Impact of Supercapacitor Placement in Renewable Integrated Microgrid to Minimize Post-fault Frequency Fluctuation

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***Abstract*—Microgrid structure provides economically attractive electricity supply to customers with less impact on the environment. Microgrid losses frequency support when its operation switches from grid connected mode to islanded mode. Hence, controlling of frequency is of utmost importance in islanded mode. During post-fault condition, frequency gets deviated and hence, lack of necessary steps to minimize frequency deviation results in tripping of generators. This ultimately leads to disconnection of utility power at consumer ends. By using energy storage devices efficiently, frequency deviation can be minimized during post fault condition. Storage device can provide energy when grid connection is not available. Because of high power density and high charging/discharging rate, supercapacitor is used as a storage device for providing post fault condition power in microgrid. In this paper, impact of supercapacitor in microgrid to minimize the frequency deviation has been investigated through a number of case studies. Results show that placement or location of supercapacitor has significant impact on stabilizing frequency fluctuation under post-fault scenarios in microgrid.**

Keywords—Distributed generators (DGs); Frequency deviation; Microgrid; Supercapacitor

I. Introduction

Due to the growing demand for renewable energy sources, the manufacturing of solar photovoltaic (PV) arrays and wind turbines has advanced considerably in recent years. Hence, the costs of these renewable power generation technologies have declined steadily. They can replace some of fossil energy sources to reduce green house gas emissions and air pollution. The increase in penetration of renewable based distributed generators (DGs) in electrical proximity to one another has brought about the concept of microgrid. Microgrid brings in benefits such as enhanced local reliability, reduced feeder losses and local voltage support [1], [2]. The steady progresses in development of microgrid and renewable energy technologies are opening up new opportunities for utilization of energy resources.

Though from reliability and economic point of view microgrid islanded mode of operation is interesting, stability issues such as frequency and voltage regulation have slowed down the application of this new mode. The intermittent nature of most installed renewable energy sources further complicates microgrid operation. Classic regulation methods used in conventional power generators cannot be applied to these non-dispatchable energy sources. The situation becomes even more complicated when the type of DG is considered. The electronic interfaced generation unit, which constitutes the majority of distribution generation units, is assumed as a zero-inertia generation. Though these units are much faster than rotating generations to be controlled, they lack inertia, which plays an important role in system stability [3].

The control of real and reactive power output of the sources is essential to maintain a stable operation in a microgrid. Several studies have been carried out to enhance stability of multiple DG integrated microgrid system. Impact of placement of capacitor in improving first swing stability of such microgrid system has already been studied in [4]. However, once the stability is ensured, fast recovery of voltage and frequency under post-fault scenario is equally important. The frequency and voltage in an islanded microgrid should be maintained within predefined limits. The frequency variations are very small in strong grids; however, large variations can occur in islanded grids. Battery packs and fuel cells are used as a long-term energy back-up system to use solar and wind energy resources more efficiently and economically. Supercapacitors as short-term energy storages are used to compensate transient conditions because they can be charged and recharged rapidly in the condition of uncertainty and sudden interruption [5].

In this paper, impact of placement of supercapacitor in islanded microgrid has been studied under post-fault scenario. We have found out the worst case scenario for fault at various locations under islanded mode. Then the best location of supercapacitor for minimizing frequency deviation under post-fault condition has been sorted out. Finally, suitable or minimum required rating of through time-domain simulations. supercapacitor for frequency deviation has been found out. Paper structure is as follows: Section II represents introduction to microgrid (renewable sources and backup generators). Section III describes supercapacitor and its operation and performance and modeling with diagram. Then section IV shows the results and analysis. All the results have been simulated in MatLab based simulation platform.

II. DISSTRIBUTED GENERATORS IN MICROGRID

Renewable or non-conventional electricity generators employed in DG systems or microgrids are known as distributed energy resources (DERs) or micro sources. One major aim of microgrids is to combine all of non-conventional/renewable low-carbon generation technologies. We have used wind turbine and diesel generator as DER in our test microgrid system.

A. Wind turbine

As majority of the global installed wind turbines are of Doubly-Fed Induction Generator (DFIG) type, a DFIG turbine has been used here as renewable DG. Fig. 1 shows the block diagram of its construction. . The principle of the DFIG is that rotor windings are connected to the grid via AC/DC/AC converter. This is divided into two components: the rotor-side converter (C_{rotor}) and the grid-side converter (C_{grid}). C_{rotor} and C_{grid} are Voltage-Source Converters that use forced-commutated power electronic devices (such as IGBTs) to synthesize an AC voltage from a DC voltage source. The power captured by the wind turbine is converted into electrical power by an induction generator and it is transmitted to grid by stator and the rotor windings. The control system generates the pitch angle command and the voltage command signals V_r and V_{gc} for C_{rotor} and C_{grid} respectively in order to control the power of the wind turbine, the DC bus voltage and the reactive power or the voltage at the grid terminals.

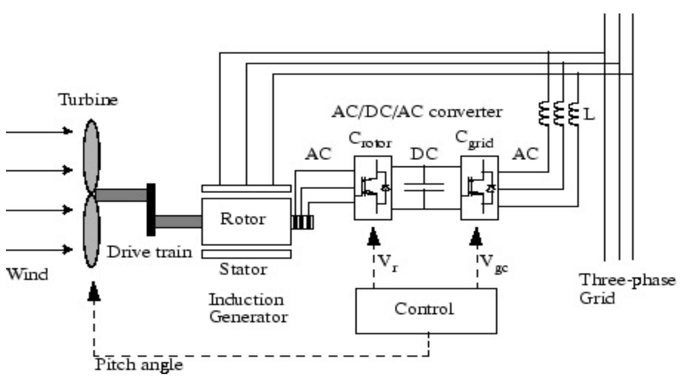

Fig. 1. Wind Turbines and the Doubly Fed Induction Generator System [6].

B. Diesel generator

A simple diesel generator consists of (a) a strong magnetic field, (b) conductors rotating through that magnetic field, and (c) a mean by which a continuous connection is provided to the conductors as they are rotating. Fig. 2 shows the internal structure of AC diesel generator. The magnitude of AC voltage generated by an AC generator is dependent on the field strength and speed of the rotor. Most generators are operated at a constant speed; therefore, the generated voltage depends on field excitation. Diesel generators are widely used as back-up power supply in microgrid environment [7].

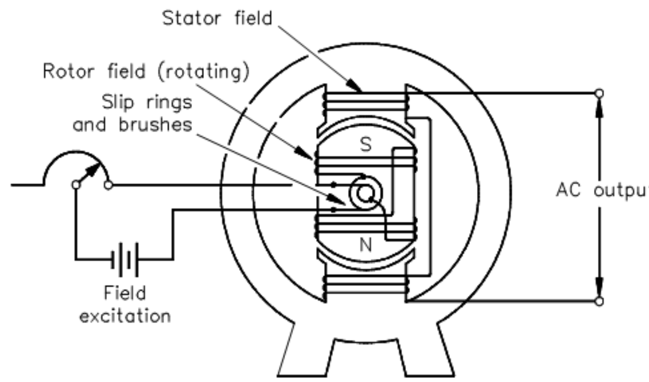

Fig. 2. Simple AC Diesel Generators [8].

III. SUPERCAPACITOR IN MICROGRID SYSTEM

Supercapacitors are also known as ultra capacitors or electric double layer capacitors (EDLCs). These capacitors have greater capacitance values than any other available types of capacitor [8]. Supercapacitors have the highest capacitive density available today and this feature could be utilized in applications normally reserved for batteries [10].

A. Supercapacitor energy storage system

Supercapacitors are passive electronic components that, unlike batteries, store energy by physically separating positive and negative charges. Fig. 3 shows the basic structure of supercapacitor. The positive and negative electrodes are separated by a separator. The electrodes are made with porous material. There are pores with size in terms of nanometer where ions can travel freely. It stores the energy in the double layer formed near the carbon electrode surface. They offer high power densities and provide significant energy storage capacities [11].

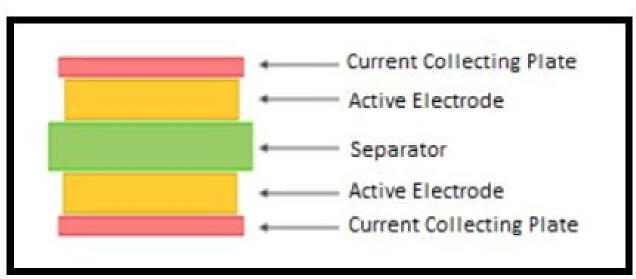

Fig. 3. EDLC based on electric double layer Technology [11].

The maximum power that can be drawn from the supercapacitor can be expressed as following as per maximum power transfer theorem [11]:

$$P_{max} = \frac{U_{max}^2}{4ESR} \quad (1)$$

Where;

P_{max} is the maximum dischargeable power
ESR is equivalent series resistance of supercapacitor
U_{max} is the maximum voltage of the supercapacitor

B. Characteristics

In comparison to a battery, a supercapacitor has a longer lifecycle, faster charging and discharging rate, higher efficiency, and wider operating temperature range. Super-capacitors have much higher power density than batteries; they also can meet the high instantaneous power demand during acceleration while the batteries can usually provide power for the constant speed vehicle operation [12]. Due to the fast charging rate and high power density, supercapacitors can be used in power system to provide power in post-fault condition.

C. Modeling

The first-order circuit model of a super capacitor is shown in Fig. 4. It consists of an equivalent series resistance and a series inductance, and the leakage current is represented by a resistor in parallel with the capacitor. The series resistance ranges from a few milliohms to several tens milliohms [9]. Due to their material composition and design structure they have a high power density and low equivalent series resistance (ESR). These characteristics lead to higher efficiency, faster charge and/or discharge capacity, and low heating losses.

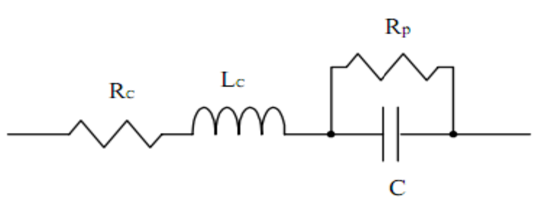

Fig. 4. Equivalent circuit model of supercapacitor [9].

The inductance depends on the construction and can be ignored for low frequency operation. The leakage resistance can also be ignored for short-term operation.

Frequency deviation allowed for islanded microgrid ranges from 59.3Hz to 60.5Hz (i.e. 0.988p.u. to 1.008p.u.) and fault must be cleared within 0.16second [13]. The next section presents the simulation results, which show the impact of placement of supercapacitor in islanded microgrid under post-fault condition.

IV. Results

A. Test system

A 16 bus 23 kV primary distribution system (with a total load of 28.7MW and 17.3MVAr) as shown in Fig. 5 with minor modifications [14] has been used in this paper and all results presented in this paper have been simulated with Power System Analysis Tool Box(PSAT) 2.18 [15] and MatLab 7.8.0. Bus 3 and bus 2 are connected to wind turbine and diesel generator respectively assuming availability of primary resources at those locations. The initial sets of results have been presented in [16].

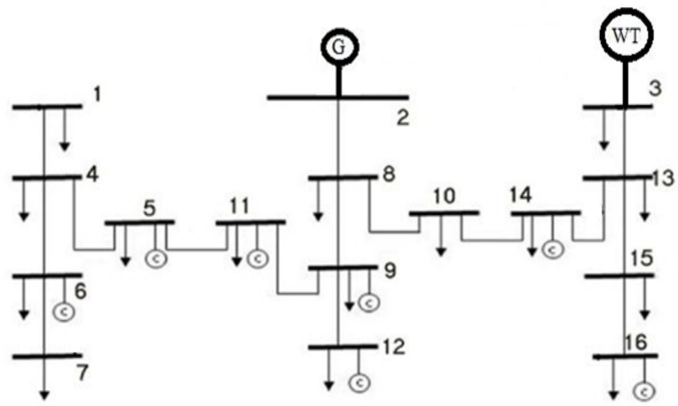

Fig. 5. Test Distribution system with generation units.

B. Simulation Results

Step 1: Finding the Worst fault location

Initially the worst fault case has been sorted by placing three phase short circuit individually at each bus of the system. The fault impedance has been taken as Z=0.132 ohm. It occurred at time t=1sec and was cleared at 1.2sec. Fig. 6 and 7 shows frequency deviations at bus 11 with fault at bus 3 and 12 respectively.

Minimum frequency deviation due to fault occurred at bus 3 whereas; maximum deviation was found due to fault at bus12.

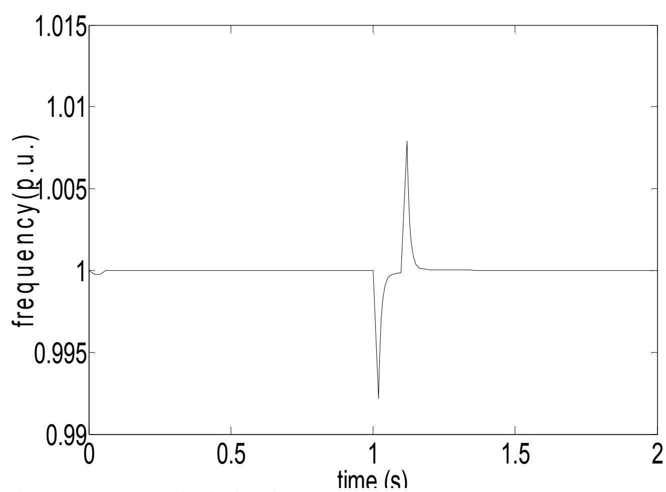

Fig. 6. Frequency for fault at bus 3.

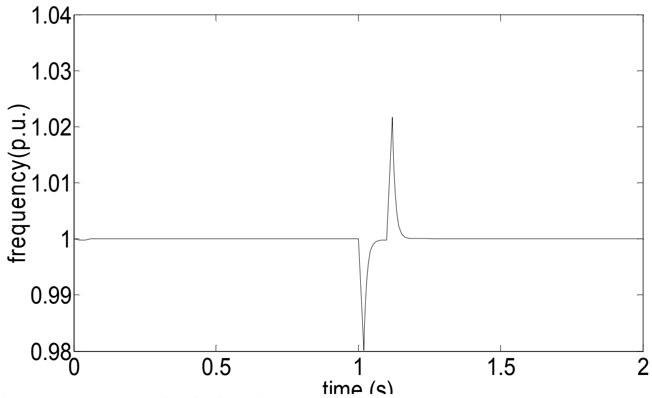

Fig. 7. Frequency for fault at bus 12.

Step2: Finding the best location of supercapacitor

In the second step, the impact of placement of supercapacitor in minimizing frequency deviation due to fault at bus 12 has been examined. Fig. 8 and 9 shows frequency deviations by varying the supercapacitor location at each bus individually. It has been found that minimum frequency deviation occurs with supercapacitor at bus 1 (as in Fig. 8).

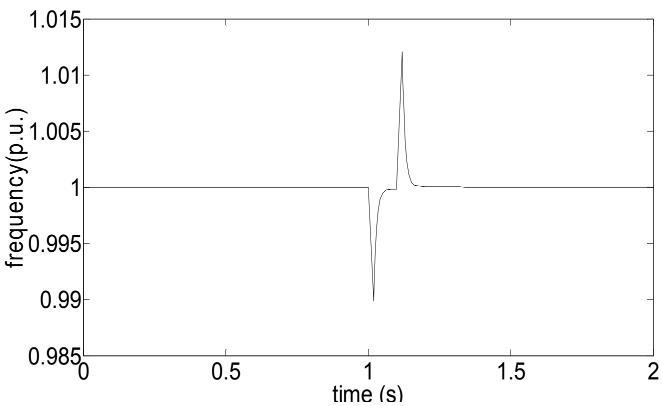

Fig. 8. Frequency deviation with supercapacitor at bus 1.

Maximum frequency deviation occurs with supercapacitor placed at bus 12, which has been shown in Fig.9. Susceptance value of supercapacitor chosen for all the simulations in step 2 is 0.3p.u.

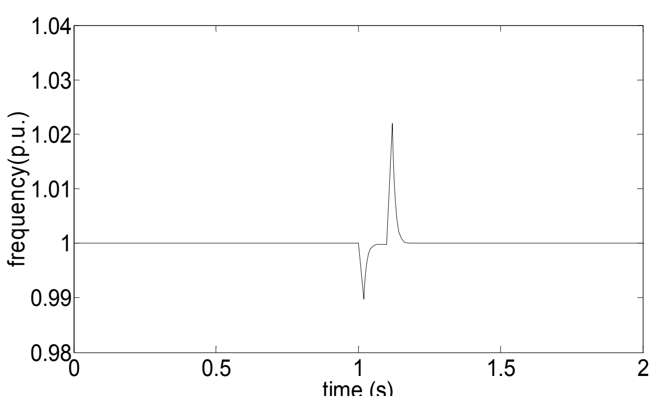

Fig. 9. Frequency for supercapacitor at bus 12.

Step 3: Finding the best rating of supercapacitor

In order to bring the frequency deviation within allowable limit of 0.988p.u. to 1.008p.u., susceptance value of supercapacitor at bus 1 has been varied.

Fig. 10 to 13 shows frequency deviations by varying the ratings of supercapacitor with susceptance values 0.5p.u., 0.6p.u., 0.7p.u. and 0.74p.u.

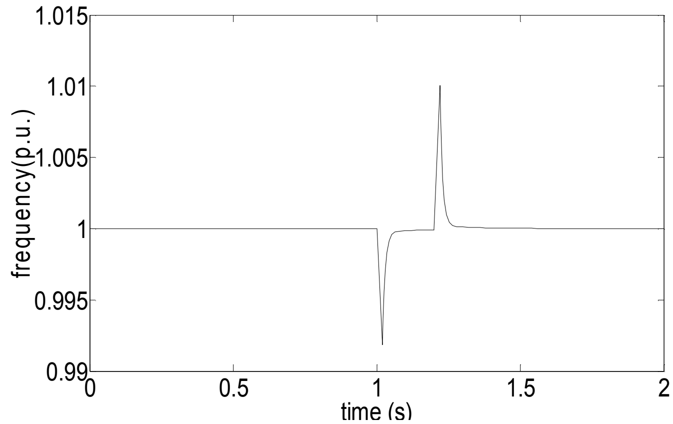

Fig. 10. Frequency for supercapacitor susceptance value 0.5p.u.

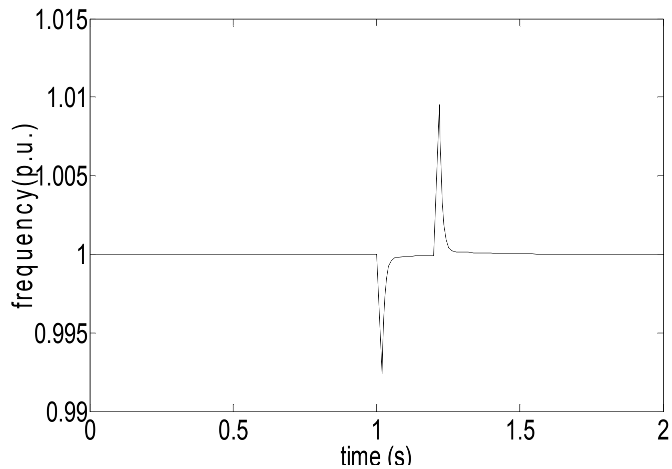

Fig. 11. Frequency for supercapacitor susceptance value 0.6p.u.

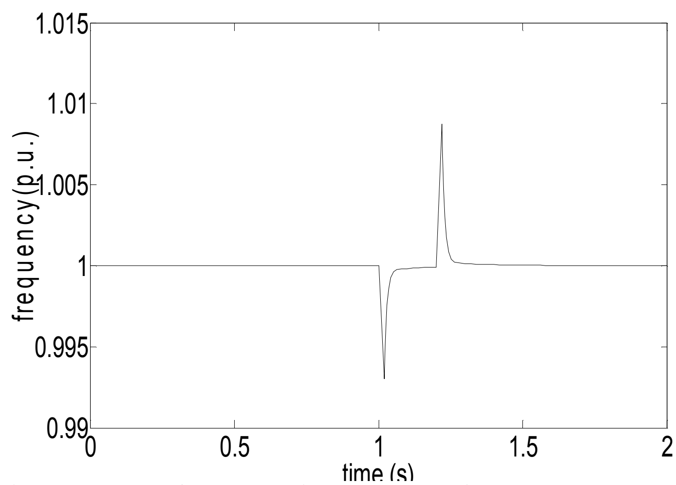

Fig. 12. Frequency for supercapacitor susceptance value 0.7p.u.

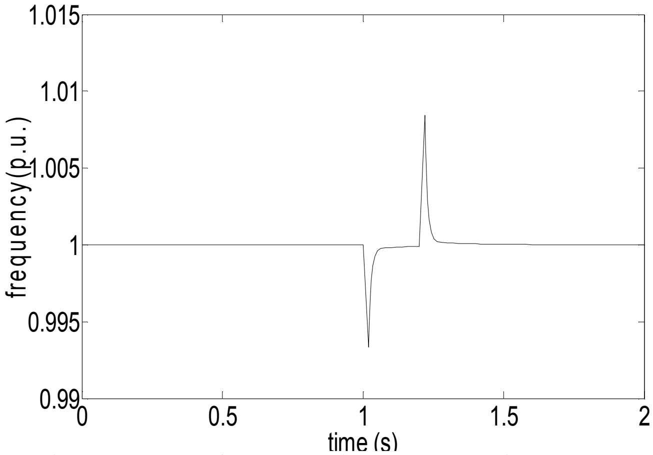

Fig. 13. Frequency for supercapacitor susceptance value 0.74p.u.

C. Analysis

By varying the fault location, we have found that maximum frequency deviations occur for fault at bus 12. Due to fault at bus 12, frequency deviated from 59.1Hz to 61.2Hz (shown in Fig. 7). Because of being the largest load in the test distribution, the highest frequency deviation occurs at bus 12. In order to make this frequency deviation within allowable limit for micro-grid, supercapacitor has been used as an energy storage device. By varying the placement of super-capacitor, it has been shown in Fig. 8 that minimum frequency deviation occurred with supercapacitor at bus 1. It was shown that with supercapacitor at bus 1, frequency deviation came down to a range of 59.6Hz to 60.5Hz. For microgrid system; frequency deviation is allowed from 59.3Hz to 60.5Hz [13]. So, bus 1 is the best location for supercapacitor. By varying the supercapacitor susceptance value, frequency deviation can be decreased. For supercapacitor with susceptance value 0.74p.u., frequency deviated from 59.7Hz to 60.4Hz, which is allowable for islanded operation of microgrid.

V. CONCLUSION

To maintain stability of the micro-grid system, frequency deviation must be maintained within allowable limit. In this study, several case studies have been carried out with various placements and ratings of supercapacitors in islanded microgrid system. Results show that, placement of supercapacitor in microgrid has significant role in minimizing frequency deviation under post-fault condition. By using supercapacitor, frequency deviation was decreased to allowable range. Future work consists of further analysis of the results, which would help to identify the reasons behind superior performance of supercapacitor at the resultant location. If necessary, existing control methodologies would also be revised with the supercapacitor in place. A cost analysis of microgrid system with the proposed placement and rating of supercapacitor would also be carried out.

ACKNOWLEDGMENT

The authors would like to express sincere gratitude to Dr. M. A. Mannan, Department of EEE, American International University- Bangladesh for his valuable suggestions during the preparation of this paper.

REFERENCES

[1] R. H. Lasseter, "MicroGrids", IEEE Power Engineering Society Winter Meeting, 2002.

[2] C. Marnay, G. Venkataramanan, "Microgrids in the evolving electricity generation and delivery infrastructure", IEEE Power Engineering Society General Meeting, pp. 18-22, 2006.

[3] Mohammadreza Fakhari Moghaddam Arani, “Incorporating DFIG-Based Wind Power Generator in Microgrid Frequency Stabilization,” Thesis for Master of Applied Science, University of Waterloo, 2011.

[4] Ali Bidram, Mohamad-esmail Hamedani-golshan, and Ali Davoudi, “Capacitor design considering first swing stability of distributed generations” *IEEE Transactions on Power Systems*, vol. 27, no. 4, November, 2012.

[5] Hamid Hassanzadeh Fard, Seyed Masoud, Moghaddas Tafreshi, Seyed Mehdi Hakimi, “Optimization of grid connected microgrid consisting of PV/FC/UC with considered frequency control,” *Turkish journal of Electrical and computer science*, 2012.

[6] Ishan Patnaik, “Wind as a renewable source of energy,” B. Tech. thesis, National Institute of Technology, Rourkea, 2009.

[7] Alex Taiwo Agbedahunsi, “Frequency Control for Microgrids using Enhanced STATCOM and Supercapacitor Energy Storage” Thesis for the degree of Doctor of Philosophy, University of Nottingham, May, 2013.

[8] “DOE fundamentals handbook of electrical science, Volume 3 of 4,” U.S. Department of Energy, Washington, D.C. 20585, June, 1992.

[9] Marco S. W. Chan, K. T. Chau , and C. C. Chan, “Effective Charging Method for Ultracapacitors,” *Journal of electric vehicles*, volume- 3, number-2, December 2005.

[10] *Supercapacitors,* Illinois capacitor incorporate, Available at- http://www.illinoiscapacitor.com/pdf/Papers/supercapacitors.pdf

[11] Rahul Nema, Dr. Anurag Trivedi, “Load Frequency Control of a Small Isolated Power Station by Using Supercapacitor Based Energy Storage System,” *International Journal of Advanced Research in Computer Engineering & Technology (IJARCET),* vol. 1, no. 10, December, 2012.

[12] Fatih congoz, “Accelerated simulation of supercapacitors using order reduction techniques and waveform relaxation methods,” M.Sc. Thesis, The University of Texas, May, 2012.

[13] S. Basso, and Richard DeBlasio, “IEEE 1547 Series of Standards: Interconnection Issues,” *IEEE Transactions on Power Electronics*, vol. 19, no. 5, pp. 1159 – 1162, September, 2004.

[14] S. Civanlar, J. J. Grainger, H. Yin, and S. S. H. Lee, "Distribution feeder reconfiguration for loss reduction," *IEEE Transactions on Power Delivery,* vol. 3, no. 3, pp. 1217-1223, July, 1988.

[15] F. Milano, "Matlab-based Power System Analysis Toolbox (PSAT)" Available on - http://faraday1.ucd.ie.

[16] Sakib Kabir**,** Abdullah Al Amin**,** Md. Anayatullah, Bithun Kumar Saha, “Supercapacitor based frequency control in renewable integrated Microgrid system.” B.Sc. Thesis, American International University-Bangladesh (AIUB), 2013.