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Perturb and Observe Maximum Power Point Tracking Technique with PID Controller for a Wind Power System

K. Keerthi Sri[1,*], K. Rama Sudha[2]

Abstract

The wind power generation system has a significant growth worldwide over the past four decades. The wind power generation system has strong coupling and linear characteristics which makes it a complicated electromechanical system. The power control strategy has a higher impact on the overall performance as the wind power generation is operated at variable and random wind speed conditions. PID control is the most used control algorithm in industrial applications. PID controllers are known for their robust performance in a wide range of operating conditions and their functional simplicity which allows engineers to work in a simple manner. The efficiency of the wind power generation is improved by proposing a PID (Proportional Integral Derivative) controller based MPPT (Maximum Power Point Tracking) scheme in the LabVIEW platform. The wind turbine is modelled in accordance with the mathematical equations in LabVIEW platform. The permanent magnet synchronous generator (PMSG) and rectifier-converter system is modelled in the LabVIEW Multisim platform. The Perturb and Observe MPPT control strategy with a PID controller is introduced to the system to obtain maximum power. The simulation tests are performed under various wind speeds. The results obtained demonstrate that PID based MPPT technique is efficient to improve wind power generation.

Keywords: Wind power generation, MPPT (maximum power point tracking), PID-controller, LabVIEW, Multisim

INTRODUCTION

The wind power generation system has a significant growth worldwide over the past four decades. The wind power generation system has strong coupling and nonlinear characteristics which makes it a complicated electromechanical system. The power control strategy has a higher impact on the overall performance as the wind power generation is operated at variable and random wind speed conditions. Wind power generation systems must adopt different control methods according to different wind speed intervals. Diagram of wind power generation circuit is shown in Figure 1. An MPPT controller is necessary to ensure electromechanical reliability of the system and improve the efficiency of the wind power generation under various wind speed conditions. PID control is the most used control algorithm in industrial applications. PID controllers are known for their robust performance in a wide range of operating conditions and their functional simplicity

***Author for Correspondence**
K. Keerthi Sri
E-mail: keerthisri.3006@gmail.com

[1]Student, Department of Electrical Engineering, Andhra University, Vishakhapatnam, Arunachal Pradesh, India.
[2]Professor, Department of Electrical Engineering, Andhra University, Vishakhapatnam, Arunachal Pradesh, India.

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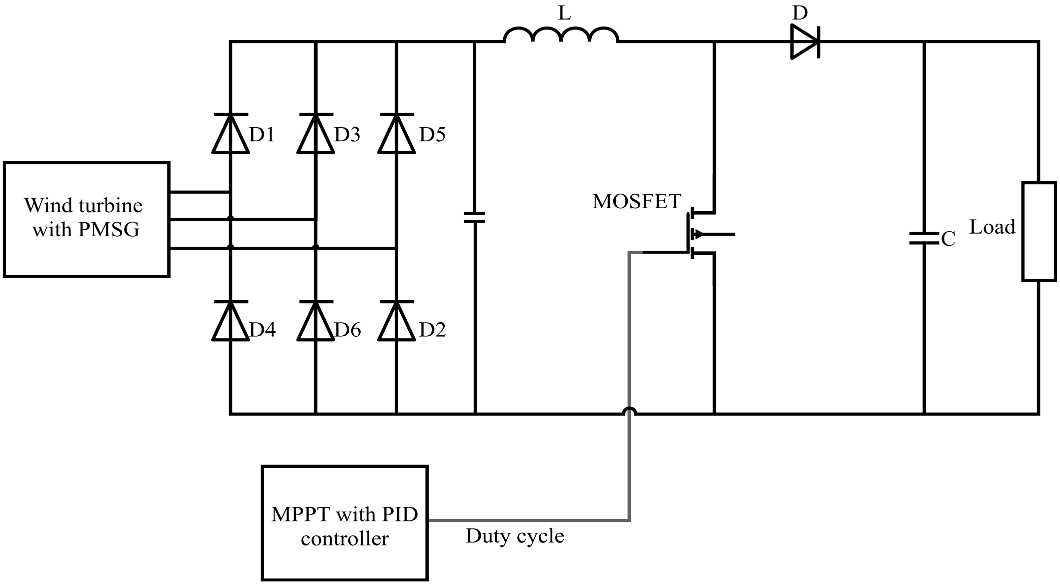

Figure 1. Wind power generation circuit.

which allows engineers to work in a simple manner. For this reason, this study proposes a PID controller based MPPT technique to improve the efficiency of wind power generation. The main contributions of this study are:

1. To model a wind power generation system in LabVIEW to estimate the efficiency of wind power generation.
2. Proposing a PID controller based MPPT technique to improve wind power efficiency.
3. Validating the PID controller based MPPT strategy for various wind speed conditions.
4. Demonstrating that PID controller based MPPT strategy is efficient in improving wind power generation.

Modelling of Wind Turbine

A wind turbine consists of a rotor which is mounted with a tower of two or more blades and a nacelle. This turbine is connected to an electric generator. The mathematical modelling of wind turbine helps to understand the wind turbine's performance under various wind speeds by considering the factors such as rotor radius, blade pitch angle and tip speed ratio. The output power and torque are determined as follows [1, 2]:

According to Newtons second law of motion:
Force = Mass × Acceleration

$$F=m\times a \tag{1}$$

Kinetic energy = Force× Distance
From Eq. (1):

$$KE=ma\times s=mas \tag{2}$$

From solid motion kinematics,

$$v^2=u^2+2as$$

where u is the initial velocity and v is the final velocity.
Therefore,

$$a = \frac{v^2 - u^2}{2s}$$

Assuming the initial velocity as zero (u=0), Then,

$a = \frac{v^2}{2s}$

From Eq. (2):

$$KE = \frac{1}{2}mv^2 \quad (3)$$

The above equation is dynamic since mass is constant. But in the case of wind with varying speed, mass is not constant. Hence the aerodynamic power P for change in kinetic energy is:

$$P = \frac{1}{2}\frac{dm}{dt}v_w^2 \quad (4)$$

Where v_w = wind velocity.

$\frac{dm}{dt} = \rho A v_W$

Where, p= air density, and

A= area through which wind is flowing.

Therefore,

From Eq. (4):

Aerodynamic power:

$P = \frac{1}{2}\rho A v_w^3$

The actual mechanical power is given by:

$$P = \frac{1}{2}\rho A v_W\left(v_u^2 - v_d^2\right) \quad (5)$$

Where,
V_u= upstream wind velocity, and
V_d= downstream wind velocity.
The mass flow rate can be written as:

$\frac{dm}{dt} = \rho A(\frac{v_U + v_d}{2})$

Therefore,
From Eq. (5):
Aerodynamic power becomes:

$P = \frac{1}{2}\rho A\left(v_u^2 - v_d^2\right)(\frac{v_U + v_d}{2})$

By solving the above equation:

$$P = \frac{1}{2}\rho A v_w^3 C_P \quad (6)$$

Where,
CP= power coefficient of the wind turbine:

$C_P = \frac{(1+\frac{v_d}{v_u})(1-\left(\frac{v_d}{v_u}\right)^2)}{2}$

Considering blade pitch angle (β) and tip speed ratio (λ),
Where,

$\lambda = \frac{v_d}{v_u}$

and it is given by:

$\lambda = \frac{blade\ tip\ speed}{wind\ speed}$

$$\lambda = \frac{angular\ speed\ of\ turbine(\omega) \times Rotor\ radius\ (R)}{wind\ speed} = \frac{\omega R}{v_w} \quad (7)$$

Then,
C_P becomes:

$C_P = C_1 \left(C_2 \frac{1}{\lambda_i} - C_3\beta - C_4 \right) \exp\left(\frac{-C_5}{\lambda_i}\right)$

Where,

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

The aerodynamic torque is given by:

$T = \frac{P}{\omega}$

Therefore,
From Eqs. (6) and (7):

$T = \frac{1}{2}\rho A v_W^2 C_P \frac{R}{\lambda}$

Considering $A = \pi r^2$
Then aerodynamic torque becomes:

$T = \frac{1}{2}\rho A v_W^2 C_P \frac{R^3}{\lambda}$

Permanent Magnet Synchronous Generator (PMSG) Model

The Permanent Magnet Synchronous Generator basically produces electrical energy from the mechanical energy obtained through wind turbines. The mathematical model of PMSG is derived from direct axis and quadrature axis reference frame in which q-axis is 90° ahead of d-axis. Neglecting eddy current and hysteresis losses and assuming the winding of the generator is symmetrical such that the mutual inductance is zero [1, 3].

The voltage equations are given by:

$u_d = -R_s i_d - L_d i_d - \Psi_f + n_p \omega_g L_q i_q$

$u_q = -R_s i_q - L_q i_q - n_p \omega_g (L_d i_d - \Psi_f)$

Where,
u_d= Stator voltage on d-axis,
u_q= Stator voltage on q-axis,
R_S= Winding resistance,
n_p= Number of poles,
T_f = Permanent magnetic flux,
ω_g= Generator rotor speed,
i_d= Stator current on d-axis,
i_q= Stator current on q-axis,
L_d= Stator inductance on d-axis, and
L_q= Stator inductance on q-axis.

The electromagnetic torque is given by:

$$T_e = \frac{3}{2} n_p [\Psi_f i_q + (L_d - L_q) i_d i_q]$$

Rectifier Model

A rectifier is a circuit which converts AC voltage into DC voltage as shown in Figure 2. It constitutes of six diodes which are connected in parallel. A capacitor is connected in parallel to the load which acts as a filter to reduce voltage ripples [1, 4].

The average DC output voltage across the load is given as:

$$V_{DC} = \frac{3\sqrt{3}}{\pi} V_s$$

Where,

$$V_s = \frac{V_{L(peak)}}{\sqrt{3}}$$

$$= \frac{Maximum\ line-to-Line\ voltage}{\sqrt{3}}$$

$$= \frac{Line\ voltage\ (V_L) \times 1.414}{\sqrt{3}}$$

The average DC output current across the load is given as:

$$I_{DC} = \frac{V_s}{R}$$

Boost Converter Model

A boost converter steps up the input DC voltage and the output voltage is thus higher than the input DC voltage. It consists of an inductor and diode connected in series and a transistor connected between the diode and inductor in parallel. A load is connected to the circuit to observe output voltage and current as shown in Figure 3. A capacitor is connected in parallel to the load which acts as a filter to reduce the voltage ripple [1, 4].

The duty ratio of boost converter is given by:

$$D = 1 - \frac{V_S}{V_O}$$

V_S= supply voltage, and

V_O= Desired output voltage.

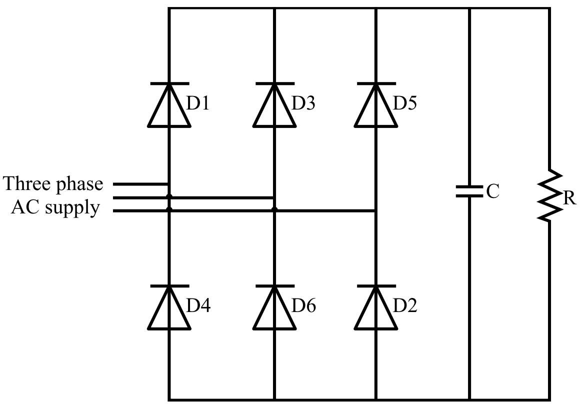

Figure 2. Three phase fully controlled rectifier circuit diagram.

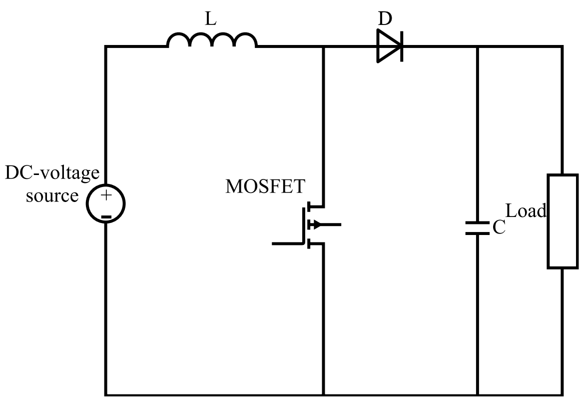

Figure 3. Boost converter circuit.

Therefore, inductance value is determined by:

$$L = \frac{D(1-D)^2 R}{0.2f}$$

where R= value of resistive load, and f= sample frequency.

Capacitance value is determined by:

$$C = \frac{D}{R\left(\frac{\Delta V_O}{V_O}\right)f}$$

$\frac{\Delta V_0}{V_0}$= voltage ripple

Perturb and Observe MPPT (Maximum Power Point Tracking) Technique

In this MPPT technique, the voltage and current are measured from the rectifier. The power is calculated from the obtained values. The output power is calculated from the voltage and current obtained through the converter circuit. This output power is compared with the rectifier output. If the output power and output voltage increases, then the duty cycle is increased. If the output power increases and output voltage decreases, then the duty cycle is decreased. If the output power decreases and output voltage decreases, then the duty cycle is increased. If the output power decreases and output voltage increases, then duty cycle is decreased as shown in Figure 2 [5, 6]. A flowchart of Perturb and Observe MPPT technique is shown in Figure 4.

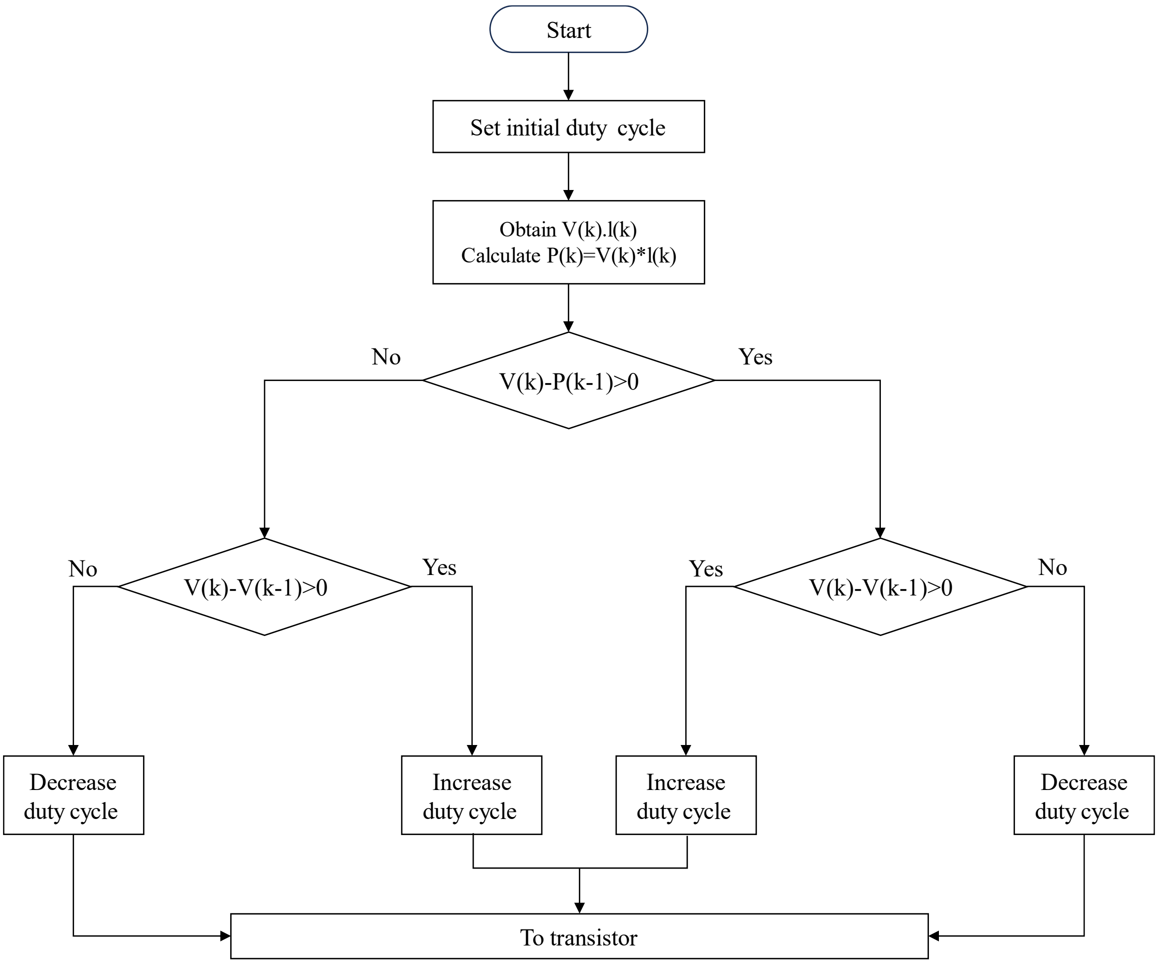

Figure 4. Flowchart of perturb and observe MPPT technique.

PID (Proportional Integral Derivative) Controller

A PID controller consists of three coefficients which are proportional, integral, and derivative. These coefficients are varied to get an optimal response. A PID controller also consists of a process variable and set point. The set point is the command given to the process variable which needs to be controlled. By increasing the proportional constant, the speed of the system is increased. The integral constant is increased to minimize the error to zero. The derivative constant is increased to increase the system capability to react effectively for changes in error and increase the speed of system [7].

The output of the controller is given by the equation,

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt}$$

Where,
e(t)= Error signal,
u(t)= Controller output signal,
K_p= Proportional constant,
K_i= Integral constant, and
K_d= Derivative constant.

DEVELOPMENT OF WIND POWER GENERATION SYSTEM

Firstly, a wind turbine is designed in the LabVIEW platform according to the mathematical modelling equations. The permanent magnet synchronous generator is designed in the LabVIEW Multisim platform. The designed PMSG is co-simulated with the wind turbine in the LabVIEW operation platform. The output torque obtained from the wind turbine is given to a permanent magnet synchronous generator. A rectifier-converter circuit is designed in Multisim according to the mathematical modelling equations. A PID controller is connected to the MOSFET in the rectifier-converter circuit [8–10]. This rectifier-converter circuit is co-simulated with the PMSG in the LabVIEW operation platform. The output obtained from the PMSG is then given to a rectifier-converter circuit. The code for perturb and observe MPPT technique is introduced in the mathscript node. The output voltage and current obtained from rectifier are given as inputs to mathscript node. The duty cycle is taken as output from mathscript node. The obtained duty cycle is given to MOSFET through Pulse Width Modulation (PWM) block. The final power is observed by taking the output voltage and current values obtained from the whole wind system.

SIMULATION

Wind Turbine

The wind turbine is simulated in the LabVIEW platform as shown in Figure 4 according to the mathematical model. The parameters of the wind turbine are shown in Table 1. The output of the wind turbine are Power coefficient (Cp), Torque (te) and wind power.

Table 1. Parameters of Wind turbine.

Parameter name	Value
C1	0.5176 F
C2	116 F
C3	0.4 F
C4	5 F
C5	21
Tip Speed Ratio (λ)	8.1
Pitch angle (β)	0°
Rotor radius (R)	0.54 m
Air density (ρ)	1.293 kg/m^3
Wind speed (υ_w)	11 m/s

Permanent Magnet Synchronous Generator (PMSG)

The PMSG is designed in Multisim platform as shown in Figure 5. The parameters of the PMSG are shown in Table 2. This PMSG is co-simulated with the wind turbine designed in the LabVIEW platform. The output torque of the wind turbine is given as input to PMSG. The output of the PMSG is observed in the LabVIEW platform as shown in Figure 6.

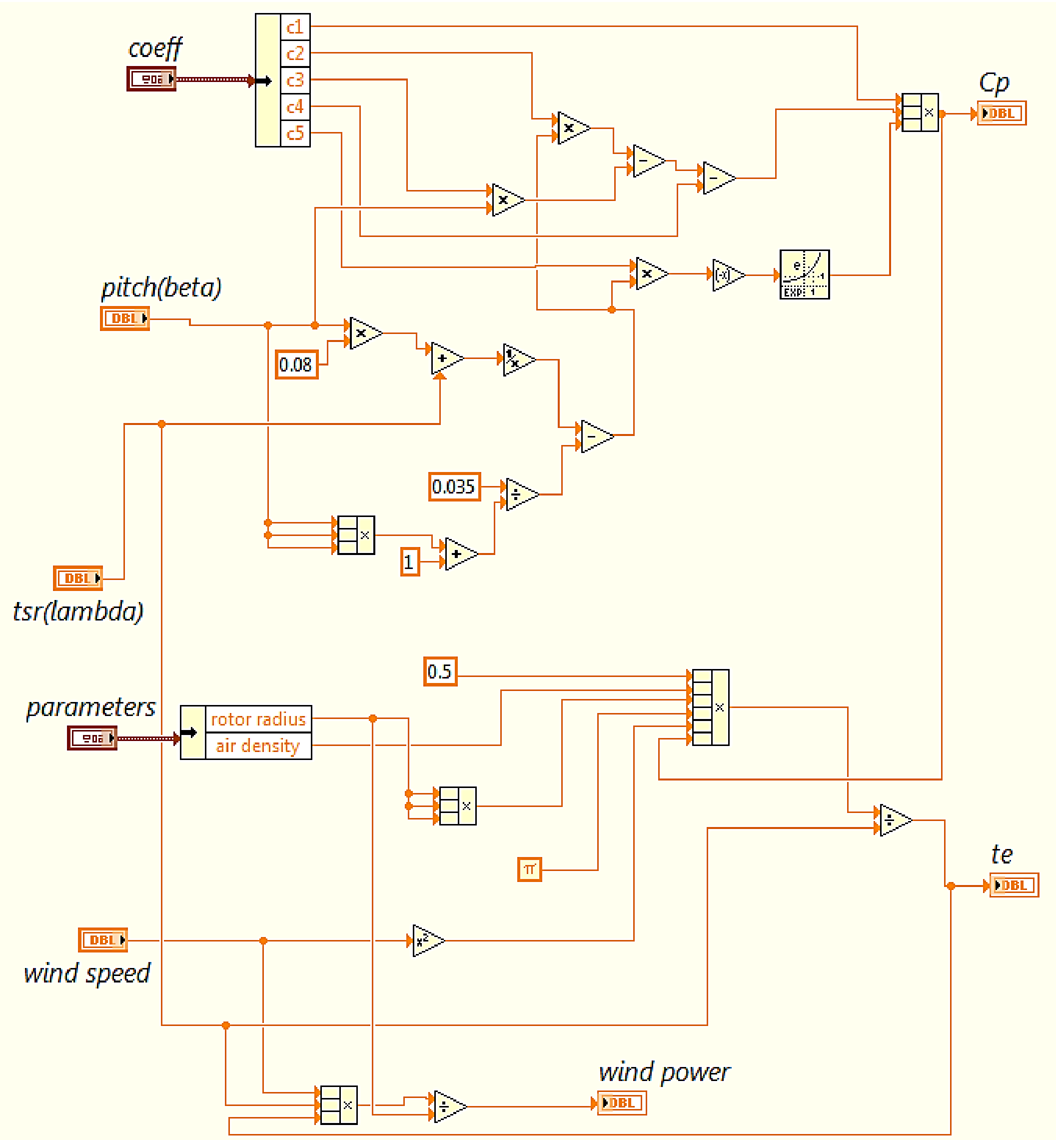

Figure 5. Simulation of wind turbine.

Table 2. Parameters of PMSG.

Parameter name	Value
d-axis inductance (L_d)	2 mH
q-axis inductance (L_q)	2 mH
Stator Resistance (R_S)	0.01
Magnetic flux (T_f)	0.04
Number of pole pairs (n_p)	2
Shaft Inertia (J)	1.2
Shaft Friction (F_s)	0.005

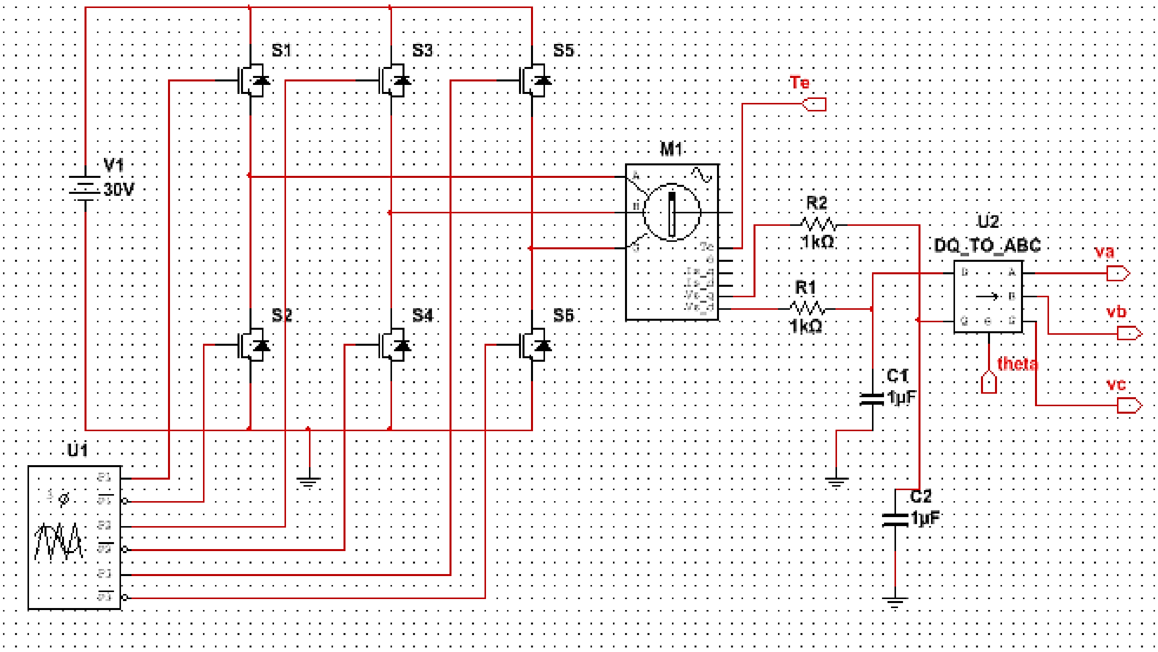

Figure 6. Simulation of PMSG.

Rectifier-converter Circuit

The Rectifier-Converter circuit is designed in the Multisim platform as shown in Figure 7. The output of PMSG is given as input to this circuit. The parameters are shown in Table 3.

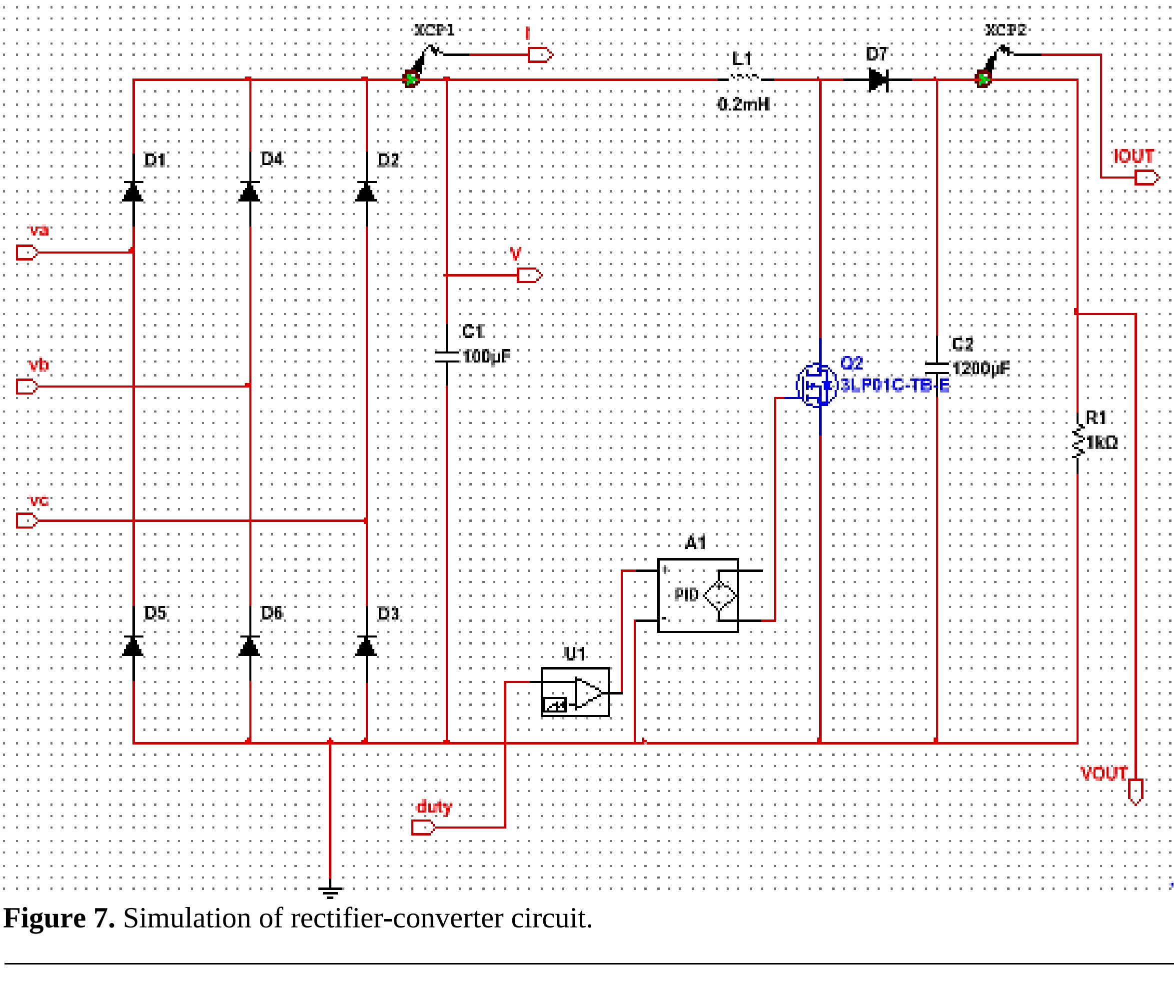

Figure 7. Simulation of rectifier-converter circuit.

Table 3. Parameters of Rectifier-converter circuit.

Parameter name	Value
Inductance (L1)	0.2 mH
Capacitance ($C1$)	100 µF
Load Resistance (R1)	1 kΩ
Capacitance ($C2$)	1200 µF
Switching Control Frequency (f)	10 kHz
Proportional Constant (K_p)	0.02
Integral Constant (K_d)	22.8
Derivative Constant (K_i)	0.000332

Whole Wind System Simulation

The perturb and observe MPPT algorithm is introduced in the mathscript node in the LabVIEW platform. The output voltage and current of the rectifier are given as input to the mathscript node. The duty cycle is taken as output from this node and given as signal to the MOSFET in the rectifier-converter circuit. Simulation of Wind power system is shown in Figure 8.

RESULTS

From Figures 8 and 9, the maximum power of 100 W is obtained from the wind energy generation system at a voltage of 10 V. Amplitude variation with time has shown in Figure 10 with regards to PMSG output voltage.

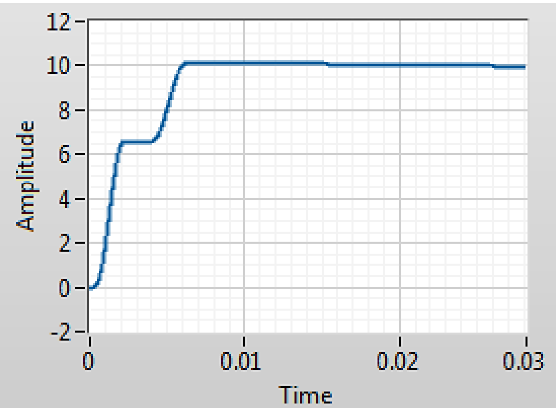

Figure 8. Load output voltage

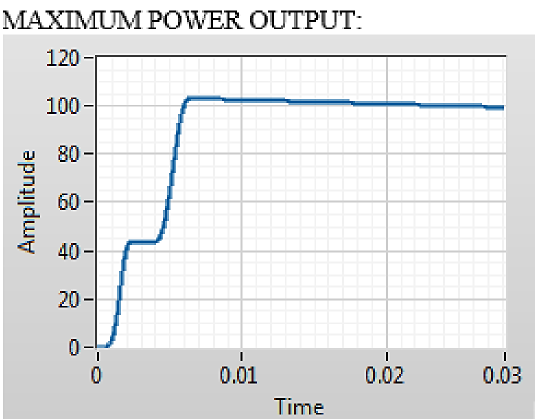

Figure 9. Load Output Power

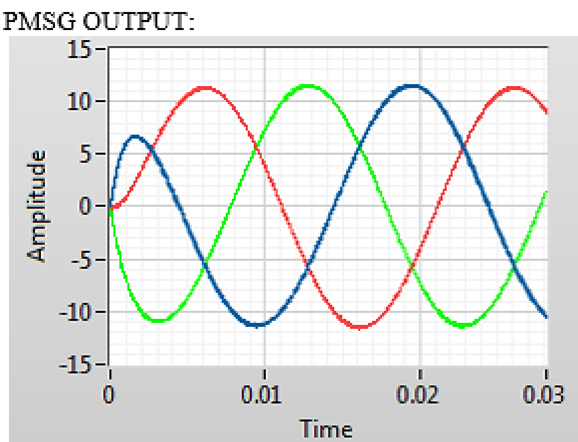

Figure 10. PMSG output voltage.

CONCLUSION

The obtained results show that the LabVIEW based MPPT technique for wind power generation can effectively simulate the various states of wind power generation. The wind power efficiency is greatly improved under various wind speed conditions. It can also be verified that PID controller based MPPT strategy is efficient in improving the wind power generation. For further research, this system can be expanded by connecting it to a grid with multiple wind turbines.

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