COORDINATED CONTROL OF HYBRID SERIES CAPACITIVE COMPENSATION FOR DAMPING POWER SYSTEM OSCILLATIONS IN DFIG BASED WIND FARM

[1] A.KIRUTHIKA, [2] DR.V.GOPALAKRISHNAN, [3] IMMANUEL JOHN SAMUEL

[1] PG Scholar/Dept. of EEE,GCT, Coimbatore-13
[2] Asso.prof/Dept.of EEE, GCT, Coimbatore-13
[3] Ph.D scholar/Dept.of EEE, GCT,Coimbatore-13

a.kirthika1993@gmail.com, gopalakrishnan.v@gct.ac.in, immanuelgct@gmail.com

ABSTRACT— *The recently proposed scheme investigates the potential use of supplemental controls of DFIG-based wind farms combined with a phase imbalanced hybrid series capacitive compensation scheme for damping power system oscillations, phase imbalanced series capacitive compensation concept has been shown to be effective in enhancing power system dynamics as it has the potential of damping power swing as well as sub-synchronous resonance oscillations in wind Farm.The hybrid scheme creates a phase imbalance duringsystem disturbances in wind energy generation. The phase imbalance causes a suppression of the energy exchanged between the electrical and mechanical sides of the turbine-generator and, therefore results in reduction of the growing torsional stresses at SSR mode. A hybrid scheme is a series capacitive compensation scheme, where two phases are compensated by fixed series capacitors (C) and the third phase is compensated by an SSSC in series with a fixed capacitor (Cc). The effectiveness of the scheme in damping power system oscillations during system faults at different loading conditions is evaluated using the MATLAB simulation program.*

I.INTRODUCTION

FLEXIBLE ac transmission system (FACTS) technologyprovides unprecedented way for controlling transmissiongrids and increasing transmission capacity [1]–[3]. FACTS controllershave the flexibility of controlling both real and reactivepower which could provide an excellent capability for improvingpower system dynamics. Several studies have investigated thepotential of using this capability in enhancing power system dynamics,e.g., damping of power oscillations and sub-synchronousresonance. The use of thyristor controlled series capacitor(TCSC), static synchronous compensator (STATCOM), and static synchronous seriescompensator (SSSC) have been the subjects of several studies evaluating their respective effectiveness in enhancing power system dynamics [4]–[17].

They are “hybrid” series compensation schemes, where the series capacitive compensation in one phase is created using a single-phase TCSC (Scheme I) or a single-phase SSSC (Scheme II) in series with a fixed capacitor (Cc), and the other two phases are compensated by fixed series capacitors (C). The TCSC and SSSC controls are initially set such that their equivalent compensations at the power frequency combined with the fixed capacitor yield a resultant compensation equal to the other two phases. Thus, the phase balance is maintained at the power frequency while at any other frequency, a phase imbalance is created. To further enhance power oscillations damping, the TCSC and SSSC are equipped with supplementary controllers.

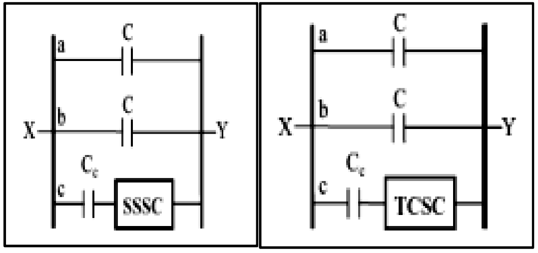

Fig.1 Hybrid series compensation

Fig. 1 shows two schemes for a phase-imbalanced series capacitive compensation. They are “hybrid” series compensation schemes, where the series capacitive compensation in one phase is created by using a single-phase TCSC (Scheme I) or a single-phase SSSC (Scheme II) in series with a fixed capacitor , and the other two phases are compensated by fixed series capacitors (C). The TCSC and SSSC controls are initially set so that their equivalent compensations at the power frequency, combinedwith the fixed capacitor, yield resulting compensation equal to the other two phases. Thus, phase balance is maintained at the power frequency while at any other frequency, phase imbalance is created. To further enhance power oscillation damping, the TCSC and SSSC are equipped with supplementary controllers.

II.SERIES COMPENSATION SCHEME

The SSSC control is initially set such that its equivalent compensation at the power frequency combined with the fixed capacitor Cc yields a resultant compensation equal to the other two phases. Thus, the phase balance is maintained at the power frequency whereas at any other frequency a phase imbalance is created.

In this paper, a single-phase three-level VSC based on sinusoidal pulse width modulation (SPWM) is built up in the Simulink model of the single-phase SSSC. This structure is suitable for high power applications as, when compared to a two-level structure, it provides less harmonics, lower switch blocking voltages and lower switching losses.

1) At the power frequency, the series reactances between buses X and Y in Fig. 1 in phases a,b and c are given by

$$X_a=X_b=\frac{1}{j\omega oC} \quad (1)$$

$$X_c=\frac{1}{j\omega oCc}-jX_{sssco} \quad (2)$$

Where $-jX_{sssco}$ is the effective capacitive reactance of the SSSC at the power frequency so that $X_a=X_b=X_c$.

2) During any other frequency, f_c

$$X_c=\frac{1}{j\omega cCc}-jX_{sssco}-j\Delta X_{sssc}. \quad (3)$$

The first terms in (2) and (3) are different because of the difference in frequency. The third term in (3) represents the change in effective capacitive reactance of the SSSC due to the action of the SSSC supplementary controller. These presented schemes would definitely be economically attractive when compared with a full three-phase TCSC or SSSC, which have been used/proposed for power swings and

subsynchronous resonance oscillations damping. Furthermore, reducing the number of thyristor valves and VSC to one-third will also have a positive impact one equipment reliability.

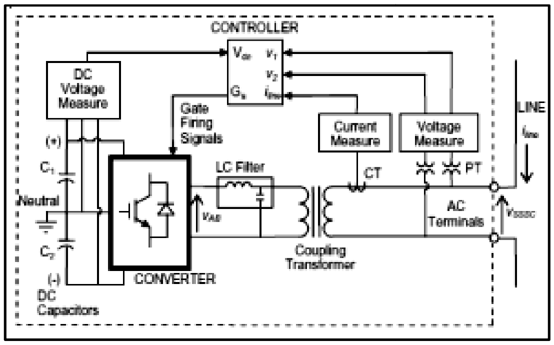

Fig.2 Schematic diagram of single phase SSSC model

In this method, both the magnitude and the phase angle of the injected voltage are varied. The DC-side voltage is kept constant. Since the converter has some real power losses due to the switching and the resistive losses, the DC voltage will decrease unlessthe DC capacitors are supplied from any source. For this reason, a small phase angle displacement is involved to compensate for the losses and to keep the DC-side voltage constant by absorbing a small amount of real power from the power system. This real power absorption is also a small contribution to the damping of power system oscillations. The capability of each converter valve to turn-off and the anti-parallel diode allow a bidirectional current flow, so that the converter can operate in both rectification and inversion modes. Proportional-Integral (PI) controllers are employed for controlling the magnitude and the phase angle of the injected voltage. The integral part of the controller helps in removing the steady-state errors.

III.MODELING OF SINGLE PHASE SSSC

This section describes the implementation and control of the adopted SSSC. Fig. 2 shows the block diagram of SSSC controller. The difference between the SSSC impedance and the reference value is processed in a proportional-integral (PI) controller. The output of the PI controller acts as a modulation index for the PWM converter.

A positive value ofX_{ref} is taken for capacitivecompensation and a negative value for inductive compensation. Only the capacitive operation of SSSC is considered in this paper. $U_s$is the supplemental signal for damping SSR.

The PLL consists of a phase detection block, a loop filter, and a voltage-controlled oscillator (VCO).

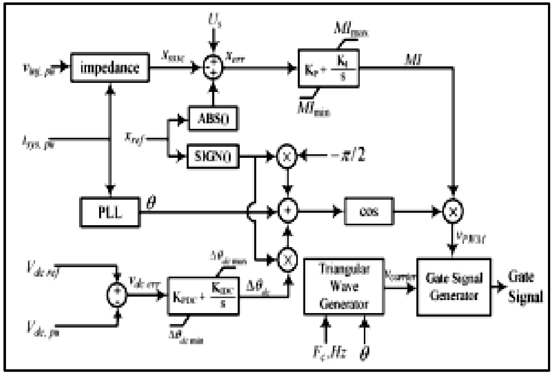

Fig.3 Block diagram of SSSC controller

The rate of convergence of the PLL increases with the increase of the gain values K and K_I,K_P,K_V. The speed of the response increases with an increase inK ; however, it creates oscillations in the response. The proper choice of the gain values is a compromise between speed and accuracy. For the FACTS applications, a fast start up period and zero steady-state error are desired [17]. The values of K_P =1,K_I =200, K_V=100 and K=200 (in p.u.) are found to obtain satisfactory response and are used in the studies conducted in this paper.

The controller parameters are adjusted through repeated time-domain simulations for different operating conditions. Increasing the proportional gain increases the sensitivity toward the error which, in turn, increases the response overshoot, while increasing the integral gain decreases the steady-state error at a cost of an increase in settling time. Thus, the choices of these gains are made so that fast settling time and minimum overshoot (less than 10%) for a step change in input are achieved.

IV.WORK BENCH

To demonstrate the effectiveness of the proposedcoordinated control of Scheme II in power system oscillations damping, the system shown in Fig. 5 is adopted as a test benchmark.

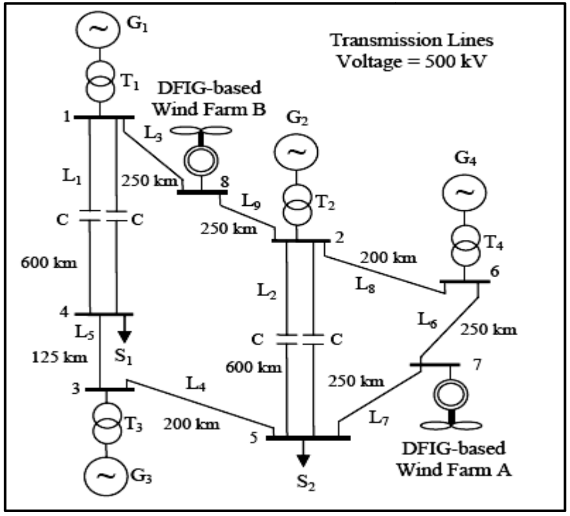

Fig.5 Three bus system work bench

It consists of three large generating stations (G1, G2 and G3) supplying two load centers (S1 and S2) through five 500 kV transmission lines. The two double circuit transmission lines L1 and L2 are series compensated with fixed capacitor banks located at the middle of the lines.The compensation degree of L1 and L2 is 50%. The compensation degree is defined as the ratio (XC/XL)* 100% for the fixed capacitor compensated phases and (XCc+XSSSC)/XL*100% for the hybrid compensated phase.

V.POWER SYSTEM OSCILLATIONS DAMPING

The supplemental controller input (stabilizing) signals could be local (e.g. real power flows) or remote (e.g. load angles or speed deviations of remote generators). If a widearea network of Synchronized Phasor Measurement (SPM) units is available, then the remote signals can be downloaded at the controller in real time without delay. Local signals are generally preferred over remote signals as they are more reliable since they do not depend on communications. In the investigations conducted in this paper, the real power flows in lines L1, L2 and L3 (PL1, PL2, PL3) are selected as the supplemental controller stabilizing signals.

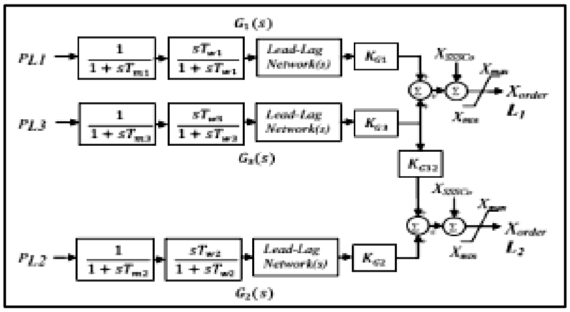

Fig.6 Supplementary controller of SSSC

VII.TIME DOMAIN SIMULATION RESULTS

A.NORMAL FIVE BUS SYSTEM

In this case there is no compensation device is connected to the system. The system has five buses which are used to connect different elements in power system network. The bus numbers one, two, three are connected to the synchronous generator their corresponding ratings are given. Three phase loads are connected in bus number four and five. Three phase fault is created at near bus number four. The corresponding simulation figure 7 and results are below.

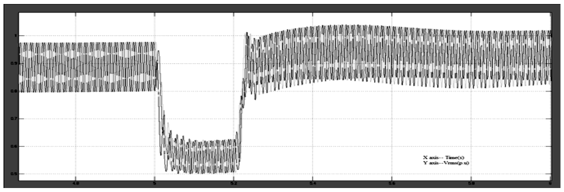

Fig.7 RMS voltage waveform at bus 1

B.FIVE BUS SYSTEM WITH SERIES CAPACITOR

In this case, the series capacitance is connected to each of parallel transmission lines which are connected between bus number one to four and bus number two to five. This series capacitance is used to reduce line impedance effect. This property of series capacitor will improve power transfer capability of transmission line and also it's reducing power system oscillations. The system simulation and bus 1 voltage waveform are given below.

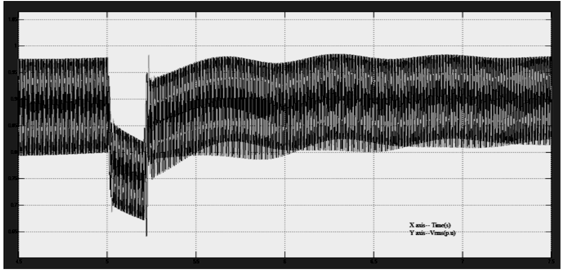

Fig.8 RMS voltage wave form at bus 1

By connecting series capacitor in transmission line it will reduce the line impedance by injecting capacitive effect in transmission line. Now the voltage magnitude reduced during fault condition compare to normal case figure.

C. FIVE BUS SYSTEM WITH HYBRID SCHEME

In this case the both series capacitor and static synchronous series compensator are connected in parallel transmission lines. The three phase fault is created at 5 second and cleared at 5.2 seconds. To control the line impedance by supplementary control of SSSC will modulate much more sensitive than series capacitor. The output of supplementary control signal is used control input firing pulse of MOSFET(Metal Oxide Semiconductor Field Effect Transistor) switches.

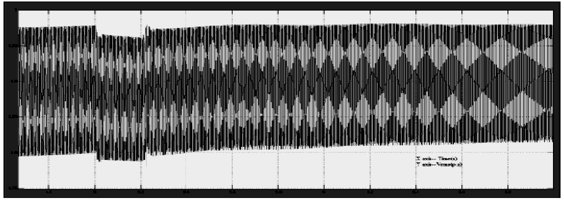

Fig.9 RMS voltage wave form at bus 1

D.GENERATOR SWING CURVES

The following figures shows output swing curve of each generator in before and after fault clearing in transmission line. The swing curve (Del) which is measured with respect to time.

I.First Generator Swing Curve

In this figure swing curve is obtained for under normal condition, with connection of fixed series capacitance in all lines and finally coordination of both fixed capacitor and SSSC is connected in one line. In this figure normal case (green line) has take more time to reach steady state value after fault clearing in system.

In this figure 9 swing curve is obtained for under normal condition, with connection of fixed series capacitance in all lines and finally coordination of both fixed capacitor and SSSC is connected in one line. In this figure normal case (green line) has take more time to reach steady state value after fault clearing in system.

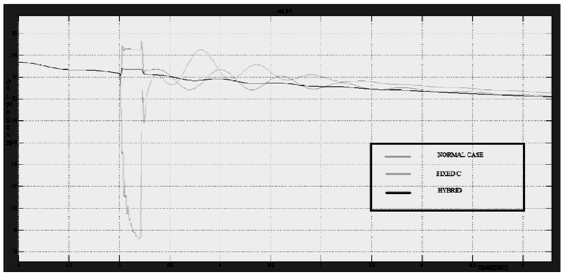

Fig.10 Swing Curve of First Generator

These oscillations will affect the rotor shaft of generator. In next case fixed capacitor (blue line) is connected in line so the oscillations are damp out compare to normal case. In next case connection of fixed capacitance and hybrid (red line) shows oscillations are damp out mostly.

II.Second Generator Swing Curve

The green line shows rotor oscillation for normal case during and after fault clearing in Figure 11.The blue line shows the rotor oscillations for five bus system with series capacitor. The oscillations somewhat damped from normal case. The red line shows oscillations of rotor for test system with hybrid compensation scheme. In this case most of oscillations are damp out compare to normal case of system.

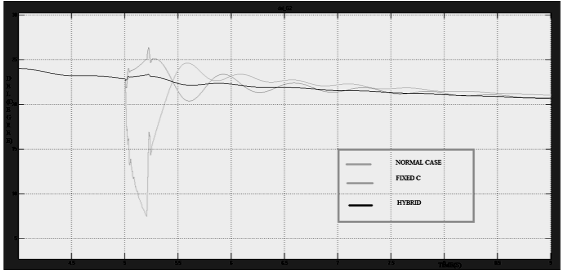

Fig.11 Swing Curve of Second Generator

III.Third Generator Swing Curve

The following diagram shows the output swing curve of third generator. In this figure X axis is time in seconds and Y axis is Del in degree.

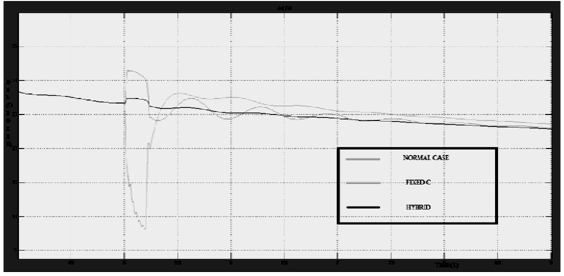

Fig.12 Swing Curve of Third Generator

The green line shows normal case of test system has long period of oscillations and blue line shows test system with series capacitor has oscillation less than normal case. The third case is test system with hybrid scheme which has small oscillations then normal and second case. In the entire case three phase fault is occurred at 5 seconds and cleared at 5.2 seconds. From the above swing curve we can conclude by connecting series fixed capacitor will improve damping of power system oscillations and further connecting coordination of hybrid (fixed capacitor and SSSC) scheme will provide better results.

VII.CONCLUSION

This paper investigates the potential use of supplementalcontrols of a DFIG-based wind farms combined with a phase imbalanced hybrid series capacitive compensation scheme for damping power system oscillations. The capability to increase system damping and improve power transfer capabilities to supply load demand in two load centers using simple controllers are also presented. The results of several case studies have demonstrated the effectiveness of the proposed supplemental controllers in improving the system dynamic performance.The controller coordinates three readily available measurements with modulating control signals into the hybrid compensation scheme in two lines. The results of several digital computer simulations of case studies on a test benchmark show that the controller improves the system.

VIII. REFERENCES

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