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Microgrid Frequency Stabilization with Motor-Generator & Supercapacitor Based System

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Abstract: **This research introduces an energy storage system to deliver microgrid frequency response - as an ultracapacitors and inverter , to deliver short term energy response. The coupling of doubely fed induction generator and squirrel cage induction machine a control system is created to monitor the grid frequency and activate an inverter to either charge or discharge a supercapacitor 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. 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.**

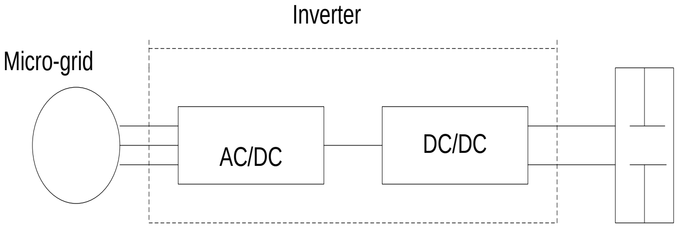
Keywords: **Capacitor, Micro grid, Super capacitor, Super capacitor Mat lab model**.

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,

A. *Microgrid Connected to the Supercapacitor:*

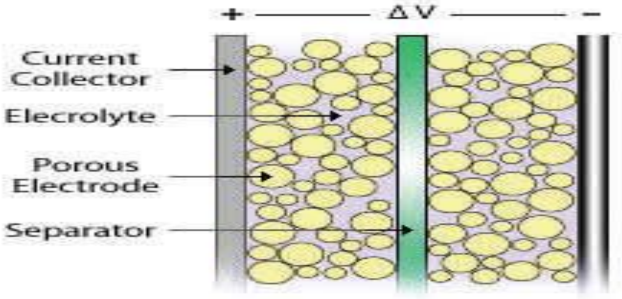
The first configuration are attaches the GTI [1] directly to the microgrid. On this particular dataset the microgrid frequency is measured to be slightly under 50 Hz at t = 0 sec and on average it falls as time progresses. Therefore the control system commands current from the GTI that will discharge power from the supercapacitors as shown by Vdc decreasing.



B. Super capacitor:

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 polymer supercapacitors. 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 the best 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.



C. Temperature Dependent Super capacitor 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.

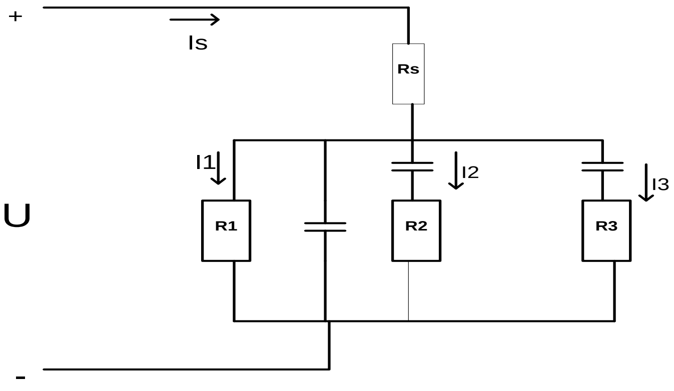


Fig.1. Dynamic Temperature Dependent supercapacitor Model

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.

D. Supercapacitor Ciruit and Supercapacitor Control Circuit:

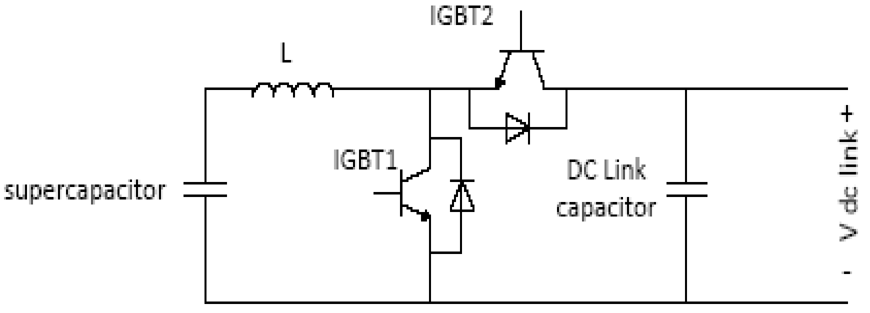


Fig.2. Supercapacitor Circuit

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

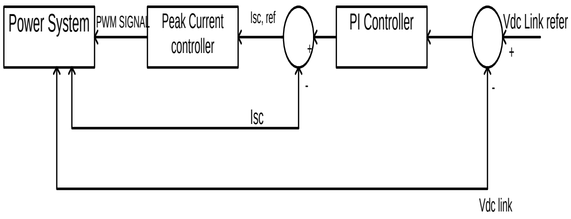


Fig. 3. SCESS boost mode control

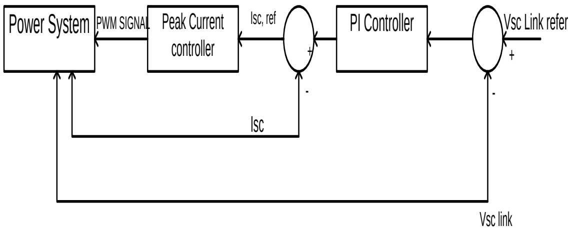


Fig.4. SCESS buck mode control

In the SCESS boost mode control, the controller consists of 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.

$$a + b = \gamma \qquad (1)$$

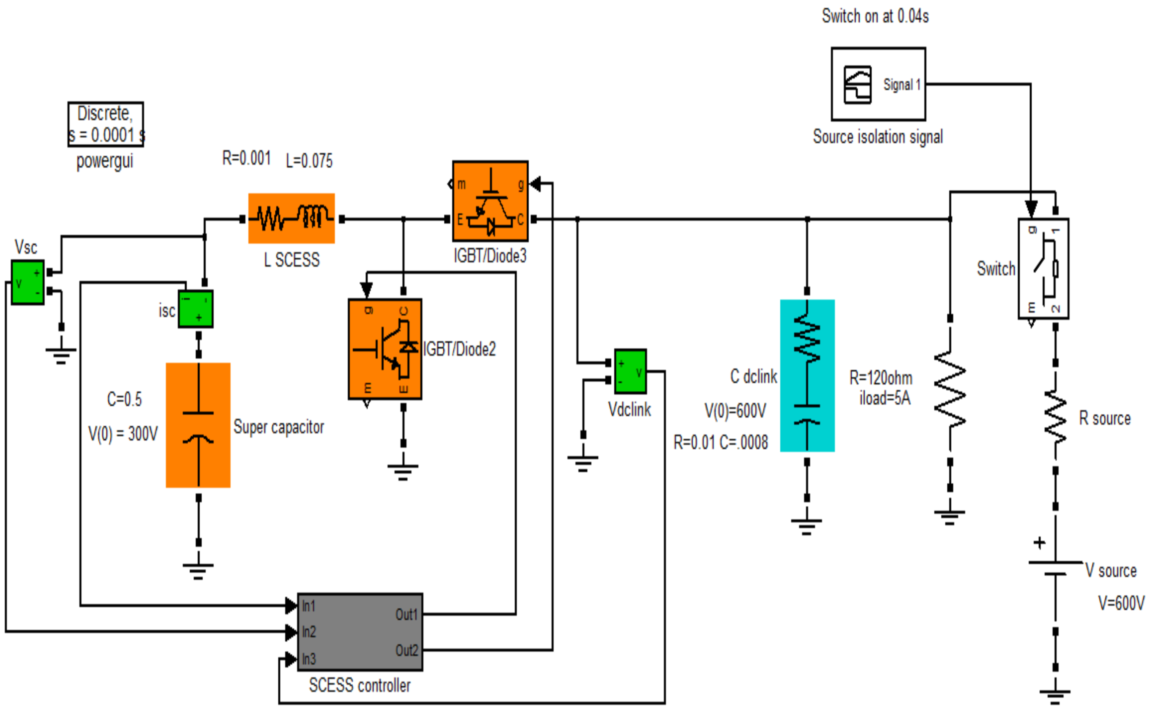


Fig.5. Supercapacitor, Boost transistor, Buck transistor and DC link simulation model in MATLAB

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.

E. Supercapacitor Parameter Calulation:

The first method is to look at modeling 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.

F. Application of Supercapacitor:

Supercapacitors are suitable for applications that needs high peak power for an interval in the range of 10-2 s < t < 102 s because traditional capacitors and batteries have to be "oversized" to meet these "severe requirements". Ultracapacitor used in standalone applications or can be connected to other energy storing devices or electrical sources. Supercapacitor hybrid systems are used as an alternative to conventional battery devices by the automotive manufacturers especially for electrical or hybrid vehicles due to possible "size reduction" and potential "enhancement in battery lifetime". Applications include, but not limited to low power applications like cameras, mobile phones, TV satellite receivers, rechargeable toys and also, to UPS and cold start applications.

G. Simulation Result of Supercapacitor Connected to Microgrid:

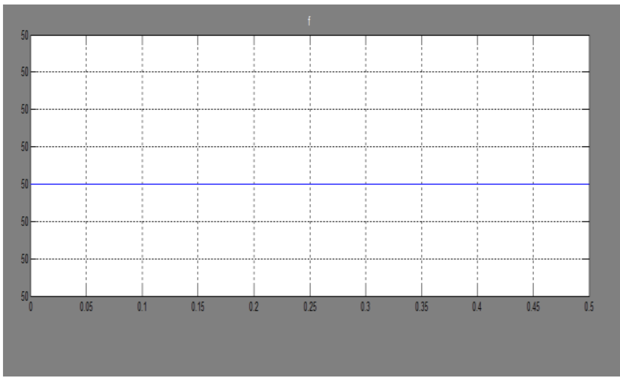


Fig.6. Frequency of microgrid at 50 Hz

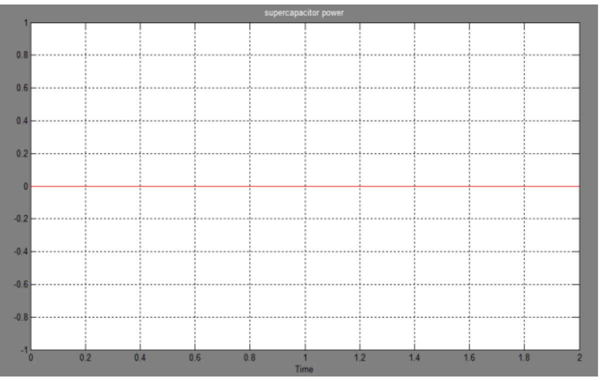


Fig.7. Power Flow from Supercapacitor

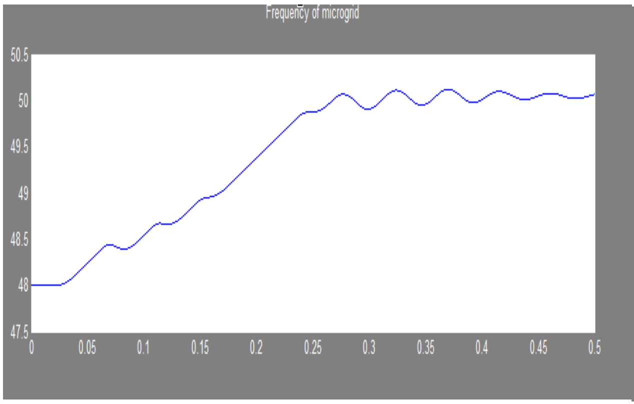


Fig.8. Microgrid frequency at 48 Hz

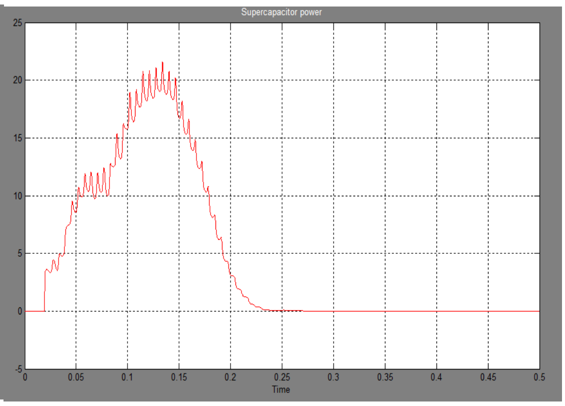


Fig.9. Power flow from Supercapacitor

H. Microgrid Frequency Stabilization Component:

The following components comprise the frequency stabilization system:

1. A squirrel-cage induction machine (SCIM).

2. A doubly-fed induction generator (DFIG) shaft coupled with the SCIM. The DFIG rotor is DC excited, and is therefore operationally equivalent to a wound rotor synchronous machine.

3. A transformer to step the voltage down from 400 V to 230 V, which is the voltage rating of the inverter.

4. A grid-tied inverter (GTI) that implements and AC/DC inverter, a DC-link, and a DC/DC converter.

5. A supercapacitor energy storage bank.

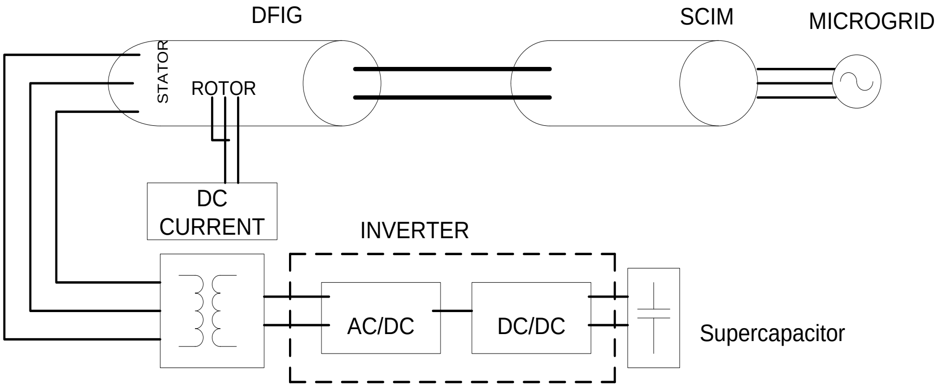


Fig.10. the system delivers frequency response with energy storage from both supercapacitors and real inertia.

I. Design goals and Implementation:

A control system is created to measure the grid frequency and then activate the inverter to either charge

A control system is created to measure the grid frequency and then activate the inverter to either charge or discharge the supercapacitor bank. When the frequency rises above the target value (e.g. 50 Hz) the system takes power from the microgrid to charge the supercapacitors.

The design goal is to achieve frequency response. When the frequency starts to rise the control system activates the inverter, which is tied to the capacitor bank, to control current in order operate the system as a load. Power now flows from the microgrid through the system to charge the supercap bank.

When the frequency drops below 50 Hz power is drawn from the supercapacitor bank, bucked, inverted, and used to drive the DFIG super-synchronously to put power into the microgrid.

J. Software Modeling and Simulation Results:

When the frequency rises above the target value of 60 Hz the control system activates the SCIM to run sub-synchronously. When the frequency starts to fall the system acts as a generator to deliver power.

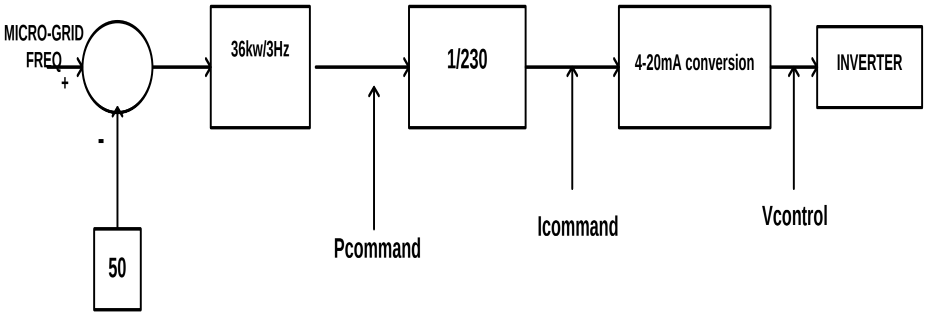
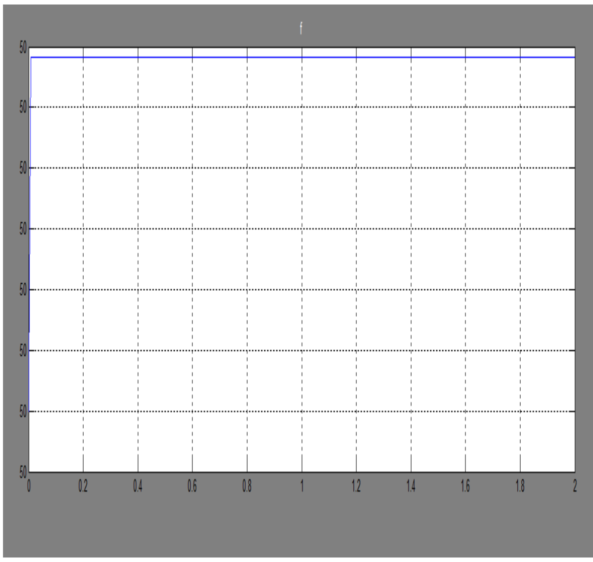


Fig.11.The control system block diagram shows that frequencies outside of the target values of 60 Hz will activate the system's power response at a rate of 36 kW/3 Hz.



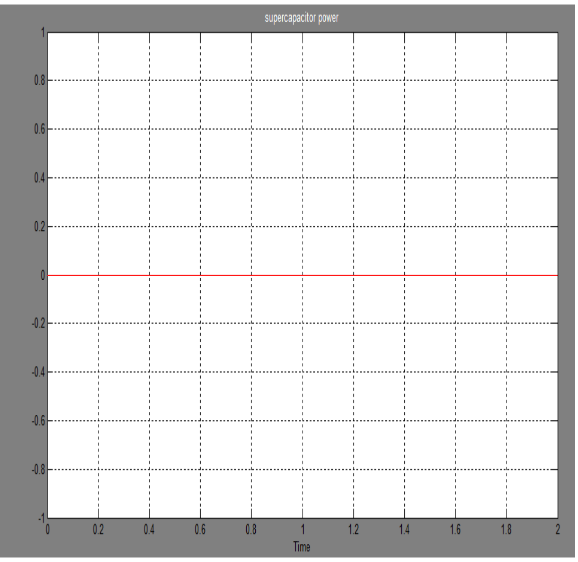
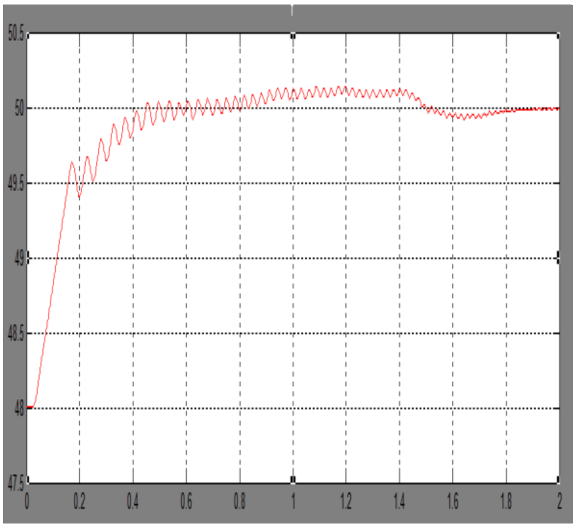


Fig: 12. Frequency response at 50 Hz **Fig: 13. No Power flow from supercapacitor**



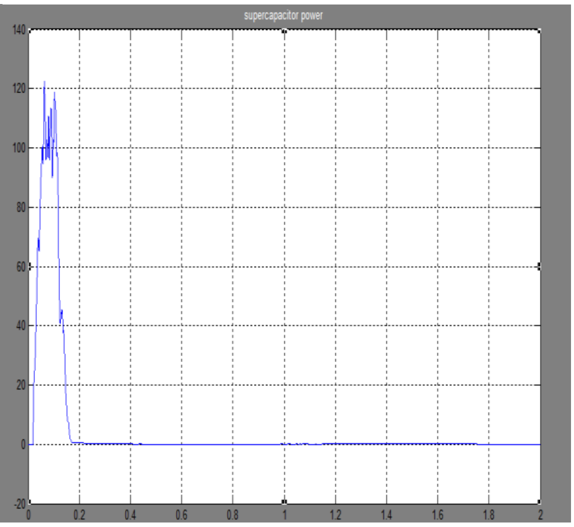


Fig.14. Frequency Response at 48 Hz **Fig: 15. Power flow from supercapacitor**

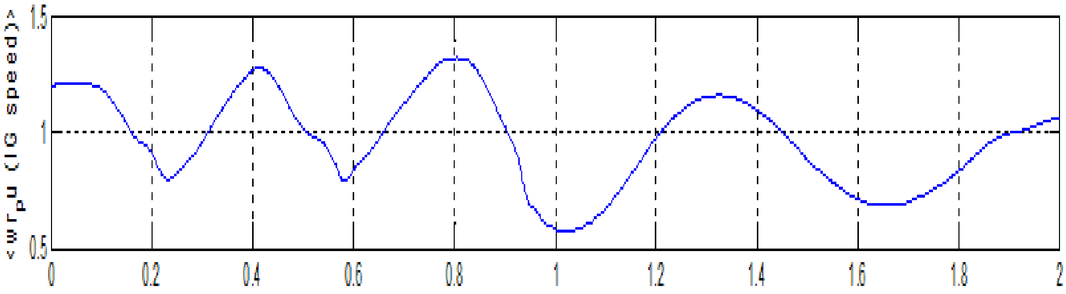


Fig.16.Variation of DFIG speed with frequency

K. Conclusion:

This research creates motor/generator and supercapacitor based system design and demonstrates its ability to deliver frequency response. The average model of the system is simulated and then the circuit is implemented in hardware and tested. The results demonstrate that the rotational inertia delivers immediate energy while the control system and supercapacitors achieve short-term response. This serves to stabilize frequency in order to improve microgrid service quality and reliability.

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