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MODELING AND CONTROL OF GRID CONNECTED WIND TURBINE GENERATOR

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***Abstract*—An ac/dc/ac power converter is an important device used to extract power from variable speed permanentmagnet wind generators and feed it into the grid. This paper describes how these converters incorporate maximum power point tracking based on its power feed to the grid at different wind speeds. Using the permanent magnet generator voltage, grid current, and grid voltage samples, the proposed system achieves an enhanced dynamic behavior. This feature effectively prevents the grid from "boost" charging the dc side of the H-bridge inverter at the start of operation. Since small wind turbines normally do not have expensive pitch control mechanisms, a thyristor-based "dump-load circuit" is employed to protect the turbine from high wind speed operation when disconnected from the grid. The thyristor controller also protects the inverter from high dc voltage input from the wind generator at high wind speed. Preliminary results are included using a laboratory 2-kW prototype converter.**

***Index Terms*—Dump-load, grid-connected, voltage compensation, wind generation.**

I. INTRODUCTION

Small-scale wind turbines interfaced to a grid via grid-connected inverters have wide-spread applications in household and community level power generation. The advantages of this arrangement are that it eliminates the need for batteries, as all the generated power can be fed to the power grid.major issues with existing grid-connected inverter systems for small wind turbines are as follows.

1) *limited* speed range: limitations with existing grid connected inverters have limited dc voltage window, which limits power extraction in both low and high wind speed regimes.

2) *High cost*: Existing grid-connected inverters adapted fromthe more common photovoltaic inverters require additional front end ac/dc conversion and voltage limiting power electronic circuitry and control algorithms. put forward block diagrams of a grid-connected wind turbine with a permanent magnetsynchronous generator that uses a back-to-back full-scalepulse width modulation (PWM) converter connected tothe grid. This increases the system cost and has preventedthe more widespread use of small grid-connectedwind turbines.Considering the usage of permanent magnet (PM) synchronousgenerators, three-phase diode rectifiers followed withdc choppers are more economical than three phase insulatedgate bipolar transistor (IGBT) converters. In [4]–[6], a simpleac–dc–ac converter for grid-connected wind power generationsystems is used with advantages that include inexpensive costand easy control of the generator load.In this paper, a power conversion circuit such as in is designed for a small-scale grid-connected wind generator system;in addition, a thyristor-based "dump-load circuit" is employed as shown in Fig. 1.The system consists of a permanent magnet wind turbinegenerator, a dump-load control circuit, a diode rectifier, aboost dc/dc converter, and a grid-connected inverter.

The outputvoltage of a PM generator is rectified to provide a dc voltagethat will vary in magnitude to reflect the turbine speed. Theboost converter makes it possible for inverters operating at lowwind speed. Macready and Coates adopt a dynamic breakingswitch to provide the regulated dc bus voltage; this paper usesan independent dump-load circuit made up of SCR, which notonly protects the inverter from high dc voltage in grid-connectedmode under high wind speed conditions, but also protects thewind turbine from overspeeding when the grid connection is lost.When compared to similar existing systems, the proposed circuit has advantages such as low cost can control "dump-load power, and can be used with a wide range of different rated inverters.

Advantages of Proposed system are it eliminate the field Cu losses ,provides better voltage regulation, Improves the input power factor also Improve power density and provides less harmonics due to PWM control

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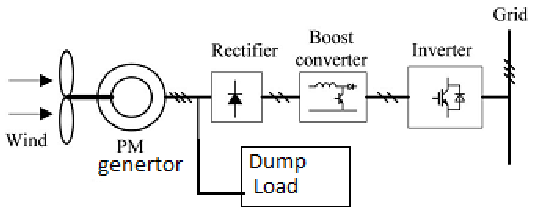
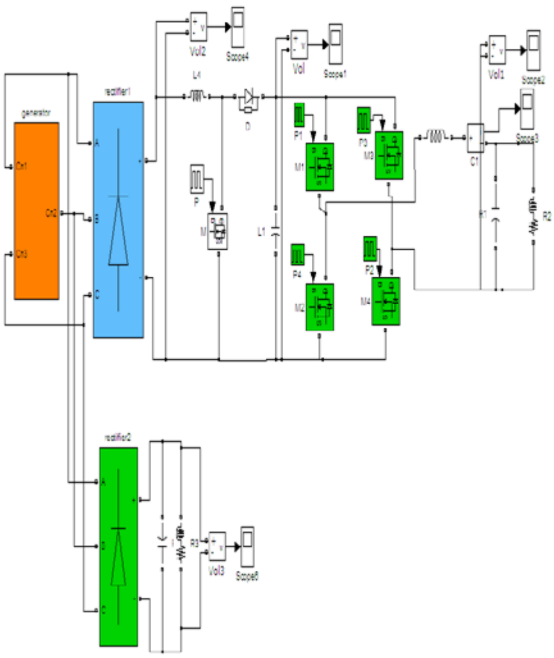
The basic working of the grid connected small scale wind turbine with the dump load circuit is shown below The system shows the usage of dump load circuit



Circuit diagram:



System Principle

The configuration of the wind source converter is shown. The ac output voltage is taken as output from ports a wind turbine. The rectifying circuit transforms the ac voltage of a wind turbine into dc voltage. The function of the boost circuit (*L* , *D*0, *V*) is to make the dc bus voltage stable . The current control voltage source inverter (CCVSI) offers sine wave current to mains. Considering the isolated characteristic of turbine winding, the system is connected to mains without the isolated transformer. The uncontrolled rectifier acts as balance load or known as dump load circuit.

A self-tuning PID control based on the former approach for wind energy conversion systems is already reported in older systems , whereby the controller parameters track feedback control, adopted dc voltage outer loop to realize the active power transfer to the grid and current inner loop ensuring fast response. The older systems does not have grid voltage *ug* feedforward control; the output of the current inner loop is zero at the start of inverter operation; it means that the output voltage of the H-bridge is also zero at that time, so the whole grid voltage *ug* is added to the inductor *L* and "boost charge" the capacitor in the dc side of the H-bridge. The dc side voltage will decrease only after the feedback current *i*ac effectively tracking the referenced current $i*$ ac , and the output of current inner loop has to generate part component to balance out the grid voltage. Fig shown still uses voltage and current loops, but with grid voltage *ug* feedforward control in addition; in this case, the voltage of *L* is zero at the start of inverter operation; thus, no current will "charge" the capacitor in the dc side of the H-bridge. And the output of the current inner loop could be smaller compare to the former control. In other words, grid voltage *ug* feedforward control enhances the dynamic character of system effectively, which prevents the grid "boost charging" the capacitor in the dc side of the H-bridge at the start of inverter operation.

The pulses to the switch can be being given by maximum power point tracking method but it makes the system more complex to work on because of its algorithm technique so we go on for simple pwm pulse technique where the triggering pulse can be given correctly without any difficulty at exact amplitude ,pulse width ,time period and phase delay.

In this system, two strategies are used to improve the output current quality. On one hand, since the converter is transformer less, decaying dc component of the output current injected to the grid is very necessary. This control system computes the dc component of *i*ac by using the grid current sample, and then compensates the dc component in the current loop. On the other hand, in CCVSI, for avoiding *V*1 and *V*2 (or *V*3 and *V*4) be open at the same time, a delay time *Td* is normally used for the switch that be about to open. The presence of *Td* results in the output voltage PWM pulse not equal to the command voltage pulse. The higher the carrier frequency, the more distortion of the output voltage, which causes non sinusoidal output current waveform. The introduction of the current loop, to a certain extent, can reduce the impact of *Td* , and in theory, *Td* can be fully compensated when the current regulation loop achieves no difference.

But $i*$ ac tracking is some difficult to achieve no difference, so this control system modified

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the PWM trigger pulse by software to compensate for the output current waveform. The strategy called current feedback compensation method detects zero-crossing of the output current *i*ac and then generates a synchronous square wave voltage added to the corresponding phase modulation wave, to eliminate the dead zone in the fundamental output voltage of H-bridge. Compared with the inverter with frequency transformer, the efficiency of a transformer less inverter is higher.

Smooth Control of the Boost Converter

For the voltage characteristics of small-scale low and wide range wind turbines, a boost converter is often added before the grid-connected inverter. The boost converter serves to control the input dc voltage of inverters. Regardless of the dc voltage output range the diode rectifier is, the input dc voltage of inverter remains steady. Meanwhile, the boost circuit increases the output power of the wind turbine. The output voltage of the boost circuit *U*dc is controlled by chip SG3525A. The output of the PI1 compensator changes the pulse signal, which corresponds to the duty ratio of the power switch *V*0 .

For low, medium, and high wind speeds, the dc voltage is controlled by the boost converter as follows.

1) *Low wind speed*: The converter will increase the dc voltage so that *U*dc > *Ug* (assuming modulation is equal to

2). During that time, because of *U*dc < *U*∗ dc, the PI1 compensator
output is saturated so the switch *V*0 gains the maximum duty ratio.

3) *Medium wind speed*: The function of the converter is to regulate the inverter dc voltage as a constant. The PI1 compensator will cease saturation to keep *U*dc near the referenced voltage *U*∗ dc.

4) *High wind speed*: The "dump-load" circuit operates as a variable resistance to control the operation voltage point of the wind turbine so as to protect the inverter from high dc voltage. When *U*dc is higher than *U*∗ dc constantly, the duty ratio of the switch *V*0 will decrease and the switch *V*0 will then be turnoff. Therefore, the boost circuit switch can transit to be off smoothly at all wind speeds.

Inverter Control with Compensation of Grid Voltage:

Given the equivalent resistance of L- and H-bridge as *R*0, the output voltage of H-bridge is *un* ; therefore, the inverter circuit can be shown .It shows the equivalent circuit . The initial state is in zero state, so the initial current is zero. The equation of equivalent circuit is

***I*ac =(1/ *R*0 + *sL)* (*Un* − *Ug*).**

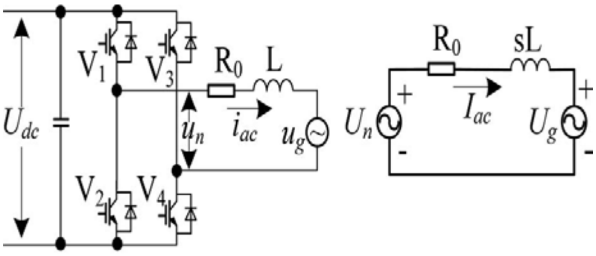


Figure.1 Inverter circuit and its equivalent circuit.

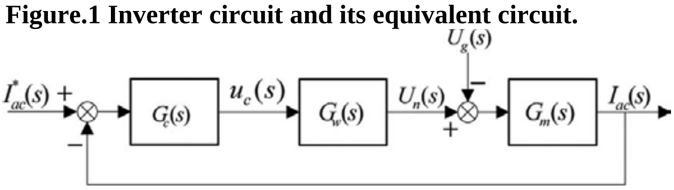


Figure.2 Dynamic framework of the current closed-loop.

The transfer function of the inverter main circuit *Gm*(*s*) can be obtained from above equation as follows

$$G_m(s) = \frac{I_{ac}(s)}{U_n(s) - U_g(s)} = \frac{1/R_0}{1 + \tau_0 s}$$

where τ_0 is the time constant, $\tau_0 = L/R_0$.

pulse width modulation technology is used to drive the power switch *V*1–*V*4 as shown and the gain of the main circuit can be looked as amplified coefficient *Kw* . When the duty ratio of PWM is changed, the output voltage of Hbridge will be influenced in the next period; the delay time is equal to the carrier wave period of PWM. Thereby, the transfer function of PWM and main circuit *Gw* (*s*) is where *Uc* is the control voltage of PWM and *τ S* is the delay time. Normally, the carrier wave frequency of PWM is about 10 kHz, so *τ S* is very small and can be simplified as , which is a one step inertial function: The system load is the grid. Considering the fact that *ue* cannot be controlled, the output power can be embodied by the grid connected current *i*ac .

Controlling *i*ac could allow access to grid-connected power. In order to make *i*ac track instruction, the routine method is to introduce negative feedback of *i*ac . Utilizing the transfer and relationship function of every part, the dynamic framework of current closed-loop is easy to achieve as shown In Fig., *I*∗ ac (*s*) is an input signal and *Gc* (*s*) is the emendator of current loop in order to gain stable and dynamic characters of current tracking.

This study uses proportional compensator *P* as *Gc* (*s*). It is clear that *Ug* (*s*) is a disturbance signal in Fig. During th e time of inverter starting, the phase error of current tracking will be significant if the current loop does not erect rapidly. In this event, the inverter absorbs energy from the grid, which

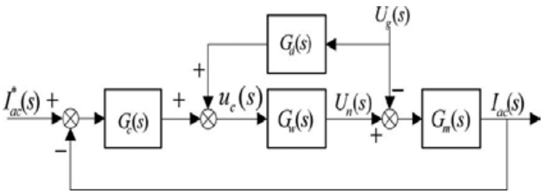


Figure.3 Dynamic framework of disturbance compensate

leads to capacitance *C*2 charging. The bus voltage will be high enough to cause overvoltage protection if the phase error of current cannot be controlled within a short time. Since *Ug* (*s*) is observable, an open-loop fore-back can eliminate its influence, which enhances the dynamic character of system.

Fig. shows *Ug* (*s*) compensating via transfer function *Gd* (*s*) to counteract the influence of disturbance. Since the rectify voltage *U*re has a relationship with the rotation speed of the wind turbine and the rotation speed decides the output power of the wind turbine, *U*re determines the input power of the inverter. Owing to the unchangeable voltage of the inverter load, the grid-connected current reflects the output power of the inverter. Thereby, the output of rectify voltage compensator works as the amplitude reference of the grid-connected current.

Grid connection control:

The wind turbine exhibits a nonlinear characteristic and the output mechanical power generated by the wind turbine is given by

$$P_w = 0.5\rho A_w C_p V_w^3$$

Where,
ρ air density (kg/m3);
Aw area covered by the wind turbine (m2);
Cp performance coefficient;
Vw wind speed (m/s).
The performance coefficient is a function of tip speed ratio *λ*
and pitch angle *β*

$$C_p = f(\lambda, \beta) = 0.5\left(\frac{98}{\lambda_i} - 0.4\beta - 5\right)e^{-(16.5/\lambda_i)}$$

λ is given by

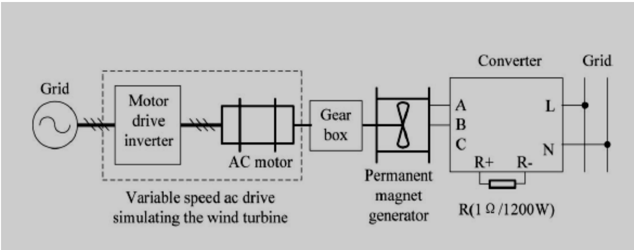
$$\lambda = \frac{\omega_r R}{V_w}$$

where ***ωr*** is the turbine rotational speed (in rad/s) and *R* is the radius of the turbine blades (in m).
By substituting ***ωr*** *,we get*

$$P_w = 0.5\rho A_w C_p \left(\frac{\omega_r R}{\lambda}\right)^3 .$$

II. RESULTS:

To further verify the performance of the proposed algorithm, a 2-kW single-phase inverter prototype based on



TMS320LF2406 A DSP is established. The experimental setup for the prototype development shown in Figis established to test the key performance measures of the converter including the wind generator.

The type of motor drive inverter is Sunfast E350. The rated parameters of the electromotor are 5.5 kW, 50 Hz, and 960 r/min. The wind generator used is a dc generator and its rated power is 1500 W. Since there is a rectifier circuit integrated in the wind generator, the output voltage of the wind generator can be connected to any two ports among A, B, and C of the converter. By changing the frequency of the general purpose inverter to simulate different wind speeds, different rotation speeds of the wind generator can be achieved.

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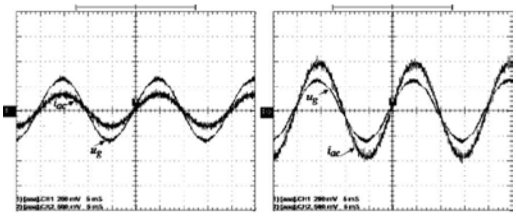
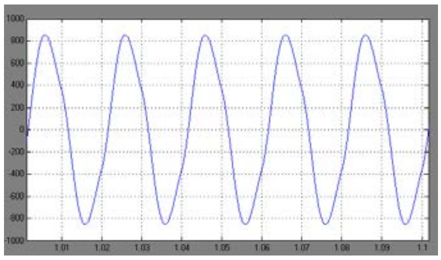
The waveforms of grid-connected current *i*ac and the grid voltage *ug* are shown in Fig. Channel 1 is the grid voltage *ug* and Channel 2 is the grid connected current *i*ac . Fig shows the variation of the total harmonic distortion (THD) of *i*ac at different power output levels, which illustrates the higher power generated, the smaller THD of current. When the output power is over 30% of the rated power, THD is less than 4%, which satisfies the requirement in accordance with IEC 61727 (total harmonic current distortion shall be less than 5% at rated inverter output).Fig. shows the power factor and efficiency of the system versus grid-connected power. Near the rated output power, the power factor is 0.99 and the efficiency is over 94%. According to the national wind farm grid code, if the voltage of wind farm remains at a level > 20% of the nominal voltage for a period that does not exceed 1 s, the plant must stay online. Therefore, the system should have the low voltage ride through capability under grid disturbances.

When a grid fault occurs, the rectify voltage of the wind generator is higher than the reference voltage of dump load, and the SCR circuit is forced to work only to consume energy under this condition. On the other hand, the grid-connected current can be limited controlled and this would be effective to enhance the transient stability of the system. In this study, a programmable ac voltage source is used working as the grid. Fig shows the transient current when the grid voltage falls to 30% of the nominal voltage. It means that the dump load and limited current control achieve the low voltage ride through requirement of wind farm.

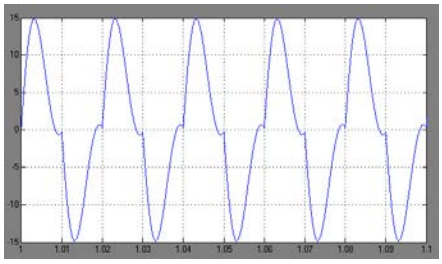


CH1: Grid voltage 300V/div; CH2: Grid current 5A/div
(a) (b)

Simulation Results :output voltage



Output Current:



III. CONCLUSION

In this paper, a small-scale wind-driver permanent magnet generator connected to the grid is proposed. Experimental preliminary results show that the output current injected to the grid satisfies IEC standards and the efficiency of the transformer less inverter is high. In addition, setup costs are very low. Further work is in progress to test the performance of maximum power tracking on an actual wind turbine in the field and to enhance the low voltage ride through capability of fixed speed wind turbine-generator system during network disturbance that will give an improved power electronic interface for wind generator to the grid.

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