A Novel Active Filter Strategy for Power Mitigation and Quality Enhancements in a Stand-Alone WECS

Ismail H. Altas[1], Emre Ozkop[1], and Adel M. Sharaf[2]

[1]Dept. of Electrical and Electronics Engineering, Karadeniz Technical University, Turkey
ihaltas@altas.org, eozkop@ktu.edu.tr
[2]Energy Research Group-UTT, University of Trinidad and Tobago, Trinidad
adel.sharaf@utt.edu.tt

Abstract

In this study, a novel sinusoidal PWM Switched Power Filter (SPF) and Dynamic Voltage Compensation (DVC) scheme using VSC/SMC/B-B controller for power mitigation and quality enhancements in medium power distribution systems are simulated. The system is based upon a stand-alone Wind Energy Conversion Scheme (WECS) using an induction generator and the proposed system control mechanisms, which are digitally simulated by using the MATLAB/Simulink/SimPowerSystems software.

1. Introduction

The demand for electrical energy and fossil fuel has increased continuously during the last two or three decades with energy shortage, dwindling world fossil fuel and non-renewable natural resources. Burning fossil fuels provides about three quarters of the world's energy. As a result of the burning, green house gases occur. Green house gases are responsible for climate change. Climate change, high oil price, limited world oil reserves, water and air pollution and rising environmental concerns are the main push ups for the search for new sustainable energy. Renewable sources such as the wind energy, effectively uses natural resources, which are naturally replenished.

Wind energy is the most attractive solution to world's energy challenges. It is clean, infinite, no charge and no tax. Wind energy is rapidly developing into a mainstream power source in many countries of the world, with over 60,000 MW of installed capacity worldwide and an average annual market growth rate 28%. Wind energy could provide as much as 29% of the world electricity needs by 2030, given the political will to promote its large scale deployment paired with far-reaching energy efficiency measures [1].

A wind energy system is dependent upon air flows. These wind conditions are always subject to local wind variations, gust changes and ambient temperature and pressure. Therefore, these situations cause sudden variations in the generator voltage levels and energy supplied from wind [2-3]. A number of the theoretical studies have been made with the aim to establish the energy capture benefits associates with variable speed operation of WECS [4-6].

Electric utilities and end users of electric power are becoming increasingly concerned about energy future and also the electric power quality. There are reasons of increased concern about the power quality. Load equipments with microprocessor-based controls and power electronic devices used in the present are more sensitive to power quality variations. To increase the system efficiency, high efficiency devices based on power electronics equipments have been increasingly used in many applications. This causes increasing harmonic levels on power systems and concerns about the future impact on system capabilities; furthermore, consumer awareness about power quality has been grown and the consumer has wanted the utilities to improve the power quality utilized. On the other hand, there are a lot of interconnected subsystems in a network. So if there is any fault in the subsystems, there will be disturbances, disruptions and the other effects, which decrease the power quality in the system.

2. Power quality

The common concerns of power quality are long duration voltage variations (overvoltage, under voltage, and sustained interruptions), short duration voltage variations (interruption, sags (dips), and swells), voltage imbalance, waveform distortion (DC offset, harmonics, interharmonics, notching and noise), voltage fluctuation (voltage flicker) and power frequency variations [7, 8]. Most reasons of these concerns stems from loads connected to electric supply systems.

There are two types of loads, linear and nonlinear. Motors, heaters and incandescent lamps are examples of linear load produce a current proportional to the voltage [9]. The nonlinear load uses high-speed electronic power switching devices to convert the AC supply voltage to a constant DC voltage used by the internal circuits. During converting, harmonic currents on the power grid are generated. Producing harmonic currents at the point of common coupling (PCC) cause several adverse effects such as a line voltage distortion at PCC, equipment overheating, transformer derating, overheating, failure of sensitive electronic equipment, interference with telecommunication systems due to harmonic noises, flickering of fluorescent lights, erratic operation of circuit breakers and relays, fuse blowing and electronic equipment shutting down, conductor overheating due to triplen harmonics in 3-phase 4-wire system, increased RMS current [10-12]. Personal computers, fax machines, printers, UPS, adjustable speed drives, electronic lighting ballasts, ferromagnetic devices, DC motor drives and arcing equipment are examples of nonlinear loads.

The IEEE standard 519-1992 establishes recommendations for harmonic control in power systems [13]. It specifies harmonic current limits at the point of common coupling as well as the quality of the voltage that the utility must furnish the user. The European harmonic standard, IEC-555, proposed absolute harmonic limits for individual equipment loads [14]. One of the solutions to minimize the effects of harmonic distortion in a power system is to use filters. There are two types of filtering, active and passive filtering. There are some limitations of passive filters. A design for specific harmonic component, undesirable series and parallel resonances, large filters components heavy and large in size, increased cost and losses, not suitable for changing system conditions are some limitations of passive filters [15]. Due to the above drawbacks of passive filters have attracted great attention and are replacing with active filters, which have many superiorities and types [16, 17]. The advantages of the simplicity and lower cost of passive filters with the higher performance of active filters to reduce harmonic distortion in power systems constitute hybrid filters. The main purpose of hybrid active/passive filters is to reduce initial cost and to reduce filter rating [18].

There are many different hybrid filter types. Some of them are built as a combination of active series and passive shunt filters, active series and active shunt filters, active and passive shunt filters, and active filter in series with shunt passive filters.

3. System description

A Standalone Wind Energy Conversion Scheme (WECS) using induction generator (IG) is studied in this paper under a time sequence of Load Excursions and Wind variations. The standalone WECS connected to the local load bus over a radial transmission line comprising the following main components, as shown in Fig. 1.

- •Wind turbine
- •Gear box
- •Step up and step down transformers
- •Distribution power lines
- •Induction generator
- •Stabilization interface scheme and stabilization controller
- •The hybrid electric load.

The hybrid composite linear, nonlinear and motorized loads are shown in Fig. 2. Each component of the proposed WECS shown in Fig. 1 is modeled in Matlab/Simulink [19] environment.

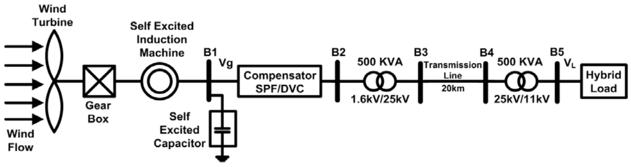

Fig. 1. Sample study 500 kVA wind energy conversion scheme

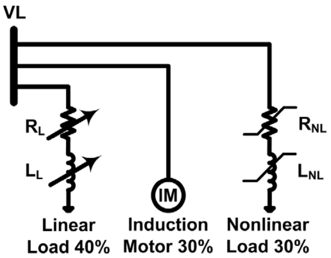

Fig. 2. Hybrid composite linear, nonlinear and motorized load model

The parameters of the proposed controller are selected by a guided trial and error off-line simulation to ensure the minimum induction load and generator voltage excursion for any large wind and load variation.

The standalone WECS sample study system unified AC system model parameters, comprising the induction generator, wind turbine, combined hybrid load, and controller parameters are all given in Appendix. The Matlab/Simulink functional model of full AC study system is given in Fig. 3.

The sample WECS standalone scheme was subjected to severe combined sequence of load switching/load variation/load excursion and wind speed variation and gusting. The novel sinusoidal PWM Switched Power Filter (SPF) and Dynamic Voltage Compensation (DVC) scheme is shown in Fig. 4.

The system real time dynamic response for a combined load/wind excursion time sequence as follows:

t=0.01s Linear Load excursion applied, +40%
t=0.03s Linear Load excursion removed, +40%
t=0.05s Wind Speed excursion applied, -20%
t=0.07s Wind Speed excursion removed, -20%

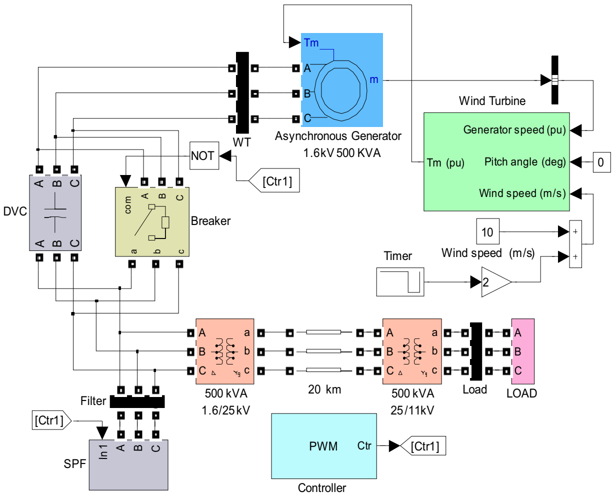

Fig. 3. The Matlab/Simulink functional model of full AC study system

Fig. 4 depicts the Pulse Width Modulator (PWM) model used with duty cycle ratio α_D control at a constant switching frequency, $f_{s/w}$=200Hz .

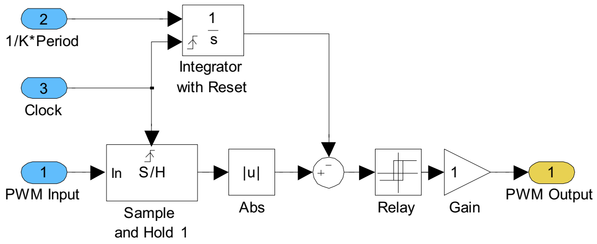

Fig. 4. Pulse Width Modulator (PWM) model

4. Novel control design

The paper presents a study of four control strategies for a Standalone Wind Energy Conversion Scheme (WECS) using induction generator (IG).

4.1. VSC/SMC/B-B controller

The global error in the VSC/SMC/B-B controller is described as follows:

$$e_t(t) = \gamma_v e_v(t) + \gamma_I e_I(t) \tag{1}$$

where

$e_v = V_{g(ref)} - V_g \, , e_I = I_{g(ref)} - I_g \;\; \gamma_\omega = 0.6 \, , \gamma_I = 0.1$

The slope of the sliding surface is designed as:

$$\sigma = \beta e_t + \alpha \frac{de_t}{dt} \tag{2}$$

with adaptive term

$$\beta = \beta_0 + \beta_1 |e_t| \tag{3}$$

where

$\beta_0 = 1, \beta_1 = 1, \alpha = 1e^{-14}$, and $|e_t| = \sqrt{(\gamma_v e_v)^2 + (\gamma_I e_I)^2}$

The control is an on-off logic; that is:

When $\sigma > 0, V_c = 1$, and when $\sigma < 0, V_c = 0.1$

Here, a ramp-up control is applied to V_c to generate $V_{control}$

The proposed system control mechanism is digitally simulated by using the MATLAB/Simulink/SimPowerSystems software. VSC/SMC/B-B Controller system block diagram is shown in Fig. 5.

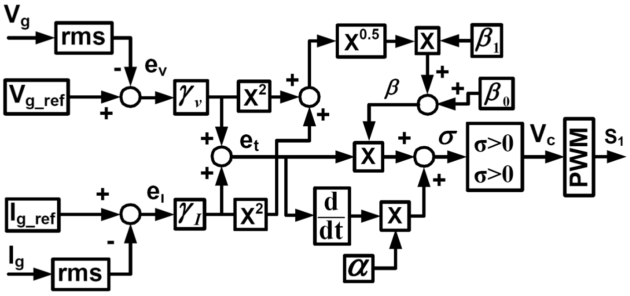

Fig. 5. VSC/SMC/B-B controller block diagram

5. Simulation results

The real time dynamic responses of the system for a combined load/wind excursion are obtained for the following time sequences.

t=0.01s Linear Load excursion applied, +40%
t=0.03s Linear Load excursion removed, +40%
t=0.05s Wind Speed excursion applied, -20%
t=0.07s Wind Speed excursion removed, -20%

The WECS dynamic performance is compared for the two cases, with and without the novel sinusoidal PWM SPF and DVC scheme using the controllers.

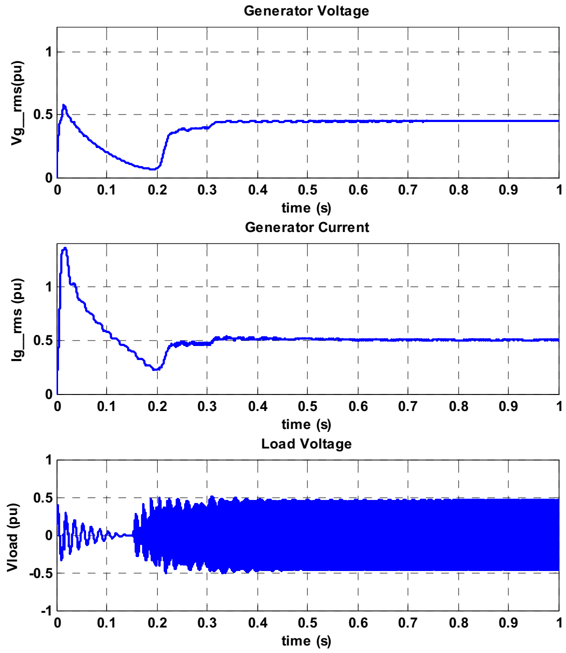

Fig. 6. The WECS dynamic performance without controller

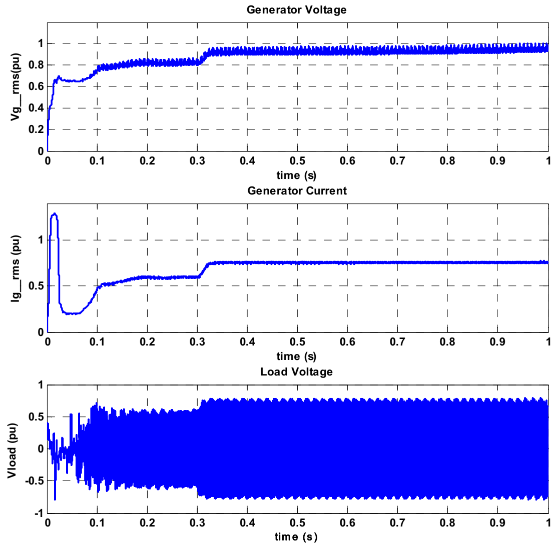

Fig. 7. VSC/SMC/B-B controller results

6. Conclusion

The paper presents VSC/SMC/B-B controller topology for power mitigation and quality enhancements in medium power distribution system, a stand alone wind energy conversion system. Improvement in generator voltage, current and also load voltage is seen with the VSC/SMC/B-B controller. This control scheme is extremely effective in ensuring voltage stabilization and enhancing power/energy utilization under severe load and wind prime mover/wind velocity excursion. A VSC/SMC/B-B controller is designed and employed in this application.

7. Appendix

7.1. Wind Turbine Model (Quasi-static model

$$T_W = \frac{1}{2\lambda}\rho ARC_P V_W^2 = \frac{1}{2\omega_W}\rho AC_P V_W^3 = k\frac{V_W^3}{\omega_W}$$

Where

ρ is the specified density of air (1.25kg/m^2), A is the area swept by the blades, R is the radius of the rotor blades, C_P is power conversion coefficient, λ is the tip speed ratio ω_W is the wind turbine velocity in rpm, and k is equivalent coefficient in per unit (0.745)

7.2. Induction Generator

3 phase, 2 pairs of poles, V$_g$=1.6 kV (L-L), Sg=500 KVA, C$_{self}$=150uF/Phase, $L_m = 3.5, H = 2, F = 0, p = 2$

$$R_s = 0.016, L_{ls} = 0.06, R_r^{'} = 0.015, L_{lr}^{'} = 0.06$$

7.3 Combined Hybrid AC Load model (@ V=1.0 pu)

Linear PQ Load (40%)

$$P_L = 0.4pu, Q_L = 0.4pu$$

Nonlinear (Voltage-dependent type) PQ Load (30%)

$$P = P_o(\frac{V_g}{V_{go}})^{\alpha}, Q = Q_o(\frac{V_g}{V_{go}})^{\alpha} \quad V_{go} = 1.0pu,$$

$$P_o = 0.3pu, Q_o = 0.3pu, \ \alpha = 2-3, \beta = 2-3$$

Three phase squirrel cage induction motor inrush type PQ load (30%)

Power: $S_M = 0.3pu$

Stator resistance and leakage inductance:

$$R_s = 0.0201pu, L_{ls} = 0.0349pu$$

Rotor resistance and leakage inductance:

$$R_r = 0.0377pu, L_{lr} = 0.0349pu$$

Magnetizing inductance: $L_m = 1.2082pu$, Pole pairs: 2

7.4. Per unit base values used

S$_{base}$=500KVA, V$_{base}$=1.6kV (L-L)

7.5. Distribution-collection line (3 phase)

$$V_{LL} = 25kV, Length\ l = 20km$$

$$R_1 = 0.01273\ \Omega/km, R_0 = 0.3864\ \Omega/km$$

$$L_1 = 0.9337\ mH/km, L_0 = 4.1264\ mH/km$$

$$C_1 = 12.74\ nF/km, C_0 = 7.751\ nF/km$$

7.6. SPF and DVC parameters

$$C_s = 100uF, R_f = 0.1\Omega, L_f = 15mH, C_f = 500uF$$

7.7. PWM

$$T_{s/w} = 1/f_{s/w}, f_{s/w} = 200Hz, \alpha_D = \frac{t_{on}}{t_{s/w}} = 0.5$$

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