Power Quality Enhancement in Distributed Generation Using D-STATCOM

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Abstract: *In this effort, a DSTATCOM (Distribution Static Compensator) is employed for control of a distributed power generating system by a proposed composite observer based control technique. The suggested control technique is employed for fundamental components extraction of distorted load currents. These extracted components are used in estimation of reference source currents to generate gating signals of DSTATCOM. The proposed control technique is employed for mitigation of reactive power, distortion in term of harmonics and load balancing under linear/nonlinear loads. The performance of DSTATCOM is observed satisfactory for these consumer loads with regulated generator voltage at point of common coupling (PCC) and self-supported DC link of VSC of DSTATCOM.*

Keywords: *DSTATCOM, Induction Generaor(IG), Load Balancing, Voltage Regulation, Power Quality.*

1. INTRODUCTION

Distributed generation (DG) system is a small-scale electricity generation, which delivers electric power near the load site or customer side. The hydro, wind, solar, biomass, biodiesel etc these are the distributed renewable energy sources. In isolated areas, a number of distributed power generation sources are available. For consumption of these resources, an induction machine can be used as a generator with suitable mode of prime movers.

A. Distributed Static Compensator (DSTATCOM)

The Distributed Static Compensator (DSTATCOM) is a voltage source inverter based static compensator shown in Fig.1 that is used for the correction of bus voltage sags. Connection (shunt) to the distribution network is via a standard power distribution transformer. The DSTATCOM is capable of generating continuously variable inductive or capacitive shunt compensation at a level up its maximum MVA rating. The DSTATCOM continuously checks the line waveform with respect to a reference ac signal, and therefore, it can provide the correct amount of leading or lagging reactive current compensation to reduce the amount of voltage fluctuations.

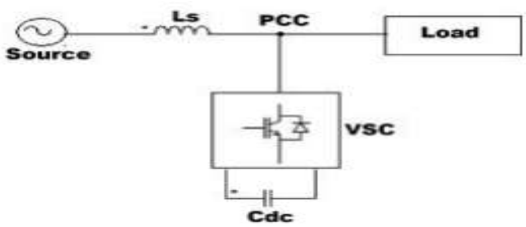

Fig.1: Schematic representation of the DSTATCOM

B. Induction Generator

The SEIG system is consists of four main components: the prime mover (wind turbine), the induction generator, the load and the exciting capacitors . The general layout of the SEIG system is shown in Figure. The wind turbine is assumed to operate with constant input power transferred to the induction generator. The real power required by the load is supplied by the induction generator by extracting power from the prime mover (turbine).

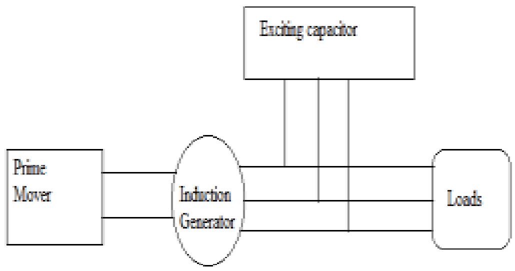

Fig 2. Self-Excited Induction Generator

When the speed of the turbine is not regulated, both the speed and shaft torque vary with variations in the power demanded by the loads. The self-excitation capacitors connected at the stator terminals of the induction machine must produce sufficient reactive power to supply the needs of the load and the induction generator. An Induction generator with prime mover is operated in three different modes such as variable power, constant power and constant speed. An effective use of an Induction generator in the field application is depending on the reactive power compensation, harmonics generated by the loads and balanced load. All these power quality problems are reduced by using the VSC (Voltage source converter). VSC is connected at the PCC for voltage regulation because during load dynamics system has poor voltage regulation.

2. Distributed generation System and Control Technique:

A 3 Phase IG based Distributed power generation system is shown in fig3. In that generated power supply is given to the linear and nonlinear loads. This power generated system required Induction machine, Exciting capacitors (Cga, Cgb, Cgc) and equivalent model constant speed prime mover as a turbine. DSTATCOM is used for Harmonic compensation, reduction of reactive power demand &Load balancing. There are some components are required for development of the DSTSTCOM such as VSC, signal conditioning and ripple filter and processing circuit and interfacing inductors(Lf). Three phase diode rectifier with resistive load(Ro) and filter inductance (Lo) is a nonlinear loads. The output of rectifier is considered as ‘io’. Another side linear load is connected as a Rheostat box (RLa, RLb, RLc) with three phase inductors (LLa, LLb, LLc). It is connected through the three pole single throw switch with 3 phase lines nearer to load end.

$$X_{cq} = -\frac{\sqrt{3}X_{ap}}{2} + \frac{(X_{bp} - X_{cp})}{2\sqrt{3}}$$

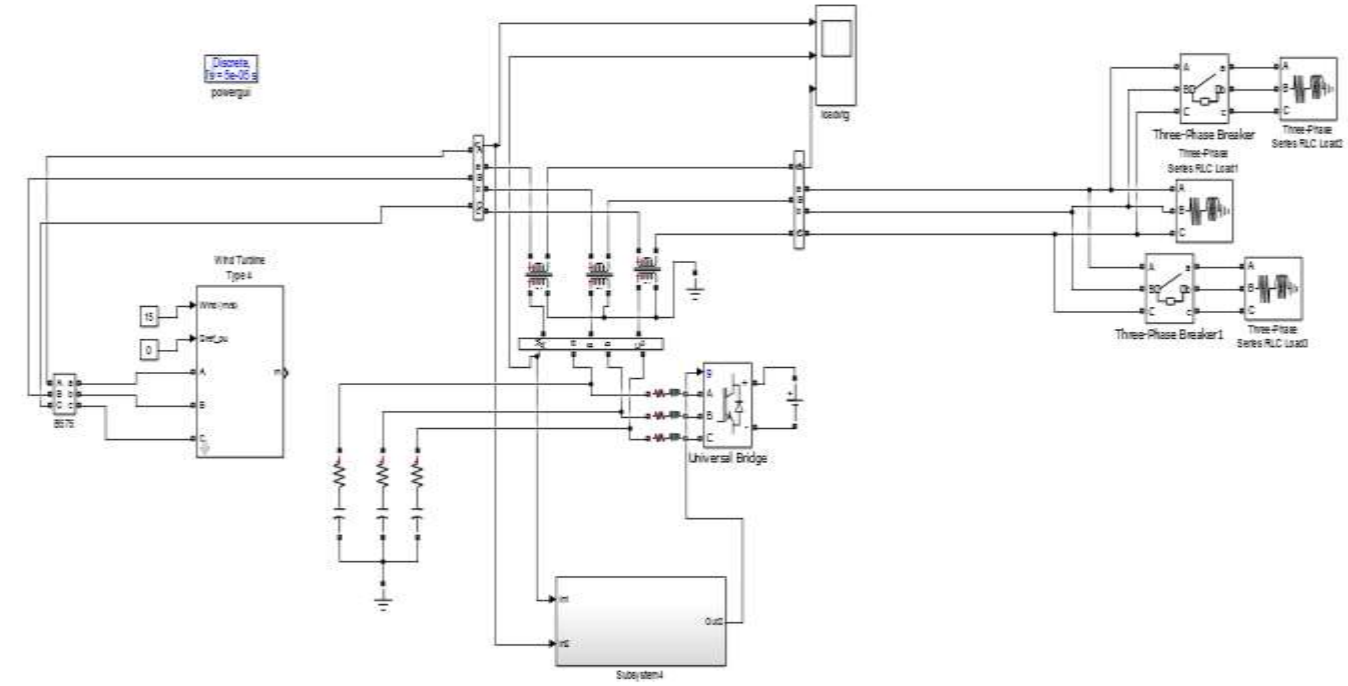

Fig.3 Schematic Diagram VSC based DSTATCOM in distributed power generation system

The block diagram of composite observer based control technique is shown in Fig. 4 for estimation of reference source currents. Two line generated voltages at PCC (vab, vbc), load currents (iLa, iLb, iLc), DC bus voltage (vdc) of DSTATCOM are sensed as input signals to control technique. The sensed generator voltages are converted to three phase voltages as vsa, vsb, and vsc for calculation of internal control variables used in control technique. Mathematical equations of this control technique for estimation of different control signals are as follows.

A. In-phase and Quadrature Unit Vector

The in-phase unit vectors (xap, xbp, xcp) are computed from three phase generator voltage at PCC (vsa, vsb, vsc) as,

$$X_{ap} = \frac{V_{sa}}{V_t},$$

$$X_{bp} = \frac{V_{sb}}{V_t},$$

$$X_{cp} = \frac{V_{sc}}{V_t}$$

where Vt = Amplitude of PCC voltage

$$V_t = \frac{2}{3}\sqrt{(V_{sa}{}^2 + V_{sb}{}^2 + V_{sc}{}^2)}$$

The quadrature unit vectors (Xaq, Xbq, Xcq) are calculated as,

$$X_{aq} = -\frac{X_{bp}}{\sqrt{3}} + \frac{X_{cp}}{\sqrt{3}},$$

$$X_{bq} = \frac{\sqrt{3}X_{ap}}{2} + \frac{(X_{bp} - X_{cp})}{2\sqrt{3}},$$

B. Fundamental Current Component Extraction from Polluted Load Currents

The infested load currents contain various types of harmonics components with mω1 (m-order) frequencies. In Fig. 4, expression of fundamental component of distorted load currents (i_{L1}) as a state vector of continuous composite observer is expressed as,

$$i_{L1} = P_1 i_{L1} + G_1 i_e$$

Where,

$$p_1 = \begin{pmatrix} 0 & \omega_1 \\ -\omega_1 & 0 \end{pmatrix}$$

and composite constant gain template G1 is decided using the defined pole location as,

$$G_1 = [g_{11}\, g_{12}]^T$$

‘1’ is represented as order of fundamental component of load current and ie is the error components between distorted load current and fundamental component of load current.

The output components of state variable (Y_1) is defined as,

$$Y_1 = Q_1 i_{L1}$$

After considering i_{L1} as a state vector and Q1= [1 0], The desired output variable from (6) is written as,

$$Y_1 = i_{L11}$$

where iL11 is the state variable corresponding to fundamental component.The values are selected for gain are $g_{11,} g_{12}$ are 42,-2 for the extraction of desired load current. $M = [G_1 : P_1 G_1]$ is a non-singular matrix and this system is controllable.

This controllable matrix (M) is full rank matrix. It revenues that rank of matrix is equal to number of unknown parameters or number of control constants in designed system. This test suggests that feedback system generates control signals that have ability to achieve desired reference signals. The actual signal must follow extracted reference signal with zero error or constant error at every time instant.
Also, The system is observable if,

$$V = \begin{pmatrix} Q_1 \\ Q_1 P_1 \end{pmatrix}$$

$$V = \begin{pmatrix} 1 & 0 \\ 0 & 314 \end{pmatrix}$$

It is a nonsingular matrix and that's why it is a observable system.The initial state can be estimated from given set of observations accumulating at given time up to 't' instant. This test proposes that necessary current signals can be projected by taking observations up to given time instant. These projected signals can be used for design of control signals. Above procedure can be applied in each phase generator load currents for fundamental component extraction. After extraction, these components are fundamental load currents as iL1a, iL1b, and iL1c.

C. Extraction of Active Power Component for Reference Source Currents

Load current is in phase with ac mains and it is a fundamental component of the distorted phase 'a' and it moves with certain phase angle with the reference in-phase template. A sample and hold logic (SHC1) is used with iL1a as the input and the output of ZCD1 is as pulse of trigger. The output signal of sample and hold logic is the magnitude of phase 'a' fundamental active power component of load current (ILap). Also, phase 'b' and phase 'c' load fundamental active power currents (ILbp and ILcp) are also obtained. The average magnitude of phase a, b, and c load currents are calculated as total sum divided by three.
The average amplitude of fundamental active power component of load currents of three phase is calculated as,

$$I_{Lpa} = \frac{(I_{Lap} + I_{Lbp} + I_{Lcp})}{\sqrt{3}}$$

D. Estimation Reactive Power Component of Reference Source Currents
Another zero crossing detector (ZCD2) is engaged with in-phase generator voltage vector (xap).
Another block of sample and hold logic (SHC2) is connected in iL1a as an input and the ZCD2 output
is as a pulse to starts giving triggering pulse. The output component of sample and hold logic (SHC2) is the magnitude of phase 'a' reactive power component of current (ILaq). The average amplitude of fundamental Reactive power component of load currents of three phase is calculated as,

$$I_{Lqa} = \frac{(I_{Laq} + I_{Lbq} + I_{Lcq})}{\sqrt{3}}$$

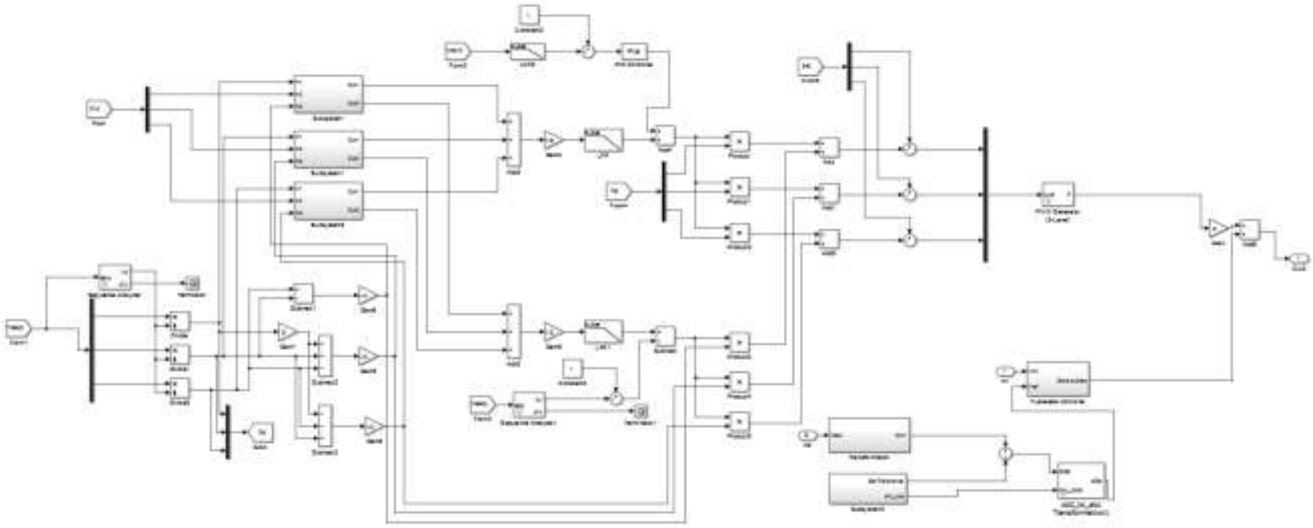

Fig.4 Block diagram of composite observer based control technique

2. TEST RESULTS AND DISCUSSION

An example of an induction generator based power generation system is developed in the laboratory with power quality features. For compensation of reactive power demand, harmonics and load balancing with regulated generator voltage at PCC voltage source converter is used. The current and voltage sensors are used for sensing of input signals to evaluation reference source currents and these reference source currents are used for generation of pulses of VSC used as DSTATCOM.In the system there are three loads are connected load1, Load2 and Load3. When Load1 is connected voltage is normal. When circuit breaker of Load2 is connected or closes then Load2 are comes in the system and voltage drop occurs. To compensate that voltage DSTATCOM is used. In the control technique the input value of the voltage is compared with the output voltage and then required current is injected in the system and voltage is compensated. When circuit breaker of Load3 is connected in the system then also voltage drop occurs but it is less then it requires less injection of current and voltage is compensated.

1. Performance of DSTSTCOM with Induction Generator under linear load 2

For the series RLC load2, when voltage drop occurs between time period 0.2 to 0.4 sec circuit breaker operate and the value of voltage is compared with the reference value using control technique. After comparing if we find the voltage drop then current is injected in the sysem by using DSTATCOM and voltage is compensated.

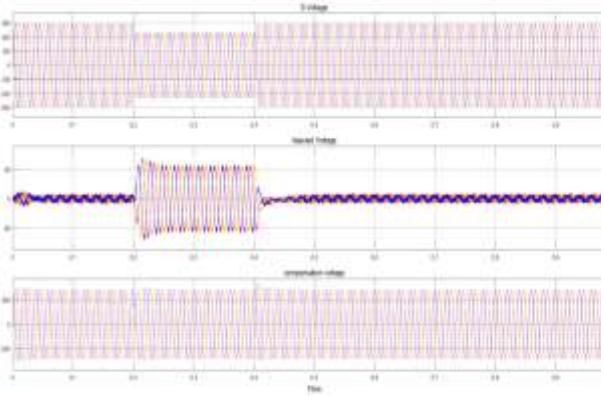

Fig5. Performance of DSTSTCOM with Induction Generator under linear load2.

2. Performance of DSTSTCOM with Induction Generator under linear load3.

For the series RLC load three in the time period 0.5 to 0.7 sec voltage drop is less therefore less current is injected in the system and voltage is compensated.

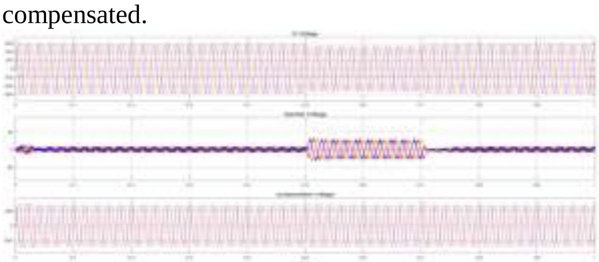

Fig6. Performance of DSTSTCOM with Induction Generator under linear load3.

3. Performance of DSTSTCOM with Induction Generator under linear load2 and Load3.

Fig8 shows the Performance of DSTSTCOM with Induction Generator under linear load2 and Load3.The circuit breaker of the both load are closes and then voltage drop occurs and current is injected in the system using DSTATCOM and voltage is compensated.

4. CONCLUSION

A model of constant speed turbine based induction generator has been applied in three-wire system. The performance of VSC based DSTATCOM has been studied using composite observer based control technique for compensation of reactive power, harmonics and load balancing in voltage regulation mode for this system.

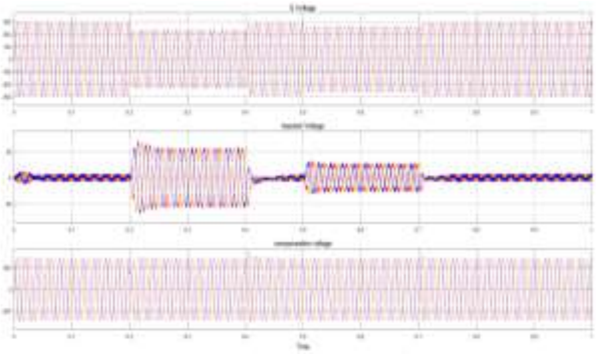

Fig7. Performance of DSTSTCOM with Induction Generator under linear load2 and Load3.

Total, satisfactory performance of proposed control technique is recorded to meet international standards. The self-supported DC link voltage of the DSTATCOM has also been regulated to reference level under voltage regulation mode. The processing time of algorithm is less due to simple structure. This system is tested under linear type of consumer loads with improved dynamic performance and additional functions compared to frequently use fixed capacitive compensation or thyristor based system. In this project we conclude that when the voltage drop occurred in the system then DSTATCOM operates and compensate the voltage and in this way power quality is maintained.

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