Mitigation of Grid Power Fluctuations using super capacitor in distributed generation System

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***Abstract*— The accurate operation of Distributed generation system to grid involves storage devices that enhance the inertia and avoid instability of the system. A fault ride through, power supervision and control technique for grid integrated Renewable distributed generation with Super capacitor energy storage system (SCESS). This paper presents the control of energy storage system (ESS).During customary operation the SCESS will be used to minimize small duration fluctuation as it has high power density and during fault at the grid side it used to store generated power from Renewable sources for later use and fault ride through based on super capacitors in context of grid-connected DGS grids. To capture the at most amount of available solar power, and wind power. Incremental Conductance (IC) method is used for maximum power point tracking (MPPT). An independent P-Q control was implemented to transfer the generated power to the grid using a Voltage source inverter (VSI). The ESS was composed of ac/dc and dc/dc converters tied by a dc link. A single sliding mode strategy was proposed to control a bidirectional dc/dc converter, capable of working preferably under all operating conditions. The switching devices were instructed by a single sliding function, dynamically shaped by references sent from the grid Side central controller. The buck converter for MPPT, buck-boost converter to connect the SCESS to the DC link. The simulation Results were carried out to verify the effectiveness of the proposed Scheme improved the performance of the systems.**

***Index Terms*— Super capacitor Energy storage systems (SCESS), Grid side Controller (GSC), Distributed generation systems (DGS), Sliding Mode.**

I. INTRODUCTION

As we all know that Power quality becoming a major factor of concern in the industry. And hence it is needed to maintain good power quality on the grid system [3]. For this reason power quality product like the active power filter (APF) & dynamic voltage restorer (DVR) are taken into account. Under nonlinear load conditions, APF is used to prevent the grid from supplying non-sinusoidal currents. The Sensitive loads facing voltage sag or swell is prevented by using DVR [1], [2]. Back–back inverter topology is introduces to integrate APF & DVR [4]. And the procedure was called as unified power quality conditioner (UPQC).

By providing compensation for sag, swell & current harmonics traditional UPQC aims to enhance the distribution grid's power quality. This paper proposes integration of energy storage & the power conditioner topology. This will permit the integrated system to contribute supplementary functionality. There is increase in power quality problems and intermittencies on distribution grid due to increase in penetration of the distribution energy resources in seconds to minute's time gauge [5].

One of the potential answers is storage integration with DERs. By decreasing intermittencies and power quality problems on the distribution grid this enhances the reliability of the DERs [5]–[8]. The situations where energy storage combination will improve the functionality are being recognized. And to make energy storage integration commercially feasible on a large scale efforts are being carried [9], [10].There is one application where energy storage integration and optimal control play an important role is smoothing of DERs [8]–[15].

To provide wind power smoothing [11], super capacitor & flow battery hybrid energy storage system are integrated into the wind turbine generator .The system is investigated using a real-time simulator. The super capacitor utilized as supplementary energy storage for photovoltaic (PV)/fuel cell, to providing optimal control a model-based controller is established [10]. In order to mitigate wind/PV fluctuations, a battery energy storage system- based control is proposed [11]. To integrate battery storage for improving PV integration into distribution grid, multi objective optimization method is analyzed [12]

Upper & lower limits of the battery size for grid-linked PV networks are determined by theoretical analysis [14]. In order to optimize the battery discharge for diffusing intermittent renewable resources, a rule-based control is offered. For reducing the intermittencies in wind power, optimal sizing of a zinc bromine-based procedure is employed [15].

It is verified from literature survey that, there is one application that requires active/reactive power support from energy storage in seconds to minutes time scale is renewable intermittency smoothing [10]. Another application which has wide recognition for reactive power valuing is reactive power support. Power quality problems on consumer grid such as voltage sag and swells are to be diminished. Real & reactive power support from the energy storage is given to compensate Sag/swell problems [11].

Power conditioner topology based integration of energy storage & grid realizes all the above mentioned proposals. Rechargeable energy storage technics such as

1. Super- conducting magnet energy storage (SMES)
2. Flywheel energy storage system (FESS)
3. Battery energy storage system (BESS)
4. Super capacitors

There are used to provide active power support for outages on distribution grid. The paper proposes super capacitor-based energy storage integration through a power conditioner into the circulation system.

II. ESS BASED ON SUPERCAPACITOR

Figure 1 represents a diagrammatic view of the interface technology approved to control the power flow between the Energy storage device & Distributed generation grid.

It comprises of an

- Inverter connected to the grid (GSC),
- DC link,
- Bidirectional dc/dc converter (ESSC),
- E energy storage device

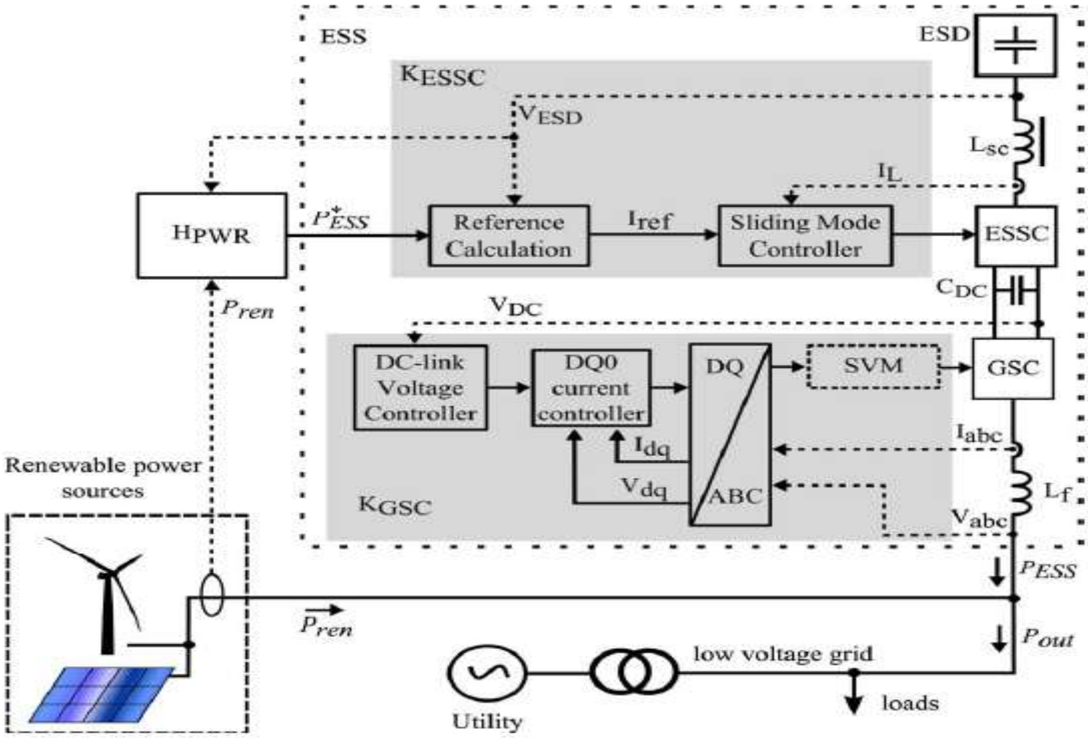

Fig.1. Adopted Power smoothing topology For ESS and Power grid

Super capacitor based Li-on batteries is other type of ESD can be utilized with the same technology& control strategy. Objective of controller of GSC, *K*GSC, in grid-linked renewable power sources grids, is to confirm the power interchange between the Energy storage device & dispersed grid.

To maintain power balance on dc link, controller controls dc-link voltage V_{dc} by injecting or by absorbing power from grid. The power exchanged b/w the ESD and the dc link is regulated by the controller of ESSC & *K*ESSC. The configuration of distributed generation grid at which ESS or ESD is connected is considered for designing controller.

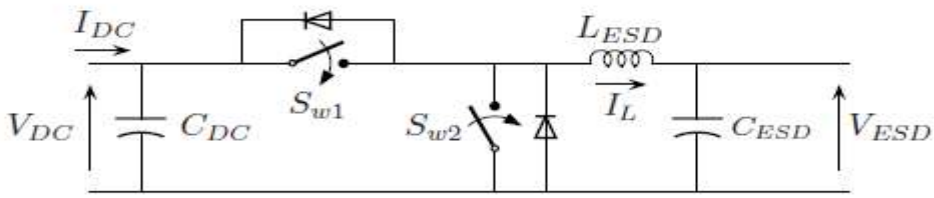

Fig.2. Bidirectional topology used for ESS

GSC gives instructions to KESSC in the form of a power reference, Pref as shown in configuration of Fig.1.This find outs when ESS must store energy & when it should insert energy into the network.

Fig. 2 demonstrates the bidirectional dc/dc topology accepted to develop ESSC. During this method energy can flow in both directions but voltage is always greater on left side (V_{dc}) than on the right side (V_{ESD}).For delivering energy to the storage device, the converter can operate in low-grade state. And for draining energy from the storage device converter should work under boost state. By adjusting the appropriate duty cycle on each switch required operating condition is established. In a complementary way switches *Sw*1 and *Sw*2 are functioned. This switching mechanism averts set points low current's irregular operation. During both operating modes antiparallel diodes serve as Free-wheeling diodes.

A certain degree of decoupling between both converters is obtained by dc-link. This allows separate configuration for each controller. Generally in grid-linked state, GSC is regulated by cascade control structure.

III. POWER SMOOTHIMG STRATEGY

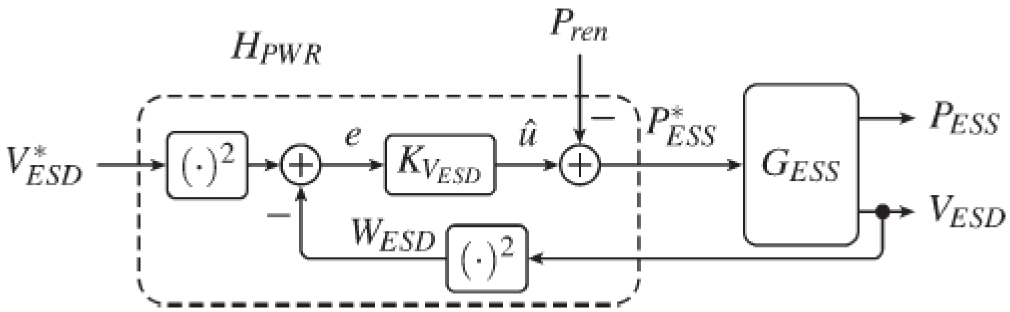

Fig.3.Power smoothing Controller

The power reference P*ESS is obtained by power smoothing controller HPWR. From renewable sources total output power is measured. By using this total o/p power along with monitored SoC of ESS, the set point for ESS is achieved. The power smoothing controller must ensure 50% on average of ESD, in order to ensure long term operation.

Hence guaranteeing a better capability to absorb or deliver power in any situation, as this avoids voltage from reaching saturation bounds. The recommended scheme for the power smoothing controller HPWR is depicted in Fig.3.

The voltage controller *KV*ESD becomes the core part of *H*PWR. This enables control signal û with its bandwidth restricted to *ωc*. The power base *P**ESS given to ESS is the power *P*ren delivered by the renewable energy source deducted from û In order to ensure a proper *SoC* of the super capacitors, the voltage controller *KV*ESD must be configured to maintain *V*ESD near to the reference *V** ESD in lower frequencies. Instantaneously, the controller *H*PWR must also generate a high-frequency signal *P*ESS able of alleviating *P*ren for frequencies exceeding *ωd*.

A. ESS Sizing

The energy that the supercapacitor can absorb or deliver for smoothing purposes is given by

$$E_{useful} = 1/2\, C_{ESD} V^2_{ESDmax} - E_{min} \qquad (1)$$

Where Emin = ½ C_{ESD}V^2 $_{ESDmin}$ denotes the energy required to raise the voltage up to V_{ESDmin} , i.e., E_{min} is the amount of energy not used due to the lower voltage limit. To have the largest possible amount of energy available for smoothing purposes, the voltage reference V*ESD is selected as the value corresponding to 50% of the SoC, i.e.,

$$V *_{ESD} = \sqrt{V^2_{ESDmax} + V^2_{ESDmin}/2} \qquad (2)$$

B. Sliding Mode Control Strategy

$$S_\omega = (\text{sign}\,(I_{ref,\,i} - I_L) + 1) / 2 \tag{3}$$

1) Startup

$I_{ref1} = I_{max}$

2) Constant power mode

$I_{ref2} = P_{ref} / V_{ESD}$

3) Voltage limitation mode (lower limit)

$I_{ref3} = \frac{Pref}{(\underline{V}_{ESD}+V_\Delta)V_\Delta}(V_{ESD} - \underline{V}_{ESD})$

4) Voltage limitation mode (upper limit)

$I_{ref4} = \frac{P_{ref}}{(\overline{V}_{ESD}-V_\Delta)}(\overline{V}_{ESD} - V_{ESD})$

For system startup, the control strategy imposes a constant current reference. The same surface, but with a negative reference can be utilized to discharge supercapacitors. In constant power stage, current reference is computed according to the current supercapacitor voltage in order to provide amount of power indicated by the GSC. Finally, when supercapacitors reach lower or upper voltage limits, a transition sliding surface is used to smoothly lead the inductor current to zero.

C. SM Control Algorithm

while ($V_{ESD} < \underline{V}_{ESD}$) **do** **Startup**

$S\omega = (\text{sign}\,(I_{ref1} - I_L) + 1) / 2$
end while
Shutdown = False
while (shutdown = False) **do**
Read V_{ESD}

if ($V_{ESD} > \overline{V}_{ESD} - V_\Delta$) **AND** ($P_{ref} > 0$) **then** **Voltage Limitation**
$S\omega = (\text{sign}\,(I_{ref4} - I_L) + 1) / 2$

use if ($V_{ESD} < \underline{V}_{ESD} + V_\Delta$) **AND** ($P_{ref} < 0$) **then** **Voltage Limitation**
$S\omega = (\text{sign}\,(I_{ref3} - I_L) + 1) / 2$

else if ($\underline{V}_{ESD} < V_{ESD} < \overline{V}_{ESD}$) **then** **Constant Power**
$S\omega = (\text{sign}\,(I_{ref2} - I_L) + 1) / 2$
end if

if ($V_{ESD} > \overline{V}_{ESD} + V_\Delta$) **then** **Protection**
Shutdown = TRUE
end if

if ($V_{ESD} < \underline{V}_{ESD} - V_\Delta$) **then** **Protection**
Shutdown = TRUE
end if
end while

The system startup,control strategy imposes a constant current reference. The same surface, but with a negative reference can be utilized to discharge the supercapacitors. In constant power stage, the current reference is computed according to the current supercapacitor voltage in order to provide the amount of power indicated by GSC. Finally, when supercapacitors reach lower or upper voltage limits, a transition sliding surface is used to smoothly lead the inductor current to zero.

IV. SIMULATION MODEL

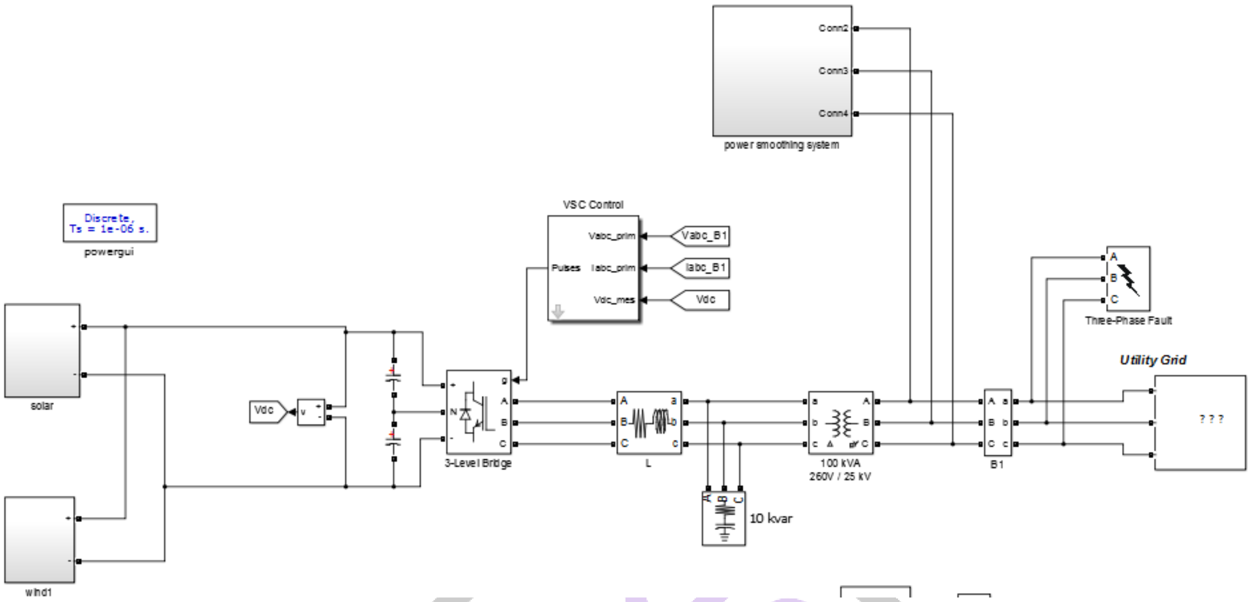

Fig.4. Simulink Model of Proposed system

V. SIMULATION RESULTS

A PV array with the specification It consists number of cells per module96,no of series connected modules per string is 5 and no of parallel string is 17.For the reference solar intensity of 1000 W/m2 and 25^{0} C, the operating voltage Vmp and current Imp at the MPPT will be 54.7*5 V=260 V, and 5.58*17 A=96A, respectively. The expected maximum output power at this operating point from this PV array is 25 kW (260V×96 A).Wind plant with specifications of PMSM ,three phase round rotor Torque in N.M =42.09,DC bus voltage =560v ,rated speed =3000RPM,Voltage constant Vpeak LL/1000rpm =86.62V, for 3000rpm =86.62*3=260V,Nominal mechanical power output and phase power of electrical generation 15kw. To demonstrate the effectiveness of the proposed controller for fault ride through and power smoothing using energy storage for grid connected PV and wind system, three phase fault is applied at the grid side,and the results are analyzed.

a) *Three Phase Grid Fault is Applied*

A three phase fault of (`100msec) is applied on the grid side and the fault is cleared after another three cycles. For comparison, two systems have been developed one with SCESS and the other one without energy storage on MATLAB Simulink. Response of system for applied fault is depicted The grid voltage after described fault is shown. Since power is being exchanged between the Distributed renewable energy and the SCESS, the power generated unaffected because of the fault at the grid side and is stored in the SCESS, The oscillation of the grid power because of the fault is reduced for a system having a SCESS than without energy storage as shows in Fig (11) and (12) the power stored in the SCESS which is generated by Distributed renewable generation during the fault. The DC link voltage is controlled by the buck boost converter for the system having the SCESS but the inverter controls this voltage if there is no energy storage. As can be seen from Fig.9 and 10. DC link voltage is kept constant to its reference value of 500 V for a system equipped with SCESS. The operation of the PV array and wind generation is unaffected if the system has energy storage as shown in Fig.(5),(6),(7),(8).Fig (13) and (14) Grid Voltage and current after a three phase fault is applied.

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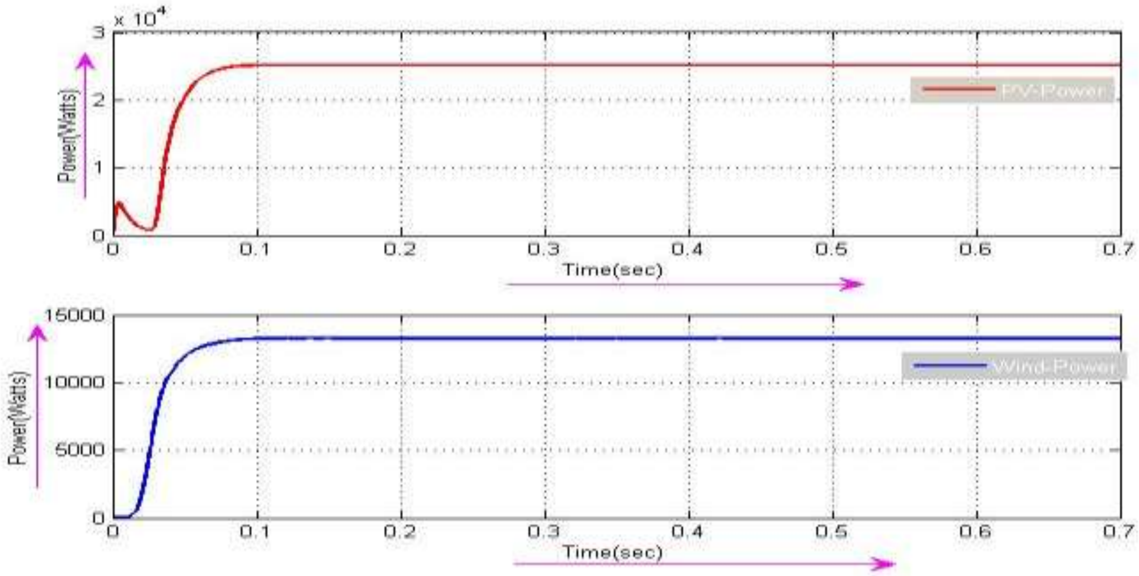

Fig 5 Solar and wind Power in watts with power smoothing system.

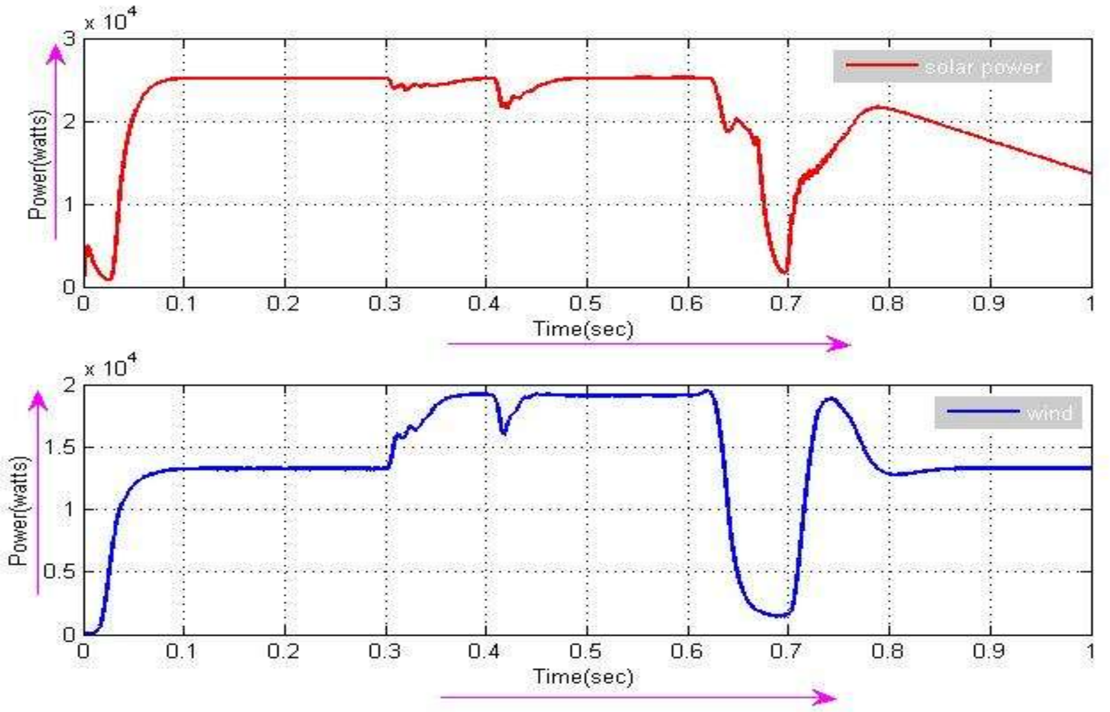

Fig .6 Solar and wind Power without power smoothing system.

The Power generated by solar and wind response of this when a three phase fault occurred at the Grid with(Fig5) and without(Fig 6) Power smoothing system. Power out put from PV system is 25KW and from wind system is 15KW,When three phase fault applied at grid side ,output power without a power smoothing system is distorted(0.4 to 0.8sec) can see in Fig 6 approaching to zero ,and in Fig 5. with a power smoothing system Power profile is maintained constant.

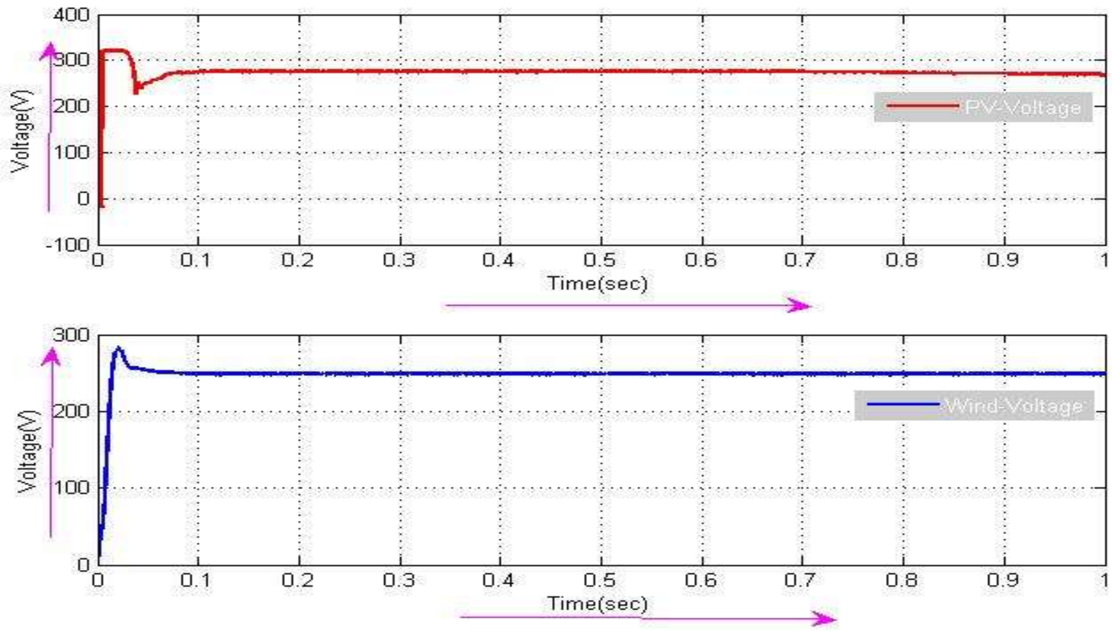

Fig .7. Solar and wind voltage waveform with power smoothing system.

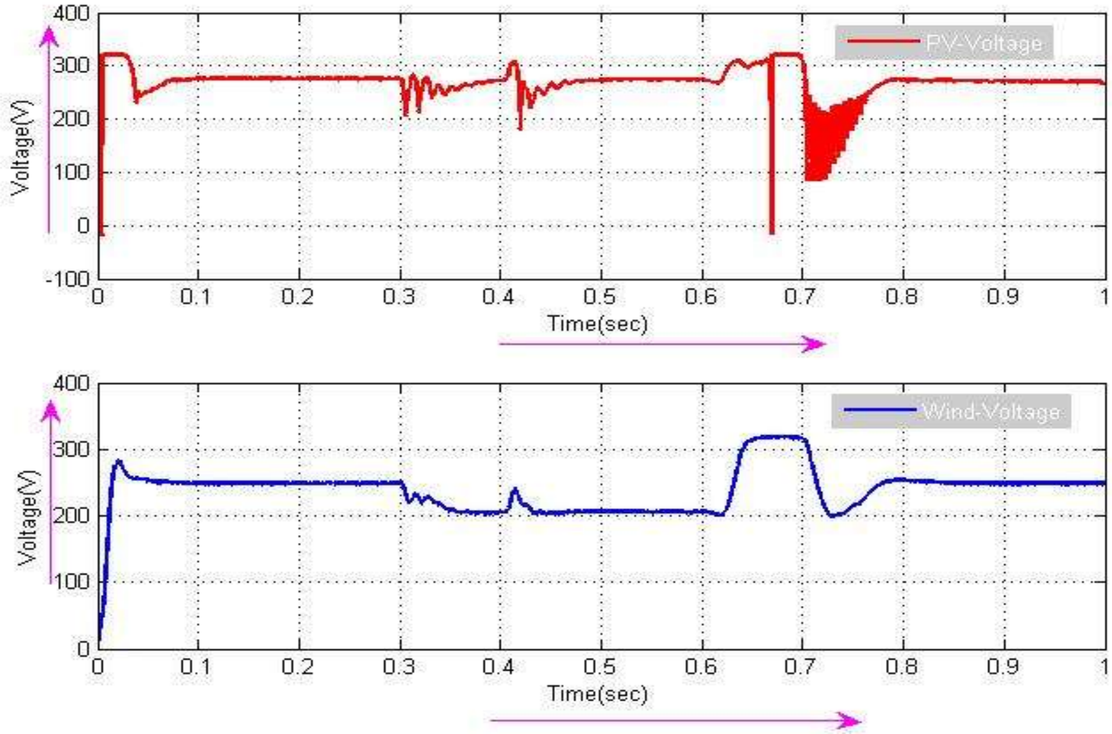

Fig .8.Solar and Wind voltage waveform without power smoothing system.

Fig 7 and 8 is the solar and wind Voltage PV-V and Wind-V,with (7) and without(8) power smoothing system, The voltage without power smoothing system is distracted due to fault can see in waveform voltage dip in the duration (0.4 to 0.8sec) but in Fig 7 it Mitigate the Voltage distortion and maintains the voltage at 260V.

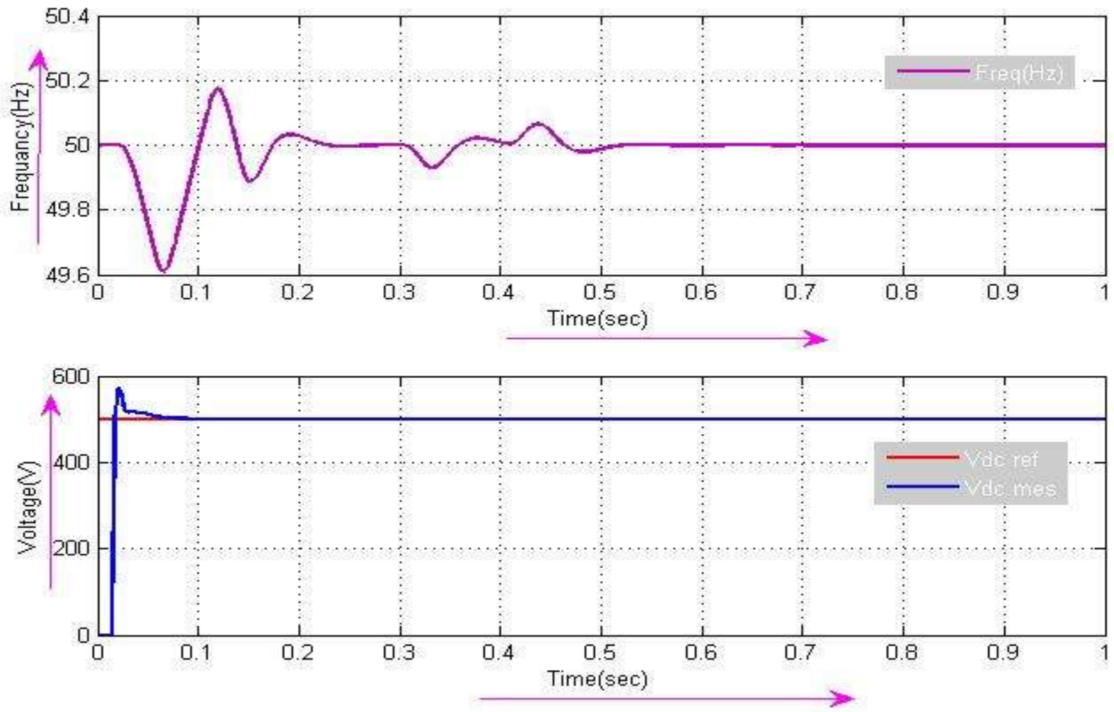

Fig 9: Frequency and Vdc reference, Vdc measured voltage without power smoothing system.

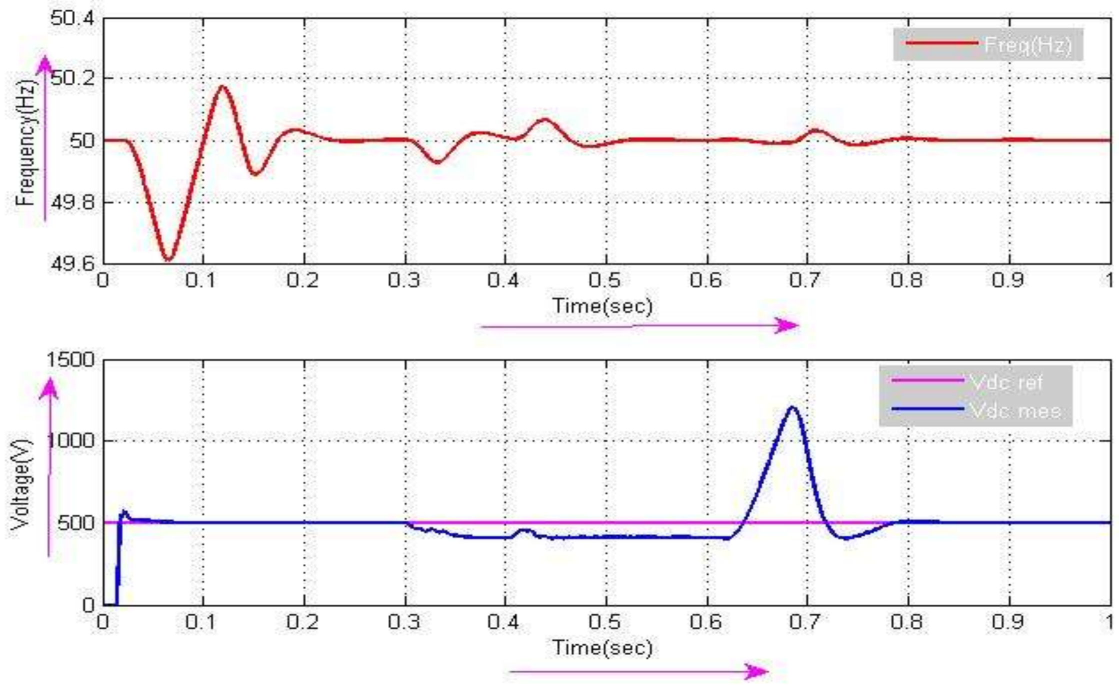

Fig 10:Frequency and Vdc measured ,Vdc reference voltage waveforms without power smoothing system.

Fig 9 and Fig 10 is the Frequency and the Vdc,ref Vdc mes waveforms ,Here System Frequency is 50Hz but due to three phase faults Frequency wave is distorted. And Vdc measured is reduced from Vref (500V). The distortion of Frequency and the Vdc measured due to fault is comparatively reduced by power smoothing system shown in Fig(10).

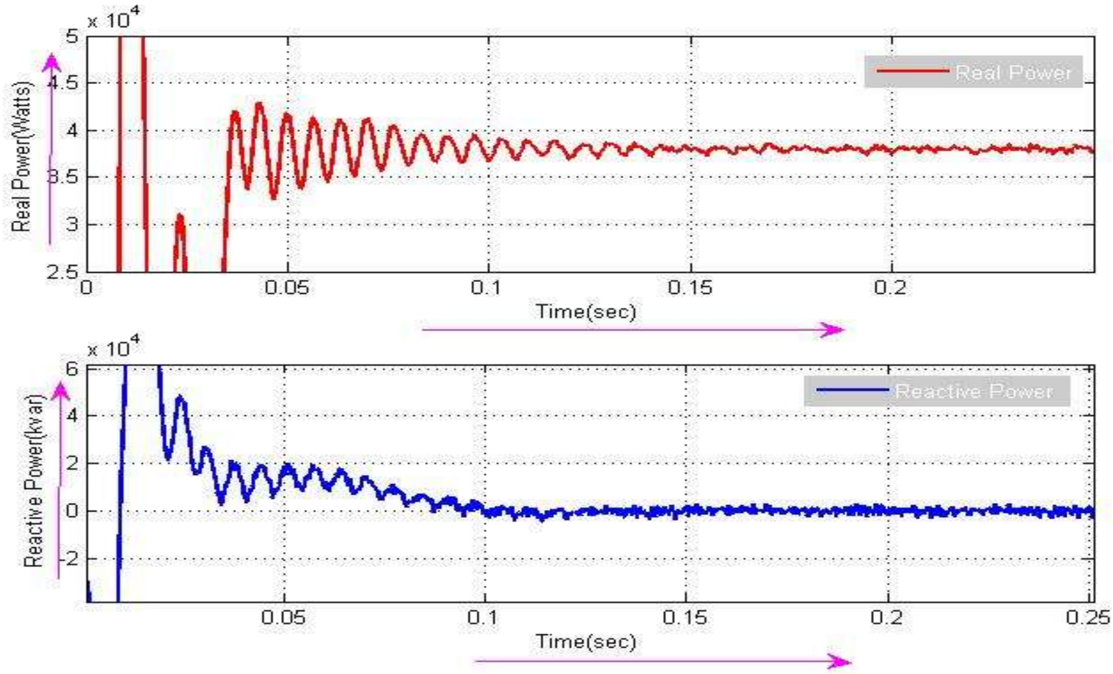

Fig 11 Real and reactive Power Measured at the grid side at faulted condition with power smoothing system.

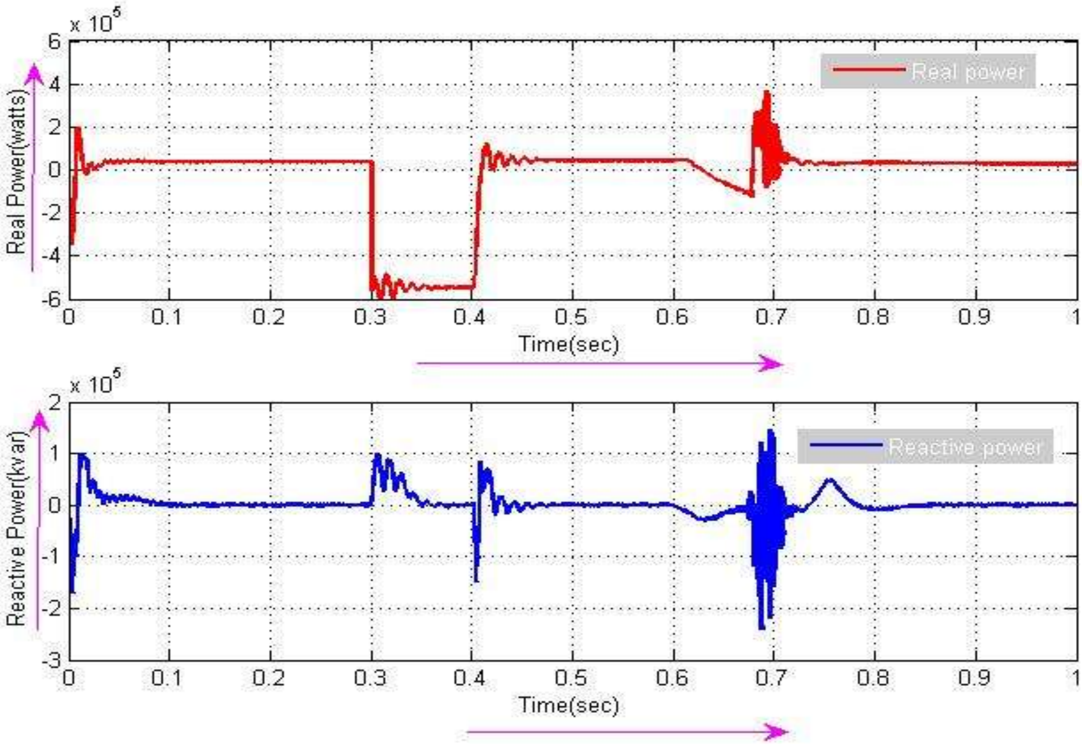

Fig 12:Real and Reactive Power measured at the grid side at faulted condition without power smoothing system.

Fig 11 and Fig 12 Is the Grid Side Real and Reactive power measured with power smoothing system(11) and with out(12) Power smoothing System ,Can see the Power distortion due to fault is not much effect on the power out put with power smoothing system(11).But in Fig 12 Real power and Reactive power Distorted in fault duration (0.4 to 0.8 sec).

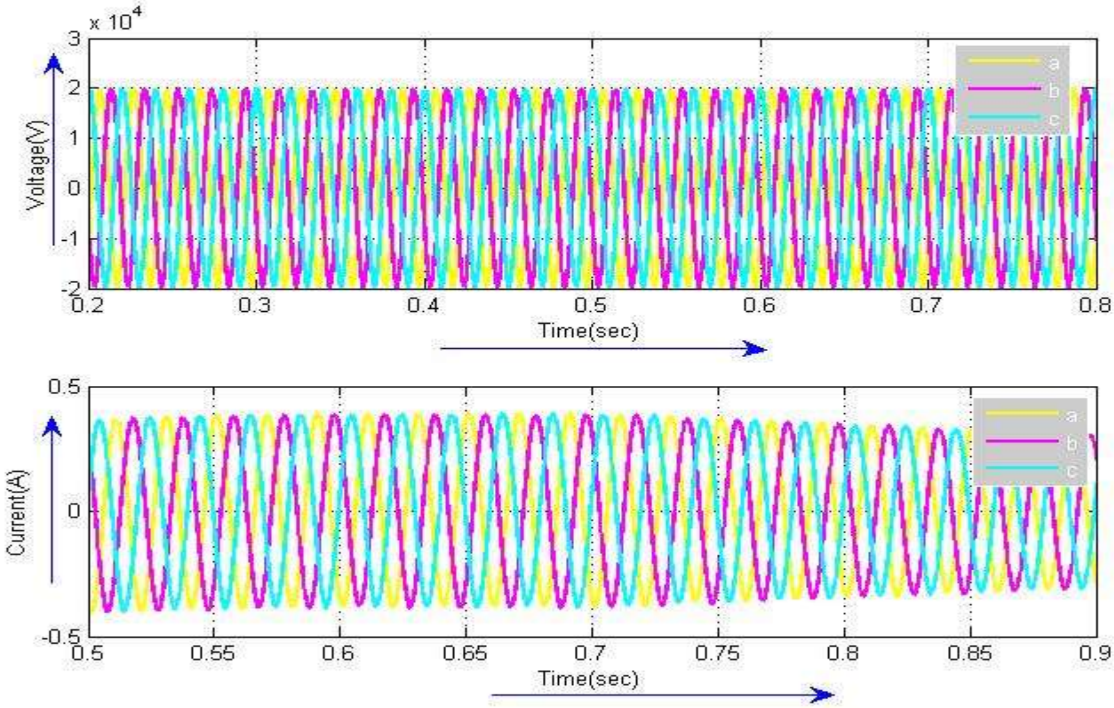

Fig 13 Grid side Voltage(Vabc) and Current (Iabc) with Power smoothing system at faulted condition.

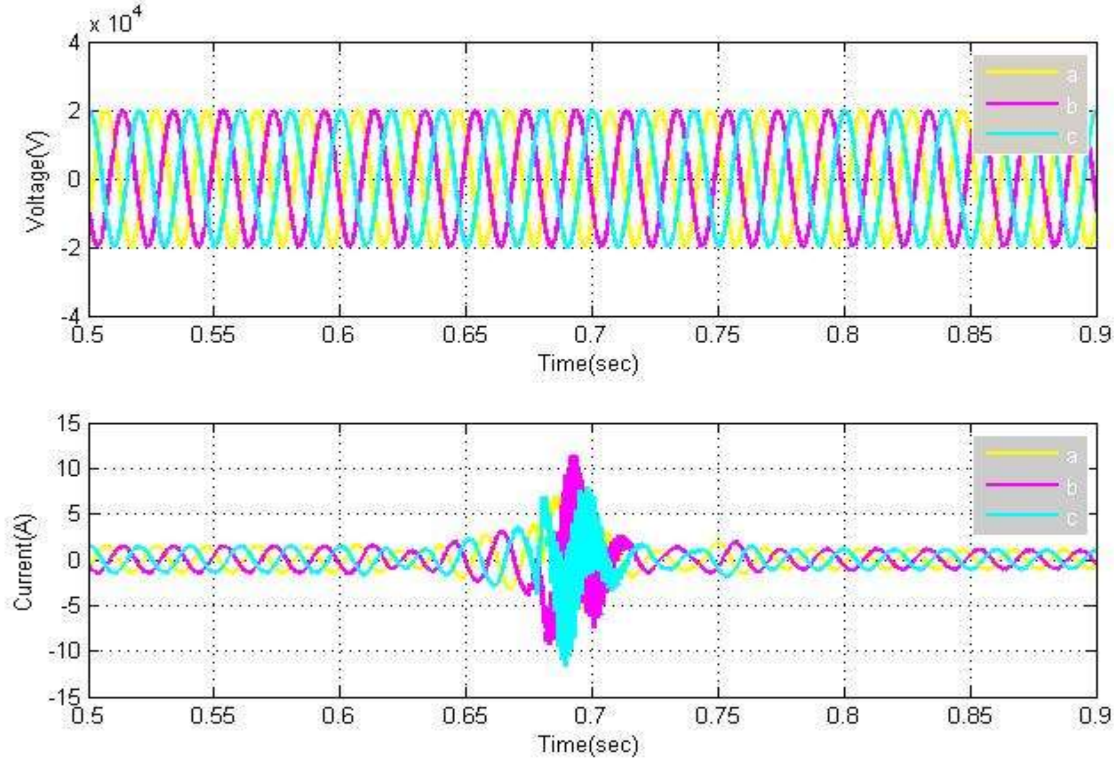

Fig 14: Grid side Voltage(Vabc) and Current (Iabc) without Power smoothing system at faulted condition.

Fig 13 and 14 Is the wave form of grid side three phase voltage and current ,when fault occurs the one with power smoothing system is not much strain on voltage and current wave form but its distortion present in the system without Power smoothing system there is a sudden rise in current waveform from duration (0.6 to 0.8sec),Fig(14).

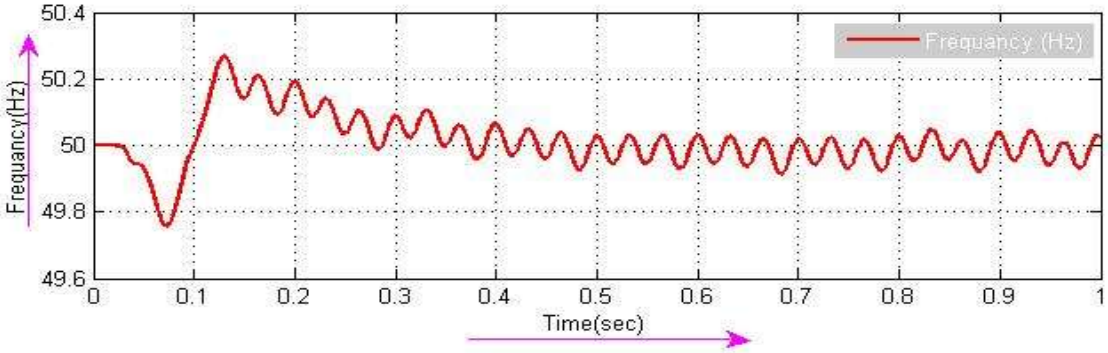

Fig 15.Frequency response of the Grid side is represented ,with Power smoothing system.

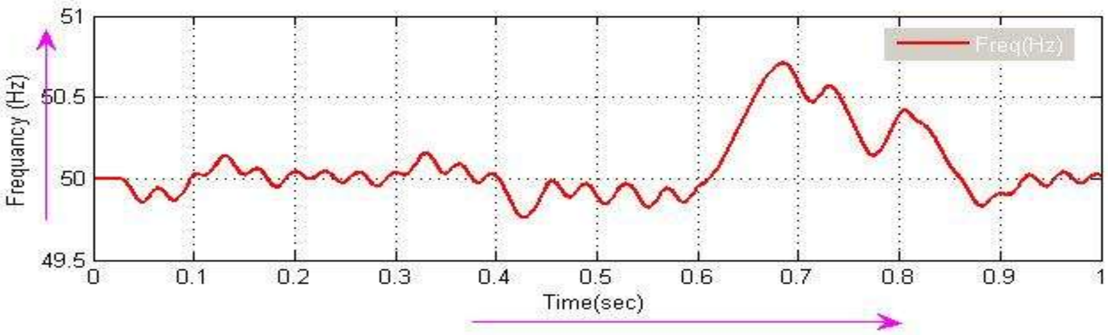

Fig 16:Frequency response of the grid power

Fig 15 and 16 Frequency response of the grid power with(15) and without(16) smoothing system ,due to fault the Frequency is distorted in Fig 16 ,from 50Hz but it's not much effected in Fig (15) with power smoothing system frequency of power is maintained constant.

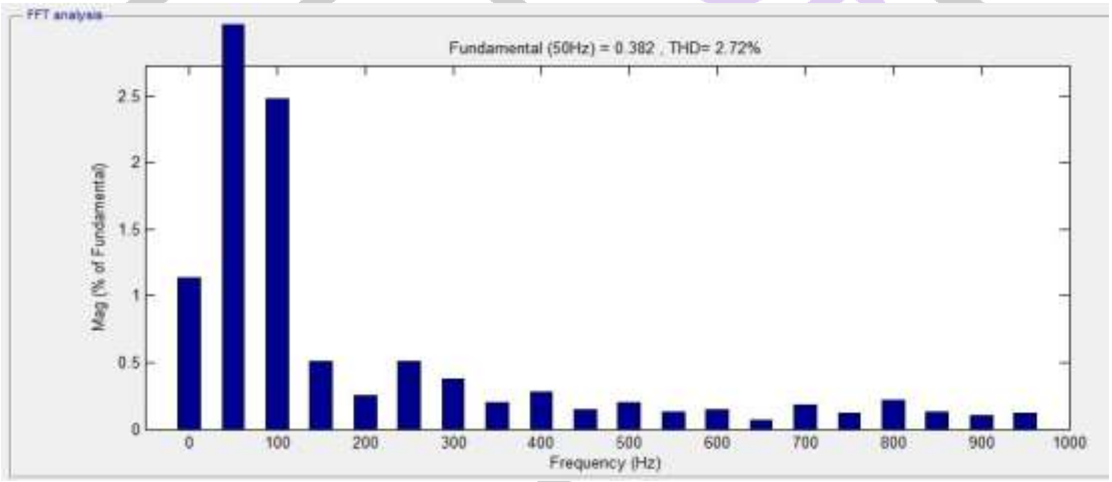

Fig 17. Shows the bar graph of the THD of different frequencies

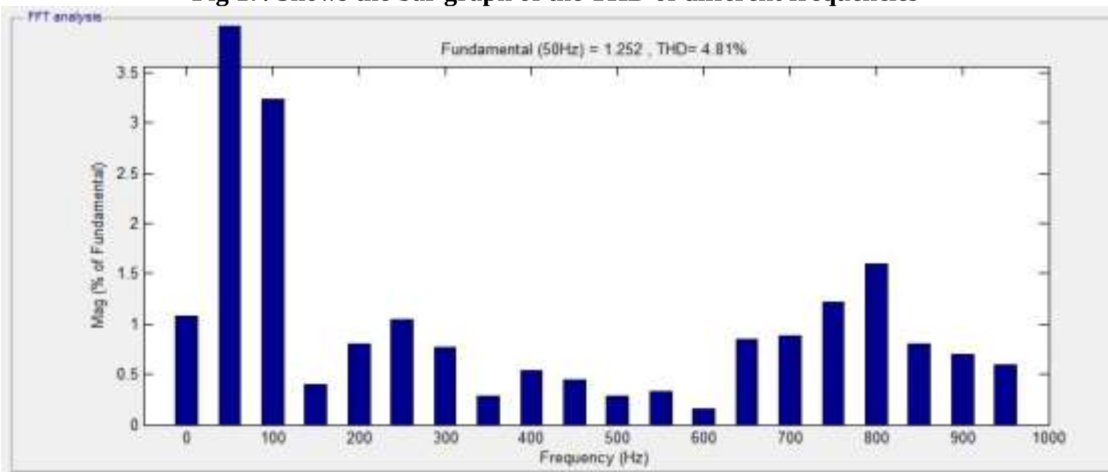

Fig 18

Fig 17 and Fig 18 ,Total Harmonic distortion(THD) with and without power smoothing system, Here the THD is 4.81% in system with out power smoothing system and THD in fig 18 with smoothing system is 2.72%. so with this can say THD is reduced after using power smoothing system.

IV CONCLUSION

This paper presented a power smoothing strategy based on supercapacitors for its application in Distributed renewable generation grids. The power smoothing strategy has been based on a voltage controller that manages the supercapacitors' state of charge while, at the same time, generating a power profile capable of smoothing the varying power of renewable sources. The fluctuations due to wind speed and irradiation variations can be smoothed more effectively by the supercapacitor connected to the DC link Distributed renewable power generation system. The proposed system enhances the Power quality and can be improved to maintain the power profile so that it will reduce the power quality issues present in the Renewable distribution grid.

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