ISSN (Online): 2349-7084
GLOBAL IMPACT FACTOR 0.238
ISRA JIF 0.351

INTERNATIONAL JOURNAL OF COMPUTER ENGINEERING IN RESEARCH TRENDS
VOLUME 1, ISSUE 6, DECEMBER 2014, PP 592-596

Novel Decoupling Design for Voltage Control of Wind-Driven IG System

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Abstract: This paper addresses a systematic approach based on Eigen structure assignment to determine the mode shape and transient response of a STATCOM utilized as an exciter for induction generators (IG). A physical control scheme, including four control loops: ac voltage, dc voltage, ac active current and ac reactive current controllers, is pre-specified for the STATCOM. A synthetic algorithm is proposed to embed these physical control loops in the output feedback path. With appropriate oscillation mode design (Eigen structure) in each state variable, the STATCOM active current and reactive current will no longer be governed by the same mode but driven by new respective modes. The simulation and experimental results demonstrated that under various system disturbances, the proposed mode decoupling STATCOM is effective in regulating IG terminal voltage.

Keywords: Eigen structure assignment, induction generator (IG), static synchronous compensator (STATCOM), voltage- sourced inverter (VSI).

I. INTRODUCTION

The conventional reactive power compensation approach employing static Var compensator (SVC), a combination of the Thyristors controlled reactors and the fixed shunt capacitors, has made it possible to provide dynamic reactive power regulation for power systems. However, because the effective reactive power generated by the SVC depends on its terminal voltage, the maximum reactive power output is thus depressed as the terminal bus is subjected to severe voltage drop. Because of the derated capacity, the controller is likely to be saturated and consequently prolongs the response time. Recent advances in reactive power compensation have used the static synchronous compensator (STATCOM), which provides shunt compensation in a similar way to the SVC but utilizes a voltage-sourced inverter (VSI) rather than capacitors and reactors. By properly modulating the VSI output voltage, the VSI output current will be changed simultaneously

II. SYSTEM MODELS AND BASIC STATCOM CONTROL SCHEME

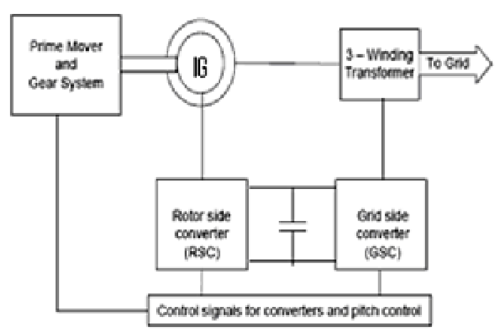

Fig. 1. STATCOM-compensated wind-driven IG system

A. Induction Generator Model: The per unit flux-linkages for the stator and rotor circuits of the induction generator described in - and -axes are as follows :

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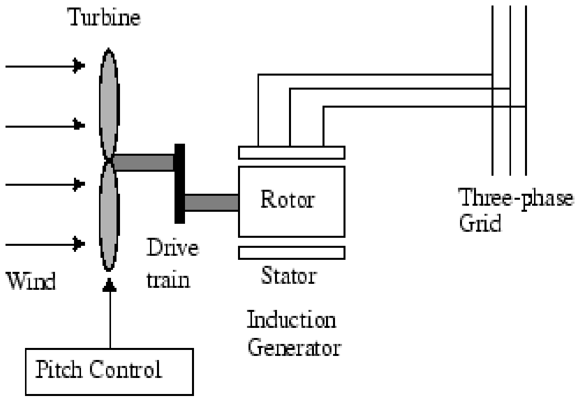

Fig 2. Induction Generator

$$\phi_{ds} = \omega_s \left(\dot{v}_{dL} + r_s i_{ds}\right) + \omega_s \cdot \phi_{qs} \quad (1)$$

$$\dot{\phi}_{qs} = \omega_s \left(v_{qL} + r_s i_{qs}\right) - \omega_s \cdot \phi_{ds} \quad (2)$$

$$\dot{\phi}_{dr} = \omega_s \left(v_{dr} - r_r i_{dr}\right) + \left(\omega_s - \omega_r\right) \phi_{qr} \quad (3)$$

$$\dot{\phi}_{qr} = \omega_s \left(v_{qr} - r_r i_{qr}\right) - \left(\omega_s - \omega_r\right) \phi_{dr} \quad (4)$$

$$Te = \phi_{ds} i_{qs} - \phi_{qs} i_{ds} \quad (5)$$

$$\dot{w}_r^{u} = \frac{1}{2H_T}\left(T_m - T_e - D_T w w_r^{u}\right) \quad (6)$$

B. STATCOM Model: The three-phase STATCOM model can be described in per unit state-space form as follows:

$$\dot{i}_{de} = -\frac{\omega_s r_f}{X_f} i_{de} + \omega_s \cdot i_{qe} + \frac{\omega_s}{X_f}\left(v_{dL} - e_d\right) \quad (7)$$

$$\dot{i}_{qe} = -\frac{\omega_s r_f}{X_f} i_{qe} - \omega_s \cdot i_{de} + \frac{\omega_s}{X_f}\left(v_{qL} - e_q\right). \quad (8)$$

The per unit dc-side circuit equation is

$$\dot{v}_{dc} = \frac{1}{C_{dc}}\left(i_{dc} - \frac{v_{dc}}{r_{dc}}\right) \quad (9)$$

$$v_{dc} i_{dc} = e_d i_{de} + e_q i_{qe}. \quad (10)$$

III.DESIGN OF THE MODE DECOUPLING CONTROLLER

$$\dot{\Delta x}_a = A_a \cdot \Delta x_a + B_a \cdot \Delta u$$
$$\Delta y_a = C_a \cdot \Delta x_a$$

Where

$$\Delta x_a = [\,\Delta x^T \quad \Delta x_c^T\,]$$
$$\Delta y_a = [\,\Delta y^T \quad \Delta x_c^T\,].$$
$$\Delta u = K_o \cdot \Delta y_a$$

A. Controller Synthesis from a Prespecified Feedback Framework

The dynamic IG system model in Section II can be linear zed around an operating point to give the following state space model:

$$\dot{\Delta x} = A \cdot \Delta x + B \cdot \Delta u$$
$$\Delta y = C \cdot \Delta x \quad (23)$$

six additional state variables: $\int \Delta v_{dL} dt$, $\int \Delta v_{dc} dt$, $\int \Delta i_{de} dt$, $\int \Delta i_{qe} dt$, $\iint \Delta v_{dL} dt$

And $\iint \Delta v_{dc} dt$, here in denoted as , were created and merged into (23) as a new state vector . We then have the augmented state space model as follows:

To overcome this problem, two additional control loops, F_d and , F_q (corresponding to states and) were included into the output-feedback control by

Letting $K_{12} = K_{p1} . K_{p3} + F_d$ and $K_{21} = K_{p2} . K_{p4} + F_q$, respectively

IV. EXPERIMENTAL SETUP:

Fig. 3 shows the STATCOM-compensated IG system. The experimental IG is driven by a torque controlled servomotor which emulates a wind turbine. The torque command of the servomotor driver is calculated based on the rotor speed and the mechanical power that emulates the wind power at various wind speed. A three-phase VSI-based STATCOM shown in Fig. 3 was set up in the laboratory to verify the proposed controller

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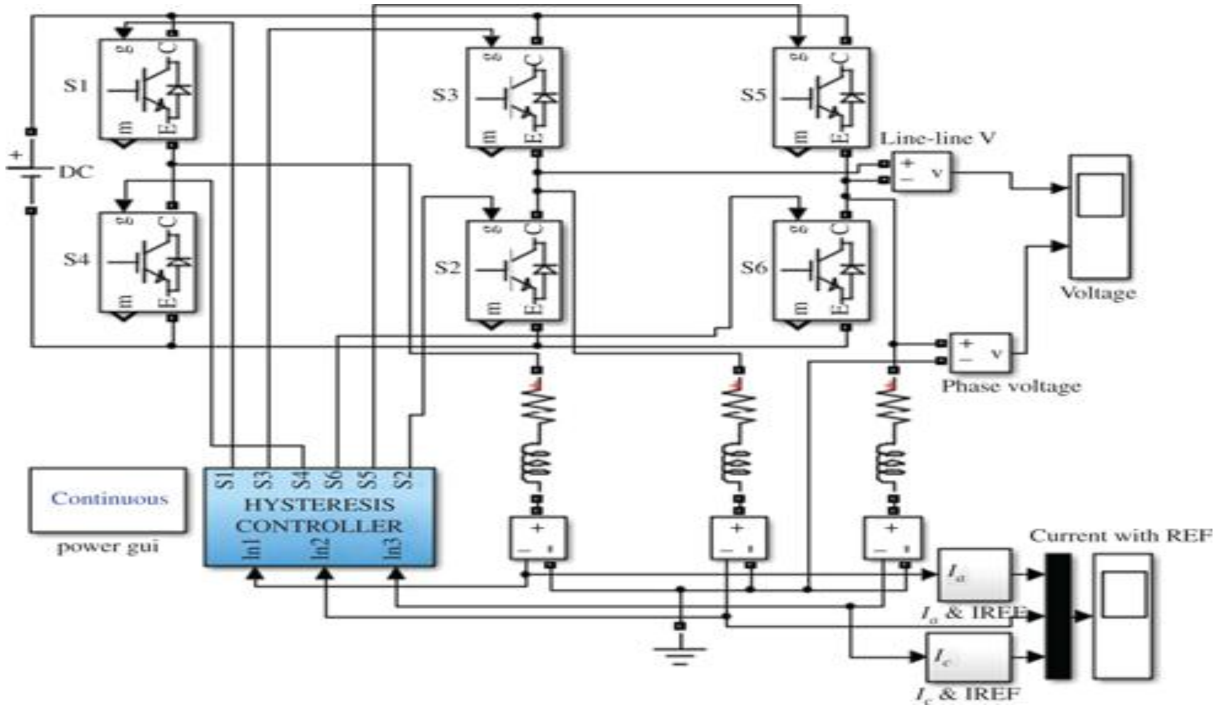

Fig 3. Simulation of three-phase hysteresis controller

A three-phase VSI-based STATCOM shown in Fig. 3 was set up in the laboratory to verify the proposed controller. An intelligent IGBT module with rated at 1200 V, 50 A was used as VSI switches. The load voltages, STATCOM ac currents, and dc voltage were simultaneously sampled using a multi-channel data acquisition system featured a 12-bit high-speed A/D converter and all the control and signal processing arithmetic were performed on a PC platform. To avoid ac harmonic current distortion and high-frequency noise interference stemmed from VSI voltage modulation, care must be taken when designing the low-pass filter prior to the collection of the analog signals. A Sallen-Key filter with a unity dc gain was realized to attenuate the analog input signal in 40 dB from pass band (300 Hz).

V. SUMMARY OF CONTROLLERS CONTROLLER-C1:

Control structure: output feedback. Control design: linear quadratic control

Controller-C2a: Control structure: Neglect feed forward gains (Fd, Fq). Control design: linear quadratic **control Controller-C2b:** Control structure: Neglect feed forward gains (Fd,Fq). Control design: exchange the control gains in d-axis and q-axis derived from controller-C2a.

Controller-C3a: Control structure: Neglect coupling gains (Pd, Pq). Control design: control algorithm proposed by this paper

Controller-C2b: Control structure: Neglect feed forward gains (Pd, Pq). Control design: exchange the control gains in d-axis and q-axis derived from controller-C3a.

VI. SIMULATION AND EXPERIMENTAL RESULTS

A. Dynamic Simulation of the STATCOM-Compensated IG System for Performance Comparisons between Controllers:

To show the advantages of the proposed STATCOM controller over the traditional approach, the dynamic responses are investigated for the studied system in Fig. 1 subject to a three phase short circuit fault starting at and lasting for six cycles at load bus. Three controllers with various control structures and control designs were adopted here for comparison as described in Table I. Because only

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the control structures were presented, the control gains for those systems are derived using the same control algorithm to investigate the system performance under various control structures. To further highlight the need for a control design analytical approach, the control gains of controller C2a in the d-axis and q-axis are exchanged as a new controller C2b. The controller C3b is then determined in the same way as controller C3a.

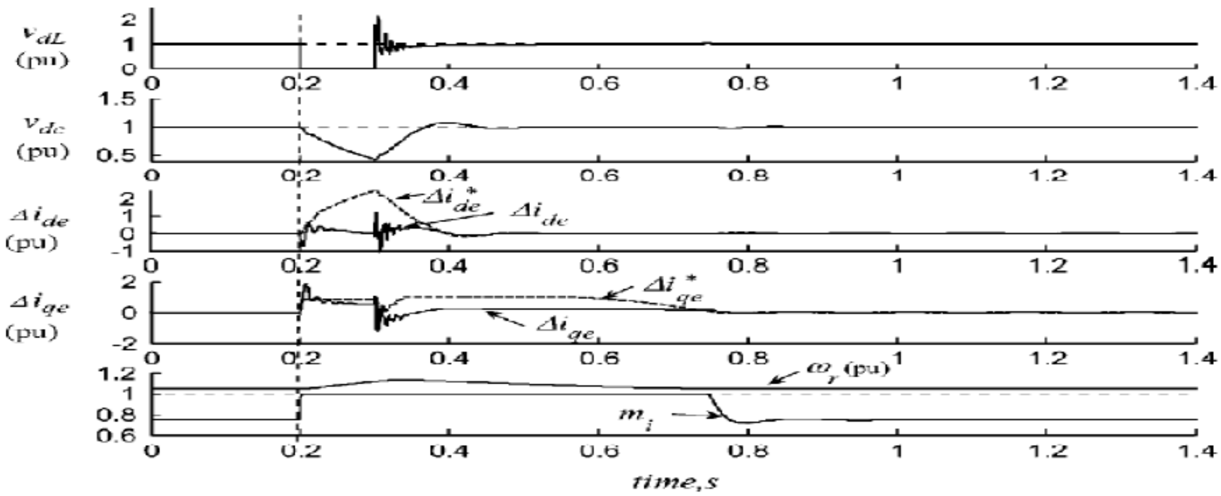

Fig. 4. System responses of the STATCOM-compensated IG system following a 6-cycle short circuit fault with the proposed controller

The modulation index mi would remain at the upper limit until the fault is cleared. It is also observed from the response curves in Figs. 4–7 that based on the proposed controller the dclink voltage, the deviation currents in d-q axes (Dide and Diqe) and the modulation index would quickly return to the original values as compared with controllers C1, C2b, C3a and C3b. Furthermore, an inert c-link voltage response with the controller C3a indicates that the coupling gains should not be left out from. Were presented the control gains for those systems are derived using the same control algorithm to investigate the system performance under various control structures.

VII. CONCLUSION

A mode decoupling STATCOM active and reactive currents control system was presented to regulate the load bus voltage and stabilize the rotor speed for an IG operated in a variable speed wind energy conversion system. The major feature of the proposed controller is that for a given feedback framework, the control gains can be systematically synthesized through the pre-specified shape of the closed-loop response. In this work, the mode shape was determined using Eigen structure assignment which suppresses the STATCOM ac current mode activities in the reactive current and active current; thereby reinforcing the reactive current activities on the load bus voltage regulation. Note that the electromechanical mode damping can also be improved while determining the mode shape of the closed-loop responses.

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