IMPROVEMENT OF POWER QUALITY OF AC MICROGRID WITH ENERGY SYSTEM USING BY ELECTRIC DOUBLE LAYER CAPACITOR

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Abstract: *Solar, wind and other renewable energy sources are becoming an important part of energy supply to the power grid. Hybrid AC Microgrid and Energy Storage Systems (HESS) with renewable energy sources can make intermittent renewable energy sources more dispatch able. Electric Double Layer Capacitor (EDLC) based energy storage system becomes one of the best choices for micro grid because of its high storage capacity, wide working temperature range, cost effectiveness and environmental advantages. To increase reliability, energy storage systems within a micro grid are essential. Energy store while in grid connected mode, when the micro grid's distributed generation (DG) systems and solar energy system produce excess power, to be used later to supply critical loads during power outages. EDLC inject or absorb energy on the DC bus to regulate the DC side voltage. The frequency and voltage of the AC side regulates by a bidirectional AC-DC inverter. The power flow control of these devices serves to increase the system's stability under load fluctuation condition and simulates by Matlab/Simulink.*

Key Words: *AC Microgrid; Renewables Energy; Electric Double Layer Capacitor; Energy Storage System; Bidirectional AC/DC Converter; Matlab/Simulink.*

1. INTRODUCTION:

Nowadays, as the demand of the quality, security and reliability of the energy and power supply has become increasingly higher and higher, the traditional bulk grid can no longer meet it because of its own flaws. Microgrid, a new type of power grid which integrates distributed generators, comes into being. It can save investment, lower energy consumption and improve security and flexibility, and therefore it will be the direction of future development [1]. As an essential part of Microgrid, energy storage system also plays an important role. Super capacitor, as a new energy storage device, becomes one of the best choices for Microgrid because of its irreplaceable advantages. It will be very economical and of no damage to the environment if using PV or wind power to build a Microgrid and transferring the power to electric field energy stored in super capacitor, which can be converted back into electrical energy when necessary [2]. Microgrid can be built in the load centralized region, and it can store the electric energy using super capacitors in normal power supply mode and maintain the power supply through super capacitors when outage occurs. The super capacitor energy storage system also plays an important role. It can store electric energy when power supply is adequate and feedback to the bulk power grid when power supply is insufficient, so that it is able to ensure that the load is always balanced. Therefore, the super capacitor energy storage system which is economical, reliable, and friendly to the environment will have a great market [3].

In the first part of this explained Microgrid and renewable energy and storage system and second parts are a fully controlled bi-directional AC-DC/DC-AC converter and it has been designed and implemented. This converter has the ability of controlling the amount of power flowing between the AC and DC grid in both directions. A vector decoupling controlled sinusoidal pulse width modulation (SPWM) technique has been used to allow the designed rectifier to maintain a constant output voltage while being able to control the active and reactive power drawn from the grid independently and third parts is simulated results of load fluctuation in the system Finally, the simulation results have been presented in MATLAB/Simulink software and the final conclusion is stated.

2. SUPER CAPACITOR ENERGY STORAGE SYSTEM:

Super capacitors, are also known as electrical double-layer capacitor, ultra-capacitor, new energy storage devices that close the gap between aluminum electrolytic capacitors and batteries in terms of power and energy density. Its capacity ranges from several farads to tens of thousands farads and its power density is 10 times more than battery's. The storage capacity of super capacitor is higher than electrolytic capacitor, and it has wide working temperature range, rapid charging and discharging, long cycle life, no pollution and emission and so on.

2.1. Characteristics of Super capacitor:

(i). Super-high Capacity. Its capacity ranges from several farads to tens of thousands farads, 2000 to 6000 times larger than the electrolytic capacitor with the same volume. (ii).Extremely high power density, the power density of super capacitor are up to 18 kW/kg or so, from which, in a short period of time, several hundred amps to several thousand amps of current can be released. This feature makes it ideal for the occasion of short term but high-power output. (iii). Rapid charging and discharging, the super capacitor can store electric energy directly without chemical reactions. The charging time is very short. It can be recharged using large current charging in tens of seconds, which is really a rapid charging. Nevertheless, the battery needs a few hours to complete charging and rapid charging also needs a few dozen minutes [4]. (iv). Long cycle life, the required energy and power content provided by super capacitors can be cycled several hundred thousand times and consequently super capacitors are virtually maintenance-free. The cyclic behavior of batteries is poor in comparison to capacitors. Batteries, which are sensitive against abuse such as over-ripples, reverse polarity and deep discharges, can withstand only some hundred up to a few thousand cycles, if kept fully charged and a conditioning discharge followed by an equalization charge is conducted periodically. (v). Little temperature influence on the normal use. Super capacitor has a superior low-temperature performance and a wide range of working temperature from -40 to 85°C. In contrast, the battery is only range from 0 to 40°C [5].

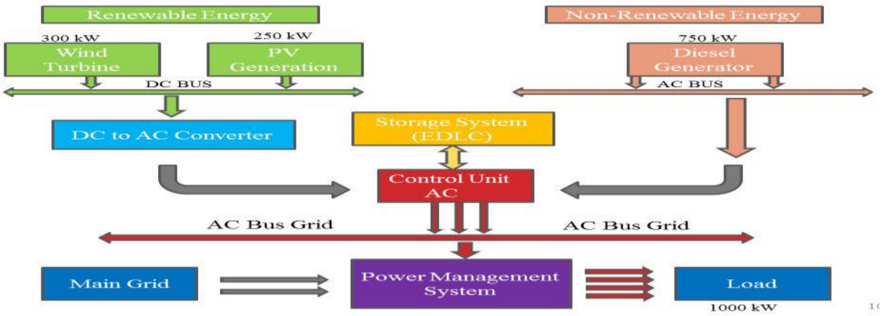

Figure 1: Proposed Structure of Microgrid Using Storage System (EDLC)

Table 1. The initial operation condition of Microgrid

Component	Power (kW)
Diesel Generator	500
Diesel Generator	250
Photovoltaic	250
Wind Power Turbine	300
Load	1000

Table 2. The parameter and base value of Microgrid

Parameter	Base Value
Active Power	1 MW
Reactive Power	0.75 Mvar
Voltage	0.4 kV
Frequency	50 Hz

Table 3. Parameters of EDLC and Battery (Lithium-Ion)

Electric Double Layer Capacitor	Battery (Lithium Ion)
Rated Capacitance (F)	Nominal Voltage (v)
10	540
Equivalent DC series resistance (ohms)	Rated Capacity (Ah)
8.9e-3	10
Number of series Capacitors	Initial state-of-charge (%)
200	100
Number of Parallel Capacitors	Battery response time (s)
1	2 sec
Operating temperature (Celsius)	
25	
Rated Voltage	
540	

3. TECHNICAL CHALLENGES ON MICROGRIDS:

A microgrid is usually connected to an electrical distribution network in an autonomous way and employs various distributed generation technologies such as micro-turbine, fuel cell, photovoltaic system together with energy storage devices such as battery, condenser and flywheel. Microgrids can use several technical problems in its operation and control when operated as autonomous systems. Technical benefits of the microgrid are an islanding implementation of distributed generation to improve the distribution system service quality and increased the power system reliability. Microgrid can be implemented to meet the increasing growth in demand and distributed generation is used to perform special task for Microgrid operation such as reactive and active power control, ability to correct voltage sags and system imbalances [6].

3.1. Voltage and Frequency Control:

In electricity system, active and reactive power generated has to be in balanced condition with the power consumed by the loads including the losses in the lines. The unbalance condition happens from power generated is not equal to the power demanded. The purpose of voltage and frequency control is to ensure that the both voltage and frequency remain within predefined limit around the set point values by adjusting active and reactive power generated or consumed.

3.2. Islanding:

Islanding is a small-scale representation of the future interconnected grid with a high density of distributed generations. The Microgrid provides a benchmark between island and the interconnected grid. It is can be used in the large interconnected grid with the high penetration of distributed generation. The islanding control strategies are very important for the operation of a Microgrid in autonomous mode. A new control strategy is to Microgrid in the distribution system. Two interface controls are for normal operation and the other control for islanded operation [7].

3.3. Hybrid Microgrid:

If the hybrid system is connected to the utility grid as in Distributed generator application the system design will be simple with reduced no of components. Since the voltage and frequency are set by the utility system.

3.3.1. Grid Tied Mode

In addition to this, the grid normally provides the reactive power. When the demand is more than the supplied power by the hybrid system, then the shortage is provided by the utility. Similarly, any excess power produced by the hybrid system can be absorbed by the utility system. In such cases, the grid does not act as an infinite bus. However, it is then said to be weak, additional components and control may need to be added. The grid connected mode hybrid system will then come to more closely resemble an isolated one.

3.3.2. Islanded Mode

Islanded grid connected hybrid system is differs in many ways from central grid connected system. Initially the system must be able to provide all the energy that is required at any time on the grid. They must be able to set the grid frequency and control the voltage. After that the system must be able to provide the reactive power required by the system. Under certain conditions, renewable generators may produce energy in excess of what is needed [8].

4. DC BUS VOLTAGE REGULATION:

The DC distribution system under study is shown in Fig. 1. It consists of a DC Microgrid that is tied to the AC grid through a controlled rectifier. The first issue that has to be considered while designing such system is having a constant output voltage on the DC network. This facilitates the integration of different sustainable energy sources. The fully controlled rectifier used in this paper is responsible for fixing the DC voltage in the system in case it is grid-connected. Otherwise, at least one of the DC-DC converters connected to sustainable energy sources has to be assigned the responsibility of regulating the DC Microgrid voltage and maintaining the power balance in the system.

4.1. Converter Description and Mathematical Modeling

A fully controlled three phase rectifier has been designed and implemented for coupling the DC network with the AC grid. A vector decoupling vector PWM control technique has been used to control the output voltage of the rectifier while having the capability of controlling both the active and reactive power drawn from the grid independently. Vector decoupling PWM control of three phase rectifiers requires coordinate transformation to the d-q frame of reference in order to obtain the desired controllability. Feedback and feedforward control techniques of such rectifiers are possible. However, they are complicated and require accurate mathematical modeling of the inverter. Hence, three PI controllers have been utilized to assist us in building the control model although the mathematical model of the rectifier is very important especially in order to have a successful decoupling of the vectors. The three phases PWM rectifier circuit used is shown in Fig. 1.

Taking line-line loop equations of the circuit,

$$\begin{pmatrix} e_a \\ e_a \\ e_a \end{pmatrix} = \begin{pmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} + \begin{pmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{pmatrix} P \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} + \begin{pmatrix} V_{ra} \\ V_{rb} \\ V_{rc} \end{pmatrix} \quad \text{Equation 1}$$

The DC output of the rectifier depends on the PWM signals driving the switches. The switching signals are designated Sa Sb and Sc. These switching signals control the relationship between the rectifier input voltages, i.e, v_{ra}, v_{rb} and v_{rc} and the DC bus voltage v_{dc} as given by the set of equalities in (2),

$$V_{ra}= \frac{S_a . V_{dc}}{2},\ V_{rb}= \frac{S_b . V_{dc}}{2},\ V_{rc}= \frac{S_c . V_{dc}}{2} \qquad \text{Equation 2}$$

Converting the system equations into rotating d-q references frame using Park's transformation,

$$\begin{pmatrix} e_q \\ 0 \end{pmatrix} = \begin{pmatrix} R+LP & WL \\ -WL & R+LP \end{pmatrix} \begin{pmatrix} i_q \\ i_d \end{pmatrix} + \begin{pmatrix} V_{rq} \\ V_{rd} \end{pmatrix} \qquad \text{Equation 3}$$

Where,

$$V_{rq}= \frac{S_q . V_{dc}}{2},\ V_{rd}= \frac{S_d . V_{dc}}{2} \qquad \text{Equation 4}$$

As for the DC side, the equation governing the DC output of the rectifier is given by (3),

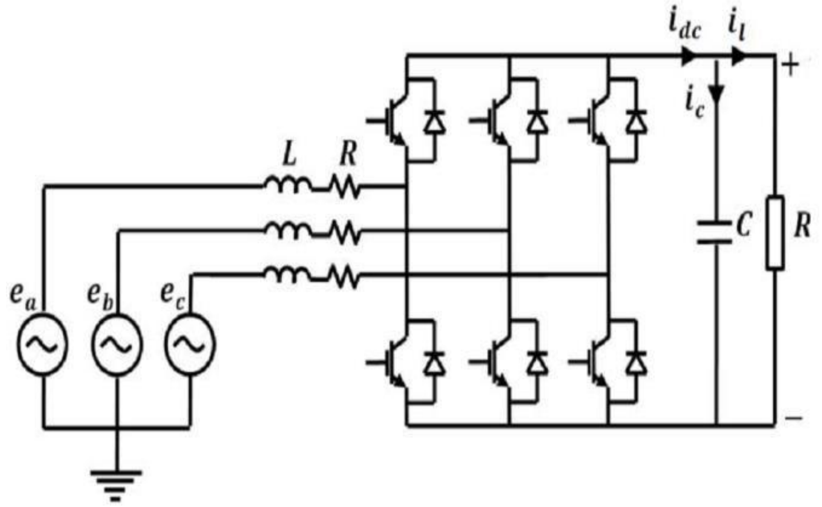

Figure 2: The three phase controlled rectifier

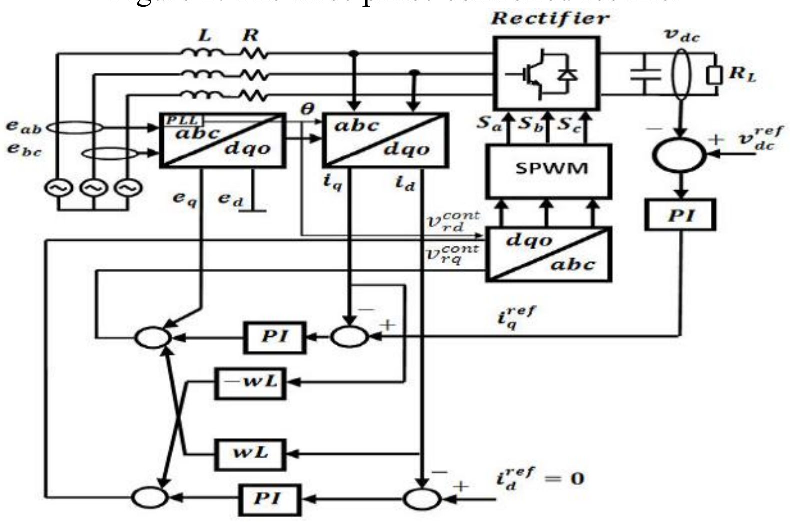

Figure 3: Vector decoupling control of the SPWM rectifier

Hence, the complete dynamic model of the system is given by (4),

$$\begin{pmatrix} \frac{di_q}{dt} \\ \frac{di_d}{dt} \\ \frac{dv_{dc}}{dt} \end{pmatrix} = \begin{pmatrix} \frac{-R}{L} & w & \frac{-Sq}{L} \\ w & \frac{-R}{L} & \frac{S_d}{L} \\ \frac{3s_q}{2c} & 0 & \frac{-1}{CR_L} \end{pmatrix} \begin{pmatrix} i_q \\ i_d \\ V_{dc} \end{pmatrix} + \begin{pmatrix} \frac{1}{L} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} e_q \\ 0 \\ 0 \end{pmatrix} \qquad \text{Equation 5}$$

The power balance equation of the system assuming that is lossless is as given by (5),

$$\frac{3}{2} V_{rq} i_q = V_{dc} C \frac{d}{dt} V_{dc} + \frac{V_{dc}^2}{RL} \qquad \text{Equation 6}$$

Voltages are the modulation signals for the PWM technique. The equations used in building the controller are:

$$V_{rq}^{cont} = wLi_d + e_q + K_p \left(i_q^{ref} - i_q\right) + K_i \int \left(i_q^{ref} - i_q\right)dt \qquad \text{Equation 7}$$
$$V_{rd}^{cont} = - wLi_q + k_p \left(i_d^{ref} - i_d\right) K_i \int (i_d^{ref} - i_d)\, dt$$

This vector decoupling control technique allows control of the active and reactive power drawn from the grid separately then it work at unity power fact or if the reference value of i_d set to zero as can be seen in the equations of active and reactive power in d-q frame of references given by (8) and (9), respectively[9].

$$P(t) = \frac{3}{2} \left(V_{rq} i_q - V_{rd} i_d\right) \qquad \text{Equation 8}$$
$$Q(t) = \frac{3}{2} \left(V_{rq} i_d - V_{rd} i_q\right) \qquad \text{Equation 9}$$

5. BI- DIRECTIONAL CONVERTER POWER FLOW:

An important feature of grid-connected DC Microgrids or DC distribution systems is the ability to inject or suck power from the grid based on the generation and loading conditions. In order to do that, a controlled AC-DC/DC-AC converter that allows bi-directional power flow has been designed. This controlled converter is responsible for controlling the amount of power flowing between the AC and the DC grids. Power flow from the AC to DC grid is very important to cover any deficiency in the demand in the DC grid due to normal or pulse loading. However, for this converter, the topology is slightly changed by replacing the C-filter (C in Fig. 1) by an L-filter (l) as shown in Fig. 2. Moreover, the DC voltage controller is replaced by a current controller as shown in Fig. 3. Based on the reference current of this controller i_{dc}^{ref} the phase shift of the modulating signals of the power electronic switches is adjusted with respect to the grid voltage such that the desired amount of power is flowing in either directions. Hence, if i_{dc}^{ref} is set to a positive value, the bi-directional AC-DC/DC-AC converter will autonomously operate in the rectifier mode and the modulating signals will be lagging the grid voltage [9].

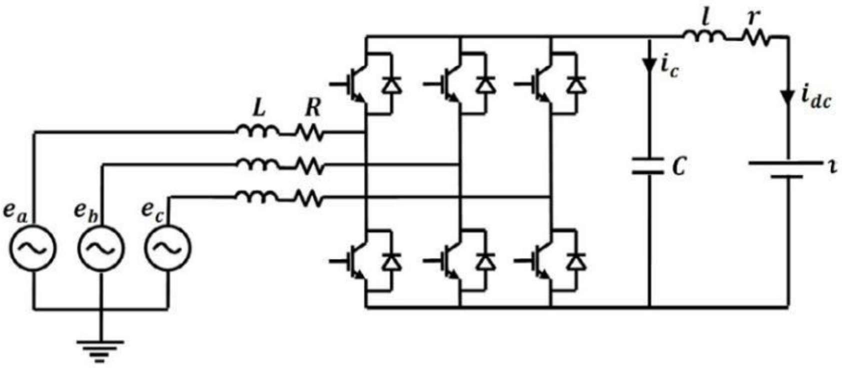

Figure 4: The three phase bi-directional AC-DC/DC-AC

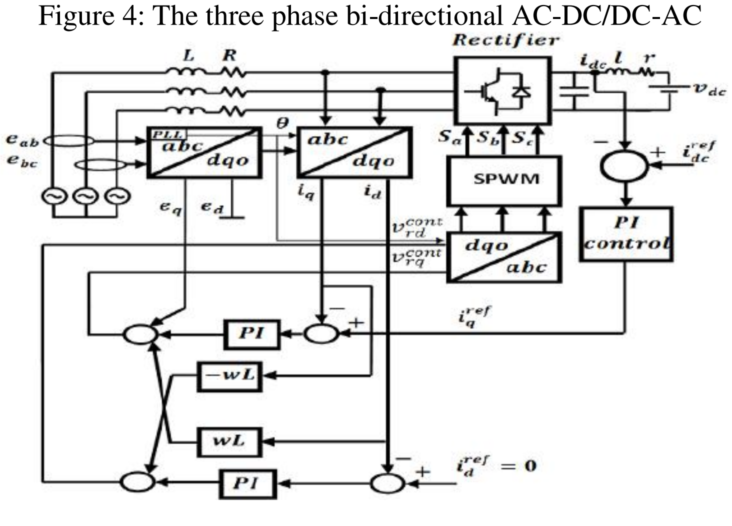

Figure 5: Vector decoupling control of the bi-directional converter

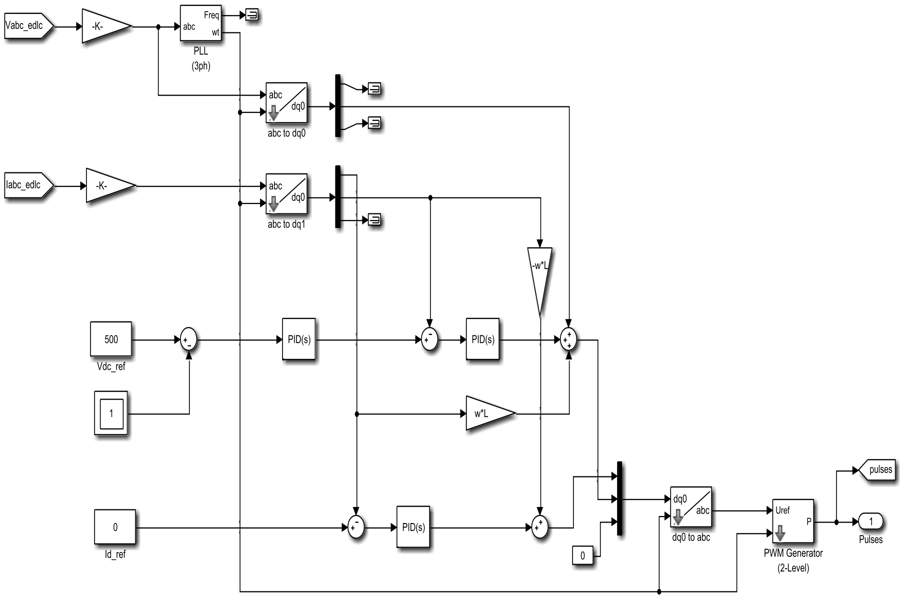

Figure 6: Control of the bi-directional converter model in Matlab

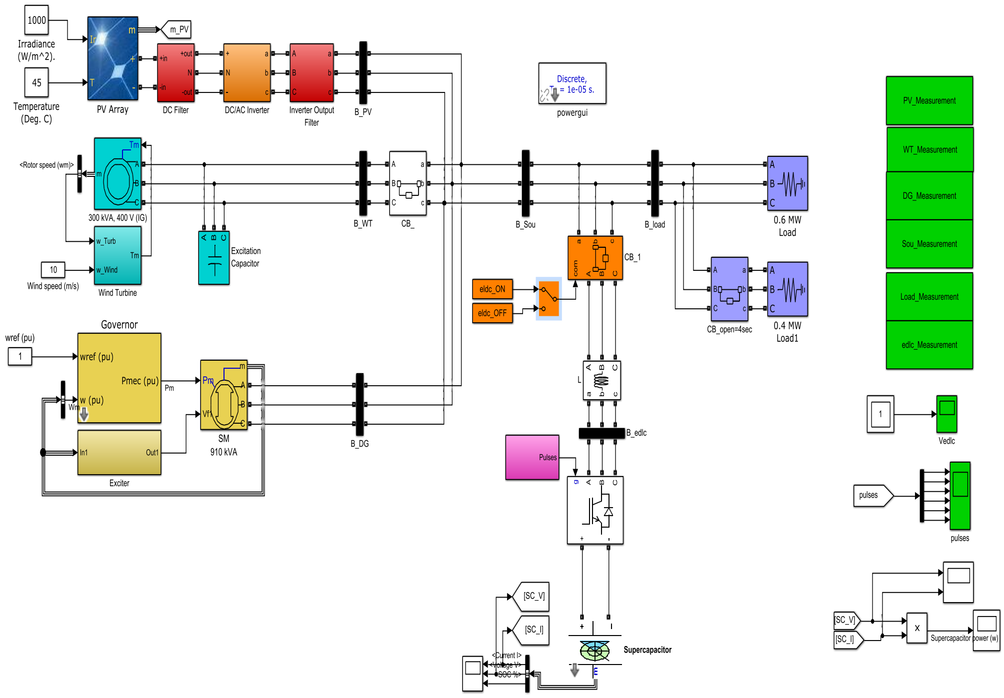

Figure 7: Connected with EDLC when load fluctuation in Microgrid model in Matlab Simulation

6. MATLAB/SIMULINK Simulation Model

It was built for the SCESS system. It consists of the power circuit and the control circuit. In this paper, setting time is during t=0 sec to t=6 sec when sudden load changes occurred at t=4sec by reducing load power from 1 MW to 0.6 MW. Since load power demand is reduced, the real power supplied from source bus is also decrease from 1.2 MW to 0.8 MW. For this source power reduction, power inputs from DG and wind turbine are nearly constant whilst the power input from PV system is decreased as shown in the following figures.

During load fluctuation, the load and source powers are reduced as shown in Figure 12. The reactive power at ELDC terminal is nearly constant. The real power injected is increased at load varying instant. Therefore it controls the frequency fluctuation. With ELDC, the frequency is change from 50 Hz to 50.5 Hz. There are only 0.5 Hz changes in frequency due to ELDC storage. Simulation results of the comparison of EDLC and Battery (Lithium-Ion) when load fluctuation in Microgrid showed Electric Double Layer Capacitor is more stable than Battery (Lithium Ion).

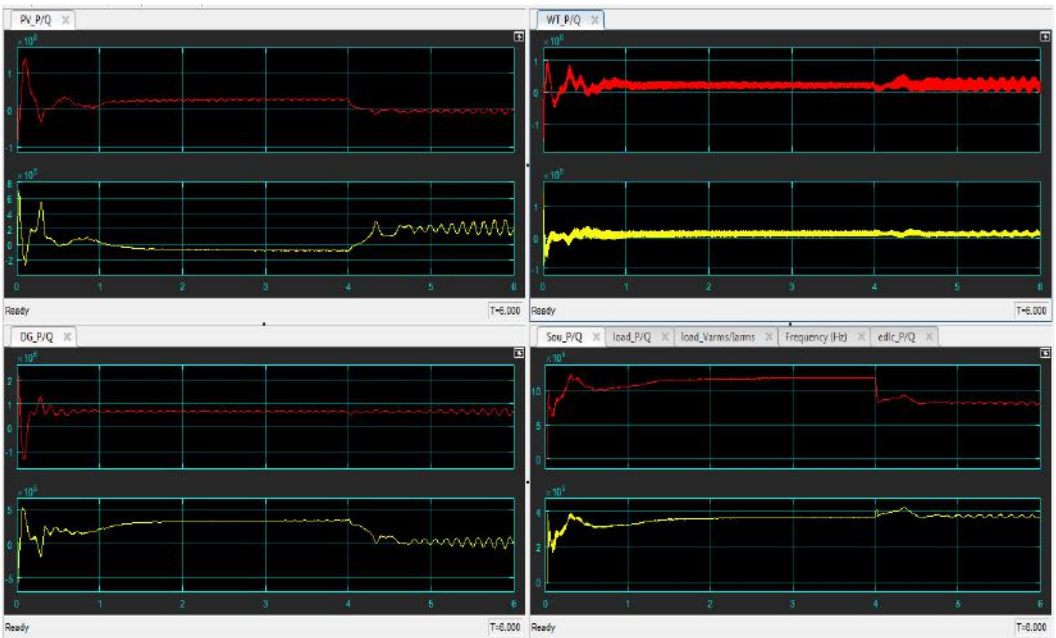

Figure 8: Simulation results of Photovoltaic, wind turbine and DG and Sources P/Q connected with EDLC when Load fluctuation

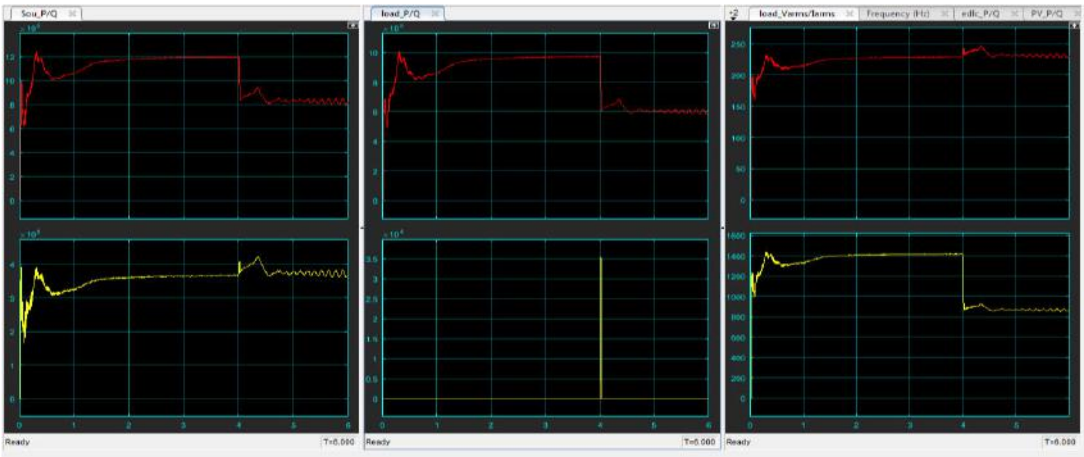

Figure 9: Simulation results Sources P/Q and Load P/Q and Load Varms/Iarms connected **w**ith EDLC when load fluctuation in Microgrid

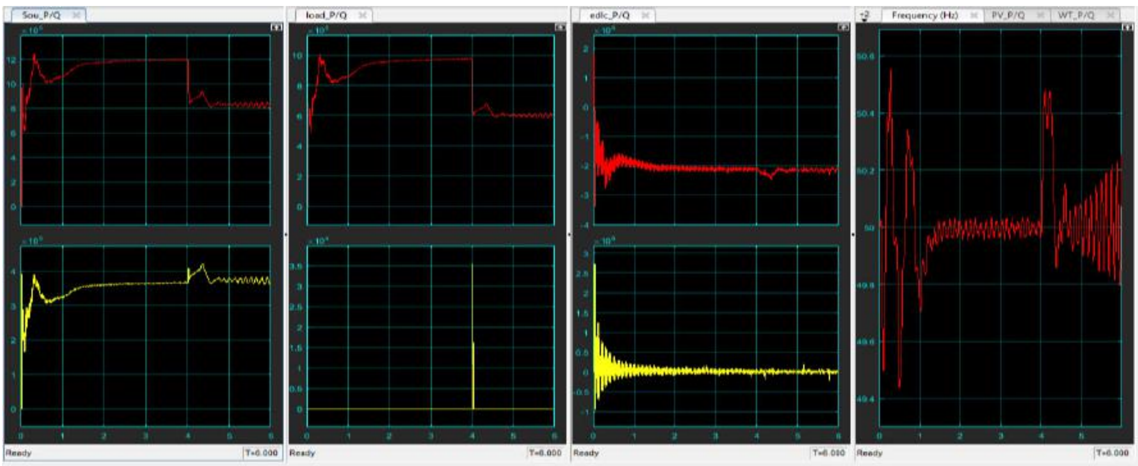

Figure 10: Simulation results Sources P/Q and Load P/Q and EDLC P/Q and Frequency connected **w**ith EDLC when load fluctuation in Microgrid

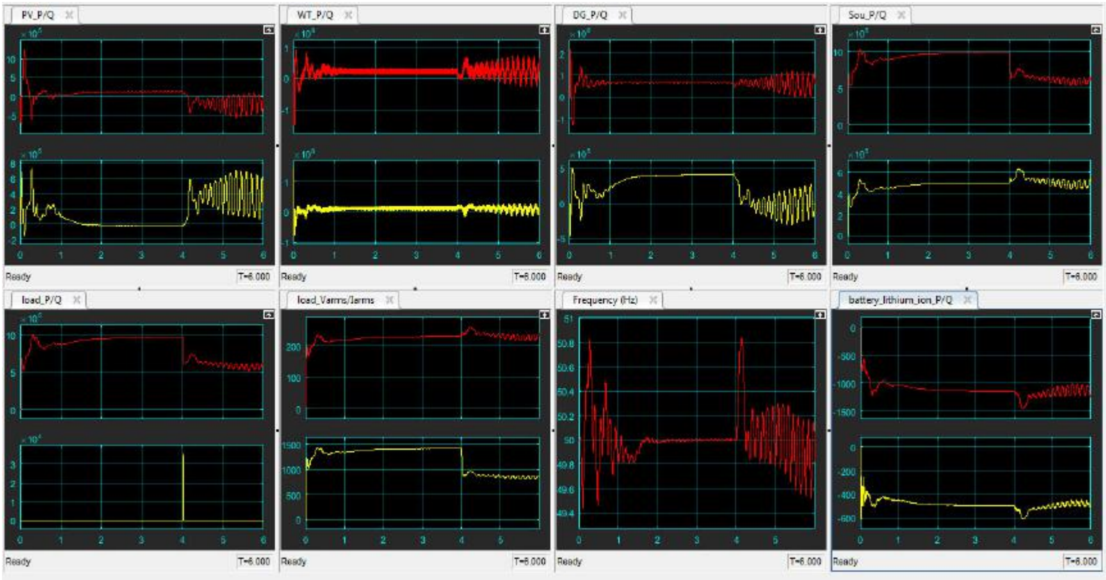

Figure 11: **PV P/Q, WT P/Q, DG P/Q, Sources P/Q, Load P/Q, Load Varms/Iarms, EDLC P/Q and Frequency** With *Battery (Lithium Ion)* when Load Fluctuation in Microgrid

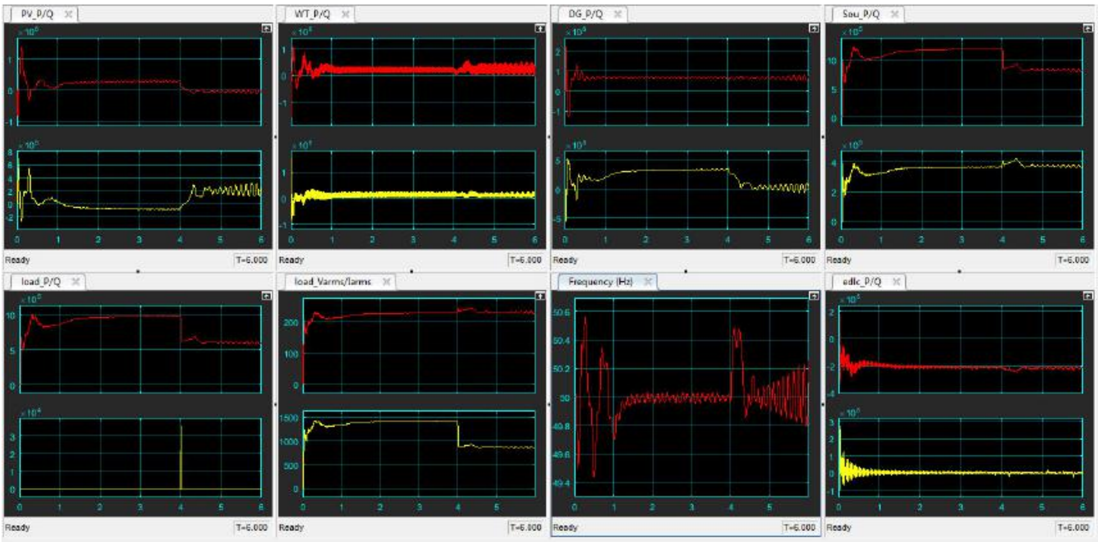

Figure 12: **PV P/Q, WT P/Q, DG P/Q, Sources P/Q, Load P/Q, Load Varms/Iarms, EDLC P/Q and Frequency** With *EDLC*_when load fluctuation in Microgrid

7. CONCLUSION:

Microgrid is being developed rapidly for its advantage of high reliability, less pollution and improved system stability. Energy storage system (EDLC) is playing a significant role in Microgrid. It can absorb extra energy when connected to the grid. When the Microgrid is in islanded mode, it can maintain frequency of the power system and improve the power quality, making the Microgrid safer and more stable. To analyse the improvement in power quality of Microgrid system, a Simulink model consisting of PV, diesel generator and wind turbine is implemented using Matlab/Simulink. Then the power quality improvement is studied with ELDC storage system and battery storage system. A vector decoupling controlled SPWM rectifier has been designed and implemented to connect the DC system to the grid. Results show very good response for the rectifier during steady state and transient operation.The simulation result shows EDLC can more stable than battery (lithium-ion) and others battery types during load changes condition. It's showed that to restrain the bus voltage fluctuation in the Microgrid and to provide voltage and frequency control functions during generation, load (demand) fluctuation, ELDC system can provide the better power quality performance for the Microgrid system.

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