MICROGRID FREQUENCY STABILIZATION WITH ULTRACAPACITOR BASED SYSTEM

MITHUL THERE
M-Tech Student
Priyadarshini College of Engineering & Arch.,Nagpur.
mithult84@gmail.com

SACHIN SUKE
Assistant Professor
Priyadarshini College of Engineering & Arch.,Nagpur.
sachin.suke_281984@rediffmail.com

SHUBHADA MULEY
Associate Professor
Priyadarshini College of Engineering & Arch.,Nagpur.
shubhada_muley@rediffmail.com

Abstract- This research introduces an energy storage system to deliver microgrid frequency response - as an ultracapacitors and inverter , to deliver short term energy response. A control system is created to monitor the grid frequency and activate an inverter to either charge or discharge a ultracapacitor depending on the measured conditions. For example, when the frequency is measured below 50 Hz, the supercapacitor deliver power into the microgrid to arrest the frequency deviation& when the frequency above 50 Hz the energy storage system absorbs power from microgrid to ultracapacitor. Microgrid frequency is stabilized by adding short term energy response. A description of the major components as well as their simulation results is described herein.

Index Terms- Capacitor, Microgrid, Ultracapacitor, Ultracapacitor Matlab model

I. INTRODUCTION

Frequency response is defined as an automatic and sustained change in the power consumption or output of a device that occurs within 5-30 seconds of and is in a direction to oppose a change in the Interconnection frequency. A group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid [and can] connect and disconnect from the grid to enable it to operate in both grids connected or island mode. Supercapacitors are very efficient storage devices located in the middle of the energy storage devices hierarchy due to their capability of delivering high power in short time which is translated by a low energy storage capacitance. A microgrid is a small-scale power grid that can operate independently or in conjunction with the area's main grid. Any small-scale localized station with its own power resources, generation and loads and definable boundaries qualifies as a microgrid. Microgrids can be intended as back-up power or to bolster the main power grid during periods of heavy demand. Often, microgrids involve multiple energy sources as a way of incorporating renewable power. Other purposes include reducing costs and enhancing reliability. The modular nature of microgrids could make the main grid less susceptible to localized disaster. Modularity also means that microgrids can be used, piece by piece, to gradually modernize the existing grid. The practice of using microgrids is known as distributed dispersed, decentralized, district or embedded energy generation.

Primary control [1] is used to manipulate the value of the frequency. It consists of two groups of methods:

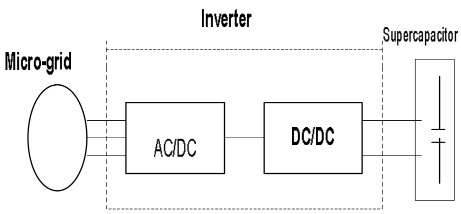
• A certain portion of the load is motors that spin slower when the frequency declines, and therefore consume less power. They also spin faster when the frequency rises thereby consuming more electricity.

• Some generators on the grid are controlled by governors that will automatically change the power output depending on the grid frequency. Microgrids generally have low inertia due to lack of large dispatchable synchronous generation. Also, non-dispatchable sources such as solar and wind generally do not have a favorable frequency response characteristic, like the motor loads described above.

II. MICROGRID CONNECTED TO THE SUPERCAPACITOR

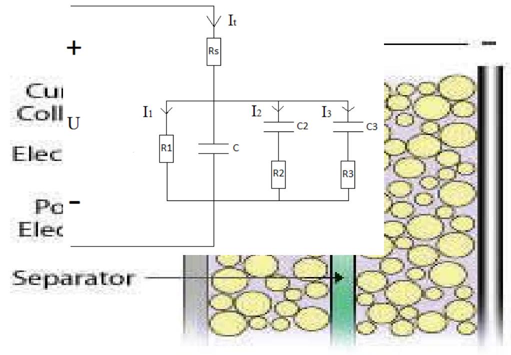
The first configuration are attaches the GTI [1] directly to the microgrid. On this particular dataset the microgrid frequency is measured to be slightly under 50 Hz at t = 0 sec. and on average it falls as time progresses.

Therefore the control system commands current from the GTI that will discharge power from the supercapacitors as shown by Vdc decreasing.



III. SUPERCAPACITOR

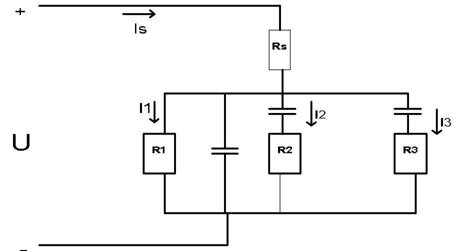
A supercapacitor (SC), sometimes ultracapacitor, formerly electric double-layer capacitor (EDLC)) is a high-capacity electrochemical capacitor with capacitance values up to 10,000 farads at 1.2 volt that bridge the gap between electrolytic capacitors and rechargeable batteries. Capacitor is very useful component in the field of engineering and it is used in various electrical and electronic circuitries. Capacitor stores energy in the form of electric field. Capacitor also known as condensers which stores energy when charge and release energy when discharge [2],[3]. When potential difference is applied across conductors of capacitor, electric field develops across dielectric and conductors hold equal and opposite charges on their surfaces. These conductors are close together thus opposite charges on conductor attract one another due to development of electric field which in results allow capacitor to store more charge [4][5]. Capacitor is characterized by capacitance; capacitance is greatest when there is narrow separation between conductors and vice versa [6]. Capacitor perform two function first is to charge and discharge electricity and second one is to block direct current. Capacitors ranges from microfarad and use for applications such as smoothening circuits for power supply, back up for microcomputers and timer circuits, filters to eliminate unwanted frequency [7]. Supercapacitor is also known as electric double layer capacitor and store more energy than normal capacitor [8]. Supercapacitors are based upon same physical principle as normal capacitor. But normal capacitor has drawback of low capacitance. Supercapacitor has overcome such drawbacks and provides high capacitance in small volume. They also have high energy density than conventional capacitors Supercapacitors are composed of two electrodes immersed in an electrolyte solution. Main difference between supercapacitor and normal capacitor is supercapacitor provides high specific surface area with thinner electrodes as compare to normal capacitors. Thus energy storage in double layer capacitor results from charge separation in thin layers formed between a solid conducting surface and liquid electrolytes containing ions [9]. In supercapacitor charge does not accumulate between two conductors, but in between surface of conductor and electrolyte [10].Hence value of capacitance and performance of supercapacitor depends upon electrode material used. Therefore depending upon design of electrodes supercapacitors are categorized into three classes i) double layer capacitors (ii) pseudocapacitors and (iii) hybrid capacitors [11],[12]. Mechanism of double layer capacitor depends on the electrostatic storage, which is achieved by the separation of charges at interface between the conductive electrode surface and electrolytic solution. Capacitance of double layer capacitor is proportional to the specific surface area of electrode material therefore carbon material such as activated carbon, carbon fibres are selected as electrode materials for double layer capacitors which provides higher capacitance than pseudocapacitors.Pseudocapacitors are electrochemical capacitors, in which energy storage is depends on transfer of electrons achieved by redox reaction with ions from electrolyte solution. The electrochemical capacitors include metal oxide supercapacitors and conducting polymersupercapacitors. Capacitance of electrochemical capacitors depends on the utilization of active material of electrodes [13]. Hybrid super-capacitor combines properties of electrolytic capacitor and electrochemical capacitor, so it has thebest features with the high specific capacitance and high energy density of electrochemical capacitor [14], [15].An ultracapacitor can be viewed as two nonreactive porous plates, or collectors, suspended within an electrolyte, with a voltage potential applied across the collectors. In an individual ultracapacitor cell, the applied potential on the positive electrode attracts the negative ions in the electrolyte, while the potential on the negative electrode attracts the positive ions. A dielectric separator between the two electrodes prevents the charge from moving between the two electrodes.



.

IV. TEMPERATURE DEPENDENT SUPERCAPACITOR MODEL

The used model is a Dynamic Temperature Dependent supercapacitor Model [18]based on structure shown in Figure 1. Three capacitors are integrated in this model: one main capacitance C, and two others C2 and C3. In general, C is the primary energy storage component, C2 and C3 model the dynamic behavior. By altering the component values, their time constants change which affects how fast they charge and discharge. R1 represents the quantification of auto discharge effect. Rs is the series resistance causing losses during charge and discharge.In fact, the functioning of supercapacitor depends on the load demand current or the source current. In addition, the temperature variation can influence on the charge/discharge time.



The main capacitance, C, is a temperature dependent variables, represented by [19]:

C=2600.Cf

where Cf designs the correction factor given by:

$$Cf=\frac{P1T^{3}+P2T^{2}+P3T^{1}+P4}{2700}$$

with T the temperature and the coefficients P1 = 0.002161; P2 = -0.0614; P3 = -0.18243 and P4 = 2701.99.

V. SUPERCAPACITOR CIRUIT AND SUPERCAPACITOR CONTROL CIRCUIT

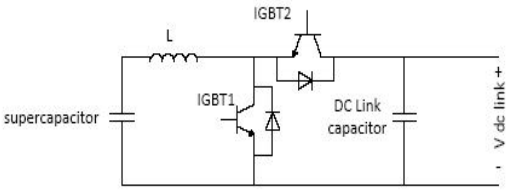


Fig. 1. Supercapacitor Circuit

The control system consists of two parts; namely boost mode control and buck mode control

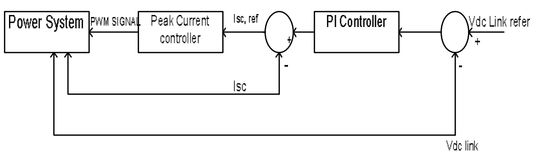


Fig. 2. SCESS boost mode control

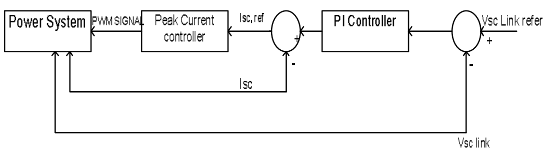


Fig. 3. SCESS buck mode control

In the SCESS boost mode control, the controller consistsof one control loop which controls the discharge current inside another control loop that controls the DC link voltage. (Figure 3) shows the control block diagram for the SCESS in boost mode [16].

In the SCESS buck mode control, the controller consists of one control loop which controls the charging current inside another control loop that controls the Supercapacitor voltage. (Figure 4) shows the control block diagram for the SCESS in buck mode [16].

In both modes, the inner current loop current control is based on peak current control mode. The details of the peak current control mode are well explained in [17]. The outer voltage controllers are conventional PI controllers.

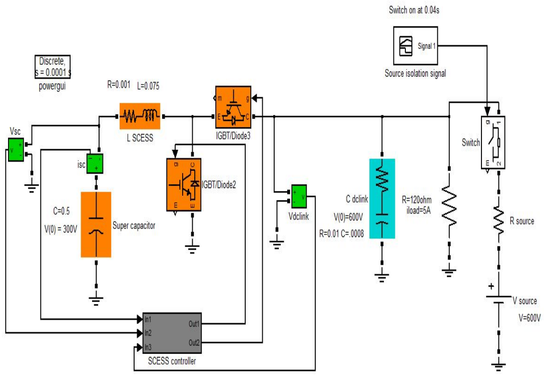


Fig. 4. Supercapacitor, Boost transistor, Buck transistor and DC link simulation model in MATLAB

A MATLAB/SIMULINK simulation model was built for the SCESS system. It consists of the power circuit and the control circuit. The power circuit (Figure 4) consists of the supercapacitor, the inductor, the boost and buck IGBTs, the dc link capacitor, the dc load, and the switched on/off dc source. The DC load and the DC source represent a simplification of the STATCOM. The DC load is used to discharge the DC link capacitor while the DC source is used to charge it.

The control circuit consists of one boost/buck logic circuit, which selects the mode of operation of the SCESS, two PI controllers, which are tuned with suitable proportional and integral gains to control the dc link and supercapacitor voltages, and two peak current controllers, which control the supercapacitor current in buck and boost modes.

V. SUPERCAPACITOR PARAMETER CALULATION

The first method is to look at modelling the voltage derivative during charging of the supercapacitor. The relation between voltage derivative and the capacitance is

$$i(t) = C\frac{di}{dt}u(t)$$

Where C is the capacitance. Using this relation the capacitance can be calculated for different parts of the voltage curve. When high currents are used, other effects than the capacitance can affect the voltage level. These effects can cause the calculated capacitance value to be incorrect.

According to

$$Q = \int i(t)dt$$

where Q stands for charge, the charge in a capacitor can be calculated using the integral of the current during one charging cycle. The capacitance value can then be calculated using

$$C = \frac{\Delta Q}{\Delta u}$$

Where _Q and _u represent differences in charge and voltage. Since the energy level can be calculated using only one value on the voltage, only two points on the voltage curve are needed to be able to calculate the energy storage capability. This means that the voltage variation during the charge is not important to be able to determine the energy content in the supercapacitor. The second method is to look at the energy stored in the supercapacitor. The main advantage of using this method is to avoid the effects of nonlinear capacitance during different charging levels. Then the expression

$$W=\frac{1}{2}C(U_2-U_1)^2$$

Can be used to calculate the capacitance.

VI. SIMULATION RESULT

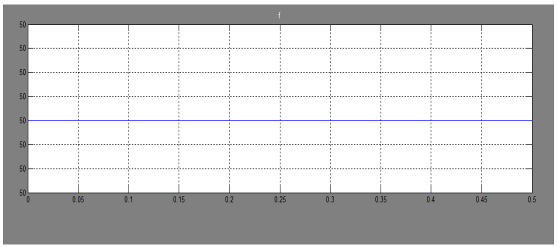


Fig.4. Microgrid Frequency at 50 HZ

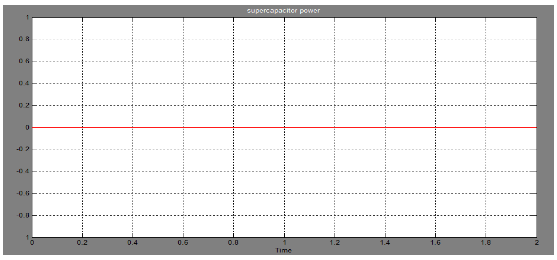


Fig.5. At 50 HZ frequency No power flow from Supercapacitor

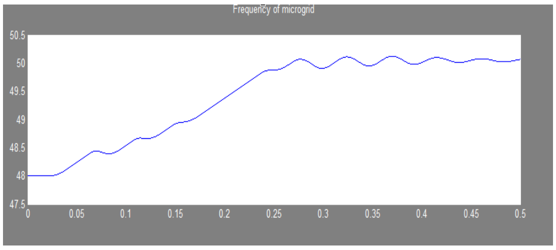


Fig.6. Frequency below 50 Hz

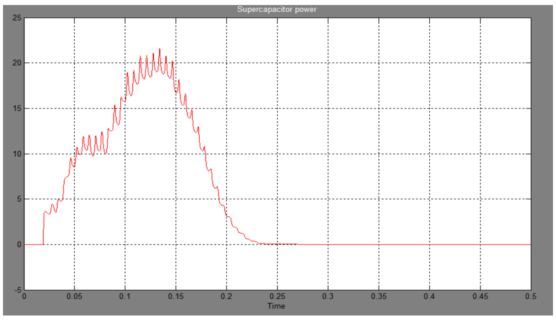


Fig 7. Power flow from Supercapacitor

CONCLUSION

Supercapacitor used in microgrid to deliver frequency response. The average model of the system is simulated. The results demonstrate that the control system and supercapacitor achieve short-term response .It is advised to charge the supercapacitor at the lowest possible temperature because it takes the shortest time to charge completely, and, it is more desirable to discharge it over the highest possible temperature, so it can last as long as possible before total discharge .This serves to stabilize frequency in order to improve microgrid service quality and reliability.

REFERENCES

[1] Rick Crispo, Ted K.A. Brekken, Member, "A Motor-Generator and Supercapacitor Based System for Microgrid Frequency Stabilization,"1st IEEE Conference on Technologies for Sustainability (SusTech),pp.162-166,2013

[2] W. E., Anderson, Calibration of High Voltage Capacitor, Vol. 94, May 1998

[3] RamasamyNatarajan, Power System Capacitors technology and Engineering, CRC Press, Mar 2005

[4] L. Borsody, "New Impregnation for Paper Capacitors", Component Parts IRE Transactions Vol. 7, issue 1, Mar 1960, Page 15 – 25, ISSN: 0096-2422

[5] *Difference between Capacitor and Supercapacitor [online] Available: http://www.differencebetween.com/difference*

[6] Simple Capacitors to Supercapacitors - An Overview [online] available: http://www.electrochemsci.org/papers/vol3/3111196)

[7] *Table of Dielectric [online] Available: http://www.sofia.usra.edu/edu/materials/activeastronomy/sec5-capacitor.pdf*

[8] B.E. Conway, Electrochemical supercapacitors, Kluwer Academics, New York, 1999.

[9] Maxwell technologies, Automotive Applications [online] Available: http://maxwell.com/ultracapcitors

[10] Ultracapacitors & Supercapacitors Forum [online] available: http://www.ultracapacitors.org/

[11] *Supercapacitors: A Brief Overview [online] Available: http://services.eng.uts.edu.au/cempe/subjects_JGZ/eet/Capstone%20thesis_AN.pdf*

[12] Andrew Burke, "The present and projected performance and cost of double layer and pseudo-capacitive ultracapcitors for hybrid electric vehicles applications," IEEE transactionson Industry Applications, vol.40, no.9, May 2005, pp356-366.

[13] Andrew Burke, M. Miller, "Electrochemical capacitors as Energy Storage in hybrid electric vehicles; present status and future prospects," proceedings of International battery, Hybrid and Fuel Cell Electric Vehicle Symposium (EVS24), 13-16 May 2009, Stavanger, Norway- pp 1-11

[14] . B. Karandikar, D. B. Telange, UdayMhaskar, Ramesh Bansal, "Validation of Capacitance and ESR Model of Manganese Oxide Based Aqueous Supercapacitor," Electric Power Componants and Systems, Taylor and Francis, July 2012, Vol. 40 pp 1105-1118

[15] Andrew Burke, "Supercapacitor: Why, How and Where is the Technology," Journal of Power Sources 2000, 91, 37-50

[16] Parashuram B. Karandikar, Dhanjay B. Talange, "Materials based Characterization of Aqueous Metal Oxide Based Supercapacitor," IEEE International Conference on Power and Energy-PEC on 2010, 2, 485-488.

[17] P. Srithorn, M. Sumner, and L. Yao, R. Parashar, "A STATCOM with supercapacitors for enhanced power

system stability" 4th IET Conference on Power Electronics, Machine and Drives , 2008 , pp.9 100.

[18] Charbel ESBER and Nazih MOUBAYED, “Impact of Temperature and Current Variation on the Supercapacitor Functioning,” ISBN: 978-0-9891305-3-0 ©2013 SDIWC,pp-158-165

[19] Johansson, p., Andersson, B., Comparaison Of Simulation Programs For Supercapacitor Modeling, Model Creation and Verification, Master of Science Thesis, Chalmers University of Technology, Gothenburg, Sweden, pp. 75--81, (2008).

★★★