Novel STATCOM Controller for Reactive Power Compensation in Distribution Networks with Dispersed Renewable Wind Energy

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***Abstract*— This paper presents a novel multi-loop dynamic error driven controller based on the decoupled (d-q) voltage and current tracking for modulating the Static Synchronous Compensator (STATCOM) used in distribution networks with dispersed renewable wind energy. The multi loop regulator adjusts the pulse switching pattern of the Voltage-Sourced Inverter (VSI) to ensure effective reactive power compensation and harmonics elimination. The effectiveness of the controller is fully validated under different operation conditions, like load switching and wind velocity excursions.**

Keywords-Reactive power compensation, Power quality, STATCOM, Renewable Wind Energy

I. INTRODUCTION

During the last two decades renewable wind energy has become increasingly popular as a consequence of strong ecological and environmental concerns and appealing economic advantage with regard to a viable and abundant renewable green power scheme especially for remote village and isolated communities. As a consequence of the technological improvement of designs, materials and manufacturing, both the size of wind turbine blades and the volume of commercial production have been steadily increasing to the point where typical peak output is now between 1 and 3 MW [1-2] Furthermore, with economic joint venture and large wind farms emerging (100-300 MW), the distributed/dispersed renewable wind energy needs to be integrated into electrical distribution grid networks.

However, the integration of dispersed renewable wind energy will pose a great challenge to the power quality and system stability in the distribution networks, when the weak nature of the grid in remote areas and uncertainty of wind are taken into consideration. The problem can be severe if wind energy penetration size exceeds 50 % of the distribution feeder capacity Moreover, the injection and propagation of harmonics are some other problems when there are non-linear loads, such as static power converters and arc furnaces connected into the distribution system [3-5].

Conventionally, passive LC filters are used to reduce harmonics and improve the power factor, but they have the demerits of large size, fixed compensation characteristic and series or parallel resonance [6-7]. Recently, the Static Synchronous Compensator (STATCOM), which is based on voltage-source or current-source inverter, plays more and more important roles in reactive power compensation and power quality improvement [8]. So far, numerous control approaches, including sliding mode control, H∞ control, neural network base control, have been applied to STATCOM dynamical control and achieve many good results [6-9]

This paper proposes a novel multi-loop dynamic error driven controller with an auxiliary DC side voltage tracking loop developed by the first author for regulating the STATCOM to ensure effective reactive compensation and harmonic suppression in distribution networks with dispersed renewable wind energy. The performance of the proposed control scheme is finally evaluated by simulation.

II. MODELLING

A. Syestem description

Figure 1 depicts the sample study system with STATCOM interface and the localized dispersed wind Energy Scheme. The system is an 11 kV distribution network with dispersed renewable wind energy, 4 linear loads at power factor 0.8 lagging, motorized load and converter type nonlinear load. Except the wind energy interfaced at bus 2 and the one at the main in-feed point representing an infinite bus as 138 kV, there is no other generation unit in the system. In this case, bus3, bus4, bus5 and bus 6 are meshed in radial structure Two step-down transformers are used at the main in-feed point and at the bus 5 where a 4160V/600kVA motor is connected and a step-up transformer is employed for WECS gird integration.

Also, the STATCOM is connected to the distribution network by a coupling transformer in series with a capacitor of 230 μat bus 5. In order to reduce the cost, a passive L-C filter tuned at the frequency of 3rd harmonics is used in shunt with the STATCOM. Since part of reactive power is compensated by the AC power filter, the power capacity of the Voltage Sourced Inverter (VSI) can be reduced and hence the cost is lower. [10] The coupling transformer in series with the

**Currently a visiting scholar at the University of New Brunswick)* capacitor can help avoid the high frequency resonance amplification between the STATCOM and the passive power filter.

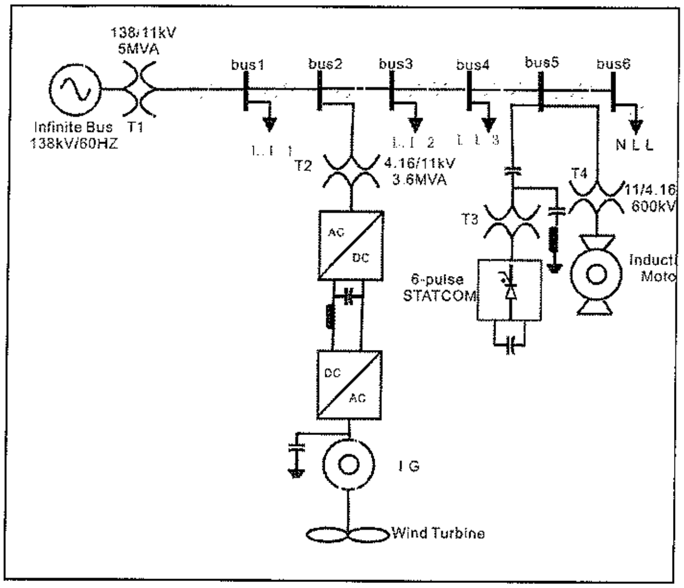


Fig 1

B. *Wind Energy Conversion Schemes*

The wind turbine model is developed based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine [10]. The mechanical power captured by a wind turbine depends on its power utilization coefficient Cp for a given wind velocity v, and can be represented by:

$$Pm=1/2Cp*S*\rho*v3 \quad (1)$$

where, 'S' is the area swept by the rotor blades, 'v' is the wind velocity and 'ρ' is its density. Coefficient Cp is a nonlinear function of two magnitudes: the pitch angle β of rotor blades and tip speed ratio λ, which is the quotient between the tangential speed of the rotor blade tips and the undisturbed wind velocity [11]. In this research, a constant pitch angle β is used and the value is assigned as 0. The based wind speed is selected at 12 m/s and the base rotational speed is set at 1.2 times of the generator synchronous speed.

Asynchronous generators with squirrel cage are by far the most common type of generator for mechanical-electrical energy conversion in wind power plants, since they are remarkable for their extremely simple but robust construction. Because of their high operating security, they can be possibly with rough handling. However, the asynchronous generator can only deliver real power to the grid, but it need reactive power supported by the grid or capacitor bank in parallel connected to its stator terminals. As a result, it may potentially bring heavy reactive power burden to the grid.

When it comes to grid integration of dispersed renewable energy, classic AC-DC-AC converters are normally used to adjust the generator output voltage and frequency. In this paper, the three phase full wave uncontrolled bridge functions as the rectification stage and a pulse-width-modulated (PWM) switching strategy is employed to guarantee a nearly stabilized voltage and minimal frequency excursions caused by the stochastic temporal nature of wind variations and changes in prime mover power from wind generation scheme.

III. MULTI-LOOP ERROR DRIVEN CONTROLLER

The novel control scheme developed by the First Author is based on the decoupled current control strategy using both direct and quadrature voltage components of the STATCOM AC output voltage. The proposed controller is implemented as shown in Fig. 2.

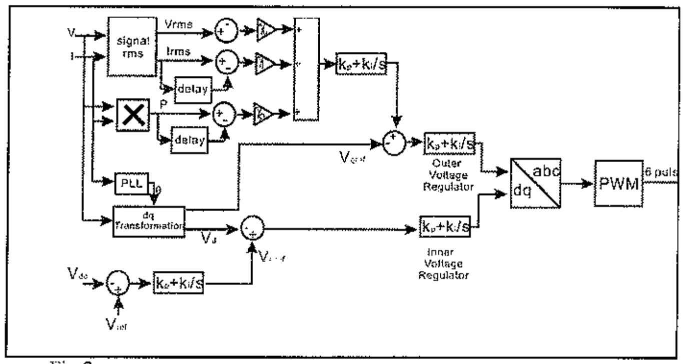


Fig 2

The phase angle of the STATCOM output voltage can be obtained by a Phase Locked Loop (PLL) and it is an important synchronizing signal when transforming between the three phase voltage command and direct-quadrature voltage command. [12]

The main regulation function is achieved by the tri-loop error driven controller, which provides the reference quadrature voltage (V_{qref}) for the outer voltage regulator. The tri-loop error driven controller comprises a voltage stabilization loop, a current dynamic error tracking loop and a dynamic power tracking loop, which function as detecting the dynamic oscillations of the voltage, current and power at the bus of concern. [13] The total error signal (E_t) is the sum of all three basic loops and it is fed into a PI controller with k_p=0.1 and k_i=1 to generate quadrature voltage reference signal (V_{qref}).

In addition, an auxiliary control loop is implemented to control the DC capacitor voltage rate variations, which depends on the reactive current flows through the STATCOM. [14] The error produced by comparing the measured DC voltage with a constant DC voltage reference signal is also regulated by a PI controller with k_p=1 and k_i=5, whose output will be used as direct voltage reference siganl (V_{dref})

Finally, the outputs of the outer voltage regulator and inner voltage regulator, V_q* and V_d* respectively, are employed to produce the modulation reference signals of the Pulse-width Modulation. 6 pulses generated from the PWM controller are used to firing the switching devices in the VSC and the magnitude and direction of reactive power flow can be regulated.

IV. DIGITAL SIMULATION

The proposed novel FACTS based schemes for distribution networks with distributed/dispersed renewable wind energy are digitally simulated under MATLAB/SIMULINK software environment. Discrete simulation mode with a sample time of 0.1 milliseconds will be applied to the simulation of the controller to accelerate the simulation speed.

The digital simulation is carried out with and without the controlled STATCOM located at Bus5 for 0.8 seconds in order to show its performance in voltage stabilization, harmonic reduction and reactive power compensation. The dynamic performance of the proposed STATCOM controller is tested under the following disturbance sequence:

At t = 0.1second, induction motor is removed at bus 5 for a duration of 0.1 seconds;

At t = 0.3second, linear load is removed at bus 4 for a duration of 0.1 seconds;

At t = 0.5 second, wind speed suddenly decreased to 9 m/s for a duration of 0.1 seconds;

At t = 0.6second, wind speed suddenly increased to 21 m/s for a duration of 0.1 seconds;

At t = 0.7 the system was recovered to its initial state.

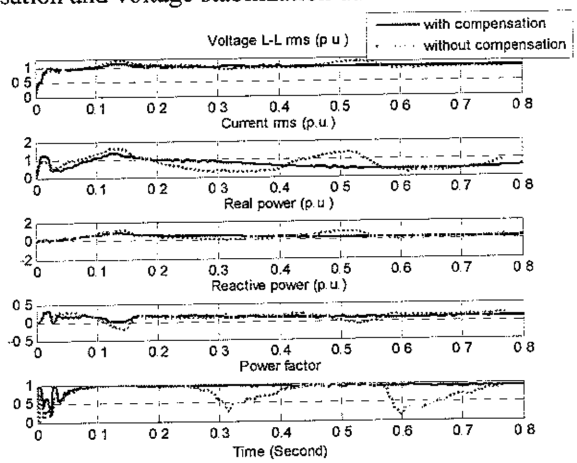
Comparison of the total harmonic distortion (THD) of the bus voltage at each bus was made for the cases with and without controlled STATCOM as shown in Table 1. The dynamic responses of voltage, current, real power, reactive power and power factor at each bus are displayed from Fig. 3 to Fig. 8

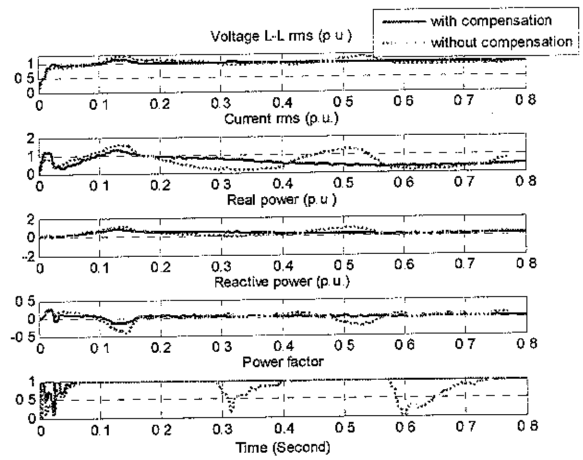
TAB 1 THE TOTAL HARMONIC DISTORTION OF BUS VOLTAGE AT EACH BUS

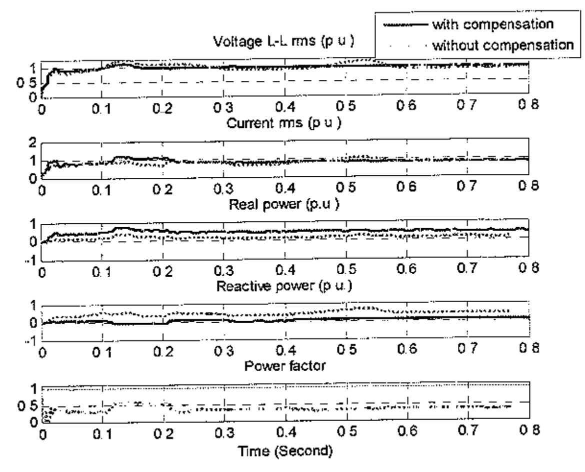
Bus Number	With Controller	Without Controller
1	4.87%	8.92%
2	5.58%	10.22%
3	6.33%	11.58%
4	4.00%	11.27%
5	3.14%	11.39%
6	4.10%	12.01%

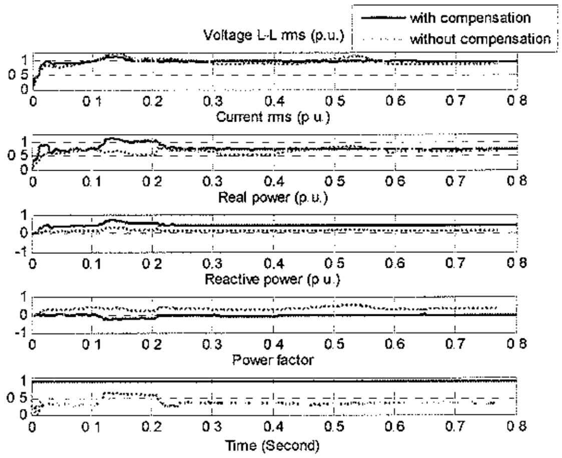
V. CONCLUSION

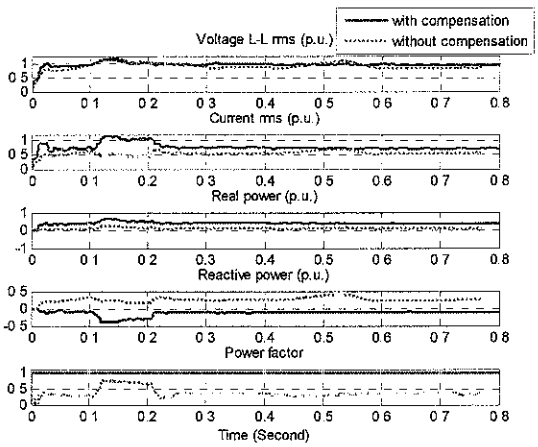
A novel control method for effectively controlling STATCOM used in distribution networks with dispersed renewable wind energy was proposed. This method was verified by MATLAB/SIMUKINK/SIM-POWER digital simulation. The simulation results indicated that the STATCOM controlled by the proposed controller is effective for voltage stabilization, power factor correction and harmonic suppression. The proposed scheme can be extended and tested in other distributed/dispersed renewable energy interface systems and can be easily modified for other specific compensation and voltage stabilization duties.

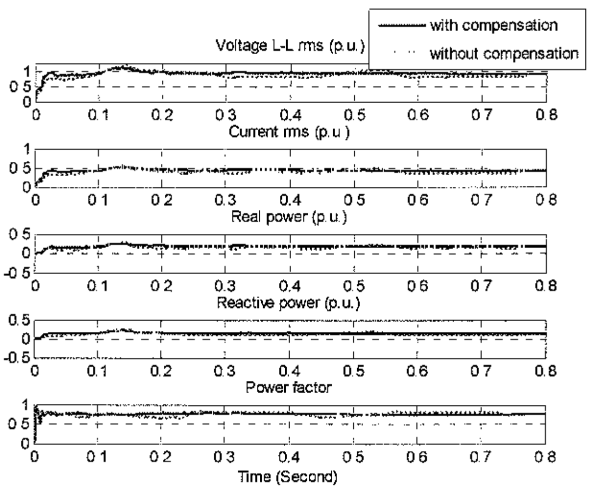












ACKNOWLEDGMENI *(HEADING 5)*

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