International Journal of Electrical Engineering and Ethics- Volume 3 Issue 4, August 2020

RESEARCH ARTICLE OPEN ACCESS

Fault Ride Through Capability of Grid Connected PV System with Enhanced Energy Storage Systems

Ms. Madhuri G. Gullapelli[1], Er. Somnath S. Hadpe[2]
1(PG Student, Department of Electrical Engineering,
Matoshri College of Engineering & Research Center, Nashik, Maharashtra, India
Email: gullapellim06@gmail.com)
2 (Assistant Professor, Department of Electrical Engineering,
Matoshri College of Engineering & Research Center, Nashik, Maharashtra, India
Email: somnath.hadpe@yahoo.in)

Abstract:

A fault ride through, power management, and control strategy for a microgrid integrated photovoltaic (PV) system with enhanced energy storage systems are presented in this paper. For to avail enhanced storage and normal operation Supercapacitor Energy storage system will be used to minimize the fluctuation as it has high power density and during fault at the grid side system will be used to store the generated power from the PV array for further use and fault ride through. To acquire the maximum available solar power, maximum power point tracking (MPPT) by Incremental Conductance (IC) method is done. To transfer the generated power to the grid using a Voltage source inverter (VSI), independent P-Q control is implemented. The Supercapacitor Energy storage system is connected to the system using a bi-directional buck-boost converter. The system model has been developed that consists of a PV module, buck converter for MPPT, buck-boost converter to connect the Supercapacitor Energy storage system to the DC link.

Keywords — **Supercapacitor Energy storage system, PV array, Microgrid, MPPT, IC, VSI**

I. INTRODUCTION

Current trends of power generation using renewable sources are very difficult to tackle problems associated with price volatility and the carbon impact of fossil fuels. This has motivated researchers to develop renewable energy-based Distributed Generation (DG) and is moving fast to meet the worldwide current needs of utilizing clean energy sources to create a clean energy future and minimizing the costs. Among the available renewable energy sources, solar energy is burning desire and the photovoltaic (PV) system provides the most simple method to convert solar energy into electrical energy without creating an environmental disturbance. The solar power converted to electrical power by the photovoltaic (PV) system can be integrated with the grid if it meets the grid code. Thus controlling the power electronics blocks that are used for grid integration is required to get the best out of solar energy.

The irradiation and temperature received at any instant oftime affect the output voltage and current of a PV cell. Due to this variations in the input parameters and the non-linear relation between voltage and current, there is always one point that gives the maximum power and these days PV panels are accompanied by maximum power point tracking (MPPT) controllers. Various MPPT design methods have been implemented over the years [1]-[4]. Out of those used methods Incremental Conductance (IC) and Perturb and observe (P&O) preferred by many researchers due to their simplicity.

Due to variation irradiation and temperature output power is unpredictable and it is totally dependent on PV as a power generation unit. To overcome this disadvantage of fluctuations, different energy storage devices are integrated to the PV system. Among these, battery and supercapacitor energy storage system are widely used in the literature because of their high energy and power densities respectively [5]-[8]. Some research work has been done to integrate supercapacitor energy storage system with STATCOM for low voltage and fault ride through as well as smoothing power fluctuation of wind energy system [9]-[11]. Research on low voltage ride through and fault response of grid connected solar inverters without energy storage is discussed in [12]-[16]. Various linear and nonlinear control techniques have been proposed recently on isolated and grid connected PV with energy storage system [17]-[21]. However, most of researchers have addressed on how to use the energy storage for other issues and control techniques. Issues related to fault ride through using the energy storage has not been discussed.

In this proposed paper, the power generated from PV arrays is used as input to the grid using a buck converter, a bi-directional buck boost converter and a VSI. Supercapacitor energy storage system has been used to minimize the fluctuation and store energy during grid fault, and is tapped on the DC link of the VSI. The energy storage is connected through a bidirectional buck boost converter and this converter controls the DC link voltage to a constant value for power delivery to the grid. By controlling duty cycle of buck converter,the maximum output voltage for MPPT has been obtained. As per the requirement of power management control unit P-Q vector is implemented to control independently the active and reactive power for grid.

II. SYSTEM MODELLING

Fig. 1 shows the configuration of grid connected to PVsystem and energy storage connected to the DC link.The PVarray is formed from a number of PV modules converts the received solar irradiation and temperature into DC current and voltage.These values are varying throughout the day depending on position of the Sun irradiation and temperature at any particular time. A buck converter is used,tomake DC power generated from the PV array suitable forthe inverter and implement MPPT.

The duty cycle of the buck converter is continuously adjustedunder varying irradiation and temperature to instantly locatethe maximum voltage or current to obtain the maximumpower output from the PV arrays.The energy storage isconnected to the DC link between the buckconverter and theinverter using a bidirectional buck boost converter. For real powerdelivery by absorbing any mismatch between the generatedpower and the power transferred to the gridThe DClink voltage is kept constant by this converter. To transfer the available powerof the DC link to either an AC load or to the main grid duringnormal operation and during fault at the grid side the DC linkpower will be stored in the SCESS a P-Q control isimplemented for the inverter.

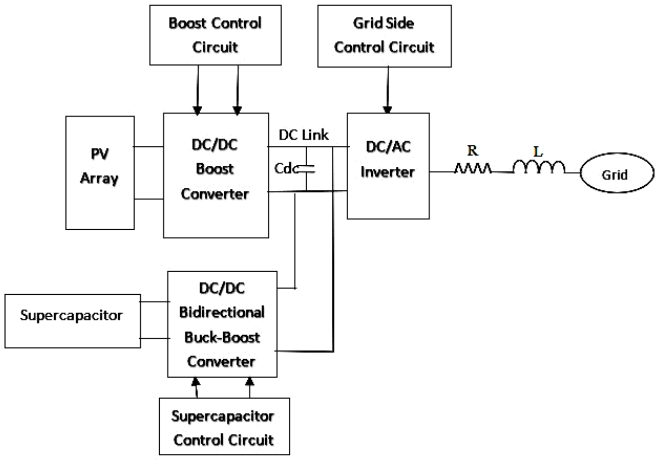

Fig. 1 Proposed system configuration

III. THEPROPOSED CONTROL STRATEGY

Tointegrate the PV system to the energy storage and to the gridand hence three control blocks are proposed namely buck converter,bidirectional buck-boost converter and VSI. The first controlblock uses IC to control the duty of the buck converter andthe MPPT. The second control block controls the DC linkvoltage to a constant value for real power delivery and P-Q control for the VSI used in thethird control block.

A. Buck Converter Controller

This converter is used to force the PV arraychange its operating point under varying irradiation andtemperature to locate the Maximum Power Point tracking. Incremental conductance (IC) method is used becauseof its simplicity in this paper to locate the Maximum Power Point by calculatingthe PV power at each instant and changes PV array'soperation point to capture the maximum available power.Input of the IC based MPPT is the PV array's output voltageVPV and current IPV and its output is the reference voltage,Vref, as shown in Fig.2. This voltage is compared with VPV andthe difference will be processed by a PI regulator [22].

Aftercomparison of a high frequency carrier signal with the outputof the PI (which is the Duty), firing pulse is generated for thebuck converter. The DC link voltage VDC is the Dutymultiplied by the PV array output voltage, VPV. The DC linkcapacitor CDC removes the offset of this voltage.

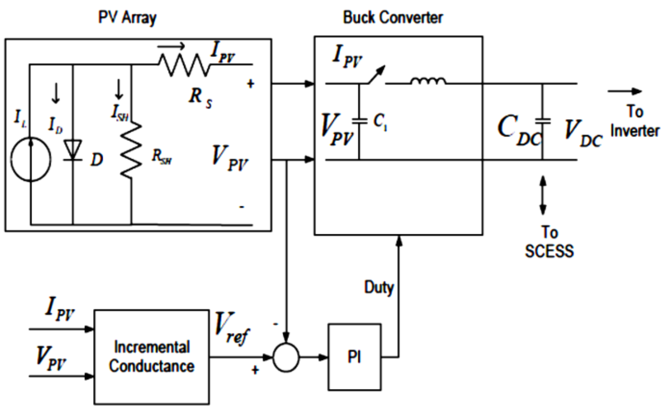

Fig.2 Buck converter controller [26]

B. Bidirectional Buck-Boost Converter Controller

The topology of the bi-directional buck-boost converter is shown in Fig. 3. To recharge the supercapacitors in one direction and as a boost converter to transfer energy to the link capacitor in the other direction the bidirectional converter acts as a buck converter. IGBTs are used as the switching devices in the circuit. The operation of the converter is controlled by the DC link voltage and the voltage of the supercapacitors. The main purpose of the bidirectional buck-boost converter is to maintain the voltage of the DC link relatively constant at a reference value. To make this buck-boost converter controller stable, a lower limit is placed on the supercapacitor voltage which is 50% of the maximum value. The state of charge (SoC) controls the supercapacitor voltage to be between $0.5V_{SC}$max and V_{SC}max so that 75% of the energy stored is utilized. The inductor L is designed from the boost mode using a duty cycle of about 0.5 [23].

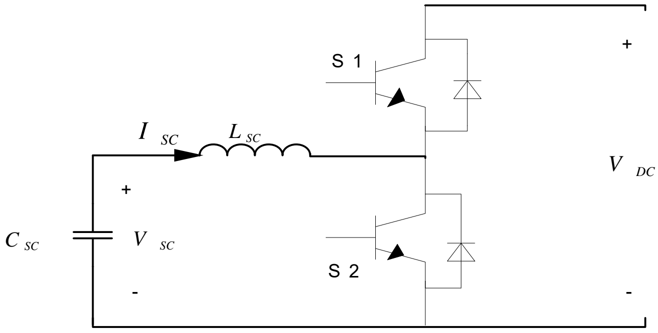

Fig.3 Bi-directional buck-boost converter [26]

C. P-Q Controller for the Inverter

The available DC link power has to be converted to three phase AC power to supply either AC loads or for grid integration using an inverter shown in Fig.4. Depending on the grid power demand or AC load, P-Q controller is implemented for the inverter.

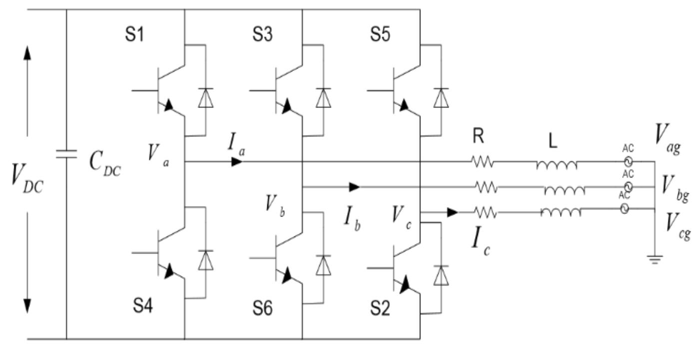

Fig. 4. Two level three phase Inverter [26]

From Fig.4, R and L are resistance and inductance of the distribution line respectively. Ia, Ib and Ic are the distribution line currents; Va,Vb, Vc are the inverter output voltages; Vag, Vbg, Vcg are the grid voltages. Using synchronous rotating reference frame (D-Q axis), decoupled active and reactive current control technique is implemented using a standard PI controller. In the current control technique, the active current component ID controls the active power and reactive power flow is regulated bycontrolling IQ.The PI controllers force these currents to track certain reference commands ID_{REF} and IQ_{REF}, respectively. Utilizing the instantaneous power theory [24].

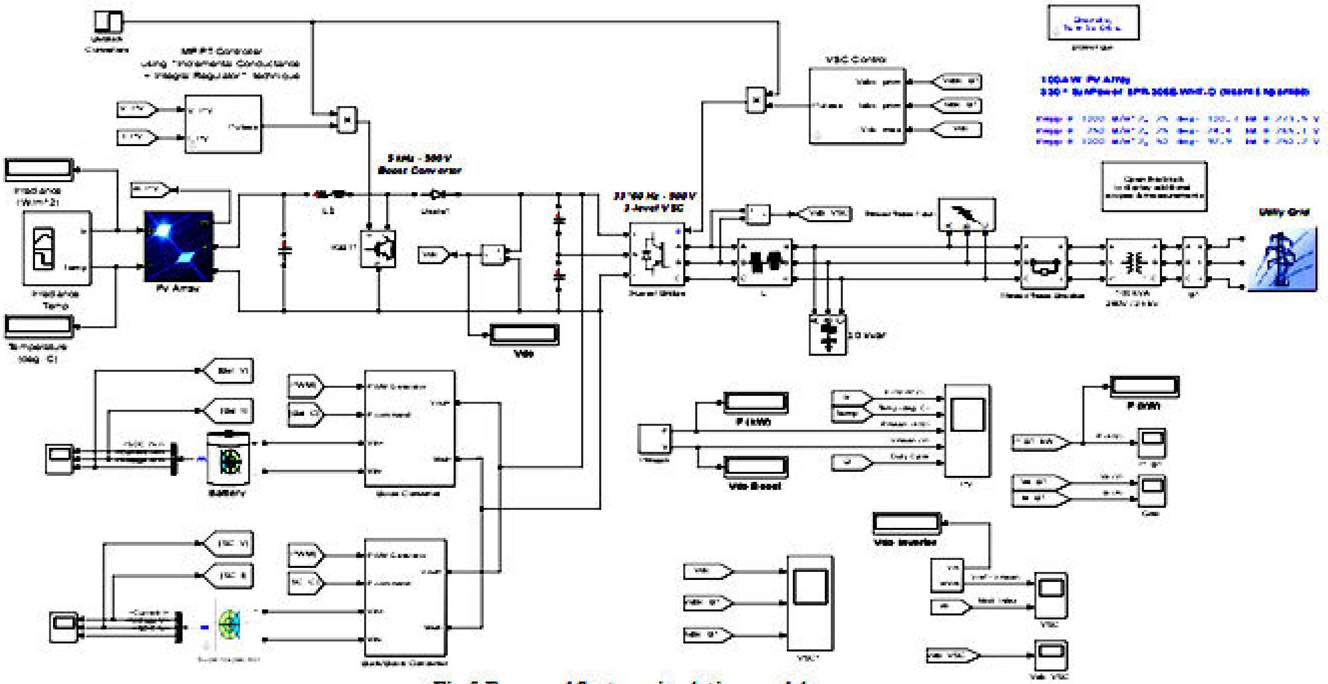

Fig.5 Proposed System simulation model

IV. RESULTS AND DISCUSSION

The system consists of 50 series connected and 20 parallel-connected modules. Fig.5 shows the complete model of the grid-connected PV system used in this paper. For the reference solar intensity of 1000 W/m2 and 50°c as shown in fig.6, the operating voltage V_{MP} and current I_{MP} at the MPPT will be 500.72 V, and 119.36A, respectively. The expected maximum output power at this operating point from this PV array is 59.77 kW (500.72V×119.36A). The SCESS is developed to have an energy capacity of 10 kW for 120 seconds (1200 kJ) to minimize the fluctuation of the 59 kW PV system. DC link voltage of 500 V and supercapacitor voltage of 250 V (0.5*500) is used, the optimum supercapacitor capacitance CSC is considered as 22.7 F for reference. [26] The P-Q controller from the PMC is set to 50kW and if the irradiation or temperature varies this set point can be varied accordingly. During a fault at the grid side, the generated power from the PV array will be stored in the SCESS. The SCESS helps the system ride through by providing active and reactive power. To demonstrate the effectiveness of the proposed controller for fault ride-through and power smoothing using energy storage for grid-connected PV during the fault, the SCESS participates in riding the fault by the system, the three-phase fault is applied at the grid side increasing the reactive power. The DC link voltage is controlled by the buck-boost converter for the system having the SCESS and verified with and without fault as shown in Fig. 7a, but the inverter controls this voltage if there is no energy storage.The operation of the PV array is unaffected if the system has energy storage, the PV array MPPT tracks the maximum voltage despite the fault. Fig7b and Fig7c. shows the three-phase voltage and current input to the grid respectively. Fig. 7d. shows the power to grid while

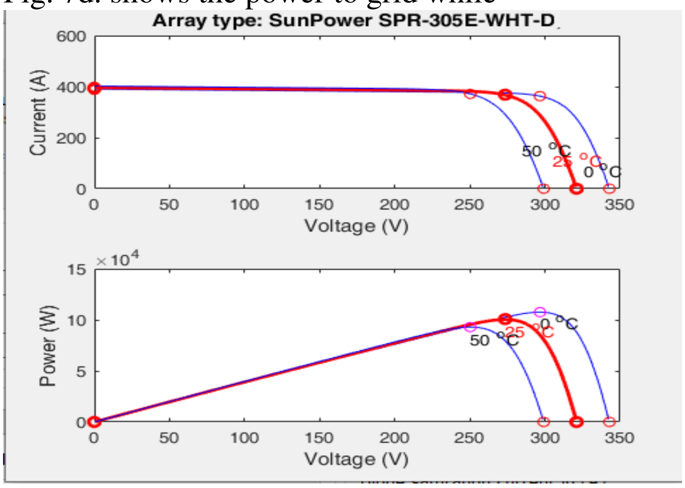

Fig. 6. PV Characteristics

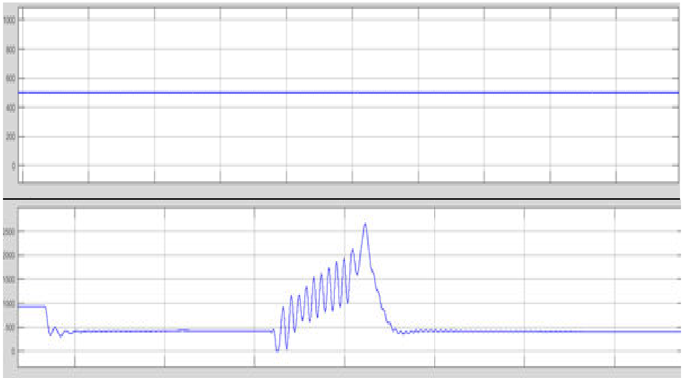

Fig. 7a. DC Voltage without and with Fault

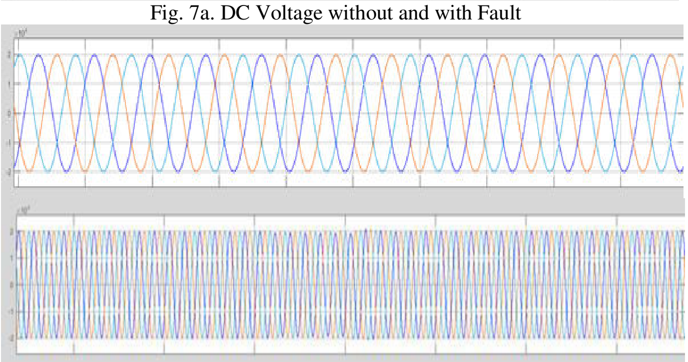

Fig. 7b. Voltage to Grid without and with Fault

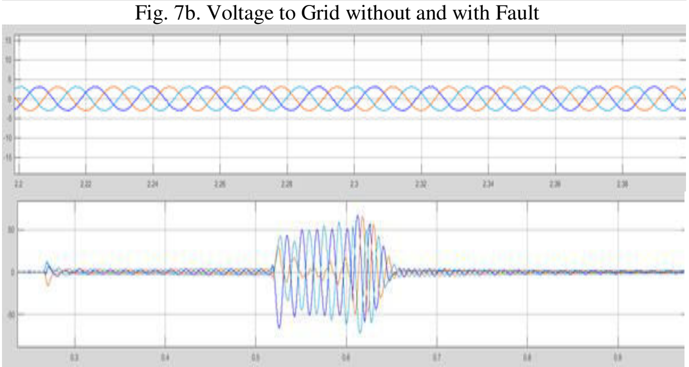

Fig. 7c. Current to Grid without and with Fault

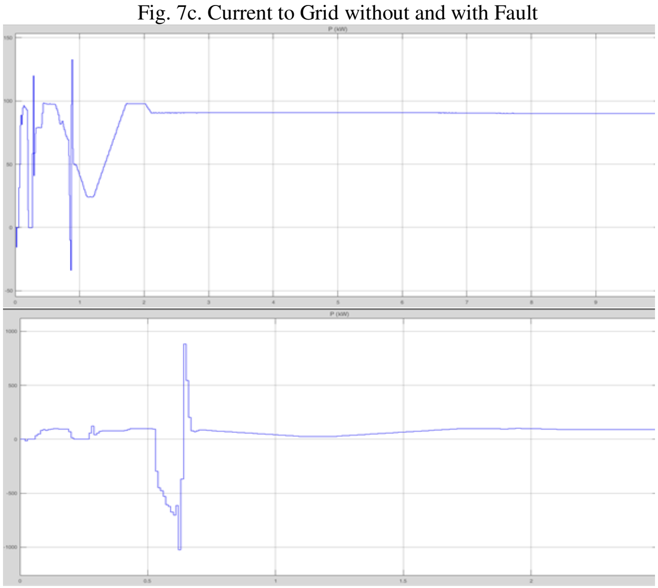

Fig. 7d. Power to grid without and with Fault

V. CONCLUSION

In this paper grid connected PV system with supercapacitor energy storage system (SCESS) for fault ride through and to minimize the power fluctuation is proposed.To track the maximum power from the PV array, Incremental conductance based MPPT is implemented. The generated DC power is connected to the grid using a buck converter, VSI, buck-boost converter with SCESS. The SCESS which is connected to the DC link controls the DC link voltage by charging and discharging process. To transfer the DC link power to the grid a P-Q controller is implemented. SCESS minimizes the fluctuation caused by change in irradiation and temperature observed during normal operation. At the same time at a grid fault the power generated from the PV array will be stored in the SCESS. The SCESS supplies both active and reactive power to ride through the fault. Simulation based results have shown the validity of the proposed controller.

REFERENCES

1. *T. Esram, P.L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," IEEE Transaction on Energy Conversion, vol.22, no.2, pp.439-449, June 2007.*
2. *J. M. Enrique, E. Durán, M. Sidrach-de-Cardona, and J. M. Andújar,"Theoretical assessment of the maximum power point tracking efficiency of photovoltaic facilities with different converter topologies," Sol. Energy, vol. 81, no. 1, pp. 31–38, Jan. 2007.*
3. *W. Xiao, N. Ozog, and W. G. Dunford, "Topology study of photovoltaic interface for maximum power point tracking," IEEE Trans. Ind. Electron., vol. 54, no. 3, pp. 1696–1704, Jun. 2007.*
4. *J. L. Agorreta, L. Reinaldos, R. González, M. Borrega, J. Balda, and L. Marroyo, "Fuzzy switching technique applied to PWM boost converter operating in mixed conduction mode for PV systems," IEEE Trans. Ind. Electron., vol. 56, no. 11, pp. 4363– 4373, Nov. 2009.*
5. *A.Schneuwly, "Charge ahead [ultracapacitor technology and applications]", IET Power Engineering Journal, vol.19, 34-37, 2005.*
6. *A.Rufer, D. Hotellier, and P. Barrade, "A supercapacitor-based energy storage substation for voltage compensation in weak transportation networks", IEEE Trans. Power Deliv., vol. 19, no. 2, pp.629-636, Apr 2004.*

7. *Y. Cheng, "Assessments of energy capacity and energy losses of supercapacitors in fast charging–discharging cycles," IEEE Trans. Energy Convers., vol. 25, no. 1, pp. 253–261, Mar. 2010.*

8. *Z. Yang, C. Shen, L. Zhang, M. L. Crow, S. Atcitty, "Integration of a StatCom and Battery Energy Storage", IEEE Transactions on Power Systems, vol. 16, 254-260, 2001.*

9. *Spyros I. Gkavanoudis, Charis S. Demoulias," A combined fault ridethrough and power smoothing control method for full-converter wind turbines employing Supercapacitor Energy Storage System", Electric Power Systems Research, vol. 106, 62– 72, 2014.*

10. *A.H.M.A. Rahim, E.P. Nowicki," Supercapacitor energy storage system for fault ride-through of a DFIG wind generation system", Energy Conversion and Management,vol. 59 96–102, 2012.*

11. *Muhammed Yibre, M.A.Abido, "Supercapacitors for wind power Application", 2nd International Conference on Renewable Energy Research and Applications, 20-23 October, Madrid, Spain, 2013.*

12. *J. Eloy-Garcia Carrascoa,, J.M. Tenab, D. Ugenab, J. AlonsoMartineza, D. Santos-Martina, S. Arnaltesa," Testing Low Voltage Ride Through capabilities of solar inverters", Electric Power Systems Research, vol.96, 111–118, 2013.*

13. *A. Plet, Timothy C. Green," Fault response of inverter interfaced distributed generatorsin grid-connected applicationsCornelis", Electric Power Systems Research, vol. 106, 21– 28, 2014.*

14. *A. Darwish, A.S. Abdel-Khalik, A. Elserougi, S. Ahmed, A. Massoud," Fault current contribution scenarios for grid-connected voltage source inverter based distributed generation with an LCL filter", Electric Power Systems Research, vol. 104, 93– 103, 2013.*

15. *J.C. Hernándeza,, J. De la Cruzb, B. Ogayar," Electrical protection for the grid-interconnection of photovoltaic-distributed generation", Electric Power Systems Research vol. 89, 85– 99, 2012.*

16. *Yang, Fang, Lihui Yang, and Xikui Ma. "An advanced controlstrategy of PV system for low-voltage ride-through capability enhancement." Solar Energy 109 Pages 24-35,2014.*

17. *H. Fakham, D. Lu, and B. Francois, "Power control design of a battery charger in a hybrid active PV generator for load-following applications," IEEE Trans. Ind. Electron., vol. 58, no. 1, pp. 85–94, Jan. 2011.*

18. *H. Kanchev, D. Lu, F. Colas, V. Lazarov, and B. Francois, "Energy management and operational planning of a microgrid with a PV-based active generator for smart grid applications," IEEE Trans. Ind. Electron., vol. 58, no. 10, pp. 4583–4592, Oct. 2011.*

19. *N. Kakimoto, H. Satoh, S. Takayama, and K. Nakamura, "Ramprate control of photovoltaic generator with electric double-layer capacitor," IEEE Trans. Energy Convers., vol. 24, no. 2, pp. 465–473, Jun. 2009.*

20. *E. Pérez, H. Beltran, N. Aparicio, P. Rodríguez, "Predictive Power Control for PV Plants With Energy Storage" IEEE Transactions On Sustainable Energy, Vol. 4, No. 2, April 2013.*

21. *Phatiphat Thounthong,"Model Based-Energy Control of a Solar Power Plant With a Supercapacitor for Grid-Independent Applications" IEEE Transactions On Energy Conversion, vol. 26, No. 4, December 2011*

22. *Muhammed. Y. Worku and M. A. Abido, "Real-time implementation of grid-connected PV system with decoupled P-Q controllers," 2014 22nd Mediterranean Conference of Control and Automation (MED), pp. 841 – 846, Palermo, Italy, June 16-19, 2014*

23. *Phinit Srithorn, Mark Sumner, Liangzhong Yao, Ram Parashar "Power System Stabilisation using STATCOM with Supercapacitors" ISA'08 IEEE Industry Applications Society Annual Meeting 2008.*

24. *Amirnaser Yazdani and Reza Iravani, "Voltage- Source Converters in Power Systems: Modelling, Control and Applications": John Wiley and Sons, Inc., 2010.*

25. *A.V. Timbus, T. Teodorescu, F. Blaabjerg, M. Liserre, P. Rodriguez, "PLL algorithm for power generation systems robust to grid voltage faults", in: PESC06, 37th IEEE on Power Electronics Specialists Conference, pp.1–7, 2006.*

26. *Muhammed Y. Worku, M.A.Abido,"Grid-Connected PV Array with Supercapacitor Energy Storage System for Fault Ride Through" in 2015 IEEE International Conference on Industrial Technology (ICIT),DOI: 10.1109/ICIT.2015.7125526, Electronic ISBN: 978-1-4799-7800-7*