islanded mode by a circuit breaker and accordingly DGs cannot support the local loads connected to the MG. As a result, voltage and frequency of the MG may collapse. The power deficit between 23% to 31% of total generation has been considered in the studies. The proposed load shedding approach is then applied and verified to avoid this event. The results are provided via the following two scenarios.

A. *Case 1*

According to the data provided in Table I, i.e., after calculating the loads and DGs power outputs, assume that the load demand is higher than generation in the MG, i.e., $S_{MG} \leq S_{Load} + S_{Loss}$. Therefore, the MG may fall in an emergency condition. This is mostly because of the inductive loads which demands big amount of reactive power form the MG system. The following study will show how reactive power injection can help to improve the stability margin.

To show this effect the DFIG unit injects reactive power in three scenarios, i.e., 0 pu, 0.2 pu, and 0.4 pu. The results are provided in Fig. 3 and Fig. 4. Based on the voltage profile in this case (Fig. 3(b) and 4(b)), it is recommended to use standard deviation of voltage parameter (*SDV*) for load shedding. As it can be seen in Fig. 3(a), in the scenario where the DFIG injects no reactive power, the proposed load shedding approach cannot stabilize the MG, thus, the system frequency and voltage collapse. As a result, one can note that reactive power may improve stability margin of the system. DFIG active and reactive power output are shown in Figs. 3(c), 3(d), 4(c), and 4(d).

B. *Case 2*

In this case, the impact of system inertia on emergency control is demonstrated. To perform this scenario, number of wind turbines and DFIGs are increased in the test system of the case 1 (Fig. 2) Fig. 4 shows the results after implementing the proposed algorithm on the new case study. As reported in [29], it is expected that increasing penetration of wind power (i.e., increasing total amount of inertia), improves the system frequency response. This fact is depicted in Fig. 4(a). Moreover, more injection of reactive power by DFIGs improves the voltage profile (see Fig. 4(b)).

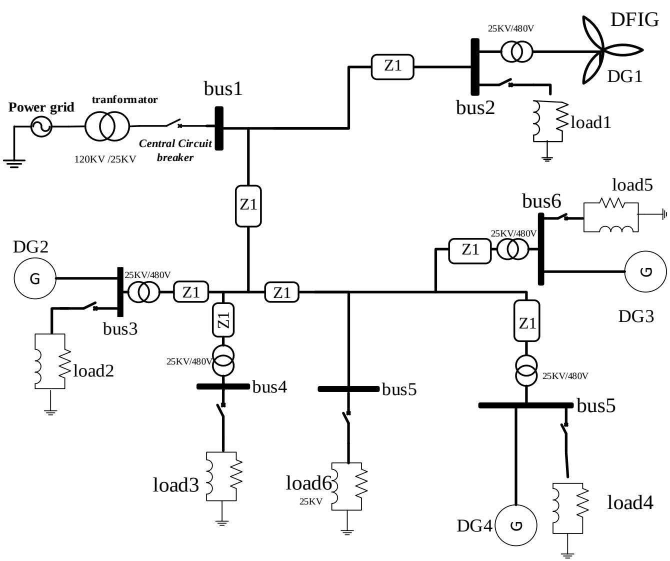
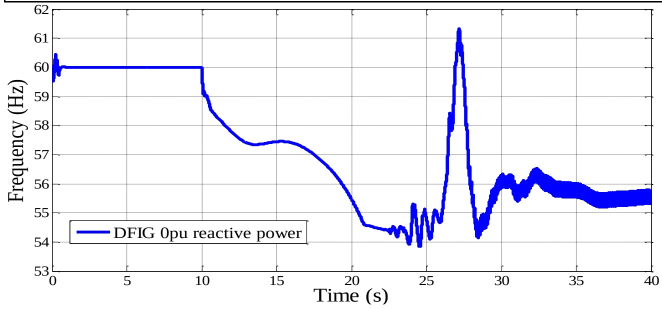


Fig. 2: The MG test system

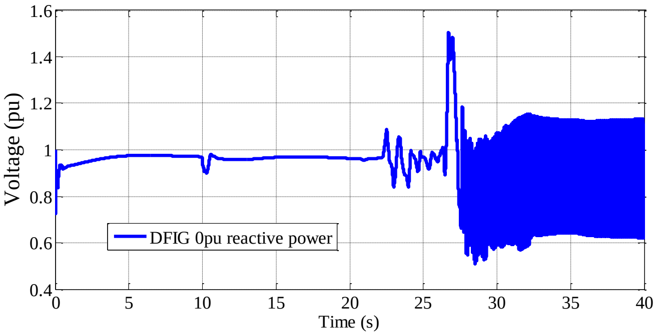
Table I

THE ELECTRICAL SYETEM PARAMETERS

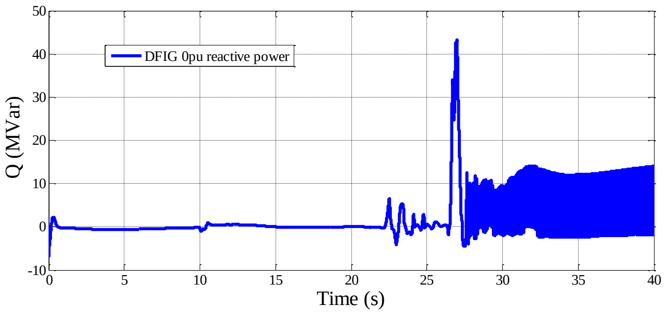
Load 1	2.9+j2.3	DG1	3.125MVA	Line parameters	Z1
Load 2	3.2+j1.6	DG2	3.125MVA	[r1 r0]	**[0.01153 0.0413]**
Load 3	4.6+j0.52	DG3	3.125MVA	[l1 l0]	**[1.05e-3 3.32e-3]**
Load 4	2.4+j0.3	DG4	10MVA	[c1 c0]	**[11.33e-9 5.01e-9]**
Load 5	3.7+j0.22	------	-------------	-------------	--------------------
Load 6	1.9+j1.2	------	-------------	-------------	--------------------



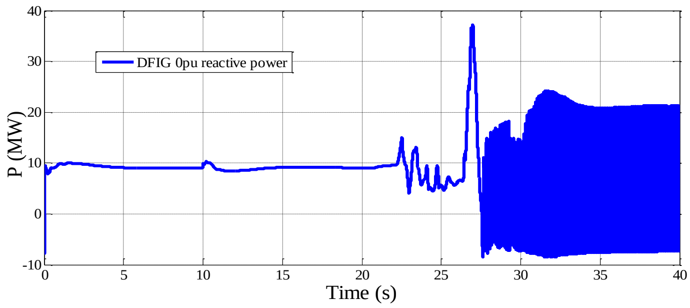
a)



b)

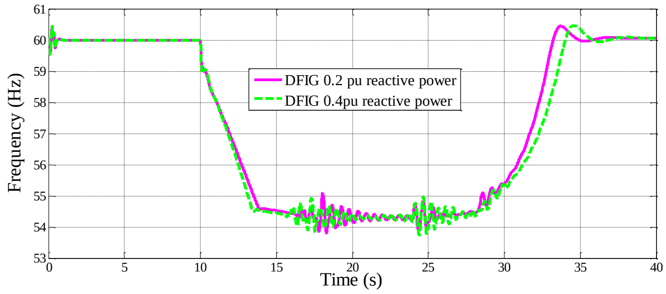


c)

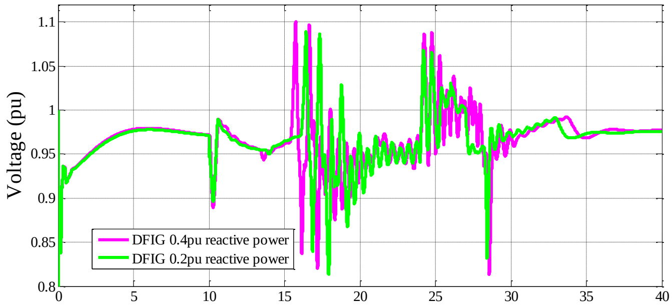


d)

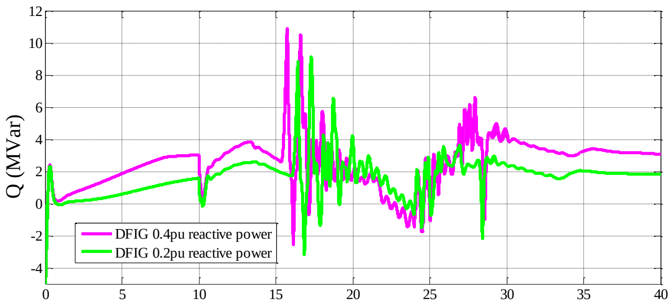
Fig. 3: MG features without DFIG reactive power injection. a) MG frequency, b) MG voltage, c) DFIG reactive power output, d) DFIG active power output.



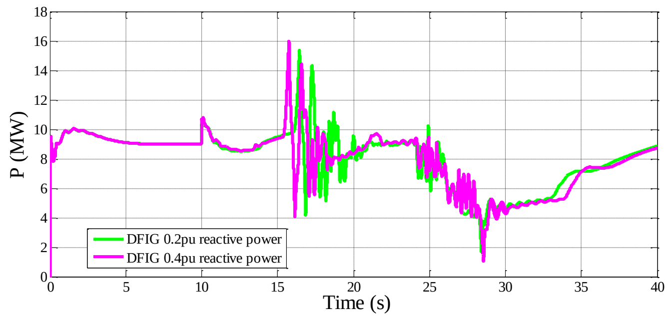
a)



b)

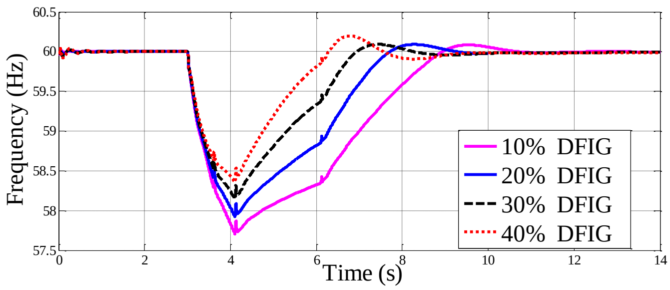


c)

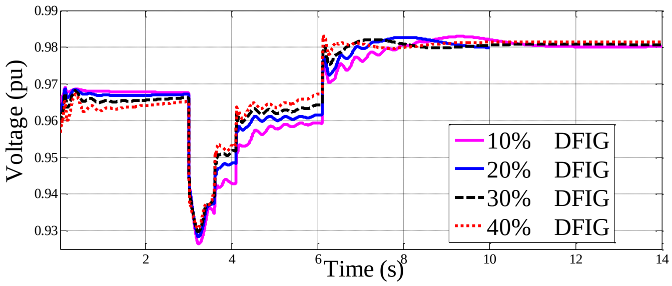


d)

Fig. 4: Performance of the proposed load shedding approach in the presence of injecting reactive power by the DFIG. a) MG frequency, b) MG voltage, c) DFIG reactive power output, and d) DFIG active power outout.



a)



b)

Fig. 5: Impact of system inertia on frequency and voltage response in emergency condition. a) MG frequency, and b) MG voltag

VI. CONCLUSION

This paper proposes a new under voltage-frequency load shedding for MGs. The proposed approach considers both voltage and frequency parameters as well as voltage standard deviation for the load shedding in emergency conditions to avoid any possibility of instability. As shown, detecting emergency conditions becomes possible at the right time, because of DFIG reactive power injection. Accordingly, this is proposed to use the voltage standard deviation for load shedding. A comprehensive MG test system is used to verify the proposed approach, where a good performance is observed. The results show that injecting reactive power can increase the stability margin of the system. Similarly, higher penetration of wind power increases inertia in the system, and, accordingly, improves the system frequency and voltage in emergency condition.

REFERENCES

[1] P. Kundur, J. Paserba, V. Ajjarapu, G. Andersson, A. Bose, C. Canizares, N. Hatziargyriou, D. Hill, A. Stankovic, and C. Taylor, “Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions,” *IEEE Trans. Power Syst*, vol. 19, no. 3, pp. 1387-1401, Aug. 2004.

[2] P. Pourbeik, P. Kundur and C. W. Taylor, "The anatomy of a power grid blackout—root causes and dynamics of recent major blackouts", *IEEE Power Energy Mag.*, vol. 4, no. 5, pp. 22-29, 2006.

[3] C. W. Taylor, "Concepts of undervoltage load shedding for voltage stability," *IEEE Trans. Power Del.*, vol. 7, pp. 480-488, Apr. 1992.

[4] U. Rudez and R. Mihalic, “Analysis of underfrequency load shedding using a frequency gradient,” *IEEE Trans. Power Del.*, vol. 26, no. 2, pp. 565–575, Apr. 2011.

[5] C. Concordia and L. H. Fink, "Load shedding on an isolated system," *IEEE Trans. Power Syst.*, vol. 10, pp. 1467-1472, Aug. 1995.

[6] H. Bevrani, M. Watanabe, and Y. Mitani, *Power system monitoring and control*. Hoboken, New Jersey: John Wiley & Sons, 2014, ch. 08, pp. 158-185.

[7] N. Panwar, S. Kaushik, and S. Kothari, "Role of renewable energy sources in environmental protection: a review," *Renewable and Sustainable Energy Reviews,* vol. 15, pp. 1513-1524, Apr. 2011.

[8] J. Lopes, C. Moreira, and A. Madureira, "Defining control strategies for analysing microgrids islanded operation," in *Proc. IEEE Russia Power Tech.*, Jun. 2005, pp. 1–7.

[9] P. Piagi and R. H. Lasseter, “Autonomous control of microgrids,” in *Proc. IEEE Power Eng. Soc. General Meeting*, Jun. 18–22, 2006.

[10] A. P. Ojeda, "A load shedding scheme for inverter based microgrids," Massachusetts Institute of Technology, 2011.

[11] F. Katiraei, M. Iravani, and P. W. Lehn, "Micro-grid autonomous operation during and subsequent to islanding process," *IEEE Trans. Power Del.*, vol. 20, pp. 248-257, Jan. 2005.

[12] H. Bevrani, G. Ledwich, and J. J. Ford, "On the use of df/dt in power system emergency control,". *Proc. IEEE Power Syst. Conf. Expo.*, 2009.

[13] B. Leonardi and V. Ajjarapu, "An approach for real time voltage stability margin control via reactive power reserve sensitivities," *IEEE Trans. Power Syst*, vol. 28, pp. 615-625, Apr. 2013.

[14] S. R. Islam, D. Sutanto, and K. M. Muttaqi, "Coordinated Decentralized Emergency Voltage and Reactive Power Control to Prevent Long-Term Voltage Instability in a Power System," *IEEE Trans. Power Syst.*, vol. 30, pp. 2591-2603, jul. 2015.

[15] M. Klaric, I. Kuzle, and S. Tesnjak, "Undervoltage load shedding using global voltage collapse index," in *Power Systems Conference and Exposition, IEEE PES*, Oct. 2004, pp. 453-459.

[16] H. Bevrani and A. Tikdari, "On the necessity of considering both voltage and frequency in effective load shedding schemes," in *Proc. IEEJ Technical Meeting, PSE-10*, Jan. 2009, pp. 7-11.

[17] O. Sarchami, and H. Bevrani,“Online Voltage-Frequency Measurement Based MicroGrid Emergency Control,” *National Conference of Technology, energy and Data on Electrical and Computer Engineering, TED*, Kermanshah, May 30-31, 2015, Iran.

[18] G. Andersson, P. Donalek, R. Farmer, N. Hatziargyriou, I. Kamwa, P. Kundur, *et al.*, "Causes of the 2003 major grid blackouts in North America and Europe, and recommended means to improve system dynamic performance," *IEEE Trans. Power Syst.*, vol. 20, pp. 1922-1928, Nov. 2005.

[19] U.S. – Canada Power system Outage Task Force, ″Final report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations″, April 2004, *https://reports.energy.gov/* – *Accessed August 2009, Pages* 1 – 228.

[20] J. Tang, J. Liu, F. Ponci, and A. Monti, "Adaptive load shedding based on combined frequency and voltage stability assessment using synchrophasor measurements," *Power Systems, IEEE Transactions on,* vol. 28, pp. 2035-2047, 2013.

[21] E. E. Aponte and J. K. Nelson, "Time optimal load shedding for distributed power systems," *IEEE Trans. Power Syst.*, vol. 21, pp. 269-277, Feb. 2006.

[22] C. Gouveia, J. Moreira, C. Moreira, and J. Pecas Lopes, "Coordinating storage and demand response for microgrid emergency operation," *IEEE Trans. Smart Grid*, vol. 4, pp. 1898-1908, Dec. 2013.

[23] H. Bevrani, *Robust power system frequency control*, 2 ed. vol. 85: Springer, 2014.

[24] D. Xu and A. A. Girgis, "Optimal load shedding strategy in power systems with distributed generation," in *Power Engineering Society Winter Meeting, 2001. IEEE*, Columbus, OH, 2001, pp. 788-793.

[25] A. Saffarian and M. Sanaye-Pasand, "Enhancement of power system stability using adaptive combinational load shedding methods," *IEEE Trans. Power Syst.*, vol. 26, pp. 1010-1020, Oct. 2011.

[26] H.-M. Kim, T. Kinoshita, and Y. Lim, “Talmudic approach to load shedding of islanded microgrid operation based on multiagent system,” Journal of Electrical Engineering & Technology, vol. 6, no. 2, pp. 284-292, 2011.

[27] F. Shokooh, "An intelligent load shedding (ILS) system application in a large industrial facility",*Conf. Rec. IEEE IAS Annu. Meeting*, pp. 417-425, 2005.

[28] http://mathworks.com/help/physmod/sps/powersys/ref/threephasepisectionline.html.

[29] V. Gevorgian, Y. Zhang, and E. Ela, "Investigating the impacts of wind generation participation in interconnection frequency response," *IEEE Trans. Sustain. Energy*, vol. 6, pp. 1004-1012, Aug. 2014.