International Journal of Emerging Technology in Computer Science & Electronics (IJETCSE)
ISSN: 0976-1353 Volume 22 Issue 1 – MAY 2016.

SUPER CAPACITOR FOR HARMONIC AND POWER FACTOR COMPENSATION

D.Srinivasan, R.Shankarganesh

Vinayaka Missions Kirupananda Variyar Engineering College
Assistant Professor, Vinayaka Missions Kirupananda Variyar Engineering College

***Abstract*— Harnessing green and renewable sources of energy is a future solution that addresses rising energy demands and growing environmental concerns. Among these, tapping wind energy using wind turbines appears to be one of the most promising solutions. A wind energy conversion system captures kinetic energy of wind and converts it into electrical energy. By nature, availability of wind energy is stochastic and intermittent. In contrast, electric power system expects a steady and planned supply of energy. This thesis addresses the gap in characteristics of wind energy supply and conventional electric energy demand. This thesis considers a *doubly fed induction generator* (DFIG) connected to a wind turbine to harness wind energy. The proposed topology connects a Supercapacitor through a buck-boost chopper to the DC link of rotor circuit. The Supercapacitor works to perform the job of a flywheel. The thesis proposes an appropriate control system that controls the output of the DFIG to constant value (PREF) eliminating short-term fluctuations. This control system works to control the buck-boost chopper and works as an inner control loop. Thereafter, this thesis proposes an optimization algorithm that considers short-term forecasted wind speeds (energy) for several minutes. It then optimizes to determine a minimum set of output values of the DFIG (PREF). It ensures that output of the DFIG has minimum changes thus minimizing intermittency in the DFIG output. This optimization algorithm forms the outer loop in the overall control strategy. The complete system is implemented in Matlab/Simulink**

***Keywords* — Converter, Super capacitor, POA,PC,PFC**

I. INTRODUCTION

Electricity from wind energy is one of the fastest growing methods of electricity generation and its penetration in the world is expected to grow up to 12% of the global demand by 2020 [1] . In this type of electricity generation, kinetic energy from moving air is converted into electricity by wind turbines that are mounted in locations where there are favorable weather patterns. Wind turbines may be employed individually, but are often installed in groups to form ―wind farms‖ or ―wind power plants‖. Electricity generated by wind farms may be used locally or transmitted on the electric grid to power homes and businesses far away. The use of wind energy reduces the environmental impact of generating electricity because it does not require fuel and does not produce pollution or greenhouse gases. While renewable energy is considered as a key solution to reduce green house gas emissions, its inherent intermittent nature poses a big challenge. One of the problems, besides being non dispatch-able and others, is associated with the quality of power generated and thus supplied into the grid. These problems become even bigger when wind generators are connected to a weakgrid and due to this reason wind power is restricted in some cases. Thus, the problem of intermittency of renewable energy sources cannot be overlooked [2]. Quality of power output from wind generators suffer due to sporadic fluctuations of wind speed.

This intermittence, an inherent characteristic of wind, imposes special requirements on the surrounding power system. Thus, wind power systems challenge the power quality, energy planning, power flow controls, and dispensability in the local grid. In some cases, it even restricts integration of the wind power. The horizontal flow of wind consists of two overlapping effects, namely Macro-meteorological and Micro-meteorological fluctuations [3]-[4]. The macro-meteorological fluctuations indicate the movements of large-scale weather patterns such as the day and night cycle, the movement of depressions and cyclones. The micro-meteorological fluctuations originate from the atmospheric turbulence with typical time scales of 1 to 600 seconds. Output of wind generators fluctuate in a similar manner to the wind speeds although they are modified by the physical and electrical characteristics of the wind generator. Experience and research show that power system is more susceptible and sensitive to medium frequency wind power fluctuations (0.01 ~ 1 Hz) [5]-[6]. Integration of an energy storage system into a wind generator can effectively suppress these power fluctuations and thus improve quality of power supplied to the connected grid. Smoothing long-term power fluctuations requires a higher capacity of storage and thus a higher cost. The cost of this solution is the main limiting factor in its application. A short term energy storage solution presents itself as the optimal solution to the problem of short term fluctuations (1 – 600 sec) [3]-[4] from size, cost and quality point of view. A varietyof options is available but different factors dictate a choice of Supercapacitor (SC) as an Energy Storage device. Supercapacitor Energy Storage Systems (SESS) are used to reduce voltage flicker, current harmonic elimination, compensation of pulsating load and uninterruptable power supply[7]-[10], but less is done in the field of wind energy[11],[12]. Superconducting Magnetic Energy Storage (SMES) System and Battery Energy Storage System (BESS) have been researched on short term wind power fluctuations smoothing [13], but SESS with less auxiliary equipment is more stable and convenient than SMES and it has longer cycle life and less maintenance compared to BESS. This research thesis focuses on decoupled control of short term power fluctuations with SESS and two quadrant DC-DC converter with an output power optimization algorithm for Doubly Fed Induction Generator (DFIG) based Wind Energy Conversion Systems (WECS). The proposed topology is shown in Figure 1 and verified by simulation in Matlab/Simulink. DFIG-WECS is shown in solid while the proposed topology is shown in shaded and dotted lines. The proposed topology consist of SC-Bank (Energy storage) connected to DFIG-WECS through a DC-DC (Buck-Boost) converter. DC-DC converter is controlled through a proposed control scheme to either extract power from or inject power into the DFIG-WECS based on the optimal power reference set by Power Optimization Algorithm (POA).

II. POWER QUALITY IMPROVEMENT BY SUPERCAPACITOR ENERGY STORAGE SYSTEM

Proposed system as shown in Figure 1 consists of DC-DC converter, SC-Bank, Control Scheme and Power Optimization Algorithm. The operating principle can be outlined as: The instantaneous value of Pref-optimal is defined by Power Optimization Algorithm for a given wind data set using a proposed optimization algorithm. Control scheme block The control scheme aims to hold DFIG's output POt equal to Pref-optimal Compares output power POt with Pref-optimal Controls DC-DC converter to either work in Buck or Boost mode to extract or inject power so that POt becomes equal to Pref-optimal SC-Bank either works as storage or source of energy This chapter presents the DC-DC converter, SC-Bank and Control scheme (the inner control loop).

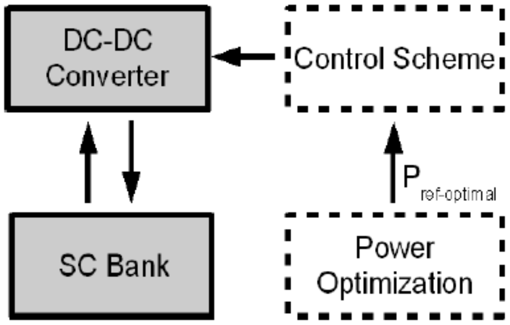

Figure 1: Proposed topology (dotted and shaded)

SUPERCAPACITOR

The concept and usage of capacitors is not new, however supercapacitor (SC) with low Equivalent Series Resistance (ESR) is a relatively new technology. SC with high ESR, suitable for low current applications, has existed for some time now; the breakthrough in the technology is the SC with low ESR. In this work, we consider SC with low ESR. In terms of power, SC power density supersedes both capacitor and battery but in terms of energy density, SC is better than capacitors but lags behind batteries. Supercapacitors are different from other capacitors in terms of the electrodes used. Supercapacitors are based on a carbon (nanotube) technology [26]. The carbon technology used in these capacitors creates a very large surface area with an extremely small separation distance by a physical barrier made from activated carbon that when an electrical charge is applied to the material a double electric field is generated which acts like a dielectric. The thickness of the electric double layer is as thin as a molecule. The surface area of the activated carbon layer is extremely large yielding several thousands of square meters per gram. This large surface area allows for higher power densities. SC model used in this study is shown in Figure 7 and is adequate for this kind of study [17]. A selection criterion for storage systems is usually based on: Storage capacity, Available power, Depth of discharge or Power transmission rate, Charge / Discharge time, Efficiency, Durability (cycling capacity), Costs, Feasibility, Self-discharge, Mass and volume densities of energy, Monitoring and control equipment, Operational constraints, Reliability, Ease of maintenance, Simple design, Operational flexibility and Environmental aspects [14].

III. SIZING OF THE SUPERCAPACITOR

In general, the energy in the Supercapacitor is given by $Esc=1/2 . Csc . Vsc^2$

where Esc is energy, Csc is capacitance and Vsc is voltage of the SC. Defining lower limit of voltage (Vscmin) and relating Esc= Psc td and solving for Csc gives

$Csc = 2\ Psc\ td / (Vscnom - Vscmin)^2$

where td is the period of time that we want to eliminate fluctuation in WECS output, 120 seconds in this case. Csc is the required capacitance to perform this function.Average current mode control is used to regulate the output voltage of the bidirectional dc–dc converter in both *Buck* and Boost modes, while charging and discharging the UCAP bank. While the UCAP-APF system is discharging power, the dc-link voltage Vout tends to be less than Vref, which causes the reference current Iucref to be positive, there by operating the dc–dc converter in Boost mode. Along similar lines, when the UCAP-APF system is absorbing power from the grid, the dc-link voltage Vout tends to be greater than Vref, which causes the reference current Iucref to be negative and the re by operating the dc–dc converter in Buck mode. Average current mode control technique is widely explored in the literature[19], and it was found as the ideal method for UCAP-APF integration as it tends to be more stable when compared with other methods like voltage mode control and peak current mode control. This is a major advantage in the present topology, where the stability of the dc–dc converter has to be ensured over a wide operating range and in both Buck and Boost modes of operation. Average current mode controller and the higher level integrated controller are shown in Fig.4, where the actual output voltage Vout is compared with the reference voltage Vref and the error is passed through the voltage compensator C1(s), which generates the average reference current Iucref. This is then compared with the actual UCAP current (which is also the inductor current) Iuc, and the error is then passed through the current compensator C2(s), The converter model for average current mode control is based on the following transfer functions developed.

IV. HIGHER LEVEL INTERGRATED CONTROLLER

The higher level integrated controller is designed to make system level decisions on the inverter and dc–dc converter controllers. Based on various system parameters and the higher level integrated controller will decide on operating in one of the following modes active power support mode, reactive power support mode, renewable intermittency smoothing mode, sag/swell compensation mode, and UCAP charge mode. In active power support mode and renewable intermittency smoothing mode, the UCAP-PC system must provide active power to the grid. Therefore, the active power capability of the UCAP-PC system must be assessed by the higher level integrated controller. Based on the , and values, the reference is calculated in the higher level integrated controller, and it will decide if the UCAP has enough energy to respond to the command based on the UCAP state of charge. If the UCAP has enough capacity to respond to the request, then the dc–dc converter controller is operated in grid support mode otherwise, it is operated in charging mode, where the UCAP is recharged and the power request is met at a later time. In grid support mode, the dc–dc converter will operate in a bidirectional fashion in both Buck and Boost modes to respond to the active power requests and regulate the dc-link voltage in a stable fashion, while the inverter controller should respond such that the Commanded Pref is supplied by the inverter through current control. In reactive power support mode ,the UCAP-PC system must provide reactive power to the grid. In this mode, the UCAP-PC does not provide any active power to the grid and even the PC losses are supplied by the grid. Based on the , and values the reference , is calculated in the higher level integrated controller. In this mode, the dc–dc converter controller can be programmed to operate in grid support mode directly because the active power requirement for operating in this mode is minimal. Therefore, the goal of the dc–dc converter controller is to regulate the dc-link voltage in a stable fashion, while the inverter controller should respond such that the commanded, is supplied by the inverter through current control. In sag/swell compensation mode, the UCAP-PC system is programmed to prevent sensitive loads from disturbances on the supply-side like voltage sag or voltage swell. These disturbances require short-term energy storage, and in this mode, the dc–dc converter controller can be programmed to operate in grid support mode. Therefore, the goal of the dc–dc converter controller is to regulate the dc-link voltage in a stable fashion during both sag/swell events. It is also required that the dc–dc converter

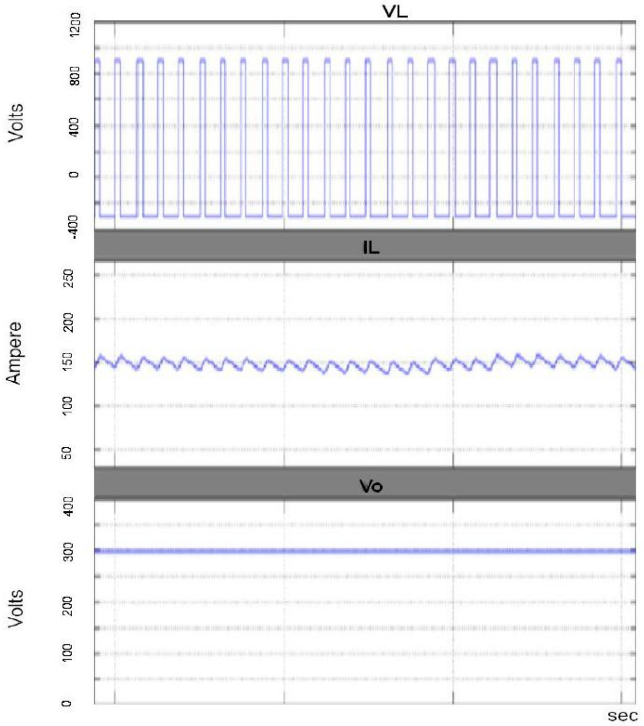

Figure 2. Output of proposed system

V. CONTROL SCHEME

Control scheme for the proposed topology shown in Figure 3 consists of System Limits Indicator (SLI), Pref Setting System (PSS), Power Control System (PCS) and Operation Control System (OCS) as shown in Figure 12.

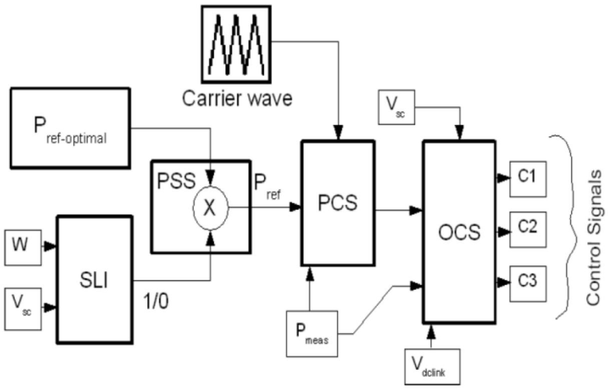

Figure 3: Control Scheme (proposed)

POWER CONTROL SYSTEM (PCS)

PCS generates gating signals for the chopper such that the DFIG's output power (POt) equals Pref-optimal. As shown in Figure 2 carrier based PWM control system compares instantaneous output power measured (Pmeas) with Pref and passes difference through a Proportional-Integral (PI) controller for comparison with triangular carrier wave to generate a control signal. Depending upon whether this difference between Pmeas and Pref is greater or smaller than triangular wave, a logic zero or one is produced respectively, to turn DC-DC converter OFF or ON and thus keep output power in the vicinity of Pref. This Control signal in essence controls operation of the DCDC converter: a) to operate in the Buck mode when energy is transferred from DC-link capacitor to SC-Bank, and, b) in the Boost mode to transfer energy from SC-Bank to the DC-link capacitor. A train of pulses (zeros and ones) produced this way controls output power of the DFIG (POt) by either injecting into or extracting power from the Super capacitor. This control signal is supplied to Operation Control System (OCS) for the final phase of the process. the overall operating principle is as follows:

Pref-optimal for given wind data is found by the Power.

Control scheme blocks

The objective is to measure and control DFIG output to Pref-optimal. The SLI block determines if W and Vsc are within their limits. PSS sets Pref to equal Pref-optimal if SLI indicates normal operation. PCS produces gating signal for the chopper to control output power (Pmeas) of DFIG such that it equals Pref-optimal. OCS checks if all the voltages within the system are within their limits. If they are within their limits, it passes the gating signal to the chopper and enables the SC. It checks to see if output power is more than zero in which case it enables SESS operation.

- The DC-DC converter is controlled by OCS, in normal condition, to either work in Buck or Boost mode to extract or inject power to regulate output power Pmeas such that it equals Pref-optimal.
- SC-Bank works as either a storage or source of energy, as a storage in Buck mode to extract energy from DC-link capacitor and as a source in Boost mode to inject energy into the DC-link capacitor.

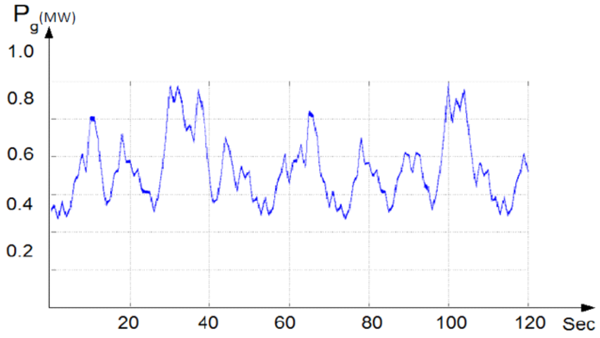

Figure 4

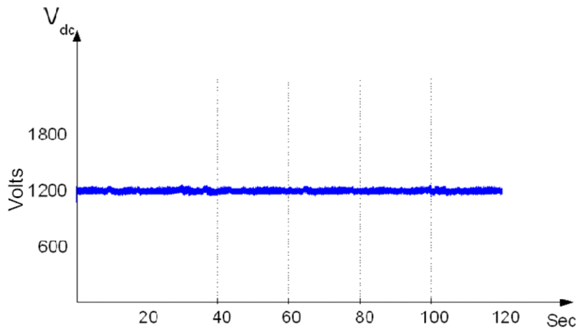

Figure 4, 5: output active power and voltage (proposed)

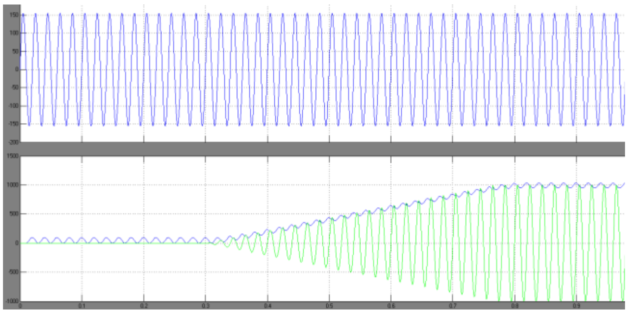

Fig.6.a.Output of the main circuit

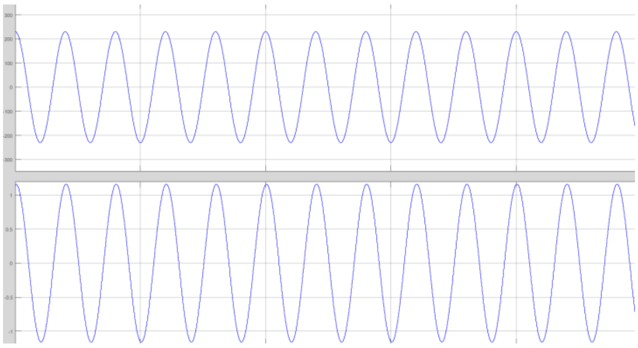

Fig.6.b.Output of the main circuit

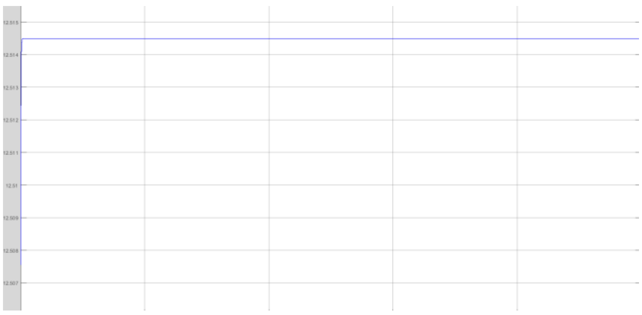

Fig.7.a.Output of the PV

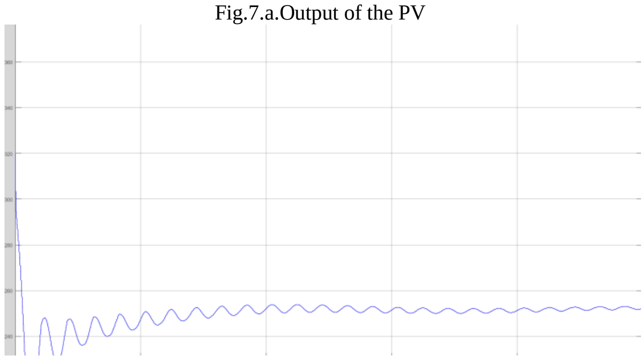

Fig.7.b.Output of the PV

VI. CONCLUSION

The simulation of the integrated system which consists of the UCAP, bi-directional dc–dc converter, and the grid-tied inverter is carried out using MATLAB/SIMULINK. Hardware experimental setup of the same integrated system is also possible to provide active power support, reactive power support and renewable intermittency smoothing to the distribution grid is dynamically tested through simulation.

REFERENCE

[1]. P. F. Ribeiro, B. K. Johnson, M. L. Crow, A. Arsoy, and Y. Liu, “Energy storage systems for advanced power applications,” Proc.

[2]. M. Branda, H. Johal, and L. Ion, “Energy storage for LV grid support in Australia,” in Proc. IEEE Innov. Smart Grid Technol. Asia

[3]. A. B. Arsoy, Y. Liu, P. F. Ribeiro, and F. Wang, “StatCom-SMES,” IEEE Ind. Appl. Mag., vol. 9, no. 2, pp. 21–28, Mar. 2003.

[4]. K. Sahay and B. Dwivedi, “Supercapacitor energy storage system for power quality improvement: An overview,” J. Elect. Syst.,

[5]. W. Li, G. Joos, and J. Belanger, “Real-time simulation of a wind turbine generator coupled with a battery supercapacitor energy storage system,” IEEE Trans. Ind. Electron., vol. 57, no. 4, pp. 1137–1145, Apr. 2010.

[6]. M. Ortuzar, J. Moreno, and J. Dixon, “Ultracapacitor-based auxiliary energy system for an electric vehicle: Implementation and evaluation,” IEEE Trans. Ind. Electron., vol. 54, no. 4, pp. 2147–2156, Aug. 2007.

[7]. Y. Chen and K. Smedley, “Three-phase boost-type grid-connected inverter,” IEEE Trans. Power Electron., vol. 23, no. 5, pp. 2301–

[8]. M. Chincilla, S. Arnalte, J. C. Burgos, and J. L. Rodriguez, “Power limits grid-connected modern wind energy systems,” Renew.

[9]. L. H. Walker, “10-MW GTO converter for battery peaking service,” IEEE Trans. Ind. Appl., vol. 26, no. 1, pp. 63–72, Feb. 1990.

[10]. D. Casadei, G. Grandi, and C. Rossi, “A supercapacitor-based power conditioning system for power quality improvement and uninterruptible power supply,” in Proc. IEEE Conf. Ind.Electron., 2002, vol. 4, pp. 1247–1252.

[11]. M. E. Ortuzar, R. E. Carmi, J. W. Dixon, and L. Moran, “Voltage-source active power filter based on multilevel converter and ultracapacitor DC link,” IEEE Trans. Ind. Electron., vol. 53, no. 2, pp. 477–485, Apr. 2006.

[12]. B. M. Han and B. Bae, “Unified power quality conditioner with supercapacitor for energy storage,” Eur. Trans. Electr. Power, vol.

[13]. H. Akagi, Y. Kanazawa, and A. Nabae, “Instantaneous reactive power compensators comprising switching devices without energy storage components,” IEEE Trans. Ind. Appl., vol. IA-20, no. 3, pp. 625–630, May 1984.

[14]. [14] H. Akagi, E. H. Watanabe, and M. Aredes, Instantaneous Reactive Power Theory and Applications to Power Conditioning, 1st

[15]. [15] V. Soares, P. Verdelho, and G. D. Marques, “An instantaneous activand reactive current component method for active filters,” IEEE Trans. Power Electron., vol. 15, no. 4, pp. 660–669, Jul. 2000.

[16]. B. Singh, V. Verma, and J. Solanki, “Neural network based selectivcompensation of current quality problems in distribution system,” IEEE Trans. Ind. Electron, vol. 57, no. 1, pp. 53–60, Feb. 2007.

[17]. J. R. Miller and A. F. Burke, “Electrochemical capacitors: Challenges and opportunities for real world applications,” Electrochem.

[18]. P. J. Grbovic, P. Delarue, P. Le Moigne, and P. Bartholomeus, “A bidirectional

[19]. three-level dc–dc converter for the ultracapacitor applications,IEEE Trans. Ind. Electron., vol. 57, no. 10, pp. 3415–3430, Oct. 2010.
[20]. G. Ma et al., "A zero-voltage-switching bidirectional dc–dc converter with state analysis and soft-switching-oriented design consideration, IEEE Trans. Ind. Electron., vol. 56, no. 6, pp. 2174–2184, Jun. 2009.