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POWER QUALITY IMPROVEMENT IN Z-SOURCE INVERTER FED WIND POWER GENERATION SYSTEM

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Abstract—This paper deals with power quality improvement of a Z-source inverter fed wind power generation system, using hybrid active power filter. The Z-source inverter is used as power electronic interface for voltage and frequency control. However, it introduces higher order harmonics into the system; the use of non-linear load also has inherent problem of poor power quality. To overcome the problems of harmonics and reactive power hybrid active power filter is introduced between system and load. The proposed wind power generation system is modeled in MATLAB / Simulink environment. Improved performance of the system after inclusion of hybrid active power filter is demonstrated through comparison on various indices like THD, reactive power compensation, power factor etc.

Index Terms—Wind power generation system, Z-source inverter, Power quality, hybrid active power filter, harmonics and reactive power.

I. INTRODUCTION

Wind power generation system has gained most popularity among all renewable energy technologies in last few decades. In 1980’s the wind turbine installations with kW ratings were installed, in subsequent years some MW rated wind turbine installations came in existence [11]. With time, it became unavoidable to observe the impact of wind power generation system on overall transmission system.

The wind power generation system injects power to the grid/load at varying frequency due to varying nature of input i.e. wind. This variable power further propagates into the integrated power system, resulting in deteriorated power quality of the system. Therefore it is necessary to condition the power output from wind power generation system, before feeding it to the grid/load [8-9]. Power electronic converters play an important role in conditioning the power output from the wind power generation system. Due to fast development in power electronic technologies with increased control and decreased size and cost; also for constant power demand imposed by consumers, applicability of power electronic converters in WPGS is further increased [26-28].

The power electronic converter acts as an interface between the generator and the grid/load. A number of configurations of power electronic interface are available in the literature; three major common and upcoming power electronic devices as used with WPGS are; rectifier-inverter interface (RII), rectifier-boost converter-inverter interface (RBCII) and Z-source inverter interface (ZSII) [1-3,10,12,25]. In general, shoot through is avoided in rectifier-inverter interface using voltage source inverter to avoid short circuit in switching devices. With boost converter inverter the requirement of additional power electronic devices and their control makes them complex to be implemented. The Z-source inverter offers superiority over conventional RII and RBCII with additional shoot through voltage across Z- source capacitor [4-7]. With this inverter output power is available with reduced distortion for the reason of elimination of dead beat period. This paper deals with Z-source inverter employed in WPGS with efficient control and less complexity.

Although sufficient literature is available in wind power generation system employing power electronic interface for voltage and frequency control [16,18]. But the power quality problems are not addressed completely. In wind power generation system using variable speed wind turbine the reactive power and harmonic distortions are present at the generator output, that too varying with varying wind conditions. Purpose of power electronic interface is to maintain the output voltage sinusoidal, but it does not comply with IEEE-519 standards to keep total harmonic distortion in system voltage and load current within specified limits [21-24].

Wind power generation system behaves like a current fed type load for its transmission losses due to distant or isolated location. Hence the parallel hybrid of passive and shunt active power filter is found suited to improve the system performance. Passive filter takes care of lower order harmonics with no dependence on system rating. Shunt active power filter compensates for reactive power generated due to variation in system voltage and injects higher order harmonic currents of opposite polarity to that of the system [13-15,17,19-20]. Improvement in the performance of WPGS with HAPF is demonstrated under steady state and during transients using simulation model.

II. Z-SOURCE INVERTER FED WIND POWER GENERATION SYSTEM

A complete model of Z-source inverter fed WPGS is shown in Fig.1. A variable speed wind turbine, an aerodynamic converter and permanent magnet synchronous generator make the power generation from wind possible. The power electronic interface provides voltage and frequency control to the power output from WPGS. The proposed Z-source inverter is an X-shaped impedance network, composed of two inductors and two capacitors, included at the DC side of the inverter as shown in Fig.2. The rectifier rectifies generator output voltage and it is inverted by Z-source inverter. The inverter produces sinusoidal voltage greater than the input voltage by shoot – through duty cycle control.

The Z-source inverter optimizes the power output better than other VSI types, as voltage source inverter provides control only as active and zero states, while with Z-source inverter additional control in shoot through intervals (occurrences of ON state of same phase leg switches simultaneously) is also possible. The pulse width modulation technique is used to provide control to the inverter for constant voltage and frequency output.

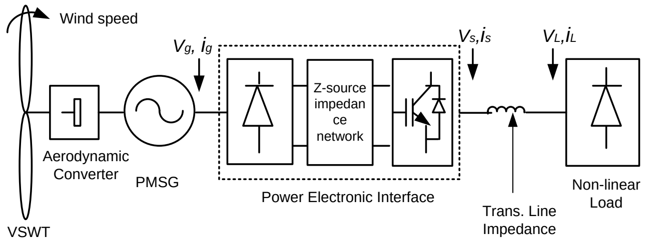

Fig.1 Schematic diagram of wind power generation system

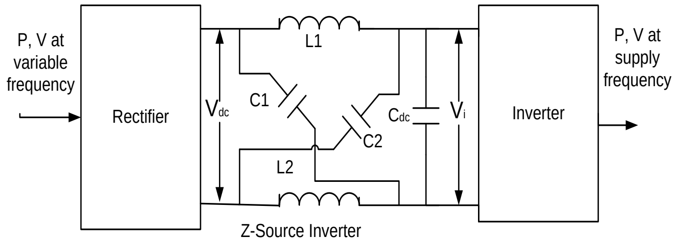

Fig.2 Schematic diagram of Z-source inverter interface

The diode bridge rectifier converts variable frequency voltage into constant voltage output. The voltage at the rectifier output is expressed as -

$$V_{dc} = (3\sqrt{3}/\pi)v_{ph}cos\alpha \qquad (1)$$

The series inductance and shunt capacitance act as input filter, current and voltage ripples are reduced by using these components. DC link current is given by-

$$di_{dc}/dt = (1/L_{dc})\left(V_{dc} - v_{ph}\right) \qquad (2)$$

Where L_{dc} is series inductance of Z-source impedance network.

The DC link voltage across the Z-source inverter may be expressed as-

$$V_i = \left(T/(T_1 - T_0)\right)V_{dc} \qquad (3)$$

Where T_1 - shoot through time period, T_0 - non-shoot through time period and T - total time period.

Inverter output peak voltage is given as-

$$V_{inv} = m_a\left(T/(T_1 - T_0)\right)V_i/2 \qquad (4)$$

Where m_a - modulation index of PWM inverter.

Voltage across capacitors is calculated as-

$$V_c = V_{c1} = V_{c2} = \left(T_1/(T_1 - T_0)\right)V_{dc} \qquad (5)$$

From above equation V_i may be rewritten as -

$$V_i = 2V_c - V_{dc} \qquad (6)$$

Current ripples in the inductor may be expressed as-

$$\Delta I = T_1T_0/(T_1 - T_0)V_{dc}/2 \qquad (7)$$

Now shoot through voltage for inverter signals is calculated as-

$$V_{sc} = T_1/T = V_c/(2V_c - V_{dcr}) \qquad (8)$$

Where V_{dcr} - reference DC link voltage for inverter signal PWM generator.

III. Performance of Z-source Inverter Interface fed WPGS

The Simulation study of Z-source inverter fed WPGS is done, when connected to non-linear load. Various parameters selected for Z-source inverter interface for WPGS for compensation capacity of 10 KVA are as follows-

V_s = 3-Φ, 400 V, f = 50 Hz

Z-source impedance network –

$L_1 = L_2$ = 0.2 mH, $C_1 = C_2$ = 1800 μF

DC link capacitance C_{dc} = 2000 μF

Figure 3(a) shows the simulation results of generator voltage (v_g) – generator current (i_g), DC link voltage (v_{dc}), inverter voltage output (v_{inv}), source voltage (v_s) – load current (i_L) and source voltage (v_s) – source current (i_s) waveforms during steady state, for Z-source inverter fed wind power generation system, while Fig.3(b) shows active power (p) and reactive power (q) waveforms for above mentioned system.

From the simulation results (Fig.3-4), it is observed that the system voltage becomes almost sinusoidal at the inverter output with dominant fifth order harmonics, while the source current having non-linear characteristic still need be conditioned. Reactive power consumption is in range of 2208.11 VAr having transients and power factor of 0.9378. With Z-source inverter it is observed that the source voltage is conditioned better compared to other interface devices available in literature, however need for power quality improvement is still felt to improve the performance of WPGS for reduction of harmonics and to compensate reactive power.

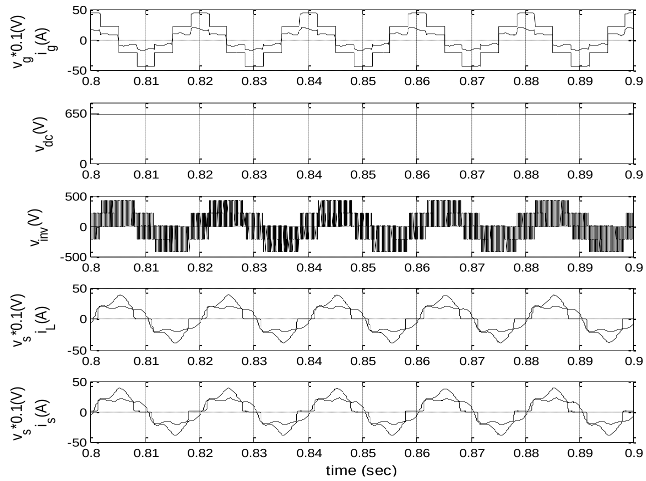

Fig.3 (a) Steady state response of ZSI fed WPGS

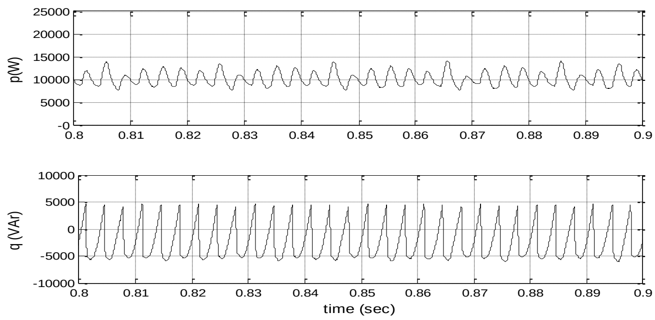

Fig.3 (b) Active power and reactive power waveforms for ZSI fed WPGS

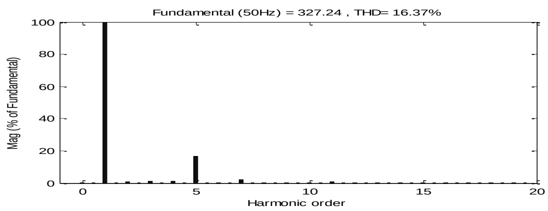

Fig.4 (a) Source voltage (v_s) frequency spectrum, for ZSI fed WPGS

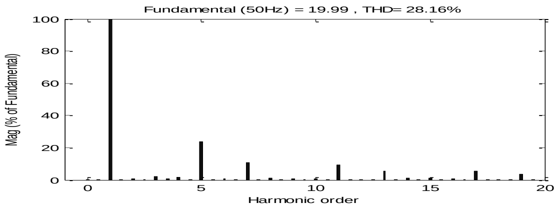

Fig.4 (b) Source current (i_s) frequency spectrum, for ZSI fed WPGS

IV. ZSI FED WPGS WITH HYBRID ACTIVE POWER FILTER

In wind power generation system the reactive power and harmonic distortions are present at the generator output, changing with varying wind conditions. Purpose of Z-source inverter is to maintain the output voltage sinusoidal, but it does not comply with IEEE-519 standards to keep total harmonic distortion in system voltage and load current within specified limits.

When wind power generation system supplies electrical power to non-linear load, the system performance shows much severe harmonic and reactive power conditions. If hybrid active power filter is connected between wind power generation system and non-linear load, it maintains the output power constant, along with reactive power compensation and also keeps harmonic distortion within specified limits. Hybrid active power filter comprise of shunt active power filter and passive filter tuned to lower order dominant harmonic frequencies.

A voltage source inverter is used as shunt active power filter, for which input DC voltage is essentially constant and independent of the load current drawn. A large capacitor placed across the DC input line of the voltage source inverter, ensures that any switching event within the inverter do not significantly change the DC input voltage. On the AC side of the voltage source inverter, ripple filter is connected, which compensates for the ripples generated in the active power filter current due to fast switching of MOSFET's.

The voltage across DC link capacitor is sensed and compared with the reference voltage; and the error signal processed in the PI controller. The controller provides

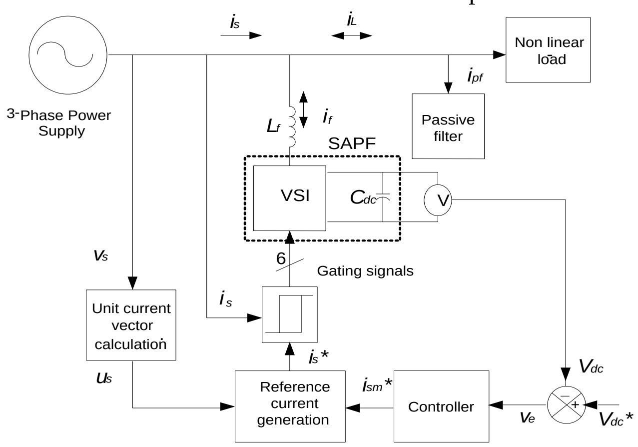

Fig.5 Schematic diagram of hybrid active power filter

conditioned signals to gating pulse generator. The hysterisis band current controller selected as pulse generator sends triggering pulses to MOSFET's of the VSI bridge. Shunt active power filter supplies compensating harmonic current to the load in response to the triggering pulses. Shunt active power filter is also responsible to supply the losses occurring in the system such that the system current remains sinusoidal with near unity power factor maintained. Shunt active power filter is usually designed for higher current ratings to resolve multiple power quality problems, thus it does not constitute an economic solution to improve power quality of high power applications. Hybrid active power filter shown in Fig.5, is chosen as a combination of low cost passive filter and low rating shunt active power filter. Passive filter takes care of lower order harmonics with no dependence on system rating. Active power filter compensates reactive power consumed by load and injects higher order harmonic currents of opposite polarity to that of system.

V. PERFORMANCE OF ZSI FED WPGS WITH HYBRID ACTIVE POWER FILTER

A hybrid active power filter is connected between Z-source inverter fed WPGS and load; simulation response obtained with the same is shown in Fig.6. Parameters selected for hybrid active power filter are given below-

Shunt active power filter-
DC link parameters –
V_{dc} = 650 V, R_{dc} = 10 KΩ, C_{dc} = 2200 μF
Ripple filter –
R_c = 0.1 Ω, L_c = 2 mH, PI controller - K_p = 0.11, K_i = 1.2
Passive filter-
Fifth tuned harmonic filter-
R_5 = 0.1Ω, L_5 = 4 mH, C_5 = 100 μF
Seventh tuned harmonic filter-
R_7 = 0.1Ω, L_7 = 2.7 mH, C_7 = 80 μF.

In Fig. 6(a) - 7(a) various waveforms, for wind power generation system with hybrid active power filter switched on at 0.2 sec are shown. The DC link voltage of shunt active power filter settles to final value within 0.05 sec. with system voltage THD reduced to 1.98 % and load current THD to 4.11 % (Fig.8). The power factor of the system has reached to 0.9991, therefore making it possible to extract optimum power with negligible harmonic losses and complete reactive power compensation (Fig.6 (b)-7(b)).

TABLE I VARIOUS POWER COMPONENTS FOR ZSI FED WPGS (R PHASE)

Compensation Type→ ↓Power component	Without compensation	With HAPF
%THD in V_s	16.37%	1.98%
%THD in I_s	28.16%	4.1%
Harmonic power, P_h (W)	452.49	8.22
Active power, P_1 (W)	9564.40	10129.67
Reactive power,Q_1 (VAr)	2208.11	0.00
Apparent power,S_1 (VA)	9815.98	10129.67
DPF	0.9743	1.0
Power factor	0.9378	0.9991

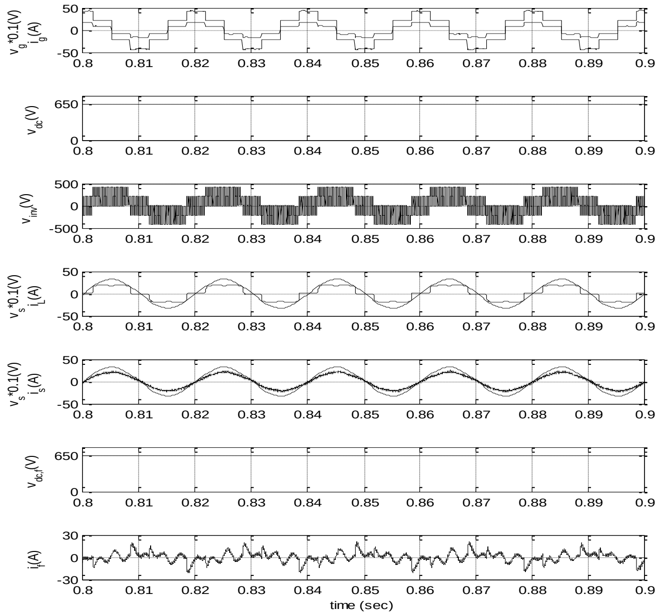

Fig.6 (a) Steady state response of WPGS with hybrid active power filter

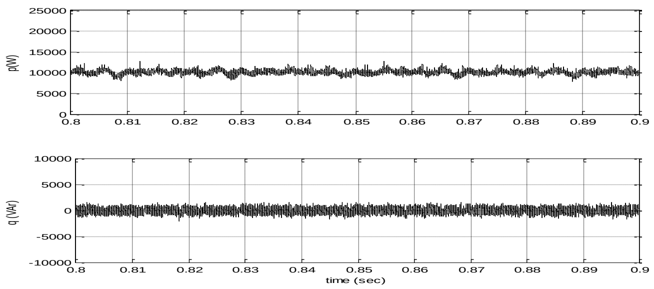

Fig.6 (b) Active power and reactive power waveforms for WPGS with HAPF, at steady state

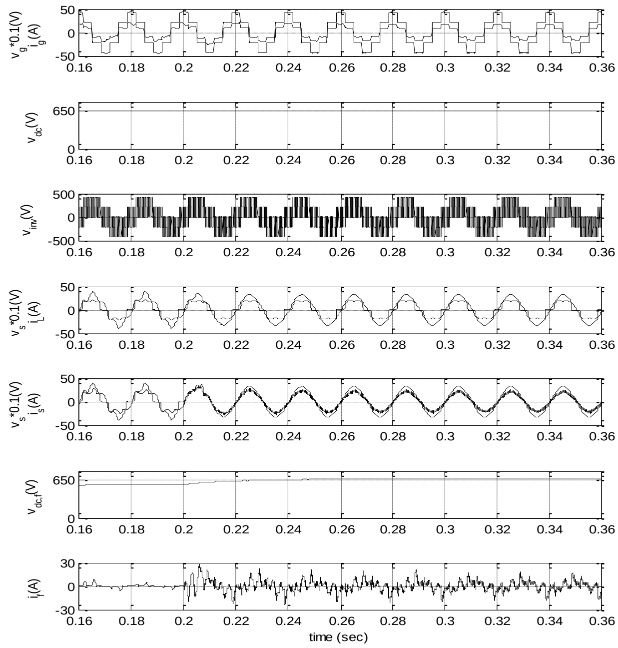

Fig.7 (a) Transient response of WPGS with hybrid active power filter, hybrid active power filter switched on at 0.2 sec.

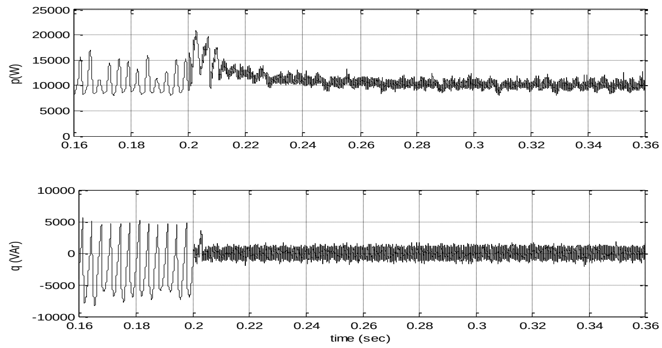

Fig.7 (b) Active power and reactive power waveforms for WPGS with HAPF under transients, both passive and active power filter switched on at 0.2 sec.

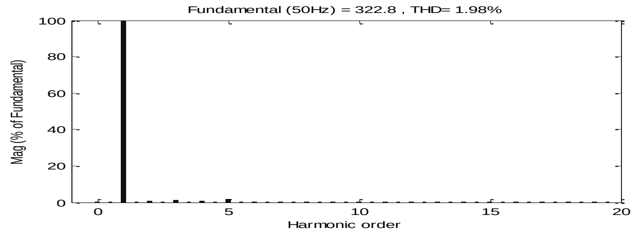

Fig.8 (a) Source voltage (v_s) frequency spectrum for WPGS with HAPF

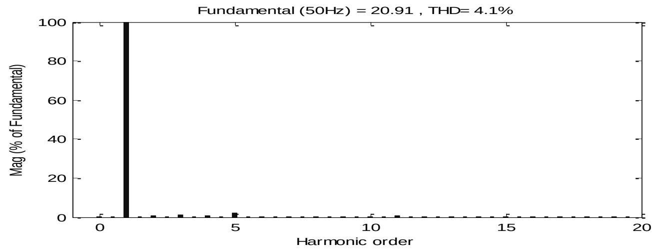

Fig.8 (b) Source current (i_s) frequency spectrum, for WPGS with HAPF

VI. CONCLUSION

Motivation towards the concern about environment and depletion of fossil fuels has lead the society towards environment friendly power generation systems. Wind power ranks atop all the other renewable energy generation systems for being never ending clean natural resource. Wind power generation systems are showing record growth on world map. Further with the advance in technology, the increase in size and reduction in cost are making the conditions favorable for wind power generation systems. It is observed that the WPGS is able to supply consistent power with ZSI at rated voltage and frequency, with reduced complexity, low switching losses and improved reliability due to elimination of dead zone, compared to other power electronic interfaces. However, generated reactive power and distortions in system voltage and load current are still not reduced as per IEEE 519 standards, when performance is judged for non-linear load supplied by WPGS.

To improve the power quality of WPGS, hybrid active power filters is suggested and results are compared on different indices with and without HAPF. The wind power generation system exhibits excellent performance, when hybrid active power filter is connected to the system. The frequency and voltage control is obtained by power electronic interface, while hybrid active power filter is responsible for active and reactive power control.

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