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PV System Connected to Grid with Supercapacitor for Fault Ride through (FRT) Capability Enhancement

Trushant Mahatkar[1], Mrs. Manjusha R. Bachawad[2]
[1]*PG Scholar, Department of Electrical Engineering, Government College of Engineering Aurangabad.*
[2]*Associate Professor, Department of Electrical Engineering, Government College of Engineering Aurangabad.*

Abstract: Nowadays renewable energy sources (RES) are integrated to the grid to fulfil the increased demand of energy. Due to the addition of various RES to grid affects the power system stability, hence for support various energy storage devices are added. The RES should stay connected to grid during fault condition, such that the grid must be equipped with FRT capabilities. In these system, the PV array and Supercapacitor energy storage will provide active power support according to the depth in grid voltage dip and inverter will make the balance between both sides during fault condition. The d-q coupled control for inverter will provide the reactive power support to ensure the grid stability. During off-peak period, the energy is stored in Supercapacitor and delivers back to grid during peak period for reliable system stability and improved power quality. This paper deals with the stability of grid by using Supercapacitor. The MATLAB Simulink result will show the effectiveness of the system in extreme low voltage environment for significant duration.

Keywords: Active and Reactive power control, fault ride through (FRT), grid side inverter, photo voltaic (PV).

I. INTRODUCTION

Due to rise in demand of electrical energy, and its limited sources and capability, more focus is diverted on RES for generation of electricity, due to its features like no fuel cost, easy maintenance, low per unit generation cost and environmental protection [1, 2]. Among the RES, solar energy and wind energy systems are more prominent. Due to the large integration of this sources to the grid causes stability and reliability problem due to its stochastic nature [3]. On this basis many grid connections require strategy so that RES should stay connected to grid during large voltage dips during fault duration, and this terms called as fault ride through (FRT) capability [4-6]. Thus by using proper power electronic converter in order to get the best out of it.

The solar energy is dependent on amount of irradiation and temperature at any instant, because of any variation in these parameters affects the output power. By using the proper DC-DC converter for PV to extract more power with various methods of MPPT [7, 8]. Different methods of MPPT have been presented many years which consist of Perturb and Observe (P&O), Incremental Conductance (IC). Mostly used technology are IC and P&O because of its simplicity [9].

The main drawback of PV system is that the same power is not available all the time due to its intermittent nature. To overcome this drawback energy storage devices are used. Various energy storage devices has been presented. The combination of PV with energy storage device will play a vital role in balancing the power gap. In this paper Supercapacitor is used due to its advantages such as fast charging & discharging, high energy & power density. Various studies has been done on integration of Supercapacitor with STATCOM to provide FRT capabilities.

II. SYSTEM CONFIGURATION

Fig.1 depicts the system configuration of PV fed grid along with Supercapacitor as an energy storage device. In this system the renewable energy source i.e. PV array is providing DC power to the grid. Stochastic nature of PV forces to use the proper MPPT controlling technique for extracting maximum power. Specifications of PV array is shown in Table 1. The boost converter is interfaced in between PV array and DC link. The Supercapacitor is connected with bidirectional buck-boost converter which is placed in between DC link and inverter. The PQ control for inverter will controls the power in either direction, in normal condition the power is fed to grid or AC load and in case of fault it will store the power in Supercapacitor [10-12]. Parameters of grid is shown in Table 2.

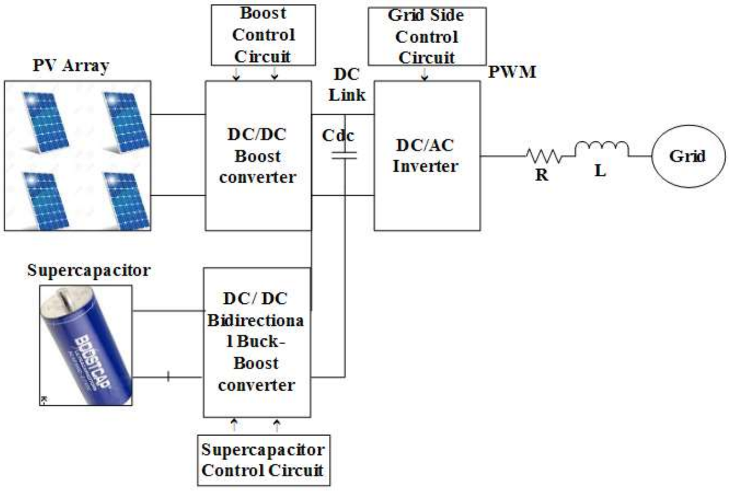

Fig.1: PV fed Grid connected system with Supercapacitor

TABLE I: SPECIFICATIONS OF PV ARRAY

Parameters	**Value**
Maximum Power	305.266 W
Maximum Power Voltage	54.7 V
Maximum Power Current	5.58 A
Open Circuit Voltage	64.2 V
Short Circuit Current	5.96 A
Serial Number	5
Parallel Number	66

TABLE II: PARAMETERS OF GRID

Parameters	**Value**
Source	3 phase,50 Hz,25 KV
Load	10 kVAR
Transformer	3 Phase,1000 kVA,260/25kV
Fault resistance	0.01 Ω

III. DESIGN OF SYSTEM PARAMETERS

TABLE III: DESIGN OF BOOST CONVERTER PARAMETERS

Parameters	**Expression**	**Value**
L	$L = \frac{V_S D}{\Delta i_L f}$ V_S - Source Voltage D – Duty Cycle f – Switching Frequency Δi_L - Input ripple current	13.481mH
C	$C = \frac{D}{R\left(\frac{\Delta V_0}{V_0}\right)f}$ D – Duty Cycle ΔV_0 - Output ripple Voltage	3.6232mF

TABLE III: DESIGN OF SUPERCAPACITOR PARAMETERS

Parameters	**Value**
Rated DC link output power (KW)	10 kW
Time of required power (S)	120 sec
Total energy required (J)	1200 kJ
Super initial voltage	250 V
Supercapacitor end of discharge voltage	125 V
Supercapacitor capacitance	38.4 F

IV. CONROL STRATEGIES

A. Control Strategy for Boost Converter

The power from PV is varying due to the change in temperature and irradiation. To extract the maximum power the MPPT technique is used. Here incremental conductance IC technique is used due to its simplicity. The PV output parameters is taken i.e. Vpv and Ipv, which is given to the incremental conductance. It generates output Vref shown in Fig.2 which is compared with Vpv. An error signal is regulated by PI controller (i.e. duty), and it generates the gate pulse for the boost converter.

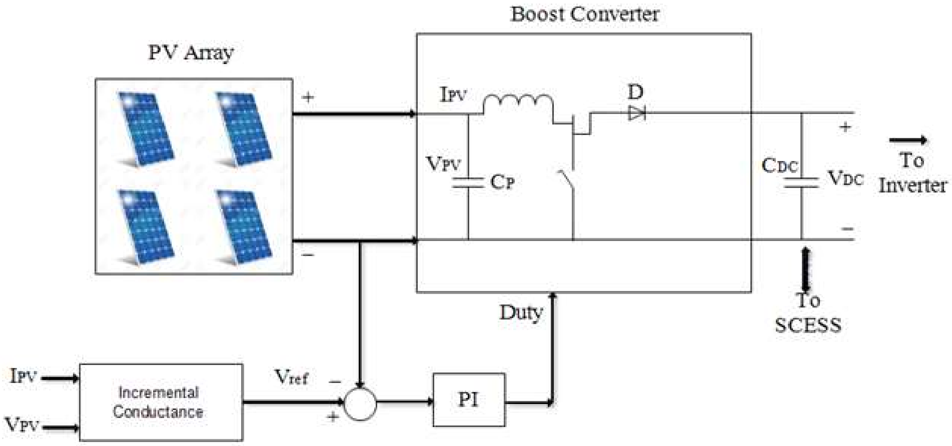

Fig.2: Incremental Conductance based MPPT and Boost Converter Control

B. Control Strategy for Bidirectional Buck-Boost Converter

The bidirectional buck-boost converter is shown in Fig.3. The Buck-Boost converter will act as buck converter in one direction and charges the Supercapacitor. In another case it will act as a boost converter in other direction and discharges the Supercapacitor in DC link to make DC link voltage constant. A lower limit is set for Supercapacitor voltage i.e. 50% below that it cannot discharged. The design of bidirectional buck-boost converter's inductance L is done in boost mode by setting duty cycle to 50%.

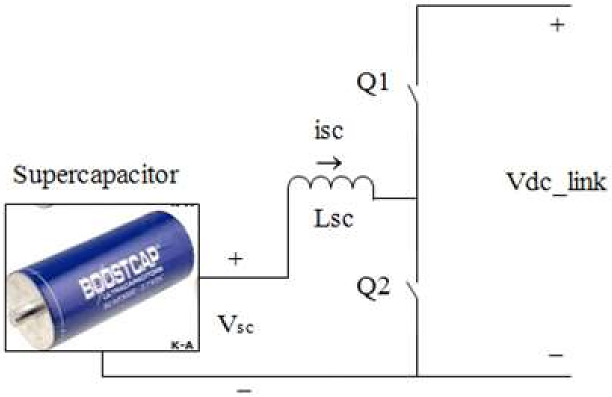

Fig.3: Supercapacitor with Buck-Boost Control

Fig.4 shows schematic diagram of buck-boost converter integrated with Supercapacitor having two cascaded loop i.e. inner and outer. The outer loop is a voltage control loop that controls the link voltage constant. By comparing Vdc with Vdcref and generates the Supercapacitor Current Iscref. This reference current signal is compared with Supercapacitor current Isc and generated the gate pulse for the IGBTs. The inner loop stores the energy in case of fault on grid side. The control signal Iscref and Vs in Laplace transform is given in equation (1) and (2):

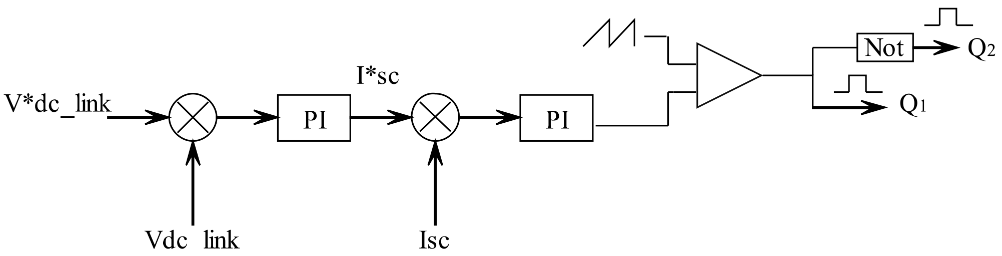

Fig.4: Supercapacitor Control for Buck-Boost Converter

$$I_{SCref}=(V_{DCref}-V_{DC})\times(k_{PO}+\frac{k_{IO}}{S}) \quad (1)$$

$$V_S=(I_{SCref}-I_{SC})\times(k_{PI}+\frac{k_{II}}{S}) \quad (2)$$

Where kp's and ki's are the proportional and integral constant for buck-boost converter.

C. Control Strategy for the Grid Side Inverter

The power available at DC link is converted into 3 phase AC power for AC load or grid. The 3 phase inverter is shown in fig 4. As per the requirement of load or grid demand the PQ controller is implemented for the inverter.

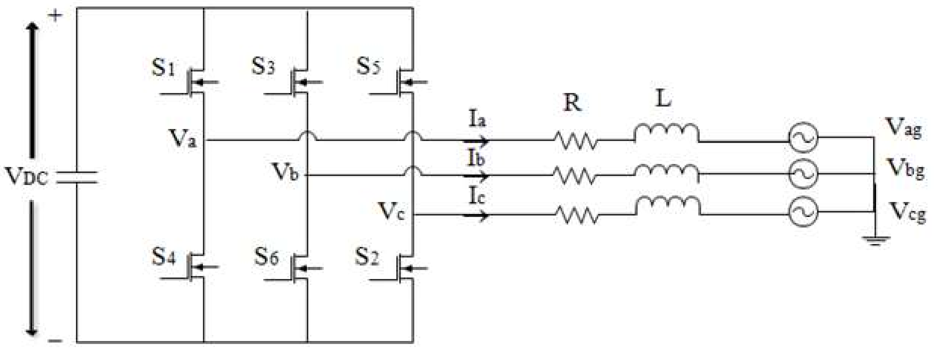

Fig.5: Three phase Two level Inverter

In Fig.5, the R and L are the transmission line parameters respectively. The Ia, Ib and Ic are the line currents and Va, Vb and Vc are the line voltages of transmission line respectively. Similarly Vag, Vbg and Vcg are the grid voltages respectively. By utilizing the synchronous rotating frame (d-q axis) the decoupled active and reactive current control technique along with standard PI controller produces I_D and I_Q currents, the I_D controls the active power and I_Q controls the reactive power. The PI controller makes these current to follow the reference current I_{Dref} and I_{Qref} respectively. The grid active and reactive power is given by equation (3) and (4):

$$P_g=\frac{3}{2}(V_{LD}I_{LD}+V_{LQ}I_{LQ}) \quad (3)$$

$$Q_g=\frac{3}{2}(V_{LQ}I_{LD}-V_{LD}I_{LQ}) \quad (4)$$

Where, P_g and Q_g are the active and reactive power of the grid.

The reference signal for active and reactive power is taken from PCC. If P_{ref} and Q_{ref} reference signal is known then I_{Dref} and I_{Qref} can be calculated by using equation (5) and (6):

$$I_{Dref}=\frac{2}{3}\left(\frac{P_{ref}V_{LD}-Q_{ref}V_{LQ}}{V_{LD}^2+V_{LQ}^2}\right) \quad (5)$$

$$I_{Qref} = \frac{2}{3}\left(\frac{P_{ref}V_{LQ}+Q_{ref}V_{LD}}{V_{LD}^{2}+V_{LQ}^{2}}\right) \qquad (6)$$

The control technique for P-Q controller is shown in Fig.6

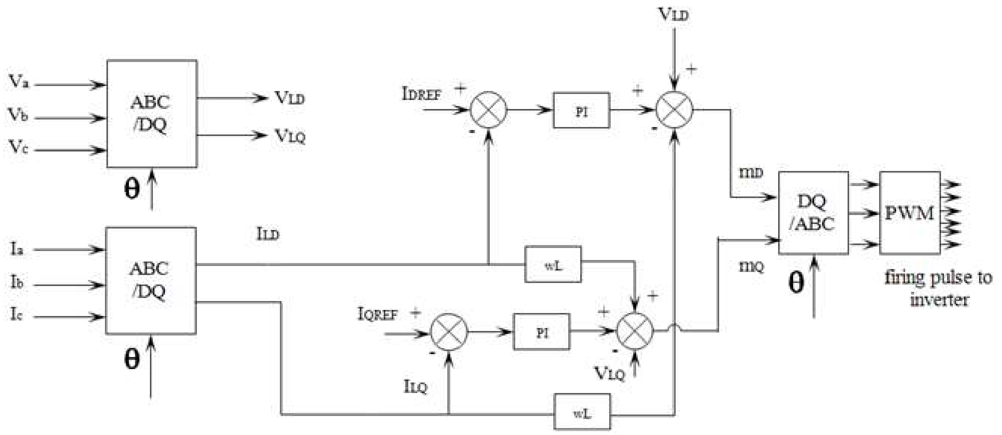

Fig.6: P-Q control for the Three phase Two level Inverter

V. SIMULATION RESULTS AND DISCUSSION

The MATLAB simulation is done on the given system and the results are shown from Fig.7 to Fig.24 .The fault is introduced on grid side from 1 to 1.2 seconds and simulation results are calculated on the two conditions given as:

1. Fault without Supercapacitor
2. Fault with Supercapacitor

In first case the fault is acted on grid side without Supercapacitor system is analysed. In second case the fault is acted on the grid side along with Supercapacitor as a compensation device is introduced in the system.

The changes in the irradiation and temperature is shown in Fig.7 and Fig.8 respectively, due to the change in the variation in irradiance and temperature the PV voltage and PV output power undergoes variation shown in Fig.9 and Fig.10 respectively and corresponding duty cycle is shown in Fig.11.

The second case shows that with the introduction of Supercapacitor in the system the results are more stable, Fig. 18 and Fig.19 shows the PV voltage and PV power respectively.

The system demands the constant dc link voltage i.e 500V, but due to the fault is introduced from 1 to 1.2 seconds the dc link voltage is fluctuating shown in Fig.12. Similarly the grid side voltage in that faulty period is almost zero is shown in Fig.13 i.e. very low power is transferred to the grid. The active and reactive power transferred to the grid is shown in Fig.14 and Fig.15 respectively i.e. reactive power demand increases.

Fig.21 depicts that the constant dc link voltage of 500V is obtained due to the Supercapacitor, the grid side voltage is also stable in second case shows the fault ride through capability enhancement shown in Fig.22. The active and reactive power transferred to the grid is also more stable shown in Fig.23 and Fig.24 respectively i.e. reactive power demand is almost zero.

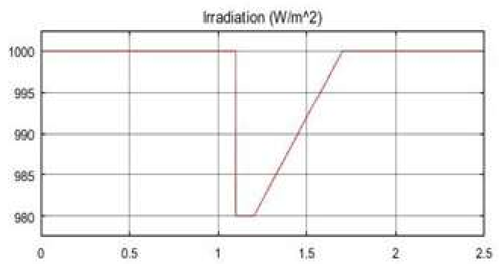

Fig.7. Variation in Irradiation of PV system without Supercapacitor

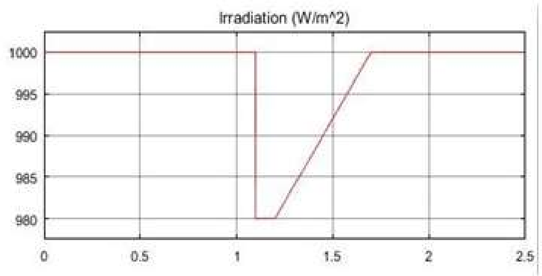

Fig.16. Variation in Irradiation of PV system with Supercapacitor

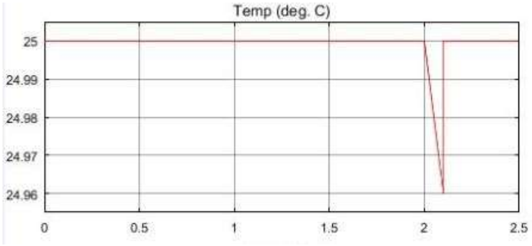

Fig.8. Variation in Temperature of PV system without Supercapacitor

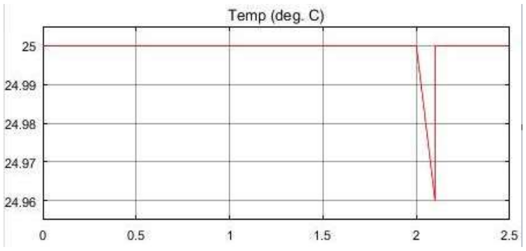

Fig.17. Variation in Temperature of PV system with Supercapacitor

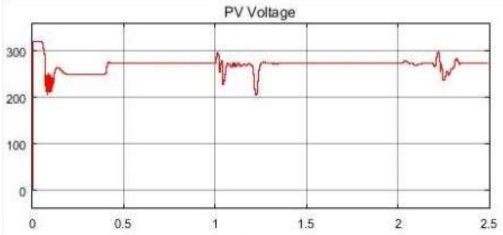

Fig.9. PV output Voltage without Supercapacitor

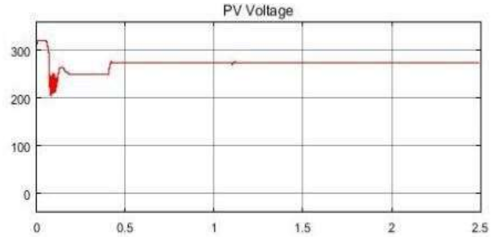

Fig.18. PV output Voltage with Supercapacitor

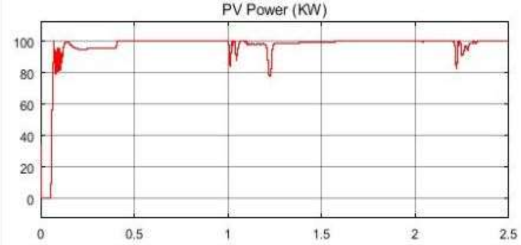

Fig.10. PV output Power without Supercapacitor

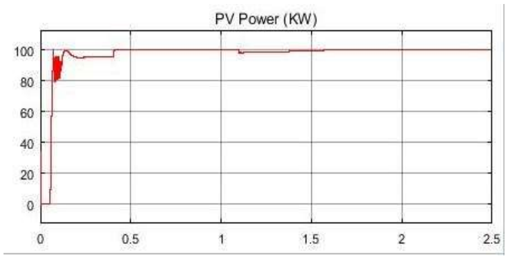

Fig.19. PV output Power with Supercapacitor

Fig.11. Duty cycle of boost converter without Supercapacitor

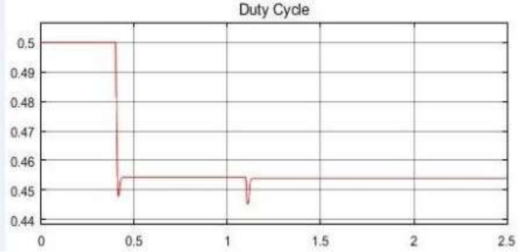

Fig.20. Duty cycle of boost converter with Supercapacitor

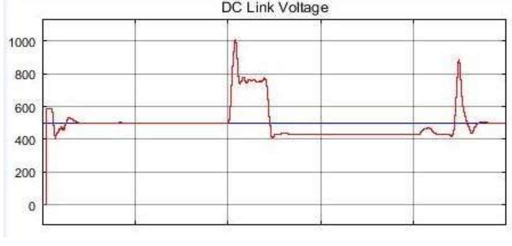

Fig.12. DC link Voltage of the system without Supercapacitor

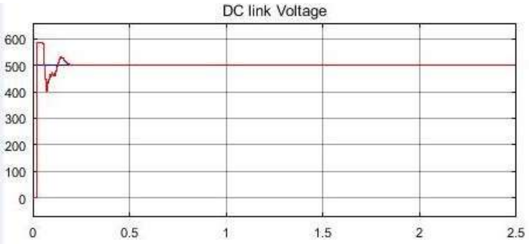

Fig.21. DC link Voltage of the system with Supercapacitor

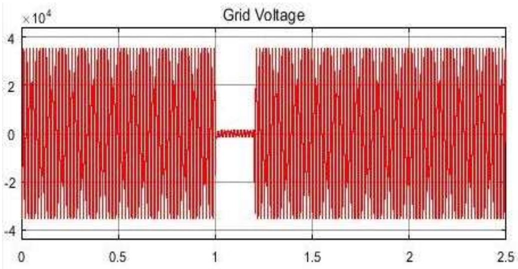

Fig.13. Grid side voltage without Supercapacitor

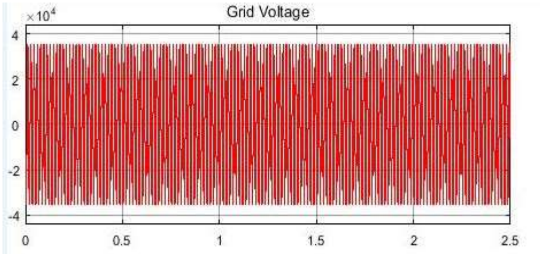

Fig.22. Grid side voltage with Supercapacitor

Fig.14. Activer Power transferred to the grid without Supercapacitor

Fig.23. Activer Power transferred to the grid with Supercapacitor

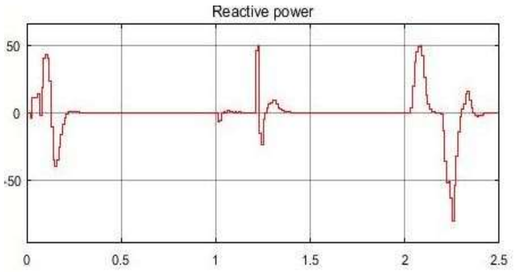

Fig.15. Reactiver power transferred to the grid without Supercapacitor

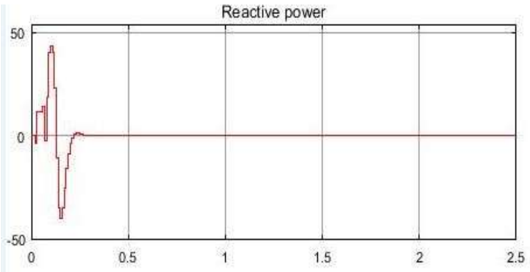

Fig.24. Reactiver power transferred to the grid with Supercapacitor

VI. CONCLUSION

The Supercapacitor system for fault ride capability enhancement in PV fed grid is used for minimizing fluctuations. In this system boost converter is used to boost the voltage of PV, the Supercapacitor is interfaced with buck-boost converter to maintain the constant DC link voltage. The d-q controller is used for the inverter to transfer the DC link power to the grid. The fault with and without Supercapcitor are discussed. The result shows that all fluctuation in case one are mitigated by the introduction of Supercapacitor in the grid. The Supercapacitor system maintains the system stability and enhancing the FRT capabilities shows the effectiveness of the given system configuration.

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