

Power Quality Improve in Low Voltage Power Distribution Systems by using PV based D-STATCOM

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Abstract:

The main aim of this paper is the voltage regulation which is one of the most important operational requirement in power network at both transmission and distribution levels. Whenever there is a penetration of photo voltaic cell power to the low voltage distributed grid, there occur the problem of mismatch in voltage and frequency in the network, perhaps caused by non linear loads, generating harmonics. In this paper one of the FACTS controller devices D-STATCOM is used to improve the voltage regulation thereby the power system stability. The above proposed model has been analyzed under various operating conditions and the performance of the model is evaluated using MATLAB SIMULINK software. The Simulink results are evaluated and the effectiveness of the given system is established.

Key words: D-statcom, Voltage Regulation, PV cell, Distributed line, Matlab.

I INTRODUCTION:

Power injection principle:

The total apparent (complex) power that is injected into a transmission line is made up of two components, namely active and reactive. The active power P component is the part of energy that is converted into physical energy form. The reactive power Q component helps create the indispensable magnetic medium needed for most of today's electromagnetic energy conversion devices and systems.

For example, the AC electric motor absorbs both active and reactive power components once it is energized by the AC source. The absorbed reactive component creates the needed magnetic field to allow the energy conversion process to take place inside the motor. The active power component is absorbed and converted into mechanical power that moves the coupled mechanical load such as a mechanical conveyor. The electric motor will store there active power as fluctuating magnetic energy in its windings as long as the conversion process continues. The majority of industrial and commercial appliances require both active and reactive power components for operation.

Both P and Q are needed instantly and in different quantities to meet the requirement of the electrical energy converting device connected to the AC source. Reactive power can be absorbed or supplied depending on the energy medium associated with the electric device. Energy absorbing or supplying components are reactors and capacitors respectively. Reactors absorb reactive power +Q and draw what is defined as lagging current. The consumed energy is stored as a magnetic energy in the reactor turns. Meanwhile, capacitors supply reactive power -Q and draw leading current, storing it as electric charge within its dielectric medium and associated charge plates. To understand P and Q flow in a transmission system, consider a simple system that is made up of sending and receiving buses with a transmission cable in between as shown in Figure 1.

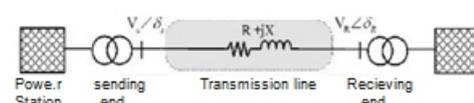


Figure 1: Simple line presentation of generating distribution unit

Thus for small line resistances, $R < < X$, the active and reactive power components can be approximated to

$$P_s = \frac{V_s V_r}{X} \sin(\delta_s - \delta_r) \dots \dots \dots (1)$$

$$Q_s = \frac{V_s^2 - V_r \cos(\delta_s - \delta_r)}{X} \dots \dots \dots (2)$$

It can be seen from the above approximated power components that power flow is dependent on four controlling variables V_s, V_r, X and $\delta_s - \delta_r$. Employing shunt compensation at midpoint in the transmission line increases both the active and reactive components of the injected power. For lossless compensator and transmission lines $V_s = V_r = V$, the injected power at midpoint is now given by

$$P_{sh} = \frac{2V^2}{X} \left[\frac{\sin(\delta_s - \delta_r)}{2} \right] \dots \dots \dots (3)$$

$$Q_{sh} = \frac{4V^2}{X} \left(1 - \frac{\cos(\delta_s - \delta_r)}{2} \right) \dots \dots \dots (4)$$

Meanwhile, employing series compensation at midpoint with voltage V_c in quadrature with respect to the line current allows the compensating elements to assist only in the reactive power control. The result in the injected power is given by

$$P_{ser} = \frac{v^2}{(1-r)x} \sin(\delta_s - \delta_r) \dots \dots \dots (5)$$

$$Q_{ser} = \frac{2v^2}{x} \frac{r}{(1-r)} \sin(\delta_s - \delta_r) \dots \dots \dots (6)$$

II- OPERATION OF D-STATCOM:

D-STATCOM controllers can be constructed based on both VSI topology and Current Source Inverter (CSI) topology (Figure 2). Regardless of topology, a controller is a compound of an array of semiconductor devices with turn off capability (i.e., IGBT, GTO, IGCT etc.) connected to the feeder via a relative small reactive filter. The VSI converter is connected to the feeder via reactor L_f and has a voltage source (capacitor CD) on the DC side. The CSI converter is connected on the AC side via capacitor C_f and has a current source (inductor L_D) on the DC side. In practice, CSI topology is not used for DSTATCOM. The reason for this is related to the higher losses on the DC reactor of CSI compared to the DC capacitor of VSI. Moreover, a CSI converter requires reverse-blocking semiconductor switches, which have higher losses than reverse conducting switches of VSI.

And, finally, the VSI-based topology has the advantage because an inductance of a coupling transformer Tr (if present) can constitute, partially or completely, the inductance of an AC filter. The following text will describe the properties of VSI-topology based DSTATCOM only, but in many respects they are the same as for CSI-based controllers.

The VSI converters for D-STATCOM are constructed based on multi-level topologies, with or without use of a transformer. These solutions provide support for operation with a high level of terminal voltage. Additionally, DSTATCOM controllers can be a compound of several converters configured to various topologies, to achieve higher rated power or lower PWM-related current ripples.

The exemplary topologies are presented in Figure 3. In the parallel configuration (Figure 3a) converters are controlled to share the generated power equally, or at a given ratio, for example proportional to the rated power of the particular converter.

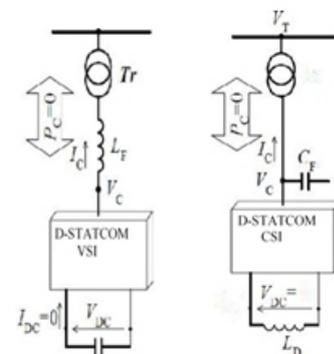


Figure 2: General topology of VSI-based and CSI-based DSTATCOM

In this solution it is necessary to provide inter converter communication at the control level to distribute information about set controller power or currents. The cascade multi converter topology (Figure 3b) is similar to the parallel configuration, but in this case the constituent converters do not share power equally, but successively, depending on the requirement.

In this case, no communication between constituent converters is required, but on the other hand it is also not possible to use common PWM strategy. The converters in this case are exactly the same as for stand-alone operation. In Figure 3c, d are presented series and parallel master-slave topologies, respectively.

The master-slave topologies require a high degree of integration between constituent converts including a control system, and are treated and realized as single, multi converter controller. The master converter (called a “slow converter”) has substantially higher rated power and, in consequence, considerably lowers PWM carrier frequency than the slave converter (called a “fast converter”). The task of the master converter is to cover the requirements for power, while the slave has to compensate AC current/voltage ripples using serial superposition of voltages (Figure 3 c) or parallel superposition of currents (figure 3d).

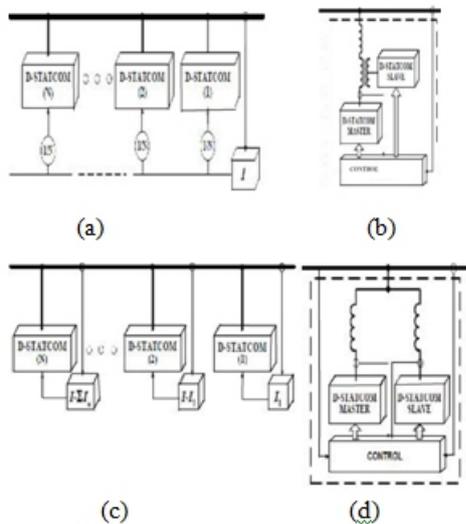


Figure 3: Multi converter topologies of D-STATCOM controller: (a) parallel; (b) cascade; (c) master - slave series; (d) master – slave parallel.

A. Principle of operation:

For the operation analysis of the D-STATCOM converter, it is possible to represent its PWM-controlled VSI with an instantaneous (averaged for PWM period) voltage source. The principle of generating instantaneous active and reactive powers by D-STATCOM is shown in Figure 4. In this figure, voltages and currents are represented with instantaneous space vectors obtained using a power-invariant Clarke transform. Three cases are presented in Figure 4: the general one, for reactive power equal to zero and for active power equal to zero. From this figure it is clear that, by generating an appropriate AC voltage, it is possible to generate arbitrary instantaneous vectors of both active and reactive power.

The real component of current is related to the equivalent series resistance modelling losses on the AC side. The possible active and reactive powers that can be generated or absorbed by DSTATCOM are limited. This limitation is related to circuit parameters and maximum ratings of VSI components. In Figure 4 is presented an exemplary limit for AC voltage, which depends on VSI DC voltage VDC.

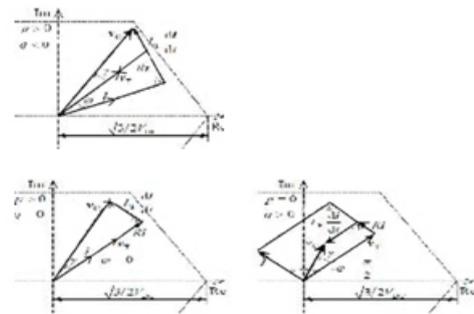


Figure 4: Principle of control of D-STATCOM instantaneous active and reactive power.

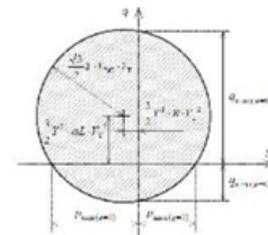


Figure 5: Operating region of two-level VSI based D-STATCOM.

This limit, together with filter inductance LF and terminal voltage VT, defines the operating region of a DSTATCOM controller. The operating region of a two level VSI-based controller is presented in Figure 5. In this figure, Y denotes the modulus of admittance on the AC side of VSI. In practice, the operating region does not limit the maximum ratings of VSI semiconductors, so the static V characteristic of DSTATCOM reactive power is symmetrical (Figure 6).

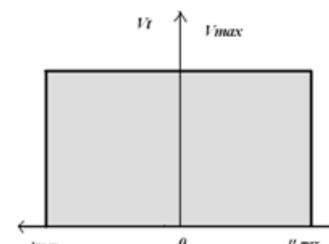


Figure 6: The V-I characteristic of D-STATCOM

The active power is consumed by the D-STATCOM only to cover internal losses. Assuming lossless operation, the averaged (but not instantaneous) active power has to be zero. There are no similar limitations for reactive power, because it is only exchanged between phases, and is not converted between the AC and DC sides of D-STATCOM VSI.

III PHOTOVOLTAIC CELL:

The world constraint of fossil fuels reserves and the ever rising environmental pollution have impelled strongly during last decades the development of renewable energy sources (RES). The need of having available sustainable energy systems for replacing gradually conventional ones demands the improvement of structures of energy supply based mostly on clean and renewable resources.

At present, photovoltaic (PV) generation is as swing increased importance as a RES application because of distinctive advantages such as simplicity of allocation, high dependability, absence of fuel cost, low maintenance and lack of noise and wear due to the absence of moving parts. Furthermore, the solar energy characterizes a clean, pollution free and inexhaustible energy source.

In addition to these factors are the declining cost and prices of solar modules, an increasing efficiency of solar cells, manufacturing-technology improvements and economies of scale. The grid integration of RES applications based on photovoltaic systems is becoming today the most important application of PV systems, gaining interest over traditional stand-alone systems.

This trend is being increased because of the many benefits of using RES in distributed (aka dispersed, embedded or decentralized) generation (DG) power systems. These advantages include the favorable incentives in many countries that impact straight forwardly on the commercial acceptance of grid-connected PV systems. This condition imposes the necessity of having good quality designing tools and a way to accurately predict the dynamic performance of three-phase grid-connected PV systems under different operating conditions in order to make a sound decision on whether or not to incorporate this technology into the electric utility grid.

This implies not only to identify the current-voltage(I-V) characteristics of PV modules or arrays but also the dynamic performance of the power conditioning system (PCS) required to convert the energy produced into useful electricity and to provide requirements for power grid interconnection. This paper presents a full detailed mathematical model of a three-phase grid-connected photovoltaic energy conversion system, including the PV array and the electronic power conditioning (PCS) system, based on the Matlab/Simulink software.

Mathematical model for P V cell:

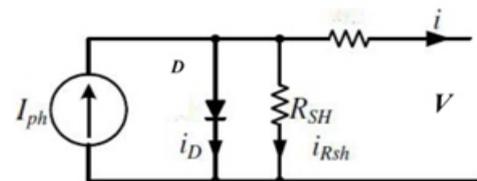


Figure7: Electrical characteristics of PV Cell model.

A. Open circuit voltage:

$$V = \left(\frac{NKT}{Q} \right) \ln \left(\frac{I_L - I_0}{I_0} + 1 \right) \text{ -----(7)}$$

Where

V is the open circuit voltage

N is diode ideality constant or (number of cell connected in series or parallel)

K is the Boltzmann constant

$(1.381 * 10^{-23} \text{ J/K})$

T is temperature in Kelvin

Q is electron charge $(1.602 * 10^{-19} \text{ C})$

I_L is the light generated current(A)

I_0 is the saturation diode current(A)

B. Light generated current:

$$I_L = \left(\frac{G}{G_{ref}} \right) * (I_{Lref} + U_{ISC} (T_C - T_{Cref})) \text{ -----(8)}$$

Where

G is the radiation (W/m²)

G_{ref} is the radiation under standard condition 1000(W/m²)=

I_{Lref} is the Photoelectric current under standard condition 0.15(A)

T_{Cref} is the module temperature under standard condition 298(K)

$\alpha_{ISC} = k_i$ is the temperature co-efficient of the short circuit current (A/K)=0.0065/K.

C. Reverse saturation current:

$$I_0 = I_{or}(T/T_{ref})^3 \exp((QEG)/(K*N)*(1/T_{ref}) - (1/T))$$

$$I_{or} = I_{scn} \exp(V_{ocn}/N*V_{tn}) \text{ -----(9)}$$

Where

V_{ocn} = normal open circuit voltage under standard condition(0.5)volt

I_{scn} = short circuit current under standard condition

(0.15)amp

I_{or} is the saturation current

N is the ideality factor 1 to 2;

E_o is the band gap for silicon 1.10ev

V_{tn}=Thermal voltage= (NKT)/Q) in volts

D. Short circuit current:

I_{sh} = h. It is the greatest value of the current generated by a cell. It is produce by the short circuit conditions: V = 0.

$$I_{sh} = I_L - I_0 ((\exp(Q(V-IR_s)/(NKT)))-1) \text{---(10)}$$

E. Irradiation:

G=radiation W/m²

Under standard condition

G =1000W/m²

IV MATLAB SIMULATION MODEL

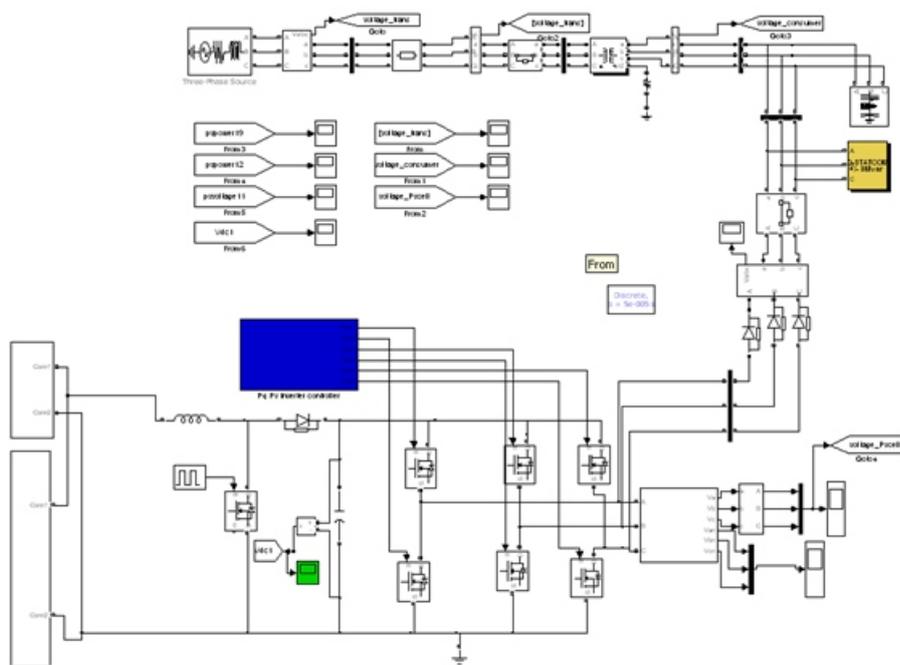


Figure 8: The Matlab model for Grid connected PV system using D-Statcom

Analysis of simulation model and results:

The grid connected PV system shown in figure 8. The power transmission voltage 25KV feed to step down transformer 25KV/400V for distribution level to the consumer. The Photovoltaic power system has been design 100KW and penetrates the PV power to power grid at near consumer distribution power line(low voltage grid) by using battery setup and DC-DC voltage booster and DC-AC inverter has been designed and shown in fig. The Photovoltaic Cell power is integrated with low voltage power grid through bus 4th bus bar as shown in figure 8. In this model we have been using Distributed Statcom for improve the power system stability.

A. Analysis of simulation results:

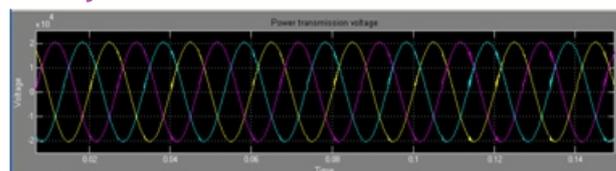


Figure 9: The power Transmission Voltage at Frequency at 50 HZ

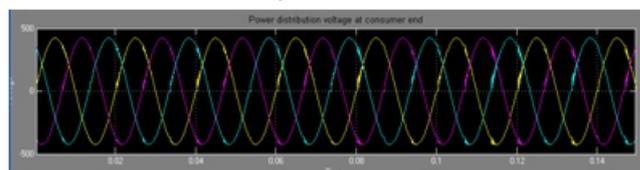


Figure 10: The power Distribution Voltage at Consumer End

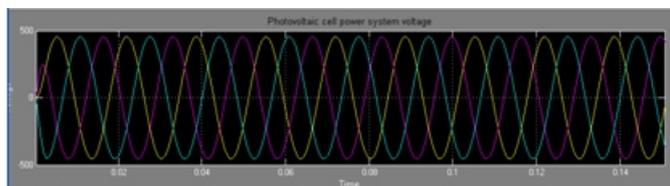


Figure11: Photovoltaic Grid connected System Voltage.

The figure 9 shows the power transmission line voltage 25KV at 50Hz, figure 10 shows the distribution voltage 440V at 50Hz consumer end and figure11 shows the photovoltaic cell power system voltage level and frequency rating 440V/50Hz this power rating 100KW integrate to low voltage distribution power grid at near consumer end.

V CONCLUSION:

In this paper we have modelled and analysed the Photovoltaic power system for power rating at 100KW and 230V at 50Hz being integrated to low voltage distribution power grid near to consumer end by using Distributed Statcom .. In this paper we have studied and analysed the operation and performance of D-Statcom. This proposed model is implemented using Matlab Simulink software and the obtained resultant waveforms were evaluated and the effectiveness of the system stability and performance of power system have been established.

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