Power Stability of Wind Energy Conversion System by using Current Source Inverter (CSI)

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ABSTRACT

Global warming as one of the most critical environmentalproblem facing by the whole world In an attempt to prevent the realization of thesefears, numerous advanced nations around the world havecommitted themselves to controlling emissions of green-house effect gases by becomin signatories to the KyotoProtocol. Wind energy is a clean energy that can avoid greenhouse gas (GHG) emissions and emits no air pollution. As wind turbine generators are driven by fluctuating wind, the power quality of the system gets when they are installed into the electric grid. This paper present a control scheme for maintaining power output stability of wind power by using Matlab/ Simulink. A current source inverter (CSI) has been used as a controller for controlling the output voltage and electromagnetic torque of the system. Three resistances are also connected in parallel to the load for the protection of over current in the system. Squirrel-cage type induction generator and Self-excited induction generators are also simulated with the controller.

Keywords

Power system stability, CSI, WECS

1. INTRODUCTION

In light of the threefold global crisis mankind is facing currently – the energy crisis, the finance crisis and the environment/climate crisis – it is becoming more and more obvioustthat wind energy offers solutions to all of these huge challenges, offering a domestic, reliable, affordable and clean energy supply.Although in absolute terms wind energy still represents a small amount of global energy supply, it should be realized that it is one of the world's fastest growing energy sources. Around the world today, wind-power already meets the electricity needs of around 16 million households, encompassing more than 35 million people. The wind-power technology is a commercial mature technology in the sense that currently there are more than fifteen manufactures offering high quality machines, that generate quality frequency for electricity network, and that is designed to operate continuously, unattended and with low maintenance, for 15-20 years. These machines are highly reliable, with an operating availability reaching about 98% [2]. The wind energy isone of the cleanest and fastest growing renewable energyamong various renewable energies worldwide due to itsavailability and pollution free nature. It is predicted by new policies scenario, moderate scenario, advanced scenario that the total cumulative installed capacity by the end of 2020/2030 is 587GW/918GW, 759GW/1600GW, 1150GW/2500GW respectively [4]. In recent years, wind energy has shown a good environmental advantages and, in number of situations, it has graduallyapproachedcost competitiveness.According to the U.S. Energy Information Administration, world electricity consumption will increase from 12,833 TWh in 1999 to 22,230 TWh in 2020, mainly driven by developing countries, where two billion people are still without access to electricity [6]. Since wind availability is sporadic and unpredictable, it is desirable to develop fast and efficientto track the optimal operation points of a variable speed wind energy system (WES) [10].A study of a 6 kv rural network in New Zealand has shown that dispersed and properly sized turbines will not only have a positive effect on losses, but also improve voltage quality [13].However, since wind is a highly intermittent energy source, it is claimed that any such benefit is likely to be small and will be site-specific [15].The intermittent nature of wind makes power system operation especially challenging. The fluctuation of wind causes fluctuations in the power delivered by the wind farm to the electricity network. Therefore, the development of systems to improve voltage stability, frequency stability and power quality is an important line of research in the wind power field.In the grid impact studies of wind power integration, the voltage stability issue is a key problem because a large proportion of existing wind farms are based on Fixed-Speed Wind Turbines (FSWTs) equipped with simple induction generators [17]. Some of the important issues related to voltage variations like steady state voltage under continuous production of power and voltage fluctuations like Flicker during operation, Flicker due to switching had been discussed in [18].Grid expansions may also lead to unwanted interference with the local environment [20].In order to provide network protection against abnormaloperating conditions, like transients and islanding conditions or to overcome various problems related to wind energy various types of electronic controllers, energy storage devices like conventional batteries, flywheels and superconductive magnetic energy storage,modulation inverter techniques have been used. Disadvantage of using these storage devices is that the energy capacity is related to the power capacity. Voltage source converter is the commonly used inverter for controlling the output of wind power but there is a danger of voltage drop in the circuit while using voltage source inverters [22]. In this paper a Simulink model is developed for wind turbine system and current source inverter is used as a controller to control the output power of wind turbine generator.Current source inverter (CSI) has the following several merits:The drive is current sensitive. Torque is directly related to stator current and rather nonlinearly with stator voltage The drive is regenerative. Hence the control of current ensures the direct and precise control of the electromagnetic torque.Four quadrant operation capability and nearly sinusoidal outputs.

2. STANDARD TOPOLOGY USED FOR POWER ELECTRONIC CONVERTERS

2.1 Operation of Voltage Source Inverters

Existing voltage-sourced inverter topologies producing split-phase outputs are divided into two main categories: split DC capacitor or 'neutral point clamped' inverters, and three-leg inverters. The split DC capacitor method establishes a loosely regulated balance of output voltages. Two large DC capacitors hold the neutral point of the output approximately halfway between the positive and negative voltage rails. This approach successfully balances the output voltages when the difference between loads is not too large. Basic topology has been shown in Fig. 1.

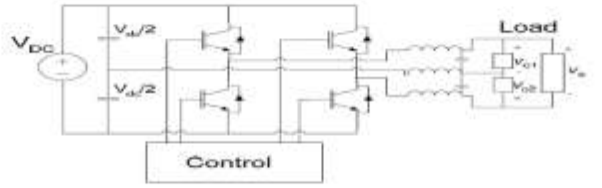

Fig. 1.Split DC capacitor method

The second category of VSI split-phase topologies relies on a third leg of switches to regulate the neutral point voltage as shown in Fig. 2. Generally, the original four switches (numbered 1 to 4 in the figure) are used to control the total output voltage, $V_{o.}$ the additional two switches (numbered 5 and 6) maintain the neutral point at $V_{dc}/2$. This can be accomplished with very simple, decoupled control, where switches 1 to 4 work as in the single-phase case and switches 5 and 6 alternate with a 50% duty cycle to hold the average neutral point voltage halfway between the DC rails.

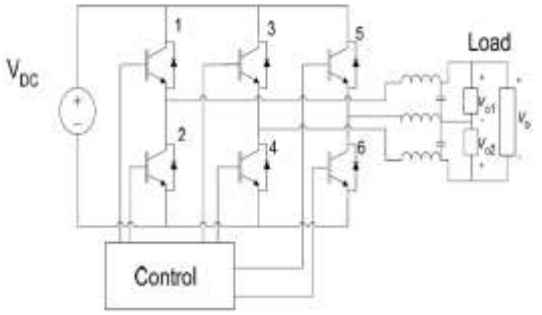

Fig. 2.Third-leg method

2.2 Current Source Inverters

An alternative to the voltage source inverter is the current source inverters (CSI) shown in Fig 3.A current-sourced inverter controls its output voltage by alternately directing its DC input current into an output filter capacitor in the forward and reverse directions. The output capacitor is charged when current is injected into its positively-charged rail and discharged when current is injected into its negatively-charged rail. Periods when the capacitor is being actively charged or discharged will be referred to as active states. There is a third mode of operation, in which the DC current circulates through the two switches in a single leg of the inverter and does not enter the output capacitor in either direction. This is known as a shoot-through state. When the inverter is in a shoot-through state, the output capacitor will slowly discharge through the connected load.

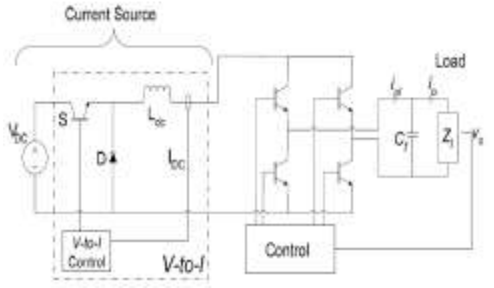

Fig. 3Implementation of voltage source-to-current-source conversion circuit

2.3 Sinusoidal Pulse width Modulation

Sinusoidal Pulse Width Modulation (SPWM) is employed to control the switching of the CSI controller.The simplest way to generate a PWM signal is the interceptive method, which requires only a saw tooth or a triangle waveformand a comparator. In this method the modulation index is defined as the ratio of the peak amplitude of the modulating sine wave (V_s) to the peak amplitude of the triangular carrier wave (V_{tri})where this ratio is less than or equal to 1 ($m \leq 1$).

$$m = \frac{V_s}{v_{tri}} \qquad (1)$$

The frequency modulation ratio (m_f) is defined as the ratio of the triangular carrier frequency (f_{tri}) to the frequency of the control signal (f_1).

$$m_f = \frac{f_{tri}}{f_1} \qquad (2)$$

The frequency of the triangular carrier is kept constant and determines the switching frequency as shown in Fig 4. When the switching frequency is much higher than the generated frequency and for $m \leq 1$, which indicates operation in the linear region, low frequency harmonics cannot appear in the PWM waveforms. Hence, the distortion is minimal and it is reasonable to neglect higher harmonics and consider only the fundamental components for subsequent calculations

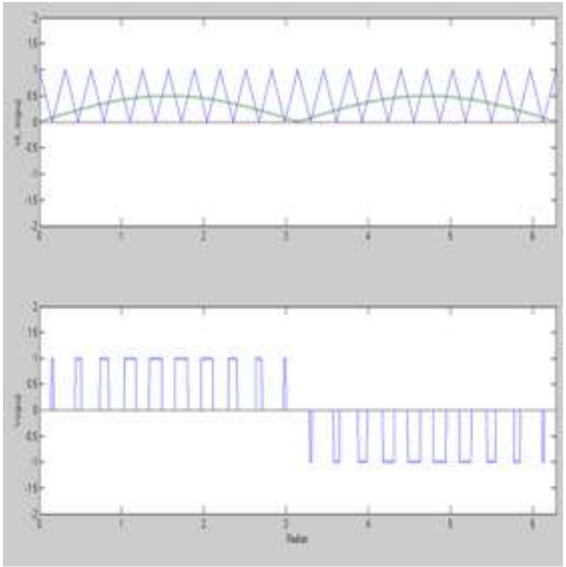

Fig. 4. The carrier and modulating signals, the output voltage waveform

3. SIMULINK MODEL OF WIND TURBINE

3.1 Wind Turbine

The model of wind turbine is based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine. The Simulink model of theWind Turbine is shown in Fig 5:

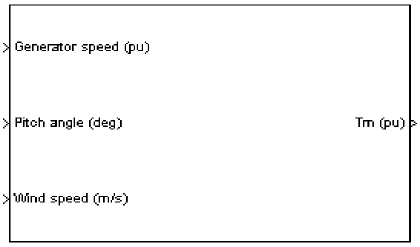

Fig. 5.Block of Wind Turbine

The output power of the turbine is given by the following equation [15].

$$P_m = C_p(\lambda, \beta)\,\frac{\rho A}{2}\,v_w^3 \quad (3)$$

Where$P_m$is the mechanical output power of the turbine (W), C_p is the Performance coefficient of the turbine,ρ is the air density (kg/m^3), A is the turbine swept area (m^2), v_w is the wind speed (m/s), λ is the tip speed ratio of the rotor blade tip speed to wind speed, β is the blade pitch angle (deg)

Eq. 13 can be normalized in the per unit (pu) system:

$$P_{m\_pu} = k_p C_{p\_pu} v_{w_{pu}}^3 \ (4)$$

Where$P_{m_pu}$is the power in pu of nominal power for particular values of ρ and A, C_{p_pu} is the performance coefficient in pu of the maximum value of C_p, v_{w_pu} is the wind speed in pu of the base wind speed. The base wind speed is the mean value of the expected wind speed in m/s.k_p is the power gain for C_{p_pu}=1pu and v_{w_pu}=1pu, k_p is less than or equal to 1.

A generic equation is used to model C_p (λ, β)

$$C_p(\lambda, \beta) = c_1\left(\frac{c_2}{\lambda_i} - c_3\beta - c_4\right)e^{\frac{-c_5}{\lambda_i}} + c_6\lambda (5)$$

Where c_1 =0.5176, c_2 = 116, c_3 = 0.4, c_4 =5, c_5 = 21 and c_6 = 0.0068.

With

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} (6)$$

a.Program Code Used in SIMULINK for Wind Turbine

```
functionTe=Ab(v,cp)
%cp=[0.7 0.88 0.9];
%cp=0.7;
%v=[2.5 ;10; 11; 13];
%v=2.5:0.5:25;
s=length(v);
Te=cp*v*(-6.72);
fori=1:s
end
```

3.2 Output of Wind Turbine

Fig 6 shows the output of wind speed with power. As the wind speed increases power also increases. Wind turbine parameters used in simulation is given in Table 1.

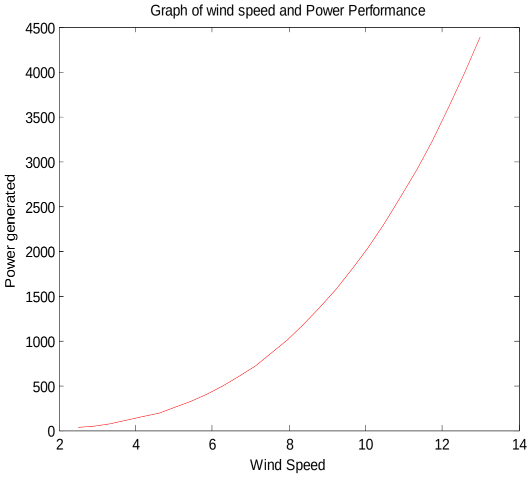

Fig. 6 Graph of wind speed and Power performance

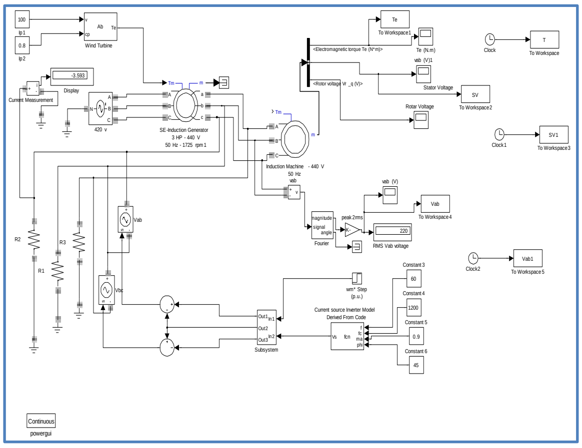

Fig. 7.Complete simulation circuit diagram

4. SIMULATION STUDY AND RESULTS

The whole model is simulated for the stability of wind power by using current source inverter as a controller as shown in Fig. 7. A self-excited induction generator, current source inverter connected in parallel to the load, a 3-phase induction motor as a load and a control scheme has been applied for controlling electromagnetic torque of the motor.Three resistances are connected in parallel to the supply for protecting the system from over current. Voltage measurement block has been used for measurement of instantaneous voltage between two electric nodes. By applying the variable supply or suddenly change in load the Simulink model shows the stability results for voltage, electromagnetic torque and stator voltage of wind energy conversion system. Parameters used for induction generators and for induction motor has been shown in Table 2 and Table 3.

TABLE 3
PARAMETERS OF INDUCTION MOTORS

Symbol	Quantity	
Pn	Nominal power	3*746 VA
Vn	voltage (line-line)	220 V
fn	frequency	60Hz
Rs	Stator resistance	0.435 ohm
Ls	Stator inductance	$4*10^{-3}$H
Rr'	Rotor resistance	0.816 ohm
Lr'	Rotor inductance	$2*10^{-3}$ H
Lm	Mutual inductance	$69.3*10^{-3}$ H

TABLE 2
PARAMETERS OF INDUCTION GENERATORS

Symbol	Quantity	
Pn	Nominal power	3930 VA
Vn	voltage (line-line)	440 V
fn	frequency	50Hz
Rs	Stator resistance	0.03965 ohm
Ls	inductance	0.0397 H
Rr'	Rotor resistance	0.02 ohm
Lr'	Rotor inductance	0.04 H
Lm	Mutual inductance	1.354 H

4.1 C Program Code for CSI Inverter Model

```
functionVs = fcn(f,fc,ma,phi)
Vrin=1;
wt=1:100;
ma1=1:100;
Vt=1:100;
beta=1:100;
Vs=1;
alpha=1:100;
Vout=1:100;
C=1:100;
CO=1:100;
CS=1:100;
CS1=1:100;
% Z is the load impedance in per unit.
Z=1;
% ma is the modulation index
% phi is load-phase-angle
% fc is frequency of the carrier signal.
PART I
% Calculating load parameters.
phi=phi*pi/180;
% R and L are the load resistance and inductance respectively.
R=Z*cos(phi);
L=(Z*sin(phi))/(2*pi*f);
PART II
% Calculating the number of pulses per period,N
N=fc/f;
for k=1:2*N
for j=1:20
   % finding the generalized time counter
i=j+(k-1)*2;
   % finding the time step
wt(i)=i*pi/(N*50);
   %finding the half period of the output voltage.
if(sin(wt(i)))>0
hpf=1;
else
hpf=-1;
end
% calculating the modulating signal
ma1(i)=ma*abs(sin(wt(i)));
 % calculating the sawtooth waveform
if rem(k,2)==0
Vt(i)=0.02*j;
if abs(Vt(i)-ma*abs(sin(wt(i))))<=0.011
      m=j;
beta(fix(k/2)+1)=3.6*((k-1)*50+m)/N;
else
      j=j;
end
else
Vt(i)=1-0.02*j;
if abs(Vt(i)-ma*abs(sin(wt(i))))<0.011
      l=j;
alpha(fix(k/2)+1)=3.6*((k-1)*50+l)/N;
else
      j=j;
end

end
   % calculating the output voltage waveform
ifVt(i)>ma*abs(sin(wt(i)))
Vout(i)=0;
else
Vout(i)=hpf*Vrin;
End
```

The overall purposed system has been demonstrated through computer simulations in terms of the power system shown in Fig. 7. Parameters of wind turbine, induction generator, induction motor used in simulations are also shown in Fig 7 and in Table 1-2 and 3respectively.

4.2 Variable Waveform of System Voltage

Unregulated waveform of system voltage has been shown in Fig. 8. This voltage is given as input to the self-excited induction generator. This variable voltage has been controlled by using CSI as a controller.

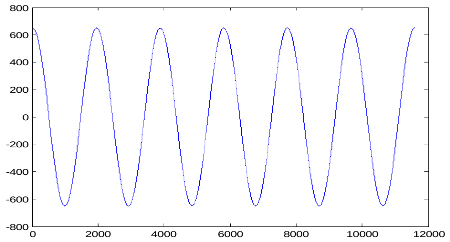

Fig 8 Unregulated waveform of system voltage

4.3 Regulated Voltage

Fig. 9shows the regulated waveform of system voltage. CSI has been used as a controller. After a little fluctuation the system voltage becomes constant.

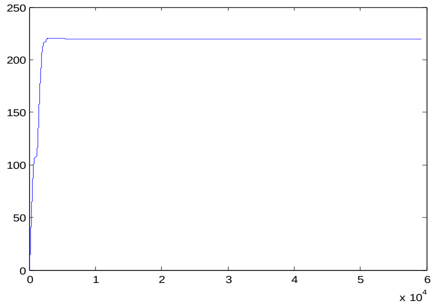

Fig. 9 Regulated waveform of system voltage

4.4 Frequency

Fig.10 shows the frequency of the system.

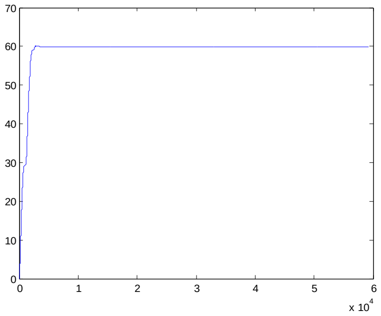

Fig. 10 Regulated frequency of system.

4.5 Output Waveforms Of Rotor Voltage And Electromagnetic Torque

Fig 11-12shows the constant output waveforms of electromagnetic torque and stator voltage by taking different wind speeds and pitch angles. After wind fluctuations the output of the system has been controlled. By using the control scheme of current source inverter, constant power of wind turbine has been achieved.

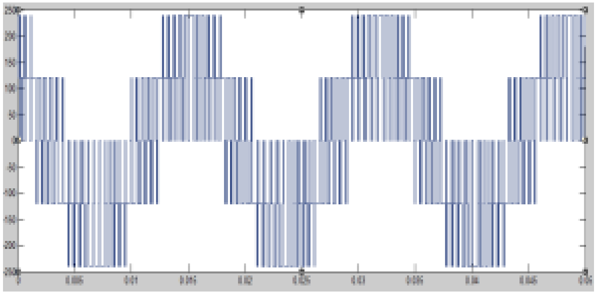

Fig. 11.Constant rotor voltage

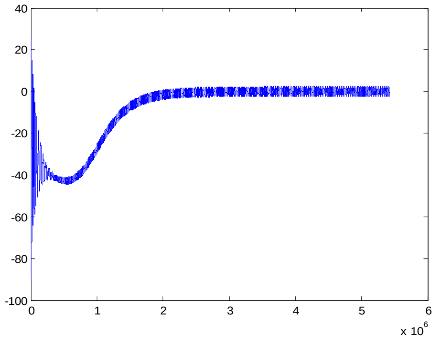

Fig. 12.Constant output of electromagnetic torque

5. CONCLUSION

Results shows that by using Current Source Inverter (CSI) stability of wind power can be achieved.By using CSI-based Controller voltage source inverter or any separate storage energy system is not required. A model is used to determine the behaviour of the wind turbine, induction generator andload. The differential equations describing the behaviour of the CSI controller are developed.

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