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Design of Solar Cell Fed DSTATCOM with Ultra-Capacitor Energy Storage for Voltage Sag Compensation

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Abstract:
This project describes the dynamic modelling and control design of a distribution static compensator (DSTATCOM) coupled with ultra-capacitor energy storage (UCES) for improving the power quality of power systems. Three modes of operation are considered, i.e. voltage control for voltage fluctuations ride-through, current/voltage harmonics mitigation and dynamic active power control. New models and control schemes are proposed. The control technique employed is based on the instantaneous power theory on the synchronous-rotating dq reference frame. Validation of models and control algorithms is carried out through simulations in SimPowerSystems of MATLAB/Simulink. Solar cell is designed to provide input to the distribution static compensator.

Index Terms:
DSTATCOM, Active Power Filter (APF), Solar cell, DC Capacitor.

INTRODUCTION:

A DSTATCOM is used to compensate the supply voltage disturbances such as sag and swell. The DSTATCOM is connected between the supply and sensitive loads, so that it can inject a voltage of required magnitude and frequency in the distribution feeder. The DSTATCOM is operated such that the load voltage magnitude is regulated to a constant magnitude, while the average real power absorbed/ supplied by it is zero in the steady state. The capacitor supported DSTATCOM is widely addressed in the literature [11]. The instantaneous reactive power theory (IRPT) [6], sliding mode controller [9], instantaneous symmetrical components [2] etc., are discussed in the literature for the control of DSTATCOM. In this project a new control algorithm is proposed based on the current mode control and proportional-integral (PI) controllers for the control of DSTATCOM. The Injection / Booster transformer is a specially designed transformer that attempts to limit the coupling of noise and transient energy from the primary side to the secondary side. Its maintasks are:

1. It connects the DSTATCOM to the distribution network via the HV-windings and transforms and couples the injected compensating voltages generated by the voltage source converters to the incoming supply voltage.
2. In addition, the Injection / Booster transformer serves the purpose of isolating the load from the system (VSC and control mechanism).

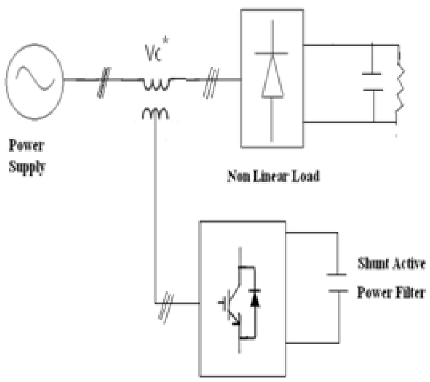

Figure 1.Block diagram of DSTATCOM series active power filter

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DSTATCOM Control Strategy

The proposed algorithm is based on the estimation of reference supply currents. It is similar to the algorithm for the control of a shunt compensator like DSTATCOM for the terminal voltage regulation of linear and nonlinear loads [6]. The proposed control algorithm for the control of DSTATCOM is depicted in Fig 5.1.

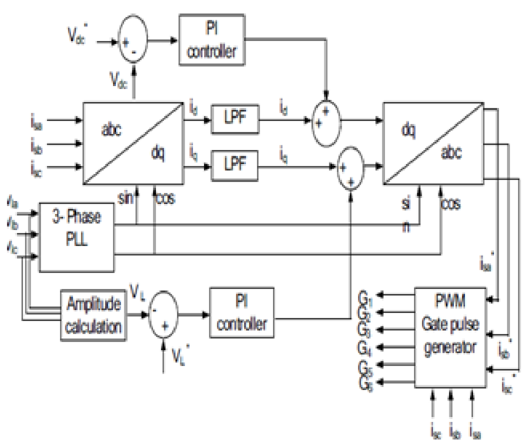

Figure 2. Control scheme of the DSTATCOM

The series compensatorknown as DSTATCOM is used to inject a voltage in series withthe terminal voltage. The sag and swell in terminal voltages are compensated by controlling the DSTATCOM and theproposed algorithm inherently provides a self-supportingdc bus for the DSTATCOM. Three-phase reference supplycurrents (i^*_{sa}, i^*_{sb}, i^*_{sc}) are derived using the sensed loadvoltages (v_{la}, v_{lb}, v_{lc}), terminal voltages (v_{ta}, v_{tb}, v_{tc}) and dcbus voltage (v_{dc}) of the DSTATCOM as feedback signals.The synchronous reference frame theory based methodis used to obtain the direct axis (i_d) and quadrature axis (i_q)components of the load current [5]. The load currents in thethree-phases are converted into the d-q-0 frame using thePark's transformation as,

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & -\sin\theta & \frac{1}{2} \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & \frac{1}{2} \\ \cos\left(\theta + \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \quad (5.1)$$

A three-phase PLL (phase locked loop) is used to synchronies these signals with the terminal voltages (v_{ta}, v_{tb}, v_{tc}). The d-q components are then passed through low pass filters to extract the dc components of i_d and i_q. Theerror between the reference dc capacitor voltage and thesensed dc bus voltage of DSTATCOM is given to a PI (proportional-integral) controller of which output is considered as the loss component of current and is added to the dc component of id. Similarly, a second PI controller is used to regulate the amplitude of the load voltage (V_t) [1]. The amplitude of the load terminal voltage isemployed over the reference amplitude and the output ofPI controller added with the dc component of i_q. Theresultant currents are again converted into the reference supply currents using the reverse Park's transformation. Reference supply currents (i^*_{sa}, i^*_{sb}, i^*_{sc}) and the sensed supply currents (i_{sa}, i_{sb}, i_{sc}) are used in PWM current Controller to generate gating pulses for the switches [3]. The PWM controller operates at a frequency of 10 kHz and the gating signals are given to the three-leg VSC for the control of supply currents.

PWM CONTROL OF ACTIVE POWER FILTER:

The main aim of an active power filter (APF) is to generate compensating currents into the power system for canceling the current harmonics contained in the nonlinear load current. This will thus result in sinusoidal line currents and unity power factor in the input power system [4].

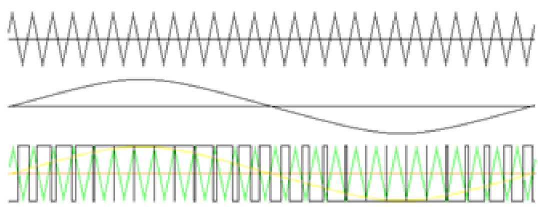

Figure 3. PWM technique

PI Controller shown in Fig. 4 is a feedback controller which drives the plant to be controlled with a weighted sum of the error and the integral of that value [8].

The proportional response can be adjusted by multiplying the error by constantK_p, called proportional gain. The contribution from integral term is proportional to both the magnitude of error and duration of error. The error is first multiplied by the integral gain, Ki and then was integrated to give an accumulated offset that have been corrected previously [8].

1) Proportional-Integral (PI) Controller

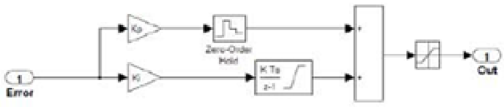

Figure 4. Discrete PI controller

SOLAR CELL:

A solar cell is a solid state device that converts the energy of sunlight directly into electricity by the photovoltaic effect. Assemblies of cells are used to make solar modules, also known as solar panels. The energy generated from these solar modules, referred to as solar power, is an example of solar energy. The origin of the PV potential is the difference in the chemical potential, called the Fermi level, of the electrons in the two isolated materials. When they are joined, the junction approaches a new thermodynamic equilibrium. Such equilibrium can be achieved only when the Fermi level is equal in the two materials [7].

This occurs by the flow of electrons from one material to the other until a voltage difference is established between them, which have a potential just equal to the initial difference of the Fermi level. This potential drives the photocurrent in the PV circuit. Photovoltaics is the field of technology and research related to the practical application of photovoltaic cells in producing electricity from light, though it is often used specifically to refer to the generation of electricity from sunlight [9]. Cells are described as photovoltaic cells when the light source is not necessarily sunlight. These are used for detecting light or other electromagnetic radiation near the visible range, for example infrared detectors), or measurement of light intensity [10].

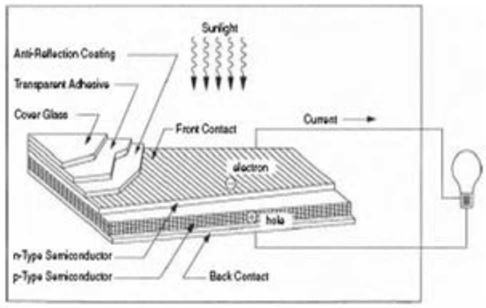

Fig 2.2: Basic construction of PV cell

SIMULATION RESULTS

Base System

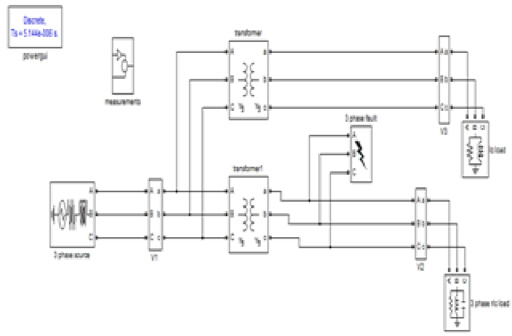

Figure 7.Base System

This is the block diagram showing source, load and transmission line in faulty conditions. The fault can be of any nature like L-G, L-L-G, L-L or 3-PHASE FAULT. In these conditions severe fault currents flow through the lines and there is a drastic drop in line and load voltages**.**

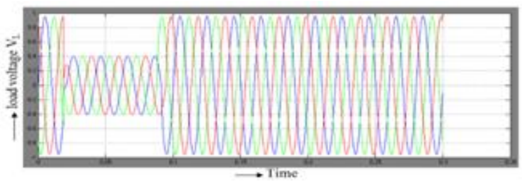

Figure 8. Load Voltage

The drop in the load voltage can be seen in above wave form due to fault in transmission line.

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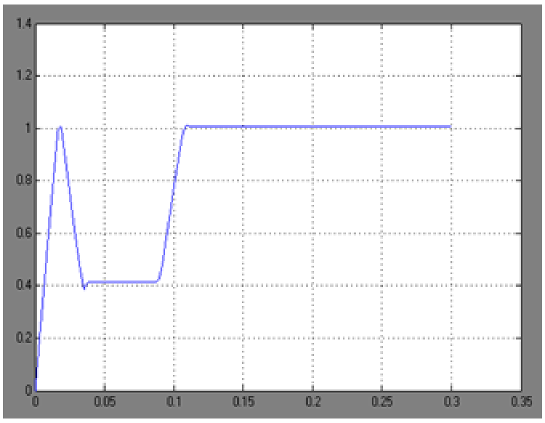


Figure 9. Voltage Sag

The sag in the voltage waveform which can be clearly observed in the above figure which is deviating from the actual voltage curve.

Base System with PI Controller

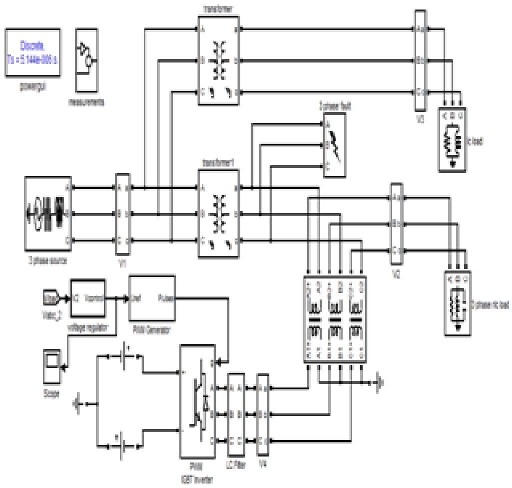
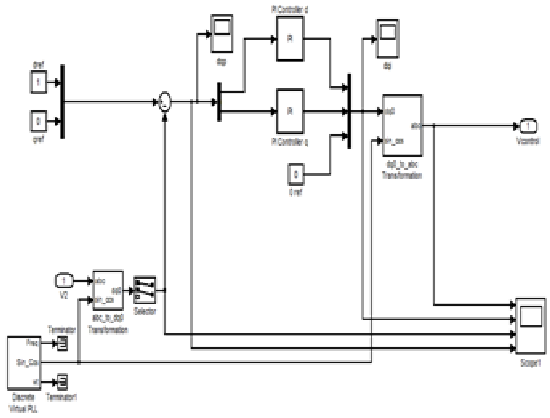


Figure 10. Base System with PI Controller

This is the block diagram showing source, load and transmission line in faulty conditions. The type and intensity of fault can be identified and corrected with the DSTATCOM and its control mechanism. And bring back the voltage levels to the normal operating value before the occurrence of fault.



The controller used in the above simulation circuitry is pi controller. Since pi being a conventional controller there is a difficulty in tuning the controller, hence solar cell controller is employed.

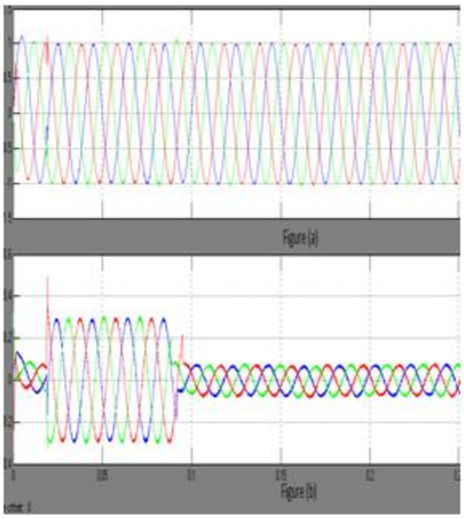


Figure 11. Injected voltage by the DSTATCOM

In the above figure the first waveform implies the compensated load voltage at the consumer side. The second waveform implies the injected voltage by the DSTATCOM into the lines to compensate the voltage drop.

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Base System with Solar cell Controller

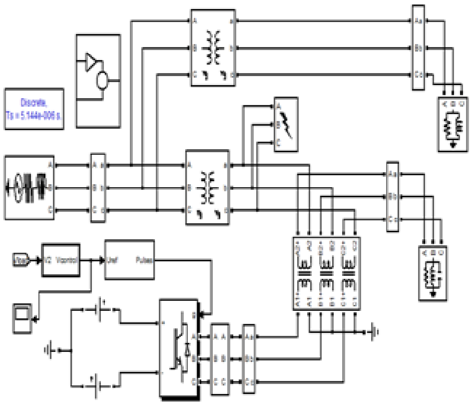


Figure 12. Base System with Solar cell Controller

This is the block diagram showing source, load and transmission line in faulty conditions. The type and intensity of fault can be identified and corrected with the DSTATCOM and its control mechanism. And bring back the voltage levels to the normal operating value before the occurrence of fault.

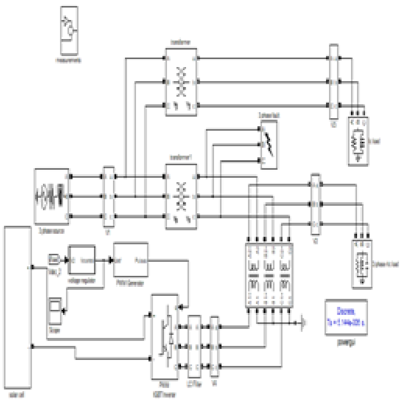


Fig 5,4 dstatcom with PV cell and ultra capacitor

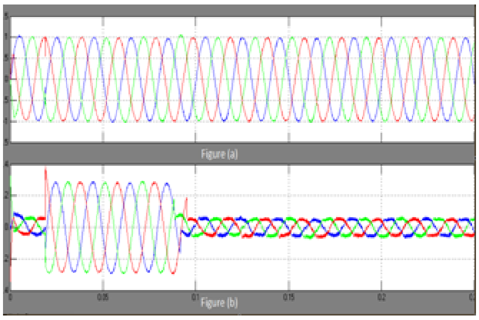


Figure 18. Injected voltage by the DSTATCOMfed by solar cell

In the above figure the first waveform implies the compensated load voltage at the consumer side. The second waveform implies the injected voltage by the DSTATCOM into the lines to compensate the voltage drop.

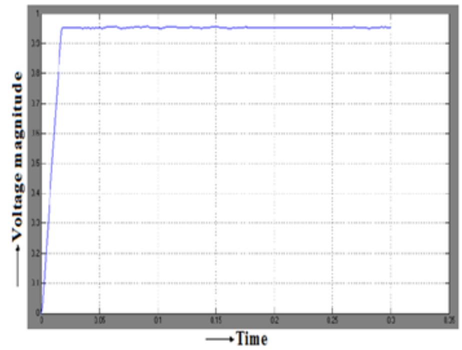
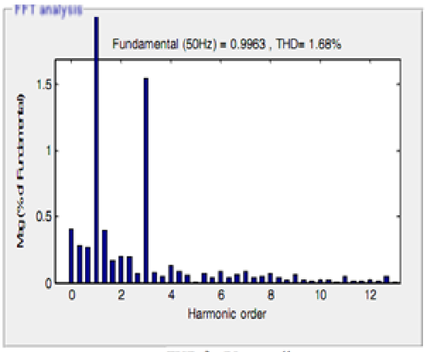


Figure 19. Voltage sag with solar cell

With the usage of solar cell controller in the control circuitry of DSTATCOM we are able to eliminate the voltage drop in the lines and consumer side providing a constant voltage at the load end. This can be concluded by observing the above voltage graphs.



THD for PI controller

Figure 20. THD with PI

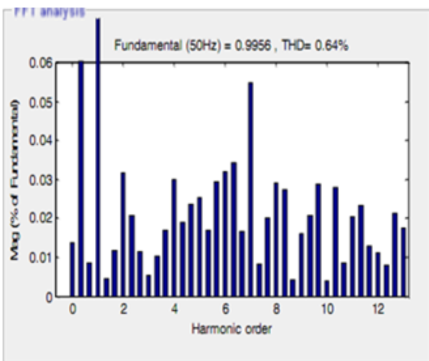


Figure 21.THD with Solar cell

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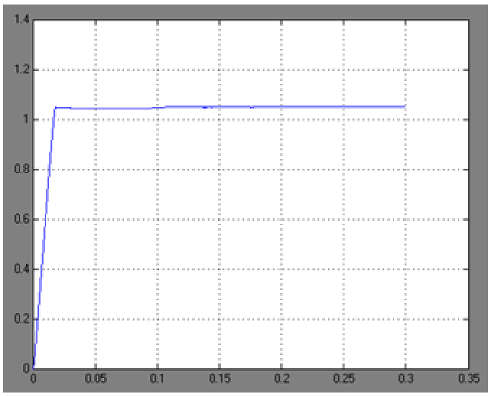

Figure 22. Load voltage magnitude after compensation using solar cell PI controller

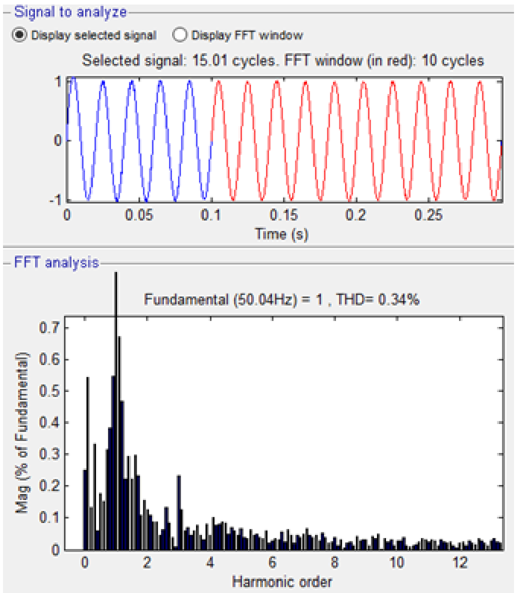

Figure 23: THD using Solar cell PI controller

CONCLUSION:

In this study, the modeling and simulation of DSTATCOM controlled by PI and FL Controller has been developed using Mat lab/Simulink. For both controller, the simulation result shows that the DSTATCOM compensates the sag quickly (70µs) and provides excellent voltage regulation. DSTATCOM handles all types, balanced and unbalanced fault without any difficulties and injects the appropriate voltage component to correct any fault situation occurred in the supply voltage to keep the load voltage balanced and constant at the nominal value.

Both controllers show an excellent performance and generate low THD (<5%). However, it can be seen that solar cell fed controller gives better performance with THD generated with only 0.64%whilst PI generated 1.68% THD. Combined solar cell PI controller is developed to improve the per unit magnitude to above 1pu.

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