Feasibility Analysis of Supercapacitor for Lightning Energy Conversion System

Suman Jana, Pabitra Kumar Biswas

Abstract*: Lightning is a very high voltage electrostatic emission consisting of highly charged electrostatic particles. However, limited literature is available in the field of the Lightning energy harvesting area due to the hazards involved and the intermittent nature of lightning. A lightning bolt does have convenient energy. Still, empirically, energy harnessing and storage is a difficult task due to confusion existed in the selection of impulse storage device. This paper presents a feasibility analysis of supercapacitors to store energy extracted from a high voltage surge. The analysis is performed by connecting the impulse generator as a source of the supercapacitor. Different loads are connected sequentially with the supercapacitor to assess the applicability of the proposed numerical model. The impulse generator is designed in the simulation model as a replica of the Tesla coil hardware constructed for the lightning energy conversion system. Lightning energy conversion system is an innovative system which can convert high voltage lightning in storable form. Also, a real-time pulse has been generated for the Seven level inverter by interfacing Atmel ATMEGA328P-PU microcontroller in the MATLAB environment. The computational model used in this paper produced 0.0027% to 0.7% SOC percentage of supercapacitor for single waveform and different loads. This paper may drive the lightning energy research towards a positive influence by its conceptual resolution.

Keywords: Supercapacitor, High voltage test, Multi-Level Inverter, Energy Storage, Lightning.

I. INTRODUCTION

The lightning bolt or sometimes called as thunderbolt is keeping an essential role in ancient mythology to research in modern meteorological and electrical science [1]-[4]. A lightning bolt or thunderbolt spark is a static electricity discharge from cloud to ground, cloud to cloud, one charged region to another charged region within a cloud or cloud to upper atmosphere [5],[6]. The charged area consists of highly charged water droplets and ice crystals inside the cloud suddenly level themselves through a charge release process called as lightning discharge [7]. The lightning occurrence can be methodized within few steps as, a) Cloud Genesis b) Charge severance c) Atmospheric breakdown d) Pilot Streamer e) Stepped Leader f) M-Components g) Attachment process h) Discharge i) Shockwave generation j) Return Stroke k) J-Process l) K-Process m) Dart Leader n) Re-Strike [8]-[11]. Natural lightning is the lightning stroke which produces naturally from the natural cloud and without any help of any artificial element [12],[13]. Artificial Lightning or Artificially Triggered Lightning is the lightning made in a laboratory environment or by triggering variously [13-[15].

Ross Gunn [1954] has published the experimental findings regarding the electrical properties of clouds. The investigated report is shown in this paper related to the role of ionic diffusion in electrically charging drops in the atmosphere. This ionic diffusion helps to produce lightning producing clouds [16]. And Martin A. Uman and D. Kenneth Mclain [1969] have published the magnetic flux density of lightning return stroke from 0.5 to 200 Km. They calculated that a lightning strike occurred in less than one millisecond. According to this calculation, the lightning impulse designed in this paper has the front-time of less than one millisecond [17]. In the case of numerical computing of lightning, John S. Nisbet [1983] proposed a dynamic mathematical computing model of the electrical behaviour of the thundercloud. Possibly that was the first numerical modelling of thundercloud electricity [18]. After that, Serge Soula and Serge Chauzy [1991] have published a report in the journal of geophysical research regarding the experiment on the electric field produced within clouds which can provide powerful lightning bolt. The maximum value of the electrical field detected was 65kV/m at 603m [19]. Recently, Phillip M. Bitzer [2016] performed a space observation of lightning and also the continuing current in lightning. This paper shows that 11.2% of lightning flashes have the continuing current, and most of them are oceanic and winter lightning [20]. Lightning energy conversion system is a system which can convert lightning energy to storable form of energy. Supercapacitor is installed in lightning energy conversion system. This paper presents a feasibility analysis in numerical computing environment to harvest lightning energy within supercapacitor. To convert the supercapacitor energy, seven-level inverter used with real-time pulse generator integration. A lightning impulse generator circuit has been experimented in MATLAB Simulink environment and validated using high voltage impulse generator hardware. A Tesla coil is used as an impulse generator in this system to validate the circuit designed in MATLAB.

II. OVERVIEW OF THE SYSTEM

This section shows a block diagram and overview of the system and describes the methodology of the system designed by interfacing micro-controller.

Revised Manuscript Received on August 30, 2020.

* Correspondence Author
Suman Jana*, Electrical and electronics engineering department, National institute of technology Mizoram, Aizawl, Mizoram, India. Email: sumanjana@live.com
Pabitra Kumar Biswas, Electrical and electronics engineering department, National institute of technology Mizoram, Aizawl, Mizoram, India. Email: Pabitra.eee@nitmz.ac.in

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

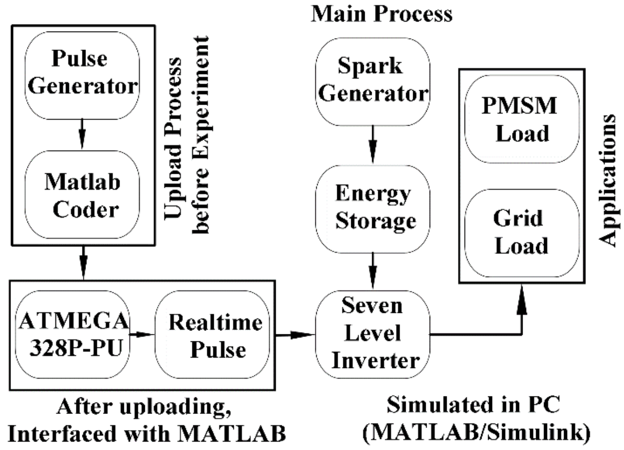

Figure 1: Methodology of the experiment

Figure 1 shows the block diagram of the system modelled in this experiment. The block diagram is organized in four process groups as, Code uploading, Interfacing with MATLAB, Main process and Applications. The spark generator is designed and integrated with a supercapacitor-based storage system followed by seven-level inverter and various applications (Permanent Magnet Synchronous Machine Load Grid Load).

A. *Lightning Spark Generator*

As lightning bolt contains extremely high power, so it's difficult to model such high-power simulation circuit. In this experiment, a spark generator circuit is modelled to achieve a similar voltage like lightning voltage with real-time weather data [21],[22]. From the relation of Energy (J), Power (P), Time (t), Voltage (V) and Current (I) the lightning voltage is calculated. According to Joule's law,

$$J = P \times t \tag{1}$$

So,

$$P = V \times I \tag{2}$$

From equation (1) and (2),

$$J = \frac{V}{I \times t} \tag{3}$$

From equation 3, impulse generator parameters are calculated by using the weather data and previously investigated parameters published in the literature. Richard Hasbrouck [1996] and V. A. Rakov [2003] investigated and reported that insulation of air break down approximately at 5 MV and more. But it may vary on the distance of cloud from the ground and the humidity of the air. Also, they have reported that a lightning bolt carries 30 kA current and deliver 500 Megajoules energy on average [23],[24]. Figure 2 shows the Lightning spark generator and its voltage waveform modelled and measured in the MATLAB/Simulink environment to assimilate with lightning energy harvester. As shown in figure 2, two stages are used in this circuit, primary stage and secondary stage. Two stages have been separated by an ideal switch.

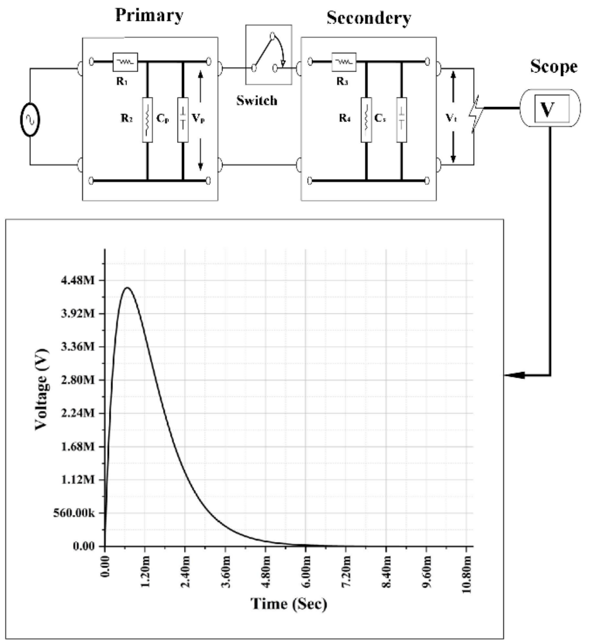

Figure 2: Spark Generator Circuit and the voltage output

In this circuit R_1, R_2 at primary stage and R_3, R_4 at secondary stage act as wave-shaping resistor. Also, the capacitors C_p at primary stage & C_s at the secondary stage are used as a voltage generator and load at closed switch condition. And for open switch condition, C_s acts as a source to form decreasing waveform at impulse terminal. If we consider C_p as a generator, then voltage change v_p may be written as,

$$\frac{dv_p}{dt} = \frac{1}{C_p}\left(\frac{v_p}{R_3+R_4} + i_t\right) \tag{4}$$

And when the switch is at open condition, the primary stage will be isolated from the secondary stage, and only secondary capacitor C_s will work as a source. Then, the time constant (τ) can write as,

$$\tau = (R_3 + R_4)C_s \tag{5}$$

And voltage (v_t) change at impulse terminal for voltage (v_s) of secondary stage capacitor may be written as,

$$\frac{dv_t}{dt} = \left(v_p - v_s\right)\left[1 - \frac{1}{e^{\left(\frac{t}{\tau}\right)}}\right] \tag{6}$$

After considering 0.004 Seconds as the total time frame for front time and tail time, impulse generator circuit produced approximately 4.2 MV potential difference as calculated from equation 3. From the calculated potential difference, the average voltages of lightning bolts are more than 4.2 MV, the spark generator designed in the system such a way that it can give an output of more than 4.2 MV spark. The simulated circuit is giving peak voltage of 4358860.241 V at 0.00065 sec. Figure 3 shows the Tesla coil used as the impulse voltage generator or lightning simulator in the lightning energy-harvesting prototype at the place of the spark generator circuit mentioned in the simulation model.

Retrieval Number: J74150891020/2020©BEIESP
DOI: 10.35940/ijitee.J7415.0891020
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

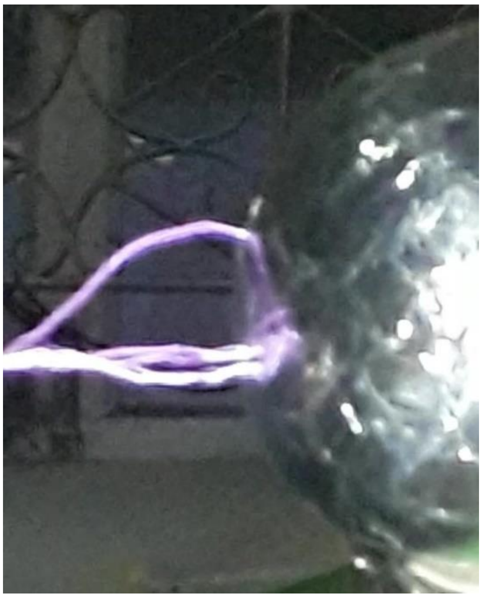

Figure 3: Tesla coil in operation as lightning simulator

The Tesla coil constructed here is produced almost 145.6 kV of the output voltage at 1004 millibar atmospheric pressure, 87% humidity and 27ºC atmospheric temperature. The output voltage and frequency of the Tesla coil are used as the input of the simulation circuit and voltage is boosted to achieve more than 4.2 MV. Average output power measured in the simulation circuit of the impulse generator is 0.5 W.

B. *Storage System*

There are battery, flywheel, capacitor, Supercapacitor, hybrid capacitors available to store electrical energy. But designing the energy storage system is very challenging and challenging work for lightning because of the short period of a lightning bolt. This paper shows a possible energy storage methodological system designed and tested in a numerical computing environment using real-time storage parameters. As shown in figure 4, Supercapacitor has mainly two-pole, i.e. Positive side and negative side. Every pole is made with four layers, i.e. Separator, Carbon electrode, Collector and again carbon electrode [25]-[27].

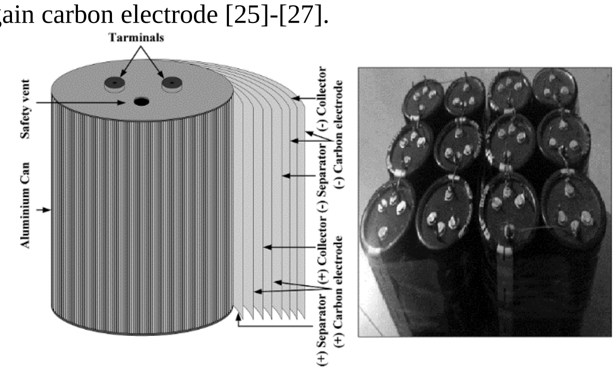

Figure 4: Supercapacitor construction and Supercapacitor bank used to design each supercapacitor in simulation model

The supercapacitor has very high charging capability. This property of the supercapacitor makes it eligible to store impulse energy [28]. It's nearly impossible to design a supercapacitor which can store all energy of single lightning bolt. But only control and decrease of lightning parameters, i.e. Voltage, Current and Temperature, can make this dream practical [29],[30].

A supercapacitor can withstand -20ºC to +70ºC temperature and can give almost 95% efficiency [31]-[33]. The self-discharge time in room temperature is also more than a week, and these features make supercapacitor eligible to store high power. Figure 4 shows the supercapacitor bank is used to design each supercapacitor in the simulation model. The voltage charging capacity of a supercapacitor depends on source voltage and time constant of the supercapacitor. For this storage capacitors, v_t of impulse terminal works as source voltage. So, if R is charge resistance of supercapacitor, then charge voltage v_{ss} may be written as,

$$v_{ss} = v_t[1 - e^{'(-\frac{t}{\tau})}] \tag{7}$$

The supercapacitor is designed here using real-time parameters of supercapacitor bank as one single supercapacitor is equaled to twelve supercapacitors connected in series. Each supercapacitor used in the simulation circuit have 99.5 F rated capacitance, and 48 V rated voltage. Operating temperature 27ºC is taken for the simulation environment.

C. *Energy Conversion*

After storing the energy, it is necessary to convert it into AC to make this energy usable for AC applications. The energy conversion system has been designed using cascaded H-bridge seven-level inverter to convert stored energy within supercapacitor for various types of load [34],[35]. Number of bridges required for three-phase cascaded H-bridge multilevel inverter is calculated using the following equation,

$$H_n = \phi_n \times (\frac{l_n - 1}{2}) \tag{8}$$

Figure 5 shows the single-phase simulation diagram of cascaded H-bridge seven-level inverter designed with twelve IGBTs in every phase.

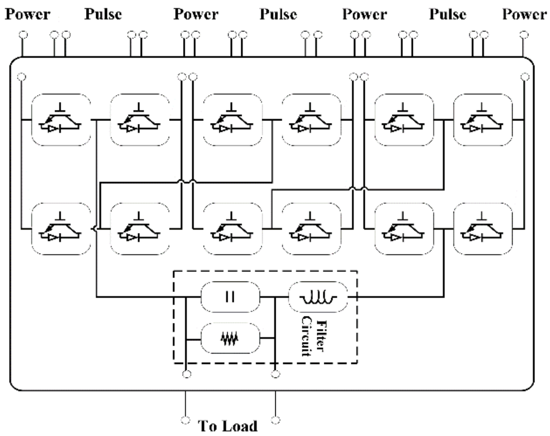

Figure 5: Single phase Simulation diagram of seven-level inverter

The inverter is connected with RLC filter circuit to reduce the harmonics in the said system. The pulses are given from ATMEGA322P-PU IC, interfaced with MATLAB.

D. *Applications*

The system is experimented with various loads to measure the performance of the spark generator, storage devices and inverter with the various types of load.

The system is integrated with PMSM to examine the response. And also, the system is integrated with Grid load to measure the system performance with Grid connection.

E. *Pulse Generator*

The next and significant part of this system is the pulse generator for the inverter circuit.

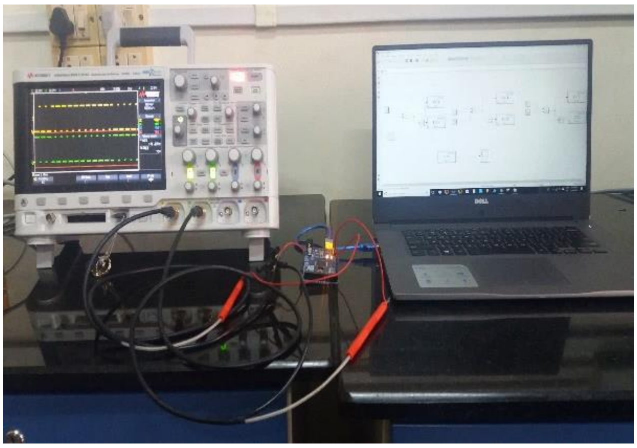

Figure 6: The hardware setup of the pulse generator for inverter

The pulse generator circuit designed in Simulink environment and converted the circuit to C++ coding using MATLAB Coder. Then code has been uploaded to microcontroller ATMEL ATMEGA328PPU using Arduino Mega.

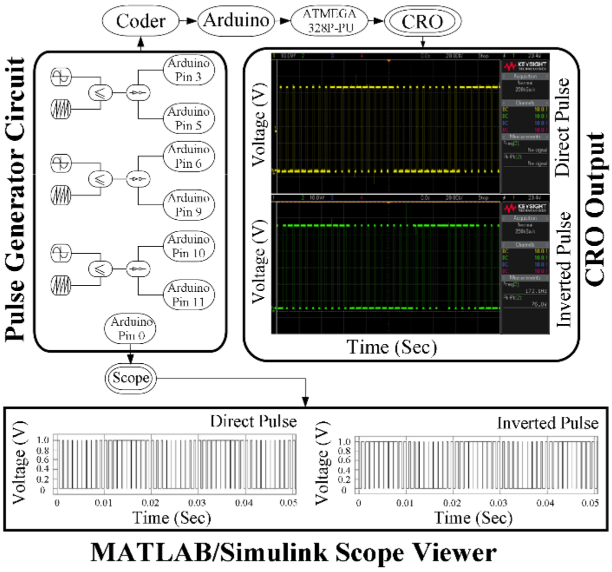

Figure 7: Pulse generator circuit and the waveform measured in both Simulink and CRO

Figure 6 shows the hardware setup of pulse generator circuit using a microcontroller and observed pulses using CRO, where the code uploaded to IC ATMEL ATMEGA328P-PU (Center) through the PC (MATLAB) at the right side and visualized by the CRO at left side. From the microcontroller ATMEL Atmega328P-PU, the real-time pulse has been given to IGBTs of seven-level inverter by interfacing microcontroller with MATLAB environment. Figure 7 shows the pulse generator circuit used and process to generate the real-time pulse. The circuit has been converted using MATLAB Coder and uploaded to the microcontroller. The output pulse of Arduino is given to the modelled system connecting the microcontroller to MATLAB through different output pins of Arduino.

Figure 7 also shows the Pulse waveform of direct pulse and inverted pulse generated by the microcontroller, which is distributed to the inverter by the pulse distributor.

III. SIMULATION DIAGRAMS

The system designed in such a way that impulse energy generated by the impulse generator stored in supercapacitor. And the energy will be converted to AC for PMSM.

A. *Simulation diagram with PMSM Load*

Figure 8 shows the simulation diagram modelled in a numerical computing environment with a permanent magnet synchronous motor load.

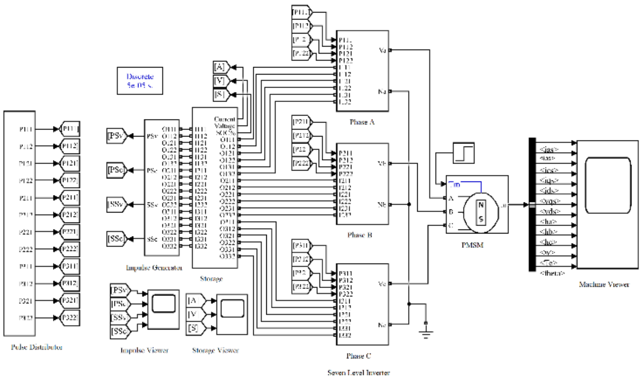

Figure 8: Three phase simulation diagram of the system with PMSM Load

The responses of PMSM and Supercapacitor bank are seen in Machine Viewer and Storage Viewer.

B. *Simulation diagram with grid connection*

In this system, the stored energy in a supercapacitor is converted to AC for grid load. This grid is modelled with five buses, i.e. A, B, C, D and E. And all the responses monitored in grid viewer.

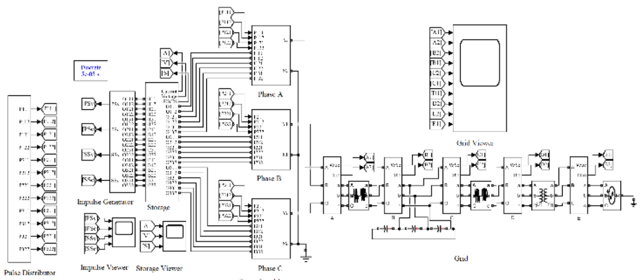

Figure 9: Three phase simulation diagram of the system with Grid Load

Figure 9 shows the simulation diagram modelled in a numerical computing environment with Grid load. The response of Grid and Supercapacitors are seen in grid Viewer and Storage Viewer.

Retrieval Number: J74150891020/2020©BEIESP
DOI: 10.35940/ijitee.J7415.0891020
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

IV. RESULT AND DISCUSSIONS

This section presents the response graphs of the system integrated with lightning spark generator, storage system and conversion system. The system is imitated in 0.1 sec time frame. All the systems are imitated in the discrete graphical user interface.

A. *Response with PMSM Load*

Various response graphs and reports of the behaviour of PMSM is discussed in this section. The supercapacitor response with PMSM load, stator current, stator voltage, torque and hall effect of PMSM are analyzed.

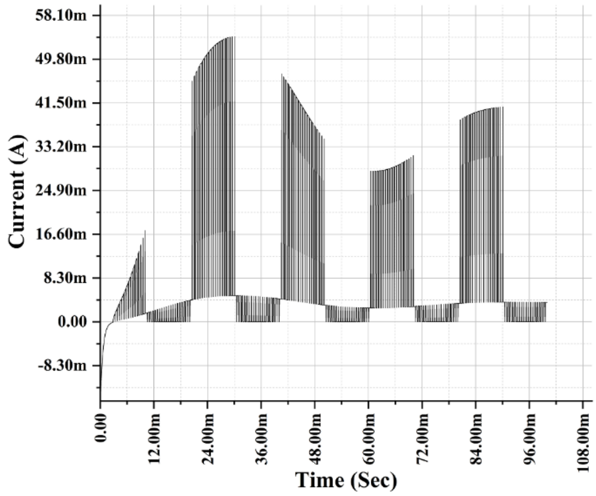

Figure 10: Supercapacitor current response with PMSM

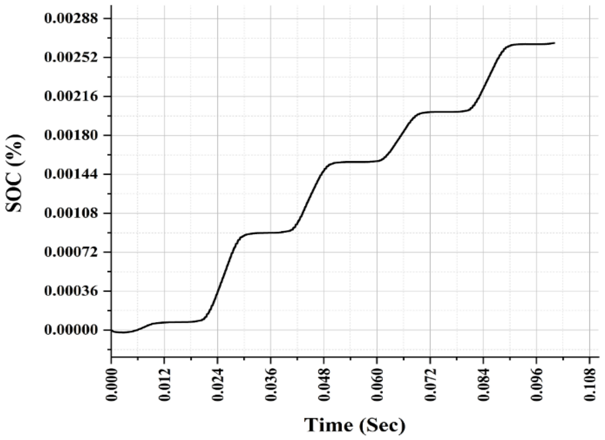

Figure 11: Supercapacitor SOC Percentage with PMSM Load

As figure 10 shows, the peak current flows at the initiation of the impulse at 0.03005th second and 0.054083913 A current flows through supercapacitor. The peak voltage with PMSM load is 6.069226873 V (maximum negative peak happened at 0.03005th second). State of charge percentage of supercapacitor shows it's charging and discharging state at a particular time. Figure 11 shows the state of charge percentage of the storage system modelled in this experiment.

The supercapacitor peak SOC percentage with PMSM load is 0.002653955% of the total capacity at 0.1 second in a 0.1-second time frame. Due to machine load, the SOC percentage is deficient in PMSM response. The current response and voltage response are viewed by machine viewer in the mentioned system.

Figure 12(a) shows the current response and figure 12(b) shows the voltage response of PMSM. As shown in figure 12(a), the stator current at phase A (I_a) has maximum peak current 6.231536106 A at 0.02605 - 0.02609 second, phase B (I_b) has maximum negative peak of 4.958829778 A at 0.0269 - 0.02694 second and phase C (I_c) also has maximum negative peak of -1.495125462 A at 0.01665 - 0.016696667 second. The peak stator current of Q-axis (I_q) is 6.342139469 A (maximum positive peak) at 0.0256 - 0.02564 second and D-axis (I_d) is 1.9279776 A (maximum negative peak) at 0.0313 - 0.03134 second.

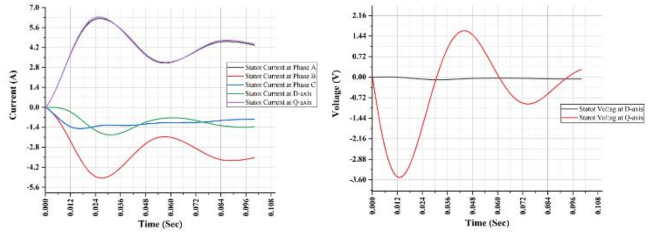

Figure 12: (a) Current response of PMSM, (b) Voltage response of PMSM

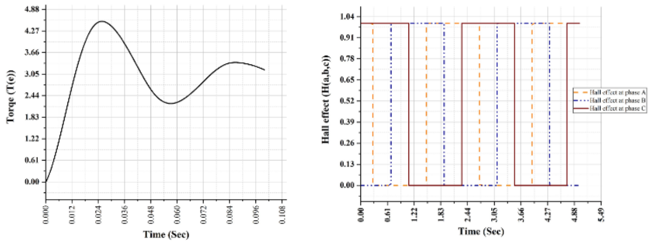

Figure 13: (a) Torque Response of PMSM, (b) Hall effect Signal

As shown in figure 12(b), the voltage of Q-axis (V_q) has the highest positive peak of 1.628908622 V at 0.044 - 0.04404 second and highest negative peak of 3.517840947 V at 0.013 - 0.013044716 second, where voltage of D-axis (V_d) has the highest positive peak of 0.0064452 V at 0.00795 - 0.00799 second and highest negative peak of 0.0911118 V at 0.03115 - 0.031198771 second.

As shown in figure 13(a), the highest torque produced in PMSM during operation at 0.0256 - 0.02564 second. Another response viewed by machine viewer is hall effect signal of PMSM. Figure 13(b) shows the hall effect signal of phase A (H_a), phase B (H_b) and phase C (H_c), where at least 1.5012965-second time frame is necessary to get full-cycle of phase A (hall effect) signal, at least 1.905296188-second time frame is necessary to get full-cycle of phase B (hall effect) signal and at least 2.308696441-second time frame is necessary to get full-cycle of phase C (hall effect) signal. Here 5-second time frame was used to measure the hall effect signal of PMSM.

B. *Response with Grid connection*

Various response graphed for Grid Load and analyzed the report of the behaviour of Grid has been discussed in this section. The supercapacitor response with grid load, voltage and current level at the different bus of the grid are analyzed.

As figure 14 shows, every full cycles of the current completes at 0.01895 second.

The supercapacitor current with the grid has the highest peak of 2.776422224 A at 0.01165 seconds. The peak voltage with supercapacitor bank is 311.916446 V negative peak at 0.01165 second. Also, the state of charge percentage is measured for grid load using storage viewer. Figure 15 shows the state of charge percentage of the supercapacitor. The supercapacitor peak SOC percentage of the grid is much better than PMSM load, i.e. 0.14364011% of the total capacity at 0.1 seconds in the 0.1-second time frame.

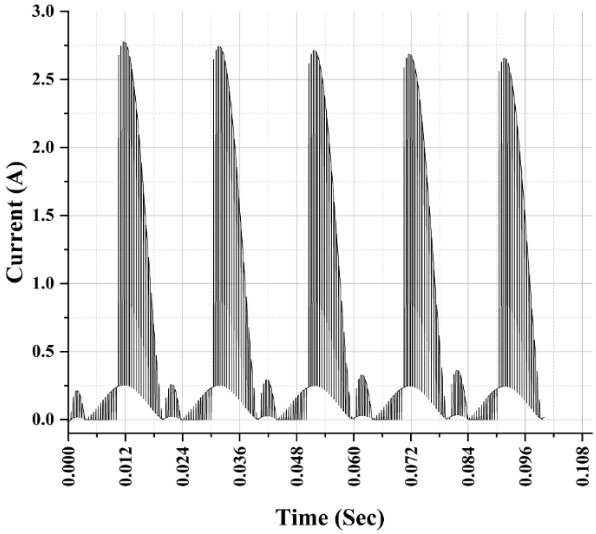

Figure 14: Supercapacitor current response with grid

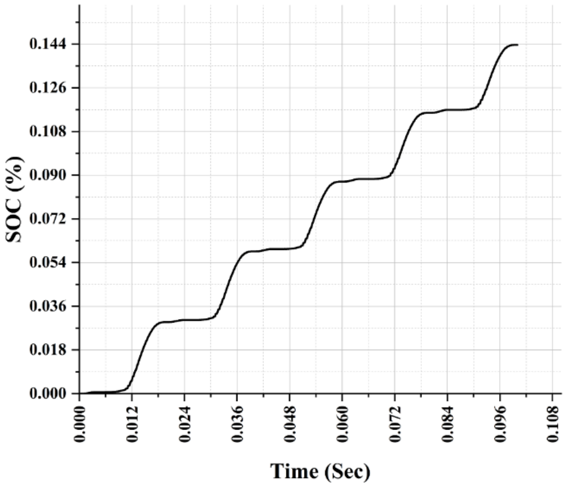

Figure 15: SOC percentage of supercapacitor with Grid connection

As shown in figure 16(a) and figure 16(b), due to the source connected at the terminal of the grid, the signal range at bus E is different than the signal at bus A, B, C and D. Phase A current at bus A (A_a), bus B (B_a) give same signal range with highest negative peak of 387.8672743 A and highest positive peak of 118.2781776 A. Phase A current at bus C (C_a), bus D (D_a) give the same signal range with highest negative peak of 349.4872188 A and highest positive peak of 79.67663366 A.

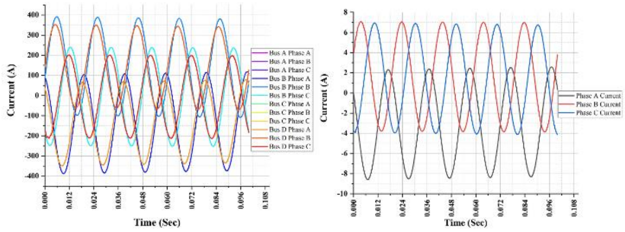

Figure 16: (a) Phase current at A, B, C and D bus, (b) Phase current at E bus

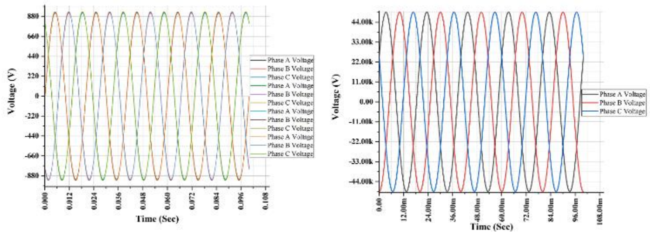

Figure 17: (a) Phase voltage at A, B, C and D bus, (b) Phase voltage at E bus

Phase B current at bus A (A_b), bus B (B_b) give the same signal range with highest positive peak of 391.4709065 A and highest negative peak of 108.8440959 A. Phase B current at bus C (C_b), bus D (D_b) give the same signal range with highest positive peak of 352.58381 A and negative peak of 70.10104538 A. Phase C current at bus A (A_c), bus B (B_c) also give the same signal range with highest positive peak of 240.227993 A and highest negative peak of 251.8628412 A. Phase C current at bus C (C_c), bus D (D_c) also give same signal with highest positive peak of 201.8142769 A and highest negative peak of 213.4129049 A. The phase A current at bus E (E_a) has the highest negative peak of 8.594274228 A, where highest positive peak is 2.582816447 A, phase B current at bus E (E_b) has the highest positive peak of 7.07463478 A, where the highest negative peak is 3.867083412 A and phase C current at bus E (E_c) has the highest positive peak of 6.962021847 A, where the highest negative peak is 4.127568235 A. Every phase has 120^0 phase difference. As shown in figure 17(a), at bus A, phase A voltage curve gives highest positive peak of 918.576035 V and highest negative peak of 918.6053119 V, phase B voltage curve gives highest positive peak of 918.5846294 V and highest negative peak of 918.6574109 V, phase C voltage curve gives highest positive peak of 918.8948977 V and highest negative peak of 918.7060882 V. At bus B and bus C, phase A voltage curve gives highest positive peak of 927.5223882 V and highest negative peak of 927.6190309 V, phase B voltage curve gives highest positive peak of 927.4816536 V and highest negative peak of 927.578536 V, phase C voltage curve gives highest positive peak of 927.8200523 V and highest negative peak of 927.6652743 V. At bus D, phase A voltage curve gives highest positive peak of 930.6235514 V and highest negative peak of 930.7386629 V, phase B voltage curve gives highest positive peak of 930.6645381 V and highest negative peak of 930.6514398 V, phase C voltage curve gives highest positive peak of 930.8142332 V and highest negative peak of 930.7116958 V.

Retrieval Number: J74150891020/2020©BEIESP
DOI: 10.35940/ijitee.J7415.0891020
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

And as shown in figure 17(b), at bus E, phase A voltage curve gives highest positive and negative peak of 49496.79618 V, phase B voltage curve gives highest positive and negative peak of 49497.47468 V, phase C voltage curve gives highest positive and negative peak of 49496.79618 V.

V. CONCLUSION

Lightning energy storage is an ignored research territory as it can create some life hazards to researchers. Regardless, as lightning produces a tremendous value of energy, it can be used as a better source of energy. The experiment presented in this article shows the possibilities to store impulse energy within supercapacitor and also the response of supercapacitor with various types of load. As mentioned in section 2, a cloud to ground lightning may have more than 500 Megajoules of energy available to harvest. And successful harvesting of the power within a single bolt of lightning can bring a revolution in the sustainable energy world. To bring this dream works out as expected, we have to limit the dangers amid lightning research. The impulse generator circuit generated a peak of 4358860.241 V with the front-time of 0.00065 seconds and tail time of more than 0.09935 seconds. Total 0.002653955% of the total capacity of each supercapacitor is getting charged within 0.1 second with PMSM load. Maybe a single lightning strike is not enough for machine load, and more than one restrikes are necessary. It may be useful for flashes of lightning contains more than one re-strike. And total 0.14364011% of the total capacity of each supercapacitor is getting charged within 0.1 second with the presence of grid load. The grid-connected supercapacitor storage gives 54.1230390116 times better response than PMSM connected supercapacitor storage. But using a small resistive load, the experimented impulse circuit is giving almost 0.7% SOC percentage. And another thing is, the responses are measured in this experiment with only 0.5 W of power. The better output of supercapacitor storage may get by increasing the power of the impulse generator. Changing the input frequency also affects the result. Previously mentioned properties of supercapacitor can make it eligible for proposed lightning energy harvesting system. So, this system has been designed with a high voltage low current type spark generator or impulse generator circuit integrated with supercapacitor storage. In future, a system can be created with very high voltage and also with high current impulse generator circuit. Using a high-power circuit, i.e. Voltage in MV range and current in kA range may increase the SOC percentage to maximum possible value. At the initial stage, we should not focus on harvesting maximum energy available in a single lightning bolt. Initially, we should learn how to control the power of the lightning bolt. If we can find out the way to control the power of lightning bolt, i.e. minimizing the current and voltage, then the harvesting task will be more comfortable. At the low power level, we can use the state of art technologies of storage devices to harvest energy from lightning. Later on, we can develop a more efficient storage system to store lightning energy.

ACKNOWLEDGMENT

This experiment was upheld and supported by National Institute of Technology Mizoram, Aizawl, Mizoram. The statistical data of Indian weather data have been taken from Mizoram state meteorological and weather data center, Aizawl with proper authorization.

Also, we are very grateful to Ms. Bhagyashree Jana, Mathematics Department, Vidyasagar University, West Bengal, Mr. Satyajit Pattyanayak and Mr. Laxman Mishra, Mechanical Engineering Department, National Institute of Technology Mizoram, Aizawl, Mizoram for helping us at various stages of experiment.

REFERENCES

1. A. Danielou, The Myths and Gods of India: The Classic Work on Hindu Polytheism, The Princeton Bollingen Series, Inner Traditions, 1991.
2. T. A. G. Rao, Elements of Hindu iconography, Motilal Banarsidass, 1993.
3. S. H. S. Jones et. al., A Greek-English Lexicon, Oxford. Clarendon Press, Oxford, 1940.
4. H. E. Davidson, Gods and Myths of Northern Europe, Penguin, Harmondsworth, Middlesex, 1990.
5. V. A. Rakov, M. A. Uman, Lightning: Physics and Effects, Cambridge University Press, 2003.
6. J. R. Holton et. al., Encyclopedia of atmospheric sciences, Academic Press 3 (2003) 459-483, 1216-1227.
7. T. Takahashi, Riming electrification as a charge generation mechanism in thunderstorms, Journal of the atmospheric sciences 35 (1978) 1536-1548.
8. M. Stolzenburg, T. C. Marshall, Charge Structure and Dynamics in Thunderstorms, Space Science Reviews 137 (2008) 355-372.
9. C. T. R. Wilson, The electric field of a thundercloud and some of its effects, Proceedings of the Physical Society of London 37(1) (1924) 32D-37D.
10. D. J. DePaolo et al., Origin and evolution of earth: Research questions for a changing planet, The National Academies Press, 2008.
11. M. A. Uman, The lightning discharge, Vol. 39, Academic Press Inc, 1987.
12. T. Koopman et al., Channeling of an Ionizing Electrical Streamer by a Laser Beam, Journal of Applied Physics 42 (1971) 1883-1886.
13. S. N. Washington, D.C., Artificial Lightning, American Association for the Advancement of Science 69 (1782).
14. N. Khan et al., Artificial Lightning, Laser-triggered lightning discharge 4 (61).
15. X. Qie et. al., Triggering Lightning Experiments: an Effective Approach to the Research of Lightning Physics, Journal of aerospace lab. 5 (2012) 1-12.
16. R. Gunn, Diffusion charging of atmospheric droplets by ions and the resulting combination coefficients, Journal of meteorology 11 (5) (1954) 339-347.
17. M. A. Uman, D. K. MClain, Magnetic Field of Lightning Return Stroke, Journal of Geophysical Research 74 (28) (1959) 6899-6910.
18. J. S. Nisbet, A Dynamic Model of Thundercloud Electric Fields, Journal of The Atmospheric Sciences 40 (28) (1983) 2855-2873.
19. S. Soula, S. Chauzy, Multilevel measurement of the electric field underneath a thundercloud and dynamical evolution of a ground space charge layer, Journal of Geophysical Research 96 (D12) (1991) 22327-22336.
20. P. M. Bitzer, Global distribution and properties of continuing current in lightning, Journal of Geophysical Research: Atmospheres (121) (2016) 1-9.
21. M. Jayaraju et. al., Impulse voltage generator modelling using Matlab, World Journal of Modelling and Simulation 4 (1) (2008) 57-63.
22. S. E. Meiners, An impulse generator simulation circuit, Miami University (2002) 1-50.
23. R. Hasbrouck, Mitigating lightning hazards, Science and Technology Review (1969) 4-12.
24. V. A. Rakov, A Review of Positive and Bipolar Lightning Discharges, American Meteorological Society (2003) 767-776.
25. R. K. K. N. Singh, A. Manivannan, Matlab based simulation of thermoelectric-photovoltaic hybrid system, International Journal of Engineering Research and Applications 3 (2) (2013) 975-979.
26. J. Ho et al., Historical Introduction to Capacitor Technology, IEEE Electrical Insulation Magazine 26 (1) (2010) 20-25.

27. R. Signorelli et al., Electrochemical Double-Layer Capacitors Using Carbon Nanotube Electrode Structures, Proceedings of the IEEE 97 (11) (2009) 1837-1847.
28. S. Jana et al., Methodological model of Lightning Energy Plant integrated with different energy extraction processes to harness Lightning Energy, IEEE Proceedings of International Conference on Electrical Energy Systems 4 (2018) 229-233.
29. V. A. Rakov, F. Rachidi, Overview of Recent Progress in Lightning Research and Lightning Protection, IEEE Transaction on electromagnetic compatibility 51 (3) (2009) 428-442.
30. A. Kumar et. al., Study of Transient Behaviour of the Capacitor Voltage Transformer, International Journal of Advance Research in Electrical, Electronics and Instrumentation Engineering 4 (5) (2015) 3993-4000.
31. Y. Fuyuan, Characterization, Analysis and Modeling of an Ultracapacitor, World Electric Vehicle Journal 4 (2010) 358-369.
32. B. E. Conway, Electrochemical Supercapacitors: Scientific Fundamentals and Technological Applications, Springer (1999) 1-8.
33. B. E. Conway, Transition from 'Supercapacitor' to 'Battery' Behavior in Electrochemical Energy Storage, Journal of electrochemical society 6 (138) (1991) 1539-1548.
34. F. Khoucha et al., A Comparison of Symmetrical and Asymmetrical Three-Phase H-Bridge Multilevel Inverter for DTC Induction Motor Drives, IEEE Transactions on Energy Conversion 26 (1) (2011) 64-72.
35. E. Levi et al., Analytical Determination of DC-Bus Utilization Limits in Multiphase VSI Supplied AC Drives, IEEE Transactions on Energy Conversion 23 (2) (2008) 433-443.

AUTHORS PROFILE

Suman Jana completed his B.Tech from West Bengal University of Technology, West Bengal, India on 2013. He received his M.Tech. Degree (EE Power system) on 2016 from Maulana Abul Kalam Azad University of Technology, West Bengal, India. He is presently Pursuing PhD in Electrical and Electronics Engineering department of the National Institute of Technology Mizoram, Aizawl, Mizoram, India. He has published a numbers of research papers in National/International Conference and Records/Journals and three filed patents. His research interests include High voltage engineering, Lightning energy, Wind energy, Solar energy and Power electronics converters.

Pabitra Kumar Biswas completed his B.Tech from Asansol Engg. College, WBUT, India. He received his ME. Degree (EE Power Electronics and Drives) on 2007 from Bengal Engineering and Science University, West Bengal, India and PhD. Degree in Electrical Engineering on 2013 from National Institute of Technology, Durgapur, India. He is presently working as an Assistant Professor in Electrical and Electronics Engineering in the National Institute of Technology, Mizoram, India. He has published a numbers of research papers in National/International Conference and Records/Journals. He has a springer book chapter and filed three patents. He has also one ongoing DST-SERB project. He has about 12 years of academic as well as research experience in repute. His research interests include Electromagnetic Levitation System, Active Magnetic Bearing and Power electronics Converters, PMSM and BLDC Motor Drives and Renewable energy.