ISSN 2395-695X (Print)
ISSN 2395-695X (Online)
International Journal of Advanced Research in Biology Engineering Science and Technology (IJARBEST)
Vol. 2, Special Issue 14, May 2016

The hierarchical three layer protection of photovoltaic generators in microgrid with co-ordinated droop control for hybrid energy storage system

Vignesh, Student Member, IEEE, Sundaramoorthy, Student Member, IEEE and Anbudasan, Student Member, IEEE

***Abstract*—this paper provides the solution for critical problems surrounded in PV microgrid in the field protection. The main requirement in operating modes of PV microgrid are, the voltage and frequency should be maintained constant and both real and reactive power flow should be balanced and it also includes the soft transition between two modes of operation and to avoid transient surge in power system. This paper proposes the integrated protection of PV microgrid with hierarchical coordination for both grid connected and stand-alone mode of operation. To enhance the system the three layers of protection schemes are introduced such as relay protection with fault tolerant breaker, a hybrid energy storage system (HESS) regulation and emergency control is provided. The numerical simulations can be carried out to demonstrate the effectiveness of the proposed system in Matlab.**

Index terms— DC fault protection, fault tolerent breaker(FTB), hybrid energy storage system (HESS), emergency control, distributed generation(DG), solar photovoltaic(PV), microgrid.

I. INTRODUCTION

Photovoltaic generators provide clean–green energy in electricity generation with PV panels and no harmful greenhouse gas emissions thus solar PV is environmentally friendly to nature. Electricity generations of distributed photo voltaic generators are effectively integrated into the power system.

The traditional droop control provides the voltage sag mitigation. It also provides the control for battery and super capacitor i.e. charging and discharging of both battery and super capacitor. The controls strategies mentioned above will provide the perfect solutions for problems faced in the microgrid.

In addition to this effective control, protection has to be provided to fulfill the requirements of PV microgrid. The microgrid has to be protected for purpose of preventing equipment damage, safety and reliability. The maximum short circuit current rating is has to be limited or less than two times of the rated current of more photovoltaic generators connected to the microgrid.

The protection provided for the photovoltaic microgrid are three layer hierarchical scheme and they are relay protection with z-source breaker, HESS regulation and emergency control. By using this protection scheme reliability of the system is maintained. The zero sequence and the negative sequence currents are used to detect the faults.

A small scale PV is considered for the grid connected mode to control both real and reactive power in the system. For the easy mode of control abc to dq0 transformation and vice versa is required. For the frequency control both battery and super capacitor is used as energy storage device and also different frequency scenarios are considered.

The current delivered by the PV generators which depends on solar radiation and temperature of the cell are found by the equation (1)

$$I_{PV} = (I_{PV,n} + K_1 \Delta T)\frac{G}{G_n} \quad (1)$$

Where $I_{PV,n}$ is the photo current at standard test condition(STC, 25^O C and $1000W/m^2$). K_1 is the ratio of the short circuit current and temperature coefficient. ΔT is the difference between actual and the nominal temperature in Kelvin. G is the radiation on the given surface in W/m^2 and $G_n$is the nominal radiation in W/m^2.

The chapter I provide the introduction to the PV (photo voltaic) generators, the requirement of microgrid and the need of the control and protection scheme for PV microgrid. The chapter II provides the control strategies and its algorithm provided for the system. The chapter III gives the hierarchical three layer protection of PV microgrid.

II. DROOP CONTROL

A. PV system control

The two modes of operation of the PV generators are grid-connected mode and stand-alone mode of operation in the power system. To satisfy the requirement of PV microgrid the three layer hierarchical control structure is given in the below architecture as shown in the fig.1.

The control structure provides the hierarchical control for photovoltaic microgrids. This provides the V/F control to the stand-alone mode of operation and PQ control to the grid connected mode in the power system. For transition between the two modes are provided by the soft transition i.e. from stand-alone mode to grid connected mode and vice versa by the transition of control.

ISSN 2395-695X (Print)
ISSN 2395-695X (Online)
International Journal of Advanced Research in Biology Engineering Science and Technology (IJARBEST)
Vol. 2, Special Issue 14, May 2016

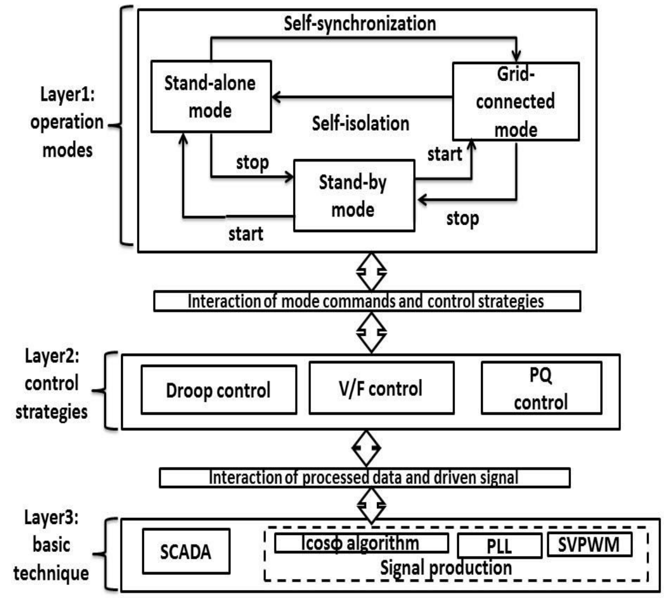

Fig.1 Block diagram for three layer of control of microgrid

B. Control for modes of operation:

1. Stand-alone mode:

The battery is the main source of supply for the load in the power system. The type of battery used in this paper is Li-ion battery. The proposed V/F control is provided for this mode as shown in the Fig.2.

In Fig.2, v_{dc} denotes the voltage across the dc micro grid and v_{abc1} denotes 3-phase voltage across ac grid. The reference voltage across dc microgrid is taken as constant 400V. I_{abc1} gives the current in the ac grid. The sinusoidal and cosine waves are generated corresponding the given grid voltage values. Then cosine and sinusoidal components are separated and multiplied and it is averaged and dq0 components are generated. The generated dq0 components are converted into abc component for the control for 3-phase given to the inverter. It is then given to sinusoidal pulse width modulation (SPWM) pulse generator for V/F control in the proposed system. The proposed V/F controller has good dynamic response.

2. Grid-connected mode:

The BESS is controlled as a power buffer in grid-connected mode of operation with PQ control as proposed in the fig.2.

By controlling the voltage and frequency of the system PQ control in 3-phase can obtained and it explained by equation (2) and (3)

$$P_{abc} = V_{abc} I_{abc} \cos\emptyset \qquad (2)$$

$$Q_{abc} = V_{abc} I_{abc} \sin\emptyset \qquad (3)$$

The equation in the dq coordinates is given as (4) and (5)

$$P = V_d I_d + V_q I_q \qquad (4)$$

$$Q = V_d I_Q - V_q I_d \qquad (5)$$

In grid-connected mode the real and reactive power control is proposed in this paper. At the grid connected mode grid is the main source of supply for the loads in the system. While the load gets increased the system shifts to grid connected mode of operation. The proposed Icosφ algorithm provides the real and reactive power control.

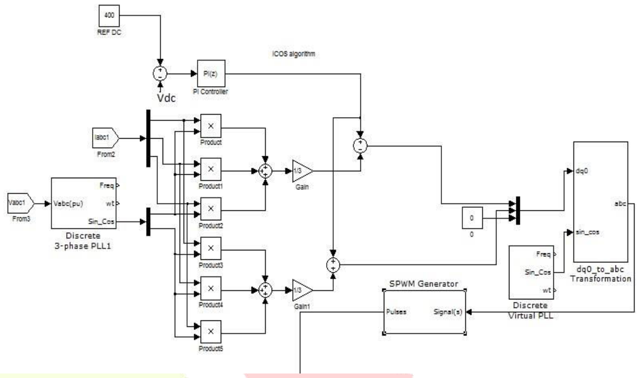

Fig.2.Icosφ algorithm for control

3. Transition from stand-by mode to grid-connected mode:

When load gets increased in the stand-alone mode of operation then the system shifts from stand-alone mode to the grid connected mode. The self-synchronization is adopted for the seamless control at the transition from stand-by mode to grid connected mode. This is a step by step process and it is given as

Step1: preparation of voltage regulation:

Voltage regulation is a regulation to set the voltage in the specified limits. The voltage at the microgrid is maintained by using the V/F control with the calculated and the reference voltage. It is given in the equation as

$$\left.\begin{array}{l} |f_{mic} - f_{grid}| \le f_{limit} \\ \left(\left(|V_{grid}| - |V_{mic}|\right)/|V_{grid}|\right) \times 100\% \le V_{limit} \\ |\theta_{mic} - \theta_{grid}| \le \theta_{limit} \end{array}\right\} \qquad (6)$$

Where f, v and ϴ are the frequency, voltage magnitude and phase angle respectively. The 'mic' and 'grid' denotes the microgrid and power distribution grid respectively. The 'limit is the threshold value.

Step2: contactor states transition:

The voltage and frequency is synchronized with the main grid, the grid-connected contactor should be turned on by the

ISSN 2395-695X (Print)
ISSN 2395-695X (Online)
International Journal of Advanced Research in Biology Engineering Science and Technology (IJARBEST)
Vol. 2, Special Issue 14, May 2016

BESS in the point of common coupling (PCC) is used. The power oscillations may occur at the time of contactor switching. To reduce this oscillations real and reactive power (PQ) control is required.

Step3: control modes transition:

Hence by tuning on the contactor at PCC, V/F control gets shifted to PQ control at the transition of stand-alone mode to the grid-connected mode.

4. Transition from grid-connected mode to stand-by mode:

When load gets decreases in the grid-connected mode of operation then the system shifts from grid-connected mode to the stand-alone mode. The self-isolation is adopted for the seamless control at the transition from grid-connected mode to stand-alone mode. This is a step by step process and it is given as

Step1: preparing for power regulation:

The hybrid energy storage system (HESS) can achieve real and reactive power flow control by adjusting the power reference. It is given in the equation as

$$\left.\begin{aligned} P_{pcc} &\leq P_{limit} \\ Q_{pcc} &\leq Q_{limit} \end{aligned}\right\} \quad (7)$$

P_{pcc} and Q_{pcc} are the real and the reactive power at PCC respectively. The P_{limit} and Q_{limit} denote the real and reactive power limit respectively or it can be stated as threshold values.

Step2: contactor states transition:

After regulating the real and reactive power flow regulation, the BESS is used to turn off the contactor at the point of common coupling (PCC). The voltage oscillations may occur at the time of contactor switching. To reduce this oscillations the V/F control is required for the system.

Step3: control modes transition:

Hence by tuning off the contactor at PCC, PQ control gets shifted to V/F control at the transition of grid-connected mode to the stand-alone mode of operation.

From the above over all controllers the voltage, frequency, real and reactive power is within the specified limits are provided for the system.

C. *Droop control:*

The droop control has to be performed for battery energy storage system (BESS) for the charging and the discharging of battery which increases the life cycle of the battery and provide safety for the battery from the overcharging. The droop control is provided by the droop graph which provides threshold limits for the charging and discharging of batteries.

The droop curve fig.3 provides the clear overview of the battery control technique. It takes the microgrid voltage as a reference voltage. The constant voltage for the microgrid provided should be of 400V. Any fault occurs or if load gets increased the microgrid voltage get reduced. If the microgrid voltage crosses below the 380V the battery should operate at the discharge mode to compensate the grid voltage and to maintain the microgrid voltage as 400V.

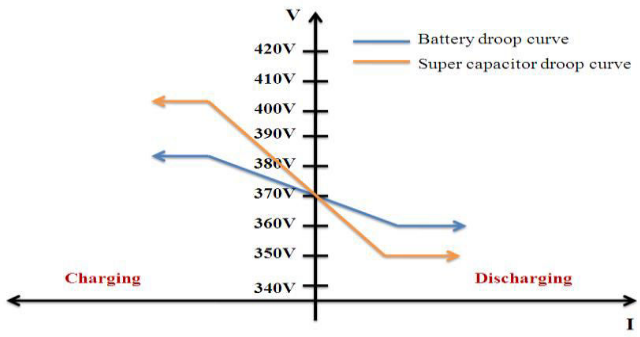

Fig.3. Proposed droop control

By balancing the load and the generation the voltage and frequency control can be maintained constant at the ac grid in all modes of operation. If load gets decreased the system voltage gets increased. If the microgrid voltage crosses beyond the limit of 380V the battery can be operated at the charging mode.

Hence charging and discharging of the batteries can be performed by using the droop curve.

III. THREE LAYER HIERARCHICAL PROTECTION

A. *PV protection structute*

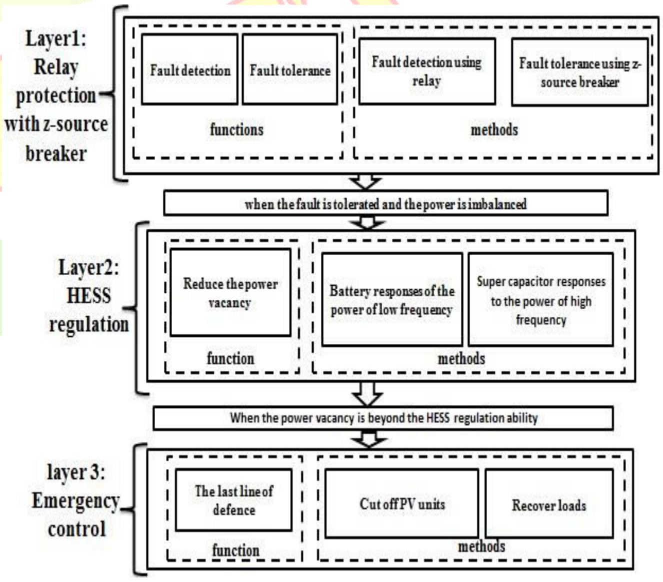

Fig.5. Three layer hierarchical protection structure

ISSN 2395-695X (Print)
ISSN 2395-695X (Online)
International Journal of Advanced Research in Biology Engineering Science and Technology (IJARBEST)
Vol. 2, Special Issue 14, May 2016

The photo voltaic generators have many more advantages than the power grid due to its small scale and the renewable energy generation. The system requires the protection system to maintain reliability, security and for the steady state operation of the microgrid.

The proposed hierarchical protection scheme Fig.5 consists of a relay protection with z-source breaker; hybrid energy storage system (HESS) regulation and emergency control are provided for the system. This proposed protection scheme is not only used for detection of faults, it also provides HESS regulation and the load shedding.

B. Relay protection with fault tolerent breaker

The fault tolerant breaker can also be called as z-source breaker. The relay protection provides the feeder protection, system protection and element protection. Different types of relay protection have to be provided for feeder, system and element protection.

The directional power protection (DPP) scheme has to be designed for this protection scheme. The two main functions have to be performed in this scheme. To perform those main two functions, two different methods have to be used. Main two functions are detection of the fault and the detected fault should be tolerated.

The fault detection can be done by using the directional over current relay design. The detected fault can be tolerated using the z-source breaker. Instead of using bulk ac breakers in the dc system with force dc current to be zero, the z-source breakers can be used to maintain security and reliability of the system.

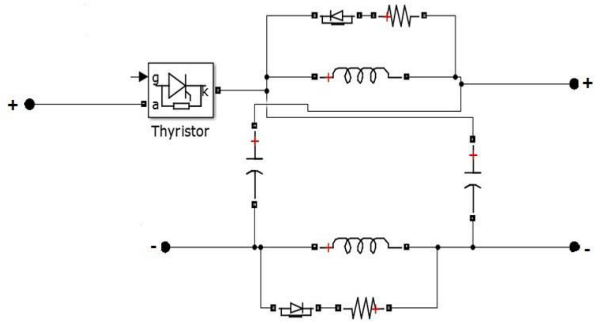

Fig.6. structure of z-source breaker

The fig.6 provides the structure of z-source breaker. At the time of occurrence of single line to ground fault (S-L), current gets increased in the system and the system voltage gets decreased. The fault current can be tolerated using charging and the discharging of inductors and capacitors in the z-source breaker. By charging and discharging, the fault current is tolerated and the voltage is maintained constant at the dc microgrid. Hence the security, steady state and reliability are provided in the proposed system.

C. HESS regulation:

The hybrid energy storage system (HESS) has battery as the power density unit and the super capacitor as the energy density unit are used in the PV generators microgrid system. The HESS regulation provides response for the load variations or the frequency variations by use of BESS and super capacitor.

When the load gets increased the frequency gets reduced at that time, Battery provides response to the power of low frequency by the process of discharging. When load gets decreased the frequency of the system suddenly increases, so super capacitor is used to provide response to the power of higher frequency. This in turn gives the reduction in the power vacancy. The fig.7 shows the HESS regulation flowchart.

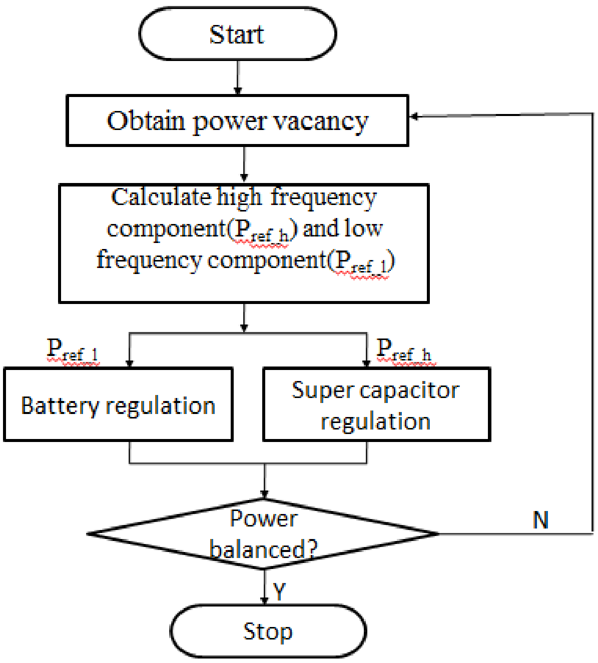

Fig.7. HESS regulation flow chart

D. Emergency control

The emergency control is the last line of defense in the power system. This control will start to work when the system voltage and frequency is not stable. This is used to recover PV units or loads and to shed PV units or loads in the system.

The power vacancy (ΔP) of the microgrid can be obtained from the SCADA system and the equivalent cut-off power (p_{cut}) can be calculated using equation (8)

$$P_{cut} = |\Delta P| - |P_{max} - P_{act}| \quad (8)$$

ISSN 2395-695X (Print)
ISSN 2395-695X (Online)
International Journal of Advanced Research in Biology Engineering Science and Technology (IJARBEST)
Vol. 2, Special Issue 14, May 2016

IV. PV GRID TOPOLOGY

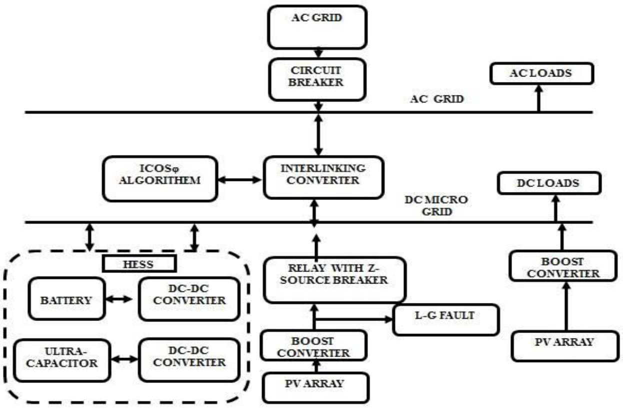

Fig.8. topology of PV generators in microgrid

V. RESULTS AND DICUSSIONS

A. PV in stand-alone mode:

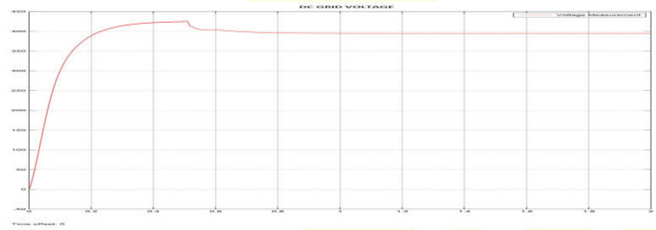
Fig.9. Voltage across DC grid

Fig.10. Voltage and current across AC load

The time from 0 to 0.5 the PV works in stand-alone mode of operation. The PV and battery has the capacity to satisfy the load. At this mode the V/F control is provided. From the fig.9 it is clear that the voltage at DC microgrid is constant and from fig.10 AC voltage as well as frequency regulation are obtained within the limits.

B. PV in grid connected mode:

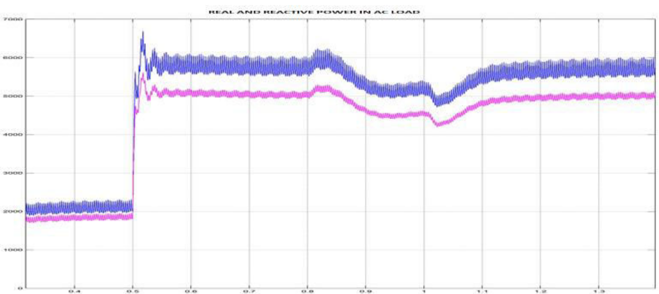
Fig.11. Real and reactive power across ac load

When load gets increased beyond the limit the system shifts from stand-by mode to grid connected mode. At the grid connected mode from the fig.11 it is clear that self-synchronization happens at the system with real and reactive power (PQ) control.

C. Relay protection with z-source breaker :

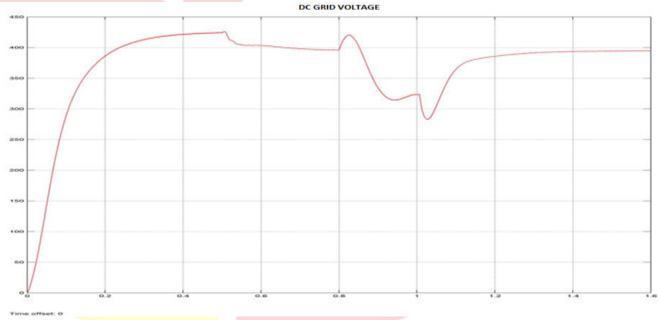

Fig.11. DC voltage at microgrid during fault

From the fig.11 it is clear that though fault exists in the system the system voltage is maintained nearly constant without clearing the fault. The system reliability is increased by using the z-source breaker.

D. Emergency control :

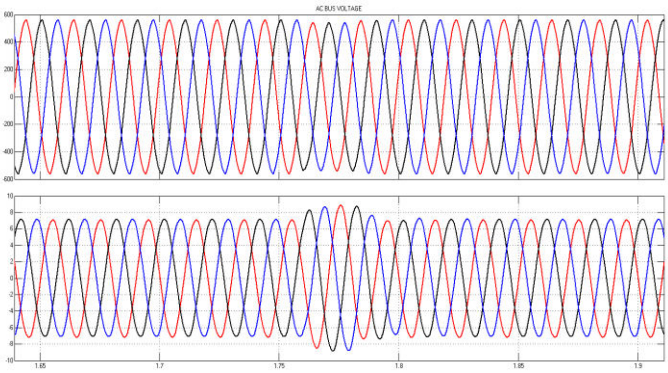
Fig.12. AC voltage and current at grid

The emergency control is implemented as shown in fig.12. When the HESS regulation crosses beyond the limit the load or PV is recovered or shed off.

VI. CONCLUTION

In this work, an integrated protection and control system with a hierarchical structure is proposed and photovoltaic micro grid is built to validate the effectiveness and feasibility of the proposed system. Icosφ algorithm is used to control the V-F for stand-alone mode and P-Q for grid connected mode for the operation of PV generators. Relay protection with z-source breaker, hybrid energy storage system regulation and emergency control are also adopted in this proposed system to achieve the protection of PV generators. The simulation result shows that the proposed system has significant stability, reliability and flexibility of PV generators are greatly improved. The performance of static and dynamic system with control and protection scheme is more efficient than without control and protection system.

REFERENCES

[1] S.Adhikari and F. Li, "Coordinated V-f and P-Q control of solar photovoltaic generators with mppt and battery storage in microgrids,"IEEE Transactions on Smart Grid, vol. 5, no. 3, pp. 1270-1281, May 2014.
[2] H.Nikkhajoei and R.H.Lasseter, "Microgrid protection," in Proc. 2007 IEEE Power Engineering Society General Meeting, 2007, pp. 1-6.
[3] W. Zhang, D. Xu, X. Li, R. Xie, H. Li, D. Dong, C. Sun, and M. Chen,"Seamless transfer control strategy for fuel cell uninterruptible power supply system," IEEE Transactions on Power Electronics, vol. 28, no. 2,pp. 717-729, Feb. 2013.
[4] Dr. Keith Corzine," Dc Micro Grid Protection with the Z-Source Breaker" IEEE Transactions on Power Electronics, vol. 28, no. 2,pp. 717-729, Feb. 2014.
[5] R M. Ding, Y. Xue, M. Mao, and L. Chang, "Research and development of distributed generation in China," in Proc. 2009 IEEE Power & Energy Society General Meeting, July 2009, pp. 1-5.
[6] V.Kamatchi Kannan and N.Rengarajan, "Control of Photovoltaic System with A DC-DC Boost Converter Fed DSTATCOM Using Icosφ Algorithm" *Journal of Applied Science and Engineering, Vol. 16, No. 1, pp. 8998 (2013).*
[7] N. Hatziargyriou, H. Asano, R. Iravani, and C. Marney, "Microgrids,"IEEE Power Energy Magzine, vol. 5, pp. 78-94, 2007.
[8] W.Najy,H.Zeineldin, and W. Woon, "Optimal protection coordination for microgrids with grid-connected and islanded capability," IEEE Transactions on Industrial Electronics, vol. 60, no. 4, pp. 1668-1677,April 2013.
[9] M. A. Redfern and H. AI-Nasseri, "Protection of micro-grids dominated by distributed generation using solid state converters," in Proc. lET 9th International Conference, 2008, pp. 670-674.
[10] P. P. Barker and R. W. de Mello, "Determining the impact of distributed generation on power systems," in Proc. 2000 IEEE Power Engineering Society Summer Meeting, 2000, pp. 1645-1656.
[11] T. Loix, T. Wijnhoven, and G. Deconinck, "Protection of microgrids with a high penetration of inverter-coupled energy sources," in Proc. 2009 CIGRE/IEEE PES Joint Symposium: Integration of Wide-Scale Renewable Resources into the Power Delivery System, July 2009, , pp.1-6.