A POWER ELECTRONIC CONDITIONER USING ELECTROCHEMICAL CAPACITORS TO IMPROVE WIND TURBINE POWER QUALITY

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ABSTRACT

The large variability in wind output power can adversely impact local loads that are sensitive to poor power quality. To mitigate large swings in power, the wind turbine output power can be conditioned by using a small energy buffer. A power conditioner is developed to smooth the wind power output by utilizing the energy of an electrochemical capacitor, or ultracapacitor. The conditioner is based on a single-phase voltage source inverter connected between the grid interconnection point and the ultracapacitor. The voltage source inverter (VSI) shunt inverter injects or absorbs active power from the line to smooth the wind power output by utilizing the short-term storage capabilities of the ultracapacitor. The ultracapacitor is connected to the DC link through a bidirectional DC-DC converter. The bidirectional DC-DC converter and VSI are constructed and field-tested on a Skystream 3.7 wind turbine installed at the Missouri University of Science and Technology.

Keywords: power electronics, electrochemical capacitors, wind power

INTRODUCTION

Due to the price volatility and carbon impact of fossil fuels, wind power generation is rapidly growing as an alternative energy source in many parts of the world. Due to the intermittency of wind speed, wind turbine output power can be highly variable. Power fluctuations from the wind turbine may cause severe power quality problems when connected to the grid. The large variability in wind turbine output power can adversely impact local loads that are sensitive to pulsating power, posing a challenge to the use of wind power extensively. The rapid growth of the wind power and its immense potential as a future energy source encourage us to find a way to smooth the intermittent wind power. Energy storage technologies can be used to improve the quality of the wind power [1-2]. In this paper, we propose the power quality conditioner with the ultracapacitor to smooth the variable wind turbine output power. The short-term storage capabilities of the ultracapacitor can be effectively used to smooth the wind power to minimize rapid power excursions that may damage sensitive local loads.

This paper presents a power conditioner that has the purpose of smoothing the wind power. The power conditioner mainly consists of power converters to shape the injected current at the point of common coupling [3]. The conditioner is based on a single-phase shunt voltage shunt inverter (VSI) connected between the grid interconnection point and the ultracapacitor. The shunt VSI injects or absorbs active power from the line to smooth the intermittent wind power by charging or discharging the ultracapacitor [4]. The ultracapacitor is connected to the DC link through a DC-DC converter. Traditionally, the VSI DC link voltage is maintained relatively constant by the shunt inverter control. In this application, we use a bidirectional DC-DC converter to maintain the DC link voltage. The bidirectional DC-DC converter acts in buck mode during discharge of the DC link and in boost mode during charging to maintain the voltage of the DC link to provide good controllability of the VSI.

Control of the injected active power via the shunt inverter is presented in this paper. The VSI controller calculates the compensating active power, which is then synthesized by using the bipolar pulse width modulation (PWM) switching sequence. The reference signal to the shunt inverter controller is obtained from a low pass filter, which has a large time constant. The fluctuating wind power is passed through the low pass filter to get the smoothed reference value. The conditioner ensures the smooth power is available at the grid interconnection point. The simulation results are presented to show the efficiency of the conditioner in smoothing the variable wind turbine output power.

The power conditioner design and control will be validated on the Skystream 3.7 wind turbine installed at the Missouri University of Science and Technology. The installed wind turbine is shown in Figure 1.

Fig. 1. Skystream wind turbine installed at the Missouri University of Science and Technology.

POWER QUALITY CONDITIONER

As shown in Figure 2, the power quality conditioner consists of a shunt inverter and a bidirectional DC-DC converter. The voltage source inverter acts as a shunt active filter compensating the active power of the wind turbine. The VSI is connected to the line through an resistor-inductor (RL) filter that reduces the unwanted harmonics. The shape of the output current of the conditioner depends on the inductor value. The value of the resistor and the inductor determines the damping in the circuit. On the other side, the VSI is connected to the DC link capacitor. The DC-DC converter with the ultracapacitor is used to reduce the size of the DC link capacitor and to maintain the voltage of the DC link relatively constant as the ultracapacitor discharges and charges. The bidirectional DC-DC converter charges the ultracapacitor in buck mode by reducing the voltage of the DC link. In the other direction, it acts in boost mode, discharging the ultracapacitor to increase the voltage of the DC link. The power conditioner injects or absorbs active power from the line through the filter to smooth the variable wind turbine output power. The DC link acts as the voltage source for the VSI.

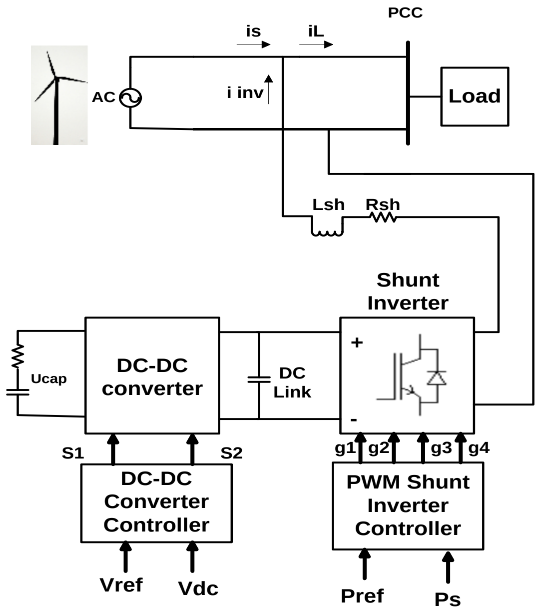

Fig. 2. Power quality conditioner.

The primary objective of the conditioner is to inject a current $i_{inv}(t)$ at the load such that the load current is relatively smooth. The smoothed current is obtained by passing the (measured and scaled) wind turbine current through a low pass filter that is tuned to provide the appropriate high-frequency cutoff. The electro-chemical capacitor is charged and discharged rapidly to supply the required current. Note that the reference (load) current is not constant, but rather a slowly varying current. If the reference current were held constant, this would imply that the electrochemical capacitor would have infinite ability to charge and discharge. By allowing the reference current to slowly vary, the energy to the load will not exceed the energy of the wind turbine (less losses). The conditioner is shown in Figures 3 and 4.

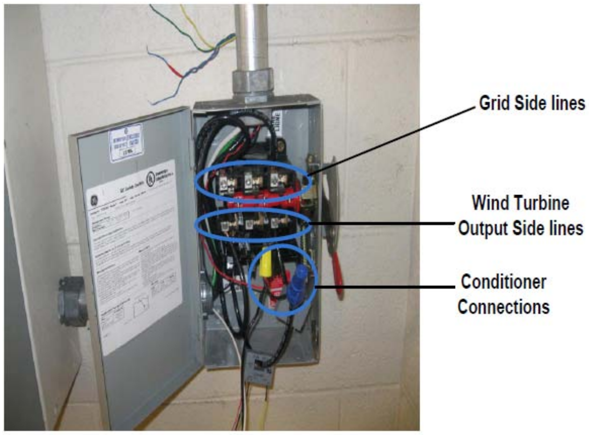

Fig. 3. Conditioner interconnections.

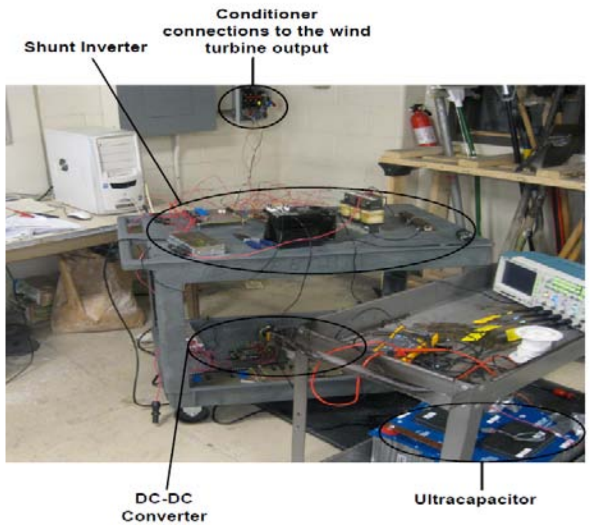

Fig. 4. Power quality conditioner hardware.

The measured injected current of the conditioner is shown in Figure 5. The blue trace is the measured unconditioned (raw) output of the wind turbine. It is highly variable with large pulsations in power and with considerable high-frequency noise. The red trace is the actual measured conditioned output current of the conditioner with a 60-second filter time constant. The green trace is a simulated conditioned output current if a 5-minute filter time constant were used.

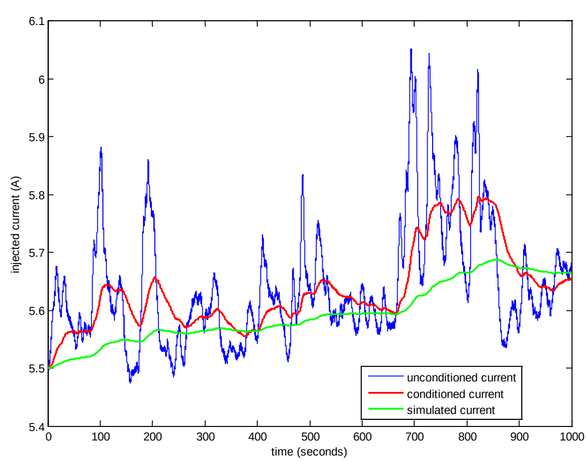

Fig. 5. Power quality conditioner output currents.

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BIOGRAPHICAL NOTE

Conference presenter: Mariesa L. Crow is the F. Finley Distinguished Professor of Electrical Engineering at the Missouri University of Science and Technology (Missouri S&T). She received her B.S. in Electrical Engineering from the University of Michigan and her Ph.D. in Electrical Engineering from the University of Illinois – Urbana/Champaign. Her area of professional interest is computational methods and power electronics applications to renewable energy systems. She is currently the Director of the Energy Research and Development Center at Missouri S&T. She is a Registered Professional Engineer in the State of Missouri and a Fellow of the Institute of Electrical and Electronics Engineers.