Analysis of D-STATCOM Control in Low Voltage Distribution System with Wind Power Generation

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***Abstract*- For the last few years, the large scale integration of wind power generation with power system grid is increasing very rapidly. Wind power generation creates some power quality problem such as voltage regulation. So this title deals with the control of D-STATCOM for maintaining voltage profile of the distribution system while employing induction machine based wind power generation. The D-STATCOM consists of three leg IGBT based CC-VSI having DC bus capacitor. A carrier less hysteresis current controller is used for deriving gating pulses for IGBT switches. The control scheme of the D-STATCOM for the grid connected wind power generation system is simulated using MATLAB/Simulink. D-STATCOM is effective for compensating reactive power, Harmonic elimination and improving power quality of distribution system.**

Keywords-D-STATCOM, Wind power generation, Control algorihm-Carrier less hysteresis current control.

I. INTRODUCTION

In recent years, there has been a rapid increase in total installed capacity of wind power generation throughout the world. The global installed capacity of wind power generation is 283MW and in India it has gone to 20MW. This increasing growth of wind power generation affects the operation of the existing power system network. Because the integration of wind power generation to the distribution system presents the problem of voltage regulation and reactive power compensation.

The most common type of wind turbine consists of squirrel cage induction generator, so it always consumes reactive power, which is not desirable for the distribution system. Also this type of generators slow down the voltage build up after the voltage collapse, this tends to voltage instability when wind turbine is connected to the distribution system. Due to wind speed variation, wind turbine produce power fluctuations. Therefore it is important to know in advance that how a group of wind turbines integrated with power system distribution network affect the power quality. Power fluctuation in wind turbine is the very important aspect in order to determine the effect of grid connected wind turbine on power quality. As stated in IEC STD 61400-21[6], which provides the measurements and evaluation of the power quality of grid connected wind turbines. This power quality problem can be solve by using custom power devices.

The role of custom power devices [1-2] plays an important role in improving power quality of the distribution system. Custom power devices adopted for the power quality enhancement. Custom power devices such as D-STATCOM, DVR, and UPQC are more commonly employed in distribution system. The concept of custom power is based on the use of power electronics controller in the distribution system for improving power quality of the distribution system. The meaning of the custom power is that customer receives specified power quality from utility or service provider.

II. D-STATCOM

(Distribution Static Compensator)

Basic Concept of The D-Statcom

A STATCOM employed at distribution side or at load side is called D-STATCOM. The D-STATCOM consists of a VSC, a DC bus capacitor, a coupling transformer connected in shunt with the ac system. STATCOM at transmission level control only the reactive power compensation and provide voltage support. Whereas the D-STATCOM is employed at the distribution level or load side and it also behaves as shunt active filter. A D-STATCOM consists of GTO/IGBT based VSI connected to the power system through coupling transformer. Generally GTOs are used for the high power application like the STATCOM for transmission level. Whereas IGBTs are used for medium to small power application and are used in D-STATCOM [6].

D-STATCOM employs either a voltage source inverter (VSI) or current source inverter (CSI) with reactive power storage as capacitor or inductor respectively. Generally voltage source inverters are widely used because of their lower sizes, less dissipation of heat and less costly capacitor compared to the inductor used in the CSI for the same power rating. So different control techniques can be used for the D-STATCOM such as current controlled D-STATCOM (CC-DS) and voltage controlled D-SATCOM (VC-DS). Out of these, CC-VSI is commonly used in the D-STATCOM for the enhancement of the power quality. There is two more subsection under this category as [5],

a) Voltage control D-STATCOM: There is a control of active and reactive power flow through the inverter by using D-STATCOM as a voltage source.

b) Current control D-STATCOM: This is the most commonly used method for controlling the power through the D-STATCOM by controlling its active and reactive current.

Principle of operation

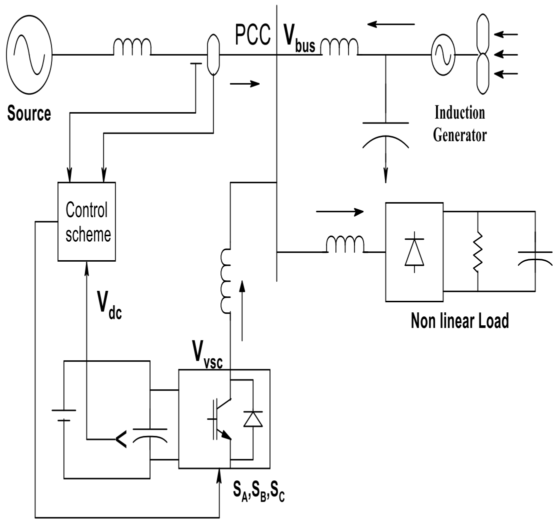

Figure 1: Schematic diagram of D-STATCOM

The operating principal of D-STATCOM depends on the reactive current generation so,

$$I=(Vbus-Vvsc)/X$$

Where,

Vbus=system voltage

Vvsc=output voltage of the VSC

X=circuit reactance

The current I generated by D-STATCOM correct the voltage sag by adjusting voltage drop across system impedances. When current injected by the D-STATCOM is kept in quadrature with the system voltage, so desired voltage correction can be achieved without injecting any active power to the system. Effectiveness of the D-STATCOM in compensating voltage sag mainly depends on, Impedance value (Zth= R+jX) and fault level at the load bus [8].

D-STATCOM is able to minimize the voltage variation and control the reactive power compensation with the system. It can provide the capacitive and reactive current to system at the PCC (point of common coupling).
There are two types of the operating modes of D-STATCOM

1) Inductive mode
2) Capacitive mode

In the Inductive mode of operation of the D-STATCOM, Vbus is in the phase with Vvsc and Vbus > Vvsc, D-STATCOM absorbs reactive power from the system. In the Capacitive mode of operation of the D-STATCOM, Vbus < Vvsc, D-STATCOM injects the reactive power to the system. In above analysis both Vbus and Vvsc are in phase, but in actual practice they have a little phase difference, so it makes possible to exchange real power flow with the system, which supply the losses of the transformer reactance and switching losses in the inverter.

D-STATCOM can also provide the real power exchange between system and D-STATCOM. If Vvsc leads the Vbus by an angle δ, then real power flow to the system. If Vvsc lags the Vbus by an angle δ, then real power flow from system to the D-STATCOM. Active and Reactive power transferred by the D-STATCOM is given as,

$$P=[(Vbus*Vvsc)/X] \sin\delta$$

$$Q=(Vbus^2/X)-[(Vbus*Vvsc)/X] \cos\delta$$

The capacitor in the D-STATCOM is used to maintain DC voltage to the inverter. The output voltage of the inverter is proportional to the DC voltage of the capacitor, which is proportional to the energy stored in the capacitor. The size of the capacitor can be selected based on its physical size, cost and performance of the D-STATCOM.

A D-STATCOM have ability to control the voltage even if the system voltage exceeds its higher or lower voltage limit, at this limit D-STATCOM act as a constant current source by properly controlling converter output voltage. Therefore at lower voltage or at higher voltage limit, D-STATCOM can provide higher reactive power compensation than SVC.

III. WIND TURBINE POWER GENERATION BASIC CONCEPT

Wind turbine is the one type of distributed energy resources. There are various DERs such as wind turbine, reciprocating engine, combustion turbine, fuel cell, photovoltaic system. Wind turbine, which convert kinetic energy of wind into useful power, which is to be used by some mechanical work, like pumping water, or to produce electrical power by using generator. It ranges from small rooftop turbines generating less than 100 kW up to large commercial wind turbines in the range of few MW.
Power available from the wind is given as,

$$P=\tfrac{1}{2} A \rho V^3$$

Where, ρ=Density of the air
=1.225 kg/m³ at sea level
A=Capture area in m²
V=Wind speed in m/sec.

There are various types of wind turbines, mainly
a. Horizontal axis wind turbine (HAWT)
b. Vertical axis wind turbine (VAWT)

In HAWTs, its blades rotating on an axis parallel to the ground and axis of blades rotation parallel to the wind flow.Also rotor shaft and electrical generator placed at the top of the tower. A gear box is also provided in the nacelle of the turbine, which turns the slow variation of the blades into a quicker rotation of the blades i.e. stepping up the speed of the generator. There are some constant speed turbines, but more energy can be generated by the variable speed turbines, which uses a solid state power converter for the purpose of integration with the system. A protective circuit can also be equipped with turbine to avoid damage at very high wind speed.
In VAWTs, blades rotating on axis perpendicular to the ground. A rotor shaft arranged vertically, because of this arrangement, transmission and generator can be maintained at ground level which allows the easy maintenance and light weight, low cost tower. But main disadvantage is that relatively low rotational speed with the consequential higher torque and hence higher cost of the drive train.

Grid connection: It is required after the power is generated, it needs to be transmitted and distributed to consumers. The wind output power directly feeding to the local loads are known as isolated wind energy system. If wind energy supplies the system that is to be connected to the grid are known as grid connected wind energy system.

IV. CONTROL STRATEGIES

For the controlling of the voltage source converter and DC link voltage, different types of control techniques [7] are used to control the D-STATCOM.

PHASE SHIFT CONTROL

This is the simplest method of maintaining constant voltage at the load terminal. This technique provides the voltage angle control and generates the phase shift between the output voltage of the VSC and system voltage. The voltage at the PCC is compared with the reference voltage, which gives the error signal, and it is fed to the PI controller to generate an angle δ to maintain voltage error to zero. Then this angle is fed to the PWM generator, which phase modulates the sinusoidal voltage signal by an angle δ, and generates the pulses for the IGBT switches.

This control technique is very robust, and requires only voltage measurement. But this technique suffers from following disadvantages,

- It does not have self supporting DC bus and it requires a separate DC source to charge the capacitor and maintain its voltage during the operation of the D-STATCOM.
- There is no provision for harmonic suppression.

Carrier Based Pwm Control

A fixed frequency carrier based sinusoidal PWM is employed for generating the switching pulses for the IGBTs switches of the VSC. In this control method instantaneous voltage and current of the supply system and load are measured. In this method abc-dq transformation is performed, therefore generating the current components id and iq, which provide compensation by controlling id and iq. Now id reference current obtained from by PI regulation of the DC terminal voltage with respect to the reference DC voltage. Similarly iq reference current can be obtained by PI regulation of the AC terminal voltage of the VSC with respect to the reference AC voltage.

Then the PI regulation of these reference currents compared to the id and iq respectively, which produces vd and vq respectively, then applied to PWM pulse generator to generate the switching pulses for the IGBTs of VSC.

In this control technique there are several disadvantages such as,

- Very little harmonic suppression is achieved, which requires additional filters to minimize the harmonics.
- Response time is more because four PI controllers are used.
- PLL is required for the synchronization with the fundamental frequency and also produce error when supply voltage is distorted.

CARRIER LESS HYSTERESIS CONTROL

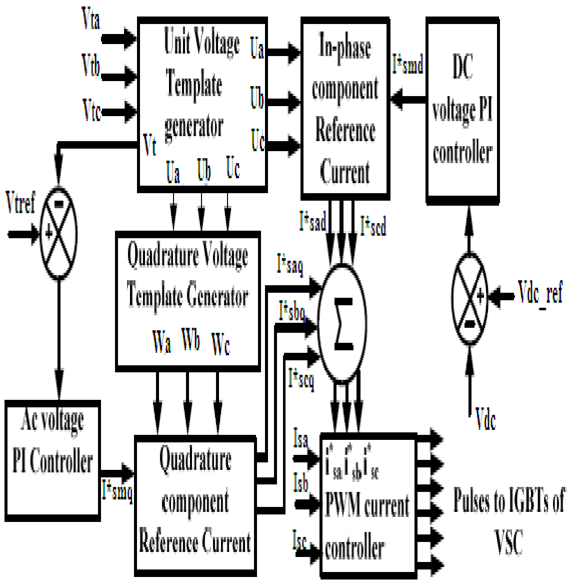

Figure 2: schematic diagram for carrier less hysteresis control of D-STATCOM

This control technique is very versatile and is widely used for the voltage regulation, power factor correction, minimization of the harmonics, and load balancing. Figure shows the PI controller based carrier less hysteresis controller. In phase unit vectors (Ua, Ub, and Uc) can be calculated as by dividing the voltages at PCC (Va, Vb, Vc) by their amplitude Vt. And Quadrature unit vectors (Wa, Wb, Wc) can be computed using In phase unit vectors.

To regulates the voltage at the point of the common coupling (PCC), a voltage (Vt) is sensed from the PCC and is compared with the reference voltage (Vtref) and its error voltage is processed in the PI controller, and PI controller gives output as I*smq, which determined the amplitude of the reactive current generated by the D-STATCOM. Now quadrature component of the reference current (I*saq, I*sbq, I*scq) can be obtained by multiplying I*smq with quadrature unit vector (Wa, Wb, Wc).

To provide the voltage control at the DC bus, PI regulation of the DC bus voltage with respect to the reference DC voltage is performed and gives the output I*smd, which shows the amplitude of the active power component of the reference source current. Now In phase component of the reference source current (I*sad, I*sbd, I*scd) can be calculated by multiplying I*smd with In phase unit vector (Ua, Ub, Uc). Now reference source current (I*sa, I*sb, I*sc) can be obtained by adding corresponding phase and quadrature components. Then PWM current controller compares the reference source currents (I*sa, I*sb, I*sc) with sensed source currents (Isa, Isb, Isc) to generates the switching pulses for the IGBTs of the D-STATCOM.

The hysteresis controller places a hysteresis band ±h around the calculated reference source current, for (Isa-I*sa) > +h, then pulses are generated for lower level switches and for (Isa-I*sa) < -h, then pulses are generated for upper level switches of the VSC.

Algorithm of carrier less hysteresis control

The magnitude of three phase voltage at the PCC is calculated as,

$$V_t=\sqrt{(2/3)(V_a^2+V_b^2+V_c^2)}$$

The unit in-phase vectors Ua , Ub , Uc are derived as

$$U_a=V_a/V_t;$$

$$U_b=V_b/V_t;$$

$$U_c=V_c/V_t;$$

Unit vectors in quadrature (Wa , Wb , Wc), are derived from the in-phase vectors (Ua , Ub , Uc), using following transformation

$$W_a= -U_b/\sqrt{3}+U_c/\sqrt{3};$$

$$W_b= \sqrt{3}U_a/2+(U_b-U_c)/2\sqrt{3};$$

$$W_c= -\sqrt{3}U_a/2+(U_b-U_c)/2\sqrt{3};$$

Quadrature component of the reference source current:

The voltage at PCC is sensed and compare with the reference voltage, and error signal obtained as,

$$V_{er}(n)=V_{tref}-V_t(n)$$

Where,

Vtref=Amplitude of reference voltage at PCC

Vt(n)= Amplitude of the three phase ac voltage at PCC at the nth instant

Quadrature component of the reference source current I*smq(n) can be obtained from the output of the PI controller for maintaining ac terminal voltage constant at nth instant, and is expressed as,

$$I^*_{smq}(n)=I^*_{smq}(n-1)+K_{pa}\{V_{er}(n)-V_{er}(n-1)\}+K_{ia}V_{er}(n)$$

Where,

I*smq(n)=amplitude of reactive power component of the source current

Kpa and Kia=proportional and integral gain constant of PI controller

The quadrature component of reference source current can estimated as,

$$I^*_{saq}=I^*_{smq}W_a;$$

$$I^*_{sbq}=I^*_{smq}W_b;$$

$$I^*_{scq}=I^*_{smq}W_c;$$

In-Phase component of reference source current:

The dc link voltage is sensed and compare with the reference dc voltage, and error signal obtained as,

$$V_{dcer}(n)=V_{dcref}-V_{dc}(n)$$

Where,

Vdcref=reference dc voltage

Vdc(n)=sensed DC link voltage of the D-STATCOM

The output of the PI controller for maintaining the dc bus voltage of the D-STATCOM at the nth sampling instant is expressed as,

$$I^*_{smd}(n)=I^*_{smd}(n-1)+K_{pd}\{V_{dcer}(n)-V_{dcer}(n-1)\}+K_{id}V_{dcer}(n)$$

Where,I*smd(n)=amplitude of the active power component of the source current

Kpd & Kid=proportional and integral gain constants of the dc bus PI voltage controller

In-Phase component of the reference source currents are computed as,

$$I^*_{sad}=I^*_{smd}U_a;$$

$$I^*_{sbd}=I^*_{smd}U_b;$$

$$I^*_{scd}=I^*_{smd}U_c;$$

Total reference source currents:

It is the sum of the quadrature and in-phase component of reference source currents,

$$I^*_{sa} = I^*_{saq} + I^*_{sad};$$

$$I^*_{sb} = I^*_{sbq} + I^*_{sbd};$$

$$I^*_{sc} = I^*_{scq} + I^*_{scd};$$

PWM current controller:

These reference source currents (I*sa,I*sb,I*sc) are compared with the sensed source currents (Isa,Isb,Isc), and current errors are computed as,

$$I_{saerr}=I^*_{sa}-I_{sa};$$

$$I_{sberr}=I^*_{sb}-I_{sb};$$

$$I_{scerr}=I^*_{sc}-I_{sc};$$

V. CONCLUSION

A comprehensive review of the D-STATCOM controller has been carried out in this paper to focus on the solution of power quality problems. A review has been presented in this paper about the methods for improving power quality aspect of the distribution system connected with wind power generation.

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