DSP Implementation of a Harmonic Reduction Strategy for a DC Link Inverter in a WECS

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Abstract— The use of alternative sources of energy appears to be an indomitable necessity to bridge the gap between supply and demand. Though a series of options continue to surface, solar and wind emerge as a viable and sustainable resources at least for most parts of the year. However the speed of wind driven generators keep fluctuating and invite interfaces to suit the system needs. The prelude endears extra emphasis in the preview of grid connected systems to avoid adversaries. The imminent actions of the power switches along with the presence of non- linear elements in the interfaces join the inductive nature of the load to introduce harmonics in the systems. It becomes essential to address the ill effects of the higher frequency components and ensure a satisfactory environment for the transfer of power. The advent of solid state processors offer a platform to process the signals and realize the design of the control methodology for the purpose of generating PWM pulses. The endeavor extends to articulate the DS processor with a function to shape the trigger pulses for the active devices in the dc link inverter in order that it eliminates the multiple frequency components and serves to enhance the fundamental component of the output voltage.

Keywords: Wind Energy Conversion Systems (WECS), DSP Implementation, Harmonic Reduction Strategy

I. Introduction

Wind Energy Conversion Systems (WECS) have been steadily gaining the world’s attention as a means of generating energy, due to increasing demands for power and environmental issues related to the use of fossil fuels. Wind turbine generators are an important part of WECS. Variable speed systems have several advantages over the traditional method of operating wind turbines, such as the reduction of mechanical stress and an increase in energy capture. The Permanent Magnet Synchronous Generator (PMSG) with variable speed operation is currently used in low-power wind turbine applications. AC-DC converter is used to convert variable voltage from the PMSG to DC voltage, thereby producing DC power. The DC is converted back to AC that is appropriate for electrical utilizations in the grid. However, the use of converters introduces high intensity of low frequency current harmonic content into the power system. This leads to reduction of efficiency in WECS and also decreases the life span of the generator.

One of the biggest problems in power quality aspects is the harmonic contents in the electrical system. Generally, harmonics may be divided into two types: (1) voltage harmonics, and (2) current harmonics. Current harmonics are usually generated by harmonics contained in supply voltage and the type of load such as resistive load, capacitive load, and inductive load. Both harmonics can be generated by either the source or the load side. Harmonics generated by load are caused by nonlinear operation of devices, including power converters, arc-furnaces, gas discharge lighting devices, etc. On the other hand, source harmonics are mainly generated by power supply with non-sinusoidal voltage waveform. Voltage and current source harmonics imply power losses, Electromagnetic Interference (EMI) and pulsating torque in AC motor drives. Any periodic waveform can be shown to be the superposition of a fundamental and a set of harmonic components. By applying Fourier transformation, these components can be extracted. The frequency of each harmonic component is an integral multiple of its fundamental. There are several methods to indicate of the quantity of harmonics contents. The most widely used measure is the total harmonics distortion (THD), which is defined in terms of the amplitudes of the harmonics.

Distortion of the voltage waveforms i.e. harmonics may cause overheating of neutral conductors and electrical distribution transformers, malfunction of electronic equipment, faulty operation of protective devices, nuisance tripping of sensitive load and the distortion of communication systems. Harmonics levels are increasing in power systems due to proliferation of non-linear loads like rectifiers, variable frequency drives (VFD), uninterruptible power supplies (UPS), switched mode power supplies (SMPS) in appliances, arc and induction furnaces, fluorescent lamps with electronic ballasts, etc. Field surveys indicate that the harmonics are significant in many industries as reported in. Harmonic resonance occurs in a power system when the power system’s natural frequency corresponds to the frequency of a source of harmonic current. Every power system has a natural frequency which is a function of the system reactance and the amount of power factor correction (PFC) capacitors connected to the system. In the event that there is a source of excitation with a frequency near or equal to the system’s natural frequency, large resonant currents can result. The capacitors themselves are not a source of natural frequency excitation current, but can have the effect of magnifying such currents. It is common for power systems that are corrected with capacitors to near unity power factor to have a natural frequency in the vicinity of 300Hz or 350Hz or the fifth or seventh harmonics. This magnification has implications in two aspects: reduced effective power factor and unreasonable indication of harmonic indices. Harmonic magnification can be reduced by relocation of PFC capacitors.

Majority of large power (typically three-phase) electrical nonlinear equipment often requires mitigation equipment in order to attenuate the harmonic currents and associated voltage distortion to within necessary limits. Depending on the type of solution desired, the mitigation may be supplied as an integral part of nonlinear equipment (e.g., an AC line reactor or a line harmonic filter for AC PWM drive) or as a discrete item of mitigation equipment (e.g., an active or passive filter connected to a switchboard). There are many ways to reduce harmonics, ranging from variable frequency drive designs to the addition of auxiliary equipment. Few of the most prevailing methods used today to reduce harmonics are (i) Delta-Delta And Delta-Wye Transformers (ii) Isolation Transformers (iii) Passive Harmonic Mitigation Techniques (iv) Active Harmonic Mitigation Techniques (v) Hybrid Harmonic Mitigation Techniques. However, in all these methods from the utility point of view it requires an extra effort and cost for them for implementing these harmonic reduction strategies. Hence it becomes appropriate to reduce the harmonics at the point of generation itself i.e, by adopting suitable PWM strategies for the switches in the power converters.

II. PROBLEM FORMULATION

A. Problem statement

The power electronic converters used in the wind energy conversion system are a source of harmonics due its switching action. The power quality of the wind power becomes poor as the voltage and current are enriched with harmonics. Hence there is a definite need to reduce the problem of harmonics to improve the power quality of WECS. A suitable switching strategy is adopted with a view to reduce the harmonics. Digital control techniques such as a Digital Signal Processor finds application in realizing the PWM pulses for the switches in the inverter. The effort emphasizes to reduce the harmonic components in the WECS through the design and implementation of a RPWM strategy for the dc link interface. The theory attempts to assuage the deleterious effects of the higher frequency components of the voltage introduced through inadvertent switching. The formulation incites to address power quality issues in terms of improving the power factor and reducing the THD. The exercise involves examining the performance through experimental testing for a range of operating loads.

B. Proposed Methodology

The focus revolves around a procedure to generate the PWM pulses with modified carrier and derived reference. The frequency of the carrier is allowed to vary in a certain range and the required reference calculated by the controller. The theory also orients to find out the necessary modulation index for the dc link inverter to regulate its output.

C. Schematic of WECS

The block diagram for the proposed WECS is shown in Figure 1. The wind speed is the input to turbine and the wind turbine produces the corresponding mechanical power output. This mechanical power provides the necessary input to the PMSG that is directly driven by the wind turbine. The PMSG generates the three phase ac voltage and feeds the diode bridge rectifier. The ac voltage is rectified into a dc and again inverted back to ac using a three phase PWM inverter. The output of the inverter feeds the three phase load. The output voltage of the inverter and the electrical torque generated by the machine can be controlled through a closed loop. The pulses to the switches are generated using the DS processor.

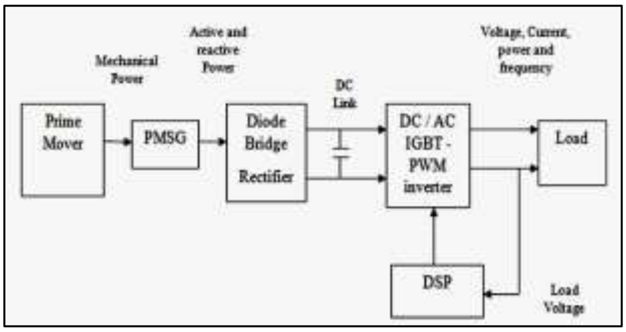

Fig. 1: Schematic of WECS

D. Experimental Prototype

The photograph is shown in Figures 2 and 3. Relating to the prototype constructed for the purpose show the dc motor coupled to a PMSM machine which operates as a generator to depict a WECS. It involves the use of a three phase diode bridge rectifier in cascade with a dc link inverter. The methodology relies on the closed loop theory to generate PWM pulses from a digital signal processor (DSP).

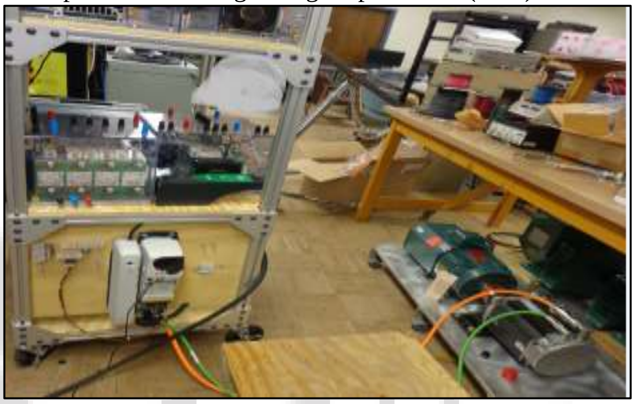

Fig. 2: Experimental setup

Fig. 3: PMSM coupled with a DC generator

E. Control Algorithm

The control algorithm is illustrated through the Figure 4.The actual voltage V_{actual} is compared against the reference voltage V_{ref}. The error signal that is transformed into a conductance through gain and is further multiplied by V_{in} to generate a current reference I_{ref}. This I_{ref} is compared against I_{in} and the error is given to a PI controller which generates the reference for the PWM. The pulses generated through the PWM are the gating signals to the switches.

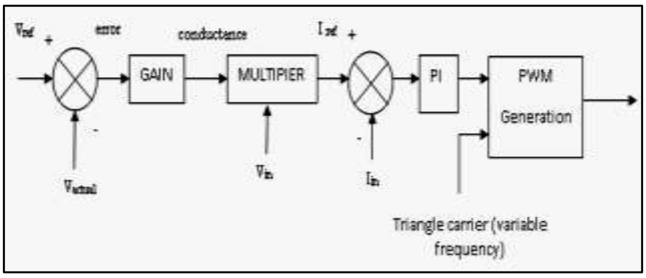

Fig. 4: Control Algorithm

III. RESULTS AND INTERPRETATION

The specifications of the PMSM machine correspond to the values listed below and accordingly the ratings of the converter and inverter interfaces are chosen.

- Rated Power: 1.1 HP
- Phase: 3 Phase
- Rated Current: 4.5 Amp
- Rated Speed: 4000 rpm
- Rotor Pole: 4 Poles

The output phase voltage THD spectrum seen in Figure 5 corresponds to an operating point of 400 watts. The index of 7.7 percent obtained reveals the merits of the RPWM strategy in enabling to minimize the level of harmonics present in the output voltage. It further underscores the benefits of the formulation in arbitrating an increase in the fundamental component of the output voltage.

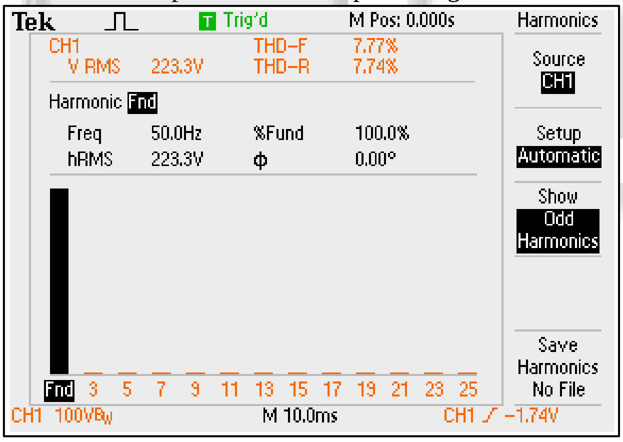

Fig. 5: THD Spectrum

The entries in Table 1 exhibit the closeness between the performance of the prototype and simulation results in terms of the parameters of the system, the power factor and the THD extricated in both cases over the range of operating loads. The readings further serve to validate the simulation results and erudite the viability of the proposed approach for use in real world applications.

Load (W)	V_{LL}(V)	V_{ph}(V)	Phase current (A)	THD in % RPWM		POWER FACTOR	
				Simulation	Hardware	Simulation	Hardware
250	358.8	224.86	0.70	8.64	9.23	0.90	0.88
400	358.3	223.30	1.25	6.95	7.77	0.93	0.92
550	357.5	222.34	1.72	5.21	5.86	0.95	0.955
700	357.3	223.13	2.1	3.10	3.76	.97	0.96

Table 1: Comparison between the prototype and hardware

IV. CONCLUSION

The significance of harmonic reduction strategy has been articulated and a random pulse width strategy developed to realize the benefits of the phenomena. The formulation has been laid to generate PWM pulses for the power switches in the dc link inverter in an effort to accordingly arrange the components of the output voltage in the spectrum.

The methodology has been pulled out through a DSP based hardware and performance extricated to display the merits of the scheme.

REFERENCES

[1] F. S. Dos Reis, S. Islam, K. Tan, J. Ale, F. Adegas and R. Tonkoski. "Harmonic mitigation in wind turbine energy conversion systems". Presented at Power Electronics Specialists Conference, 2006. PESC'06. 37th IEEE. 2006.

[2] PijusKanti Sadhu, Gautam Sarkar, AnjanRakshit, "A microcontroller-based variable voltage variable frequency sinusoidal power source with a novel PWM generation strategy",Elsevier, Measurement 45 (2012) 59–67,2011

[3] Adel Mehdi, HoussamMedouce, Salah EddineRezgui, AbdelmalekBoulahia, FatehMehazzem, HocineBenalla," Pwm Converters and Its Application to the Wind-Energy Generation", Elsevier, Energy Procedia 42 (2013) 523 – 529, 2013.

[4] WajihaShireen, SrinivasVanapalli, Hrishikesh Nene, "DSP based inverter control for alternate energy systems", Elsevier, Journal of Power Sources 166 (2007) 445–449, 2007.

[5] B. G. Shivaleelavathi, Srihari G, Prajwal S N, Rajath P Hebbar, Sudarshan Raj Keshri, "Dsp Based Converter–Inverter Control Strategy For Single Phase Wind Power Generation System", International Journal Of Electrical, Electronics And Data Communication, Issn: 2320-2084, 2014.

[6] Teena Jacob and Arun S, "Modeling Of Hybrid Wind And Photovoltaic Energy System Using A New Converter Topology", Electrical and Electronics Engineering: An International Journal (EEEIJ) Vol.1, No.2, August 2012, pp: 1-13.

[7] B. G. Shivaleelavathi& Dr. Shivakumar. E. G, "Optimal SVPWM Signal Generation for three level Inverters", IEEE International Advance Computing Conference, (IACC'09), March 6th and 7th 2009, Session 49 paper ID IEEE-APPL- 1554, Thapar university, Patiala, Punjab, pp: 3440 to 3446.

[8] N. Pogaku,M. Prodanovi´c, andT. C. Green, "Modeling, analysis and testing of autonomous operation of an inverter-based microgrid," IEEE Transactions on Power Electronics, vol. 22, no.2, pp. 613–625, 2007

[9] F. Blaabjerg, A. Isidori, F. Mario "Impact of Modulation Strategies on Power Devices Loading for 10 MW Multilevel Wind Power Converter",3rd IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG) 2012.

[10] R. Pena, J. C. Clare, and G. M. Asher, "Doubly fed induction generator using back-to-back PWM converters and its application to variable-speed wind-energy

generation", Proc. Inst. Elect. Eng.—Elect. Power Appl., vol. 143, no. 3, pp. 231–241, May 1996.

[11] Poh Chiang Loh, Member, IEEE, FredeBlaabjerg, Fellow, IEEE, and Chow Pang Wong," Comparative Evaluation of Pulse width Modulation Strategies for Z-Source Neutral-Point-Clamped Inverter." IEEE Trans. Power Electron .Vol. 22, No. 3, May 2007.

[12] Yo-Han Lee,Bum-SoekSuh and Dong-Seok Hyun, "A novel PWM scheme for a three level voltage source inverter with GTO thyristors," IEEE Transactions on Industry Applications, vol.32 , no. 2, pp.260 - 268, March-April 1996

[13] Todeschini, G., and Emanuel, A. E., "Wind energy conversion systems as active filters: design and comparison of three control methods," IET Renew. Power Generat., Vol. 4, No. 4, pp. 341– 353, 2010.

[14] Muhammad H Rashid, "Power electronics circuits, devicesand applications", third edition@2004, Pearson Education,Inc., pages: 69-294,761-777.

[15] TMS320LF/LC240x DSP Controllers Reference Guide,System and Peripherals, Literature Number: SPRU357,January 2000, pages: 1-477.

[16] TMS320LF/LC240x DSP Controllers datasheet, SPRS094I− April 1999 − Revised September 2003, pages: 1-117.

