Reactive Power Compensation in Micro Grid Based STATCOM

[1] Mr. K.Shiva Keshava Reddy, Assistant professor, EEE Dept. Samskruthi College of Engineering and Technology.
[2] Mr. A.Suresh kumar, Assistant professor, EEE Dept. Samskruthi College of Engineering and Technology.
[3] Mr. P.Vijay Paul, Assistant professor, EEE Dept. Samskruthi College of Engineering and Technology.

Abstract: Controlling of voltage and reactive power is very necessary for reliable operation of power system. Reactive power is the only reason for increase in loss of distribution system and power quality problems. These various problems could lead to complete cut out of load end from supply, which increases the risks of power blackout. The fast acting device STATSCOM is very important device that improves power factor, maintains constant distribution voltage and mitigates harmonics in distribution network. STATCOM reduces the voltage variations and voltage instability of power system and can result in fast recovery of system voltage after contingency event. This concept is the continuation of my phase 1 project on "STATCOM Application to Mitigate Voltage Fluctuation and Overcome Power Blackout Risks", which covered the simulation part. The 2nd phase concept concludes the hardware circuit details and functions of STATCOM which shows the controlling technique and application for the regulation of voltage and overcome the risks of power blackout. The proposed concept further implemented by connecting RES sources PV or Wind using Matlab/simulation software.

Keywords: STATCOM, Microgrid, Grid-tie Inverter, Voltage Control, Automatic Power Control.

I. INTRODUCTION

COEP microgrid has a AC-bus and DC-bus, interconnected together with a tie line DC -AC converter. AC-bus is connected to wind power plants, pico-hydro plant, local AC-loads and to the electricity grid with an islanding scheme. Power quality on AC bus has to be maintained in both the modes of operation of microgrid (islanded and non-islanded). Sudden islanding of utility grid creates significant voltage disturbances on AC bus.[1] The AC bus has grid tie inverters, AC-DC-AC converters, conventional synchronous generators as the sources supplying dynamic real power loads as well as reactive power loads. Supply of reactive power reduces the maximum amount of real power that can be supplied by the sources thereby resulting into poor utilization of their capacity. This provokes need of dynamic reactive power source on AC bus.[2]. STATCOM and SVC both are Flexible AC Transmission System (FACTS) devices that can be used for addressing the described problem. STATCOM has a better response time and better transient stability compared to SVC[3][4]. This makes STATCOM an ideal choice for COEP microgrid. This paper describes modelling and optimization of STATCOM on AC bus of COEP Microgrid. The paper begins with explaining STATCOM as a potential solution to voltage fluctuations and reactive power demand on the AC bus and extends to dealing with the control strategies required for the operation of STATCOM.

II. VOLTAGE FLUCTUATION PROBLEM ON AC BUS

In non-islanded mode of operation, in absence of STATCOM, local excessive reactive power demand is supplied by the utility grid. Sudden transients in the reactive power demand are taken care of by utility grid and the AC bus voltage is maintained. However, in islanded mode of operation, in absence of STATCOM, reactive power demand is completely supplied by the converters of the power sources such as wind power plants, solar plants and the conventional synchronous generators of the pico-hydro plants. With limited capability to supply the reactive power demand, islanded AC-bus of microgrid shows drastic fluctuations in the voltage. This provokes need of AC-bus voltage regulating control system to be embedded in STATCOM.

III. DESIGN OF STATCOM

A. Power Circuit

The PCB of Power Circuit is shown in (fig. 1). PCB was made using EAGLE Software. Power circuit contains the main topology of DC-AC conversion. The power circuit consists of three parallel legs, each leg consisting of two IGBTs(FGA25N120NTD) which are switched using the switching pulses obtained from the driver circuit. A Driver circuit is interfaced with the power circuit to ensure required driving characteristics of the IGBTs. The IGBTs are switched at a frequency of 2kHz. This leads to problem of high voltage spikes across the switch due to circuit inductance and also it leads to ringing. To eliminate this, RC snubber circuit is used in the STATCOM circuit. When the switch gets open, circuit eliminates the voltage transients and ringing , as it provides alternate path for the current flowing through circuit's intrinsic leakage inductance[5]. Also it dissipates the energy in resistor and thus junction temperature is reduced.

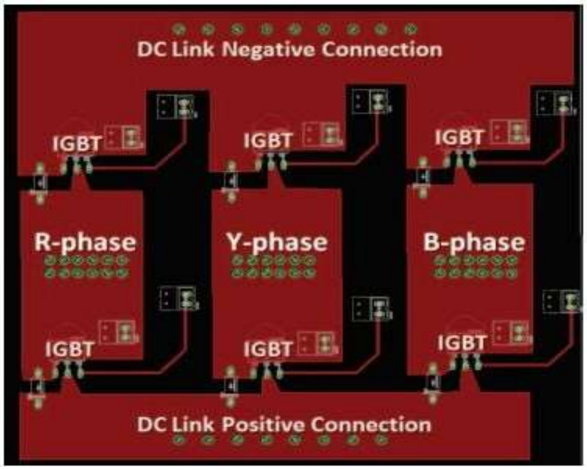


Fig.1. PCB Layout of Power Circuit

B. Control System

STATCOM includes a 2-level voltage source inverter with a capacitor bank in DC link. The voltage source inverter is driven by 3 phase SPWM waves. SPWM waves are equipped with dead band programming in high side and low side IGBT circuit. Frequency, power angle and voltage magnitude of STATCOM can be all controlled by controlling the SPWM waves. STATCOM is synchronized to the utility grid using synchronizing control systems[6][7]. The synchronizing control systems are shown in (fig. 2) It includes,

1. Frequency Control: A feedback of line to line voltage of grid is fed to the frequency measurement unit. The measured frequency is then given to the SPWM generator. Response time of frequency control systems is crucial for us to avoid power instability.

2. Phase-Lock Control System: Feedback of grid voltage is fed to SPWM generator and SPWM is held in a constant phase relation (power angle) with respect to the grid voltage. Reference given to phase control decides real power transaction with the grid.

3. Charging and Maintaining Capacitor Voltage: With no active source on DC side, charging of DC link capacitor is done by consuming real power from the grid (fig. 2). Power Angle is deliberately kept lagging so as to charge the capacitor. Under steady state conditions, power angle is constant and lagging just sufficient for the STATCOM to supply real power losses in the power circuit and filter circuit. The job of charging and maintaining the DC link capacitor voltage is done by the DC link voltage regulating control systems.

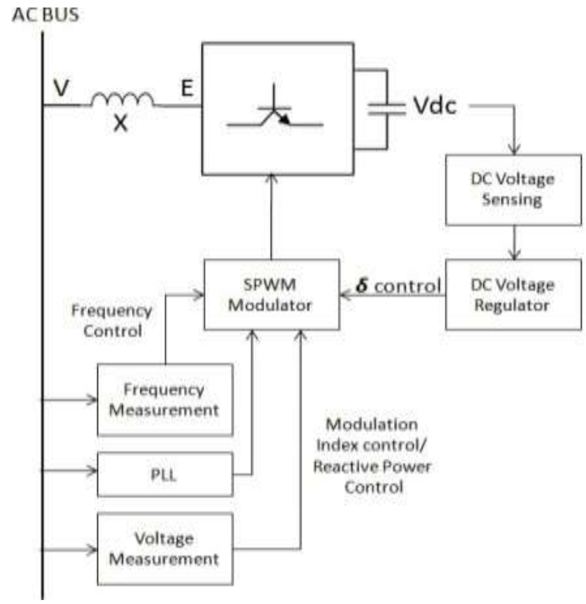


Fig.2. STATCOM with its Control Systems

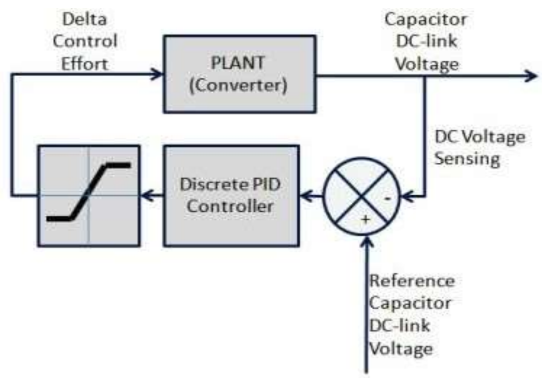


Fig.3. DC Capacitor Voltage Control

4. Supply and Consumption of Reactive Power: The STATCOM delivers reactive power or absorbs reactive power based on the formula [6]

$$Q = \frac{V(E * \cos(\delta) - V)}{X} \qquad (1)$$

where,
Q = reactive power
V = Voltage of the grid
E = Voltage at inverter side
X = reactance
δ = power angle

For positive VAR (supply of reactive power), STATCOM voltage has to be higher than the grid voltage. Increasing the modulation index of the SPWM waves serves the purpose. Reactive power flow out of the STATCOM can directly be controlled by controlling the modulation index of SPWM waves. The actual control systems are configured to maintain the AC bus voltage constant to the specified reference; which itself is indirectly done by controlling the modulation index i.e. by controlling the AC bus voltage (fig. 4).[7]

RES Based STATCOM for Reactive Power Compensation and Voltage Fluctuation Mitigation in Micro Grid

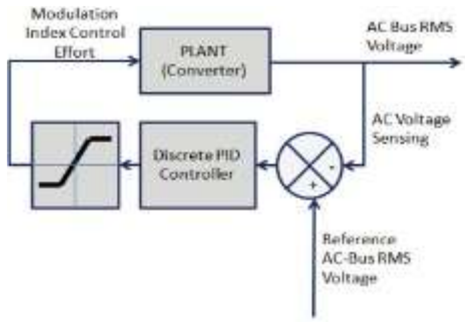


Fig.4. Reactive Power Control

C. Discrete PID Controller Design

Architecture of discrete PID controller is shown in fig. 4. Equations Used are as follows: Discrete Transfer Function of Derivative:

$$y(k) = \frac{f(k) - f(k-1)}{Ts} \quad (2)$$

Ts=sampling Time

In terms of Z-Transform:

$$\frac{Y[z]}{F[z]} = \frac{(z-1)}{(z * Ts)} \quad (3)$$

Discrete Transfer Function of Integral:

$$y(k) = y(k-1) + \frac{(f(k) + f(k-1)) * Ts}{2} \quad (4)$$

In terms of Z-Transform

$$\frac{Y[z]}{F[z]} = 0.5 * Ts \frac{(z+1)}{(z-1)} \quad (5)$$

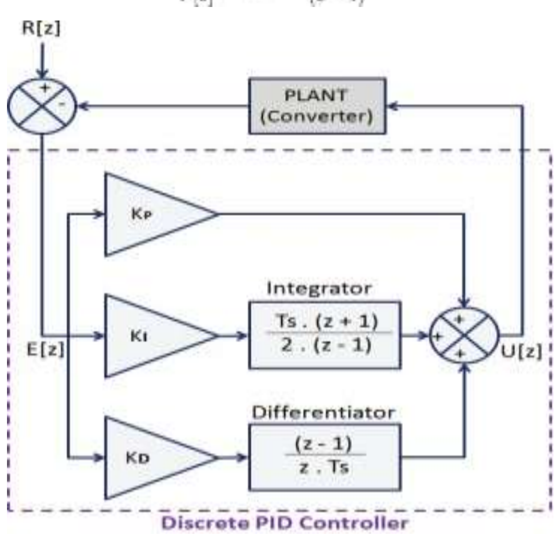


Fig.5. PID Controller Schematic

Discrete Transfer Function of PID Evaluating We get,

$$u[k] = u[k-1] + ae[k] + be[k-1] + ce[k-2] \quad (6)$$

$$a = Kp + Ki * \frac{Ts}{2} + \frac{Kd}{s} \quad (7)$$

$$b = -Kp + Ki * \frac{Ts}{2} - \frac{2Kd}{s} \quad (8)$$

$$c = \frac{Kd}{Ts} \quad (9)$$

Ts = Sampling time of the discrete system
Kp = Proportional gain
KI = Integral gain
KD = Differential gain
U[z] = input to the plant
R[z] = reference to controller
E[z] = error sequence

C. A Photovoltaic System

A photovoltaic system, converts the light received from the sun into electric energy. In this system, semi conductive materials are used in the construction of solar cells, which transform the self contained energy of photons into electricity, when they are exposed to sun light. The cells are placed in an array that is either fixed or moving to keep tracking the sun in order to generate the maximum power [7]. These systems are environmental friendly without any kind of emission, easy to use, with simple designs and it does not require any other fuel than solar light. On the other hand, they need large spaces and the initial cost is high. PV array are formed by combine no of solar cell in series and in parallel. A simple solar cell equivalent circuit model is shown in figure. To enhance the performance or rating no of cell are combine. Solar cell are connected in series to provide greater output voltage and combined in parallel to increase the current. Hence a particular PV array is the combination of several PV module connected in series and parallel. A module is the combination of no of solar cells connected in series and parallel. The photovoltaic system converts sunlight directly to electricity without having any disastrous effect on our environment. The basic segment of PV array is PV cell, which is just a simple p-n junction device. The fig.5 manifests the equivalent circuit of PV cell. Equivalent circuit has a current source (photocurrent), a diode parallel to it, a resistor in series describing an internal resistance to the flow of current and a shunt resistance which expresses a leakage current. The current supplied to the load can be given as.

Where
IPV–Photocurrent current,
IO–diode's Reverse saturation current,
V–Voltage across the diode,
a– Ideality factor
VT –Thermal voltage
Rs – Series resistance Rp –Shunt resistance

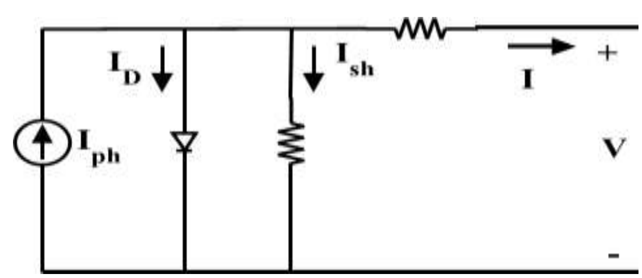


Fig.6. Equivalent Circuit of Single Diode Modal of a Solar Cell

$$I = I_{PV} - I_O\left[\exp\left(\frac{V + IR_S}{aV_T}\right) - 1\right] - \left(\frac{V + IR_S}{R_P}\right) \quad (10)$$

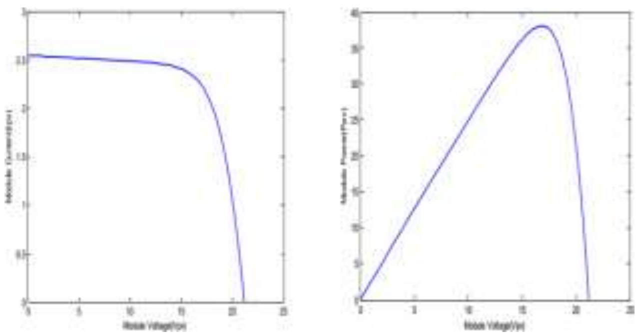


Fig.7. V-I & P-V Characteristics of a 36w PV Module

D. The Effect of Different Solar Irradiation

The Voltage vs Power characteristics and Voltage vs Current characteristics of a solar cell are mainly dependents upon the solar irradiation. If there is change in the environmental condition then the solar irradiation level change which results different maximum power. So maximum power point tracking algorithm are used to maintain the maximum power constant if there is any change in the solar irradiation level. If the solar irradiation level is higher, then the input to the solar sell is more which results more magnitude of the power with the same voltage value. Also when there is increase in the solar irradiation the open circuit voltage increases. Because, when there is more solar light fall on the solar cell, with higher excitation energy the electrons are supplied, they increase the mobility level of electron and more power is generated.

IV. MATLAB/SIMULATION RESULTS

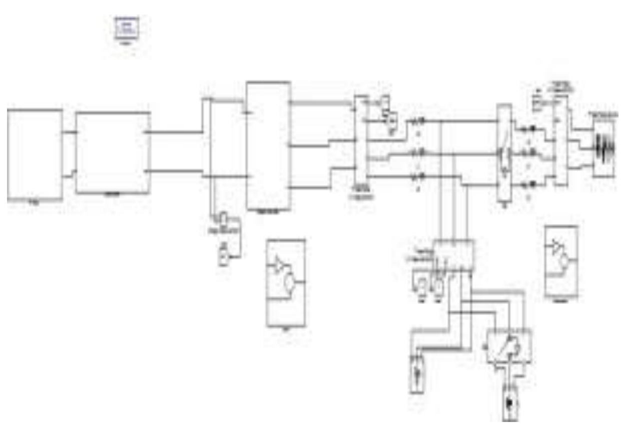


Fig.8. Matlab/Simulation Circuit of STATCOM with its Control Systems with PV

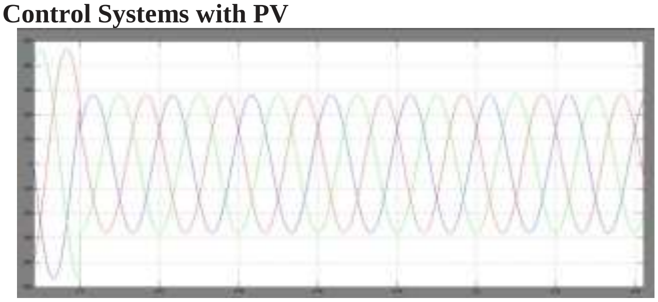


Fig.9. Simulation Wave Form of without STATCOM Voltage and Current

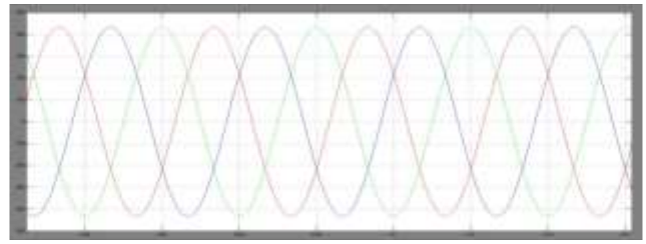


Fig.10. Simulation Wave Form of Response of AC Bus Voltage with STATCOM

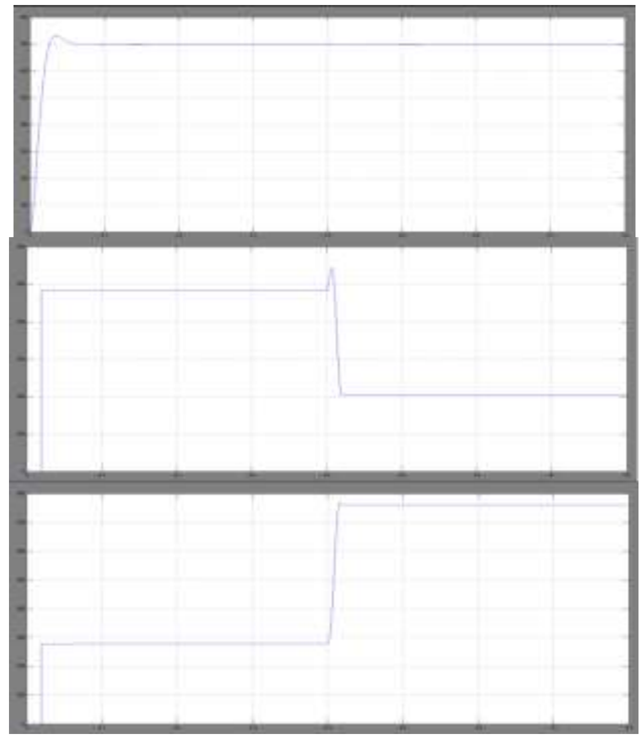


Fig.11. Simulation Wave Form Response of Dc Voltage Regulating Control System Based on Change in Reactive Power Demand

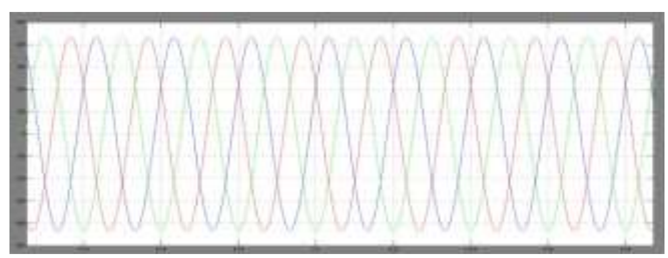
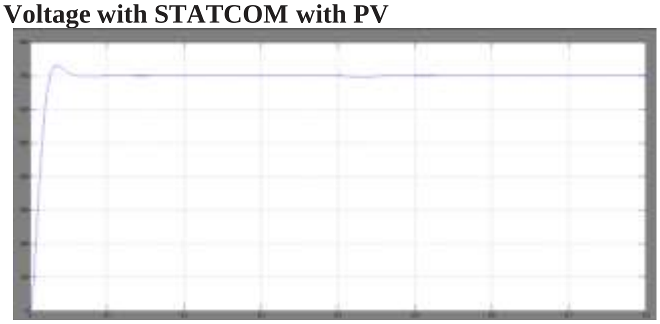


Fig.12. Simulation Wave Form of Response of AC Bus Voltage with STATCOM with PV



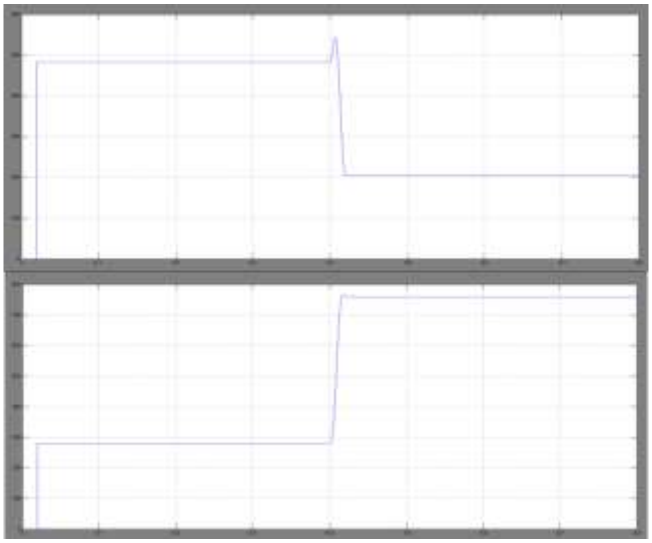


Fig.13. Simulation Wave Form Response of Dc Voltage Regulating Control System Based on Change in Reactive Power Demand with PV

V. CONCLUSION

This paper discusses application of STATCOM in a microgrid with islanding scheme. STATCOM is designed for the reactive power compensation of microgrid and AC bus voltage regulation. STATCOM is simulated along with the microgrid in MATLAB to observe and improve transient response of the controls to dynamic loading and islanding scenarios. Designed control strategy responds to AC bus voltage fluctuations and configures STATCOM to throw dynamic reactive power accordingly. During sudden excessive reactive power demand, in spite of presence of control strategy, capacitor DC link voltage shows significant voltage droop before settling to the reference value. And RES are used in PV arrays this dictates need for a better control strategy

VI. REFERENCES

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