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(Research Article)

Efficiency improvement on wind turbine through bump up stepper motor

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Abstract

This paper presents with the starting torque provision for the wind turbines which are sometimes not rotating even at cut-in wind speed, (rotation sensed through output power of the turbine) here if the power is zero above the cut-in wind speed then the turbine is not in running condition. Here we are using the sensorless sensing method, by providing some extra torque through stepper motor for starting purpose we will improve the efficiency of the wind turbines. Normally the speed of the wind is not a constant, hence by providing this type of set-up can make the wind turbine to rotate to its maximum extent (i.e. the rotation time increases,efficiency improves). Also the supply for the stepper motor proposed to be provided with solar panels to make the system more eco-friendly and self-supporting

Keywords Wind Turbine; Stepper Motor; Solar Cell; Maximum Power Point Tracking; Perturb and Observe; Motor Choosing Method.

1. Introduction

The wind energy system is considered to be one of the most promising renewable resources. In which the wind turbine starts to rotate at start-up wind speed and the power gets extract from the turbine at cut-in wind speed. Hence due to some ageing effects of gear box or due to the problem in pitch angle control (i.e. improper alignment in blade) will cause decrease in starting torque of the turbine to rotate at cut-in wind speed. Hence the power extracting time from the turbine gets decrease which cause decrease in efficiency in wind turbine systems.

Hence for to overcome this energy loss we need to provide extra torque to the turbine shaft, for that we are going to provide that deficient torque through stepper motor which should operate during the period where the speed of the wind is above the cut-in wind speed and power output of the turbine is zero. In which the stepper is going to rotate for 20 seconds after that we are monitoring for wind speed and power out output of the turbine if that conditions prevails same again means operate the stepper motor for another 20 second or else stop the stepper motor when the turbine starts rotating. Also the supply to the stepper motor proposed to be provided with solar panels along with mppt and boost converter to make the system more eco-friendly and self-supporting.

The paper is organized as follows: Section II provides the concept of wind energy conversion system. Section III describes the stepper motor mathematical modeling and motor selection. Section IV describes the MPPT technique and solar panel simulation modelling. In Section V, effectiveness and feasibility of the proposed method is demonstrated by simulation results. Conclusions are drawn in Section VI.

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2. Torque calculation

2.1. Torque supplied by the turbine to generator

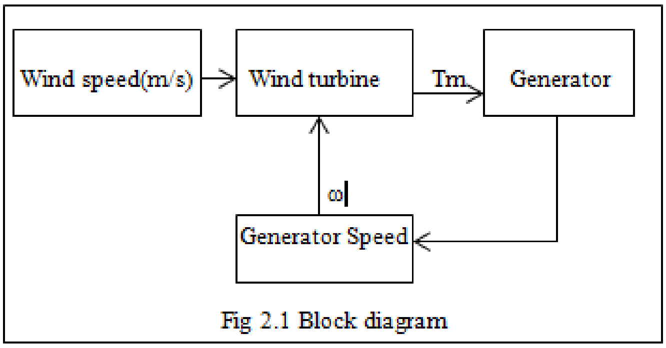


Figure 1 Torque supplied by turbine

Generally the specifications of turbine will provide you the diameter of the turbine hence with that we can able to calculate the mechanical power supplied by the turbine to generator at specified speed can be known. Hence for to drive the turbine at some constant speed during cut-in wind speed we know the torque level. By using this technique we can choose the proper stepper motor for to drive the turbine at stall conditions during cut-in wind speed

The equations which are involved in wind turbine torque calculation are as follows:

Mechanical turbine torque (turbine) = Pm/ω

Pm=mechanical power & ω=speed to rotate or generator speed

The power available in the wind is given by the flowing air mass per unit time.

Pm = 1/2 (air mass per unit time) (wind velocity)

$Pm=1/2\rho AV_w^3Cp$ ....eq(1)

Where,

ρ = air density 1.225 kg/m³ at sea level (T=273)
V_w = Up stream wind velocity.
A = rotor area.
Cp = power co-efficient
Vw=Wind velocity (m/s)
Cp = Power output from the wind turbine /Power available in the wind.

The wind turbine produces maximum power when the turbine operates at maximum value of Cp,

$$C_p = (0.3-0.0167\beta)\sin\left(\frac{\pi(\lambda+0.1)}{10-0.3\beta}\right)-0.00184(\lambda-3)\beta$$ ....eq(2)

Where β=pitch angle

The tips peed ratio has given by the following equation.

$\lambda=2\pi RN/V_w$ ....eq(3)

R=Radius of blade swept area,N=Rotatioal speed.

3. Stepper motor

Here we are going to use stepper motor as the extra drive system for to drive the turbine in stall condition during cut-in wind speed. For which the torque required for selecting the motor to rotate the wind turbine at constant speed is calculated using mechanical power of the turbine

Hence the equation for designing the hybrid stepper is as follows

Mathematical model describing the dynamics of the system [1] can be given as follows

$\frac{dia}{dt} = [Va - ia * R + Km * \omega * sin(Nr * \theta)]/L$ ....eq(4)

$\frac{dib}{dt} = [Vb - ib * R - Km * \omega * cos(Nr * \theta)]/L$ ....eq(5)

$K_m(-i_a sin(N\theta)+i_b cos(N\theta))-T_L=J(dw/dt)+K_V W$ ....eq(6)

$W=d\theta/dt$ ....eq(7)

Where,

Va → voltage applied to phase A (volt)

Vb → voltage applied to phase B (volt)

ia → instantaneous phase A current (ampere)

ib → instantaneous phase B current (ampere)

R → resistance per phase (ohm)

J → moment of inertia (kg m^2)

B → viscous friction coefficient (Nm/rad/sec)

L → inductance per phase (henry)

ω → angular speed (rad/sec)

Km→ motor back emf constant (volt/rad/sec)

Tl → load torque (Nm)

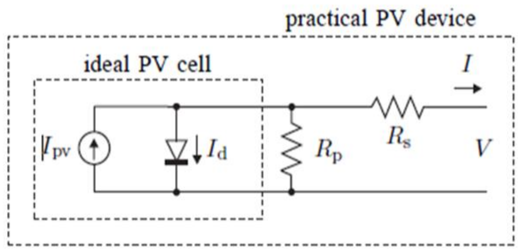
Kv→coefficient of viscous friction(Nms/rad)

N →rotor number teeth

Using MATLAB SIMLINK Tool Kit, the dynamic equation (4),(5),(6),(7) has been simulated. For dynamic simulation, the voltages (Va,Vb) are given as per the stepping sequence. Stepper motor's rotor rotates through one step angle for every step pulse. The phase Currents, angular speed and rotor position need to be evaluated for a given voltage. Interactions of voltages contribute stepping angle of rotor.

4. Solar panel design and MPPT technique

4.1. Modelling



. Single-diode model of the theoretical photovoltaic cell and equivalent circuit of a practical photovoltaic device including the series and parallel resistances.

Figure 2 Solar cell

A photovoltaic system converts sunlight into electricity. The basic device of a photovoltaic system is the photovoltaic cell. Cells may be grouped to form panels or modules. Panels can be grouped to form large photovoltaic arrays. The term array is usually employed to describe a photovoltaic panel(with several cells connected in series and/or parallel) or a group of panels. Most of time one are interested in modeling photovoltaic panels, which are the commercial photovoltaic devices. This paper focuses on modeling photovoltaic modules or panels composed of several basic cells. The term array used hence forth means any photovoltaic device composed of several basic cells.

The electricity available at the terminals of a photovoltaic array may directly feed small loads such as lighting systems and DC motors. Some applications require electronic converters to process the electricity from the photovoltaic device. These converters may be used to regulate the voltage and current at the load, to control the power flow in grid connected systems and mainly to track the maximum power point (MPP) of the device.Hence the equation required for to design the solar panels are,

$I = IpvNpar - IoNpar[exp[V + Rs\left(\frac{Nser}{Npar}\right)I/VtaNser] - 1$ ....eq(8)

Where I is the current from the solar cell(I=Ipv-Id)

Ipv=photo voltaic current

Nser,Npar=number of series and parallel connected arrays

Vt=(NskT/q) is the thermal voltage of the array with Ns cell connected in series

K=boltzmann constant[1.38.10-23J/K]

q=electron charge[1.6.10-19C]

a=diode ideality

$Ipv = (Ipv + Ki\Delta T)G/Gn$ ....eq(9)

Where Ipv,n (in amperes) is the light-generated current at nominal condition (usually 25 ^{o}C and 1000 W/m^2)ΔT=T-Tn(T and Tn being the actual and nominal temperatures [in Kelvin],respectively), G (watts per square meters) is the irradiation on the device surface, and Gn is the nominal irradiation

$Io = (Isc, n + Ki\Delta\mathrm{T})/(\exp\left(\mathrm{Voc, n} + \frac{\mathrm{Kv\Delta T}}{\mathrm{aVt}}\right) - 1)$ ....eq(10)

Io=saturation current in the diode

Isc=short circuit current

Voc=open circuit voltage

a=ideality of the diode(1<a<1.5)

ΔT=T nominal in kelvin-273 K

4.2. MPPT algorithm perturb and observe

The P&O method is the most popular MPPT algorithm due to its simplicity. Figure 3 shows the flow chart of P&O method. After one perturb operation the current power is calculated and compared with previous value to determine the change of power ÄP. If ÄP>0, then the operation continues in the same direction of perturbation. Otherwise the operation reveres the perturbation direction.

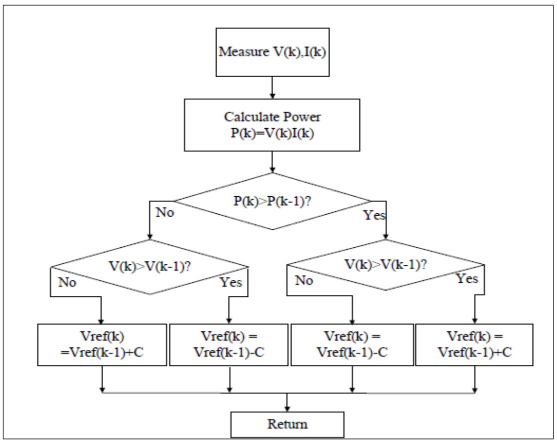


Figure 3 Perturb and Observe

5. Simulation Results

5.1. Wind turbine

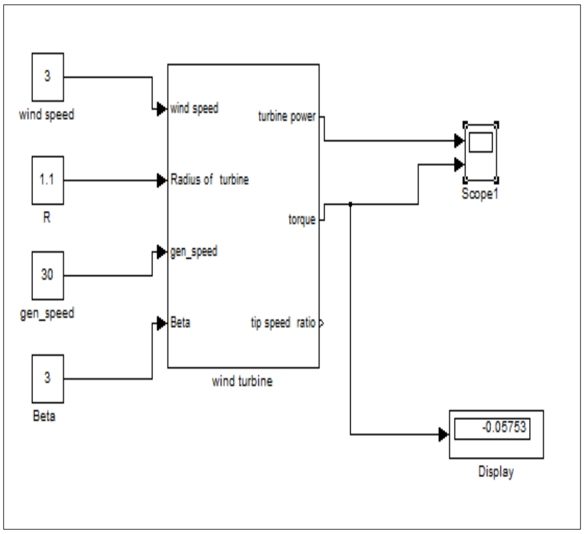


Figure 4 Simulation model of wind turbine system from eq(1)(2)&(3)

The above simulation shows the value of torque provided by 200W wind turbine(FD 2.1-200-8) with rotor diameter 2.2m with pitch angle=3^o at wind speed=3m/s and with rotational speed=30rpm is 0.05753N

5.2. Stepper motor

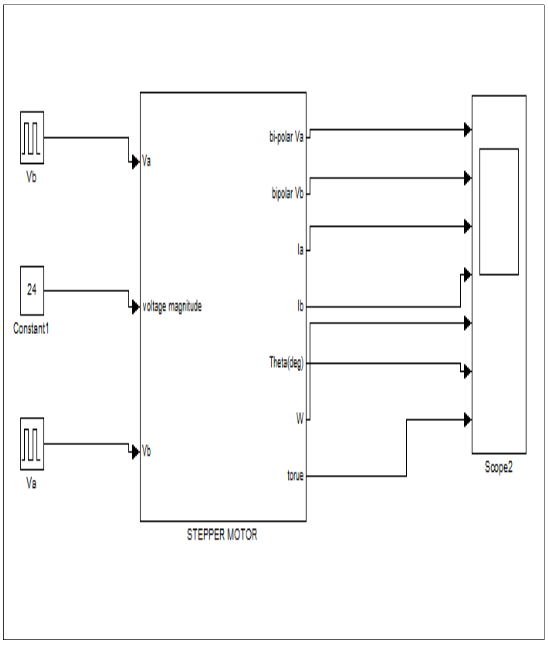


Figure 5 Stepper motor simulation from eq(4),(5),(6)&(7)

Since the parameter for simulation of stepper motor has been brought from “Position Control of a Sensorless Stepper Motor”[6]

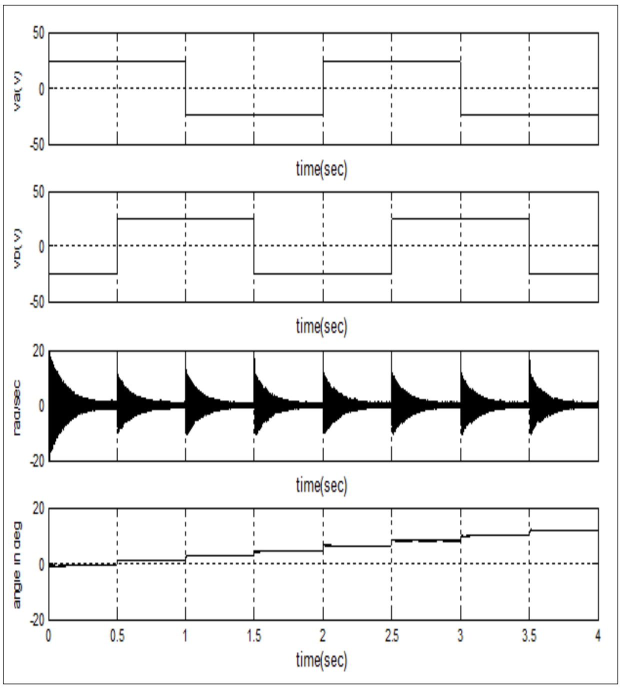


Figure 6 Half stepping simulation result

Which will provide 1.8^o step angle for each step sequence

5.3. Solar panel

Table 1 Simulation parameters for half stepping

R = 0.37 [W]
L = 0.9[mH]
K m =0.157[Vs/rad]
K v = 0.000307[Nms/rad]
J = 15.62x10-5[Kg.m^2]
N= 50
Va=Vb=24
Table1 Simulation parameters for half stepping
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K m =0.157[Vs/rad]
K v = 0.000307[Nms/rad]
J = 15.62x10-5[Kg.m^2]
N= 50
Va=Vb=24

Table 2 SLP020-24 SOLAR PANEL

Maximum Power (Pmax)=20W
Voltage at Pmax(Vmp)=34.4v
Current at Pmax(Imax)=0.58A
Open-circuit voltage(Voc)=43.2V
Short-cicuit current(Ioc)=0.68A
Kv=80mv%/^{o}C
Ki=0.065%/^{o}C,, Nss=18,Npp=4

The parameters for solar panel simulation has been brought from 24 watts panel SLP020-24 SOLAR PANEL Hence the solar cell simulation for a panel from eq (8),(9),(10) as follows,

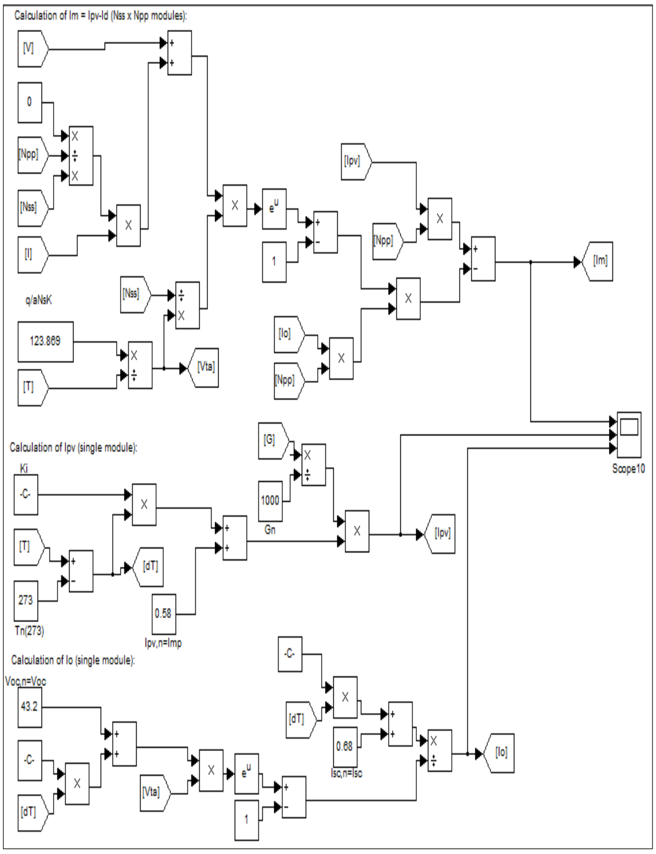

Figure 7 Solar panel simulation from eq(8),(9),(10)

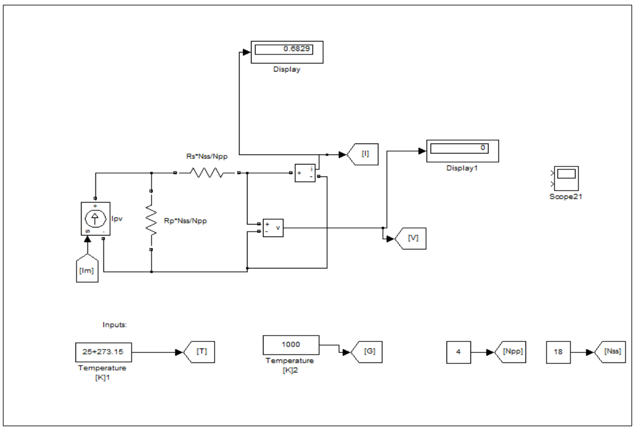

Figure 8 Short circuit current of the panel

Hence from fig.8 the short circuit current for the panel obtained from simulation is same as the panel specification SLP020-24 SOLAR PANEL

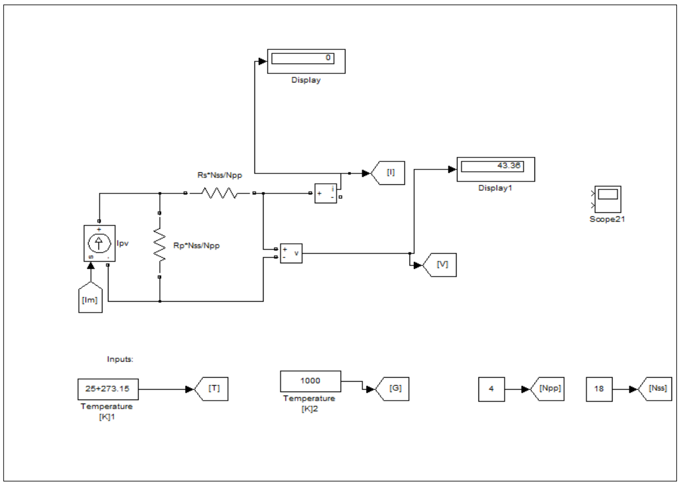

Figure 9 Open circuit voltage of the panel

Hence from fig.8 the short circuit current for the panel obtained from simulation is same as the panel specification SLP020-24 SOLAR PANEL

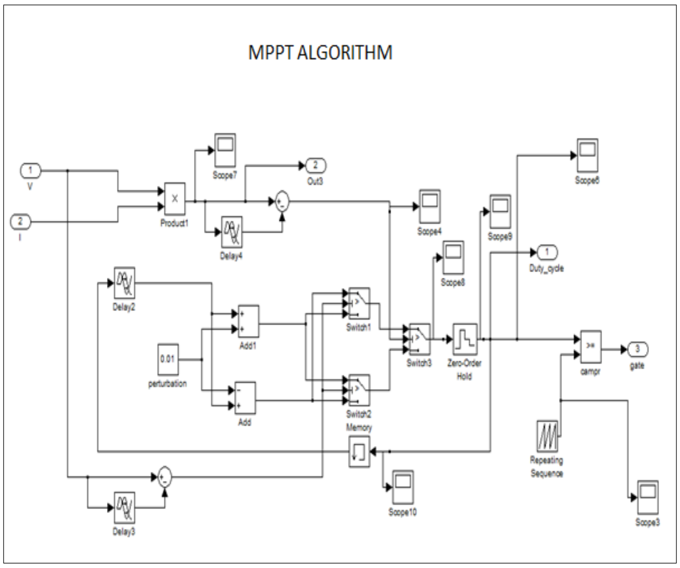

Figure 10 Perturb and Observe MPPT algorithm

Hence the perturb and observe algorithm is simulated MATLAB-SIMULINK through the flowchart in the figure.3. Which will make the solar panel to extract maximum power from the solar irradiation under different illumination condition.

5.4. Boost converter

$$V_s=18V,\ I_s=0.6A,\ K=?,\ f=20kHz,\ \eta=0.85$$

$$V_O=\frac{V_s}{(1-K)}=24V$$
$$=>K=0.25$$

$$I_O=\frac{\eta * I_s * V_s}{V_O}=0.38A$$

$$\Delta V_C=2\%\ of\ V_O=0.48V$$

$$\Delta I=5\%\ of\ I_S=0.003A$$

$$R_O=\frac{V_s}{I_s(1-K)^2}=53.33\Omega$$

$$L=\frac{K*V_s}{f*\Delta I}=75mH$$

$$C=\frac{K*I_O}{f*\Delta V_C}=9.8\mu F$$

Since boost converter are used for to provide boost up voltage for the load circuit. Here we are designing for 24v output voltage with input as 18v and input current as 0.6A

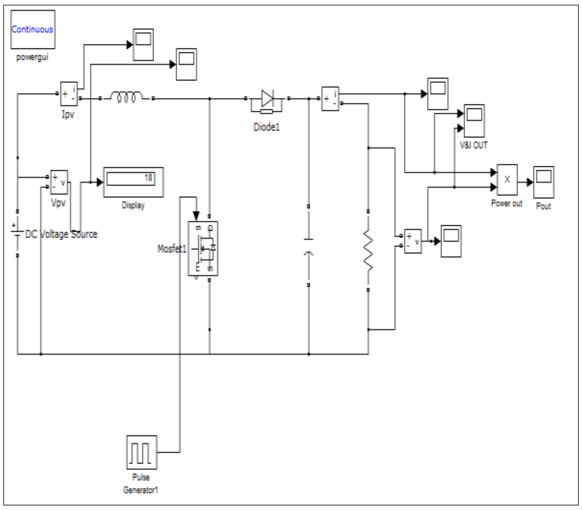

Figure 11 Boost Converter

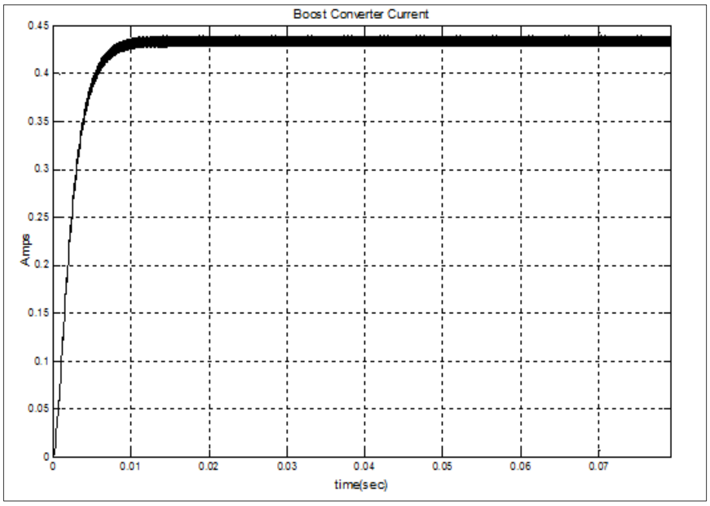

Figure 12 Current with respect to time

Since the current output of the converter provides 0.44A and output voltage as 24V,from which the selection of stepper motor for turbine should have power rating below 12watts. Here we are using 17PY-Z264U stepper motor for 300watts turbine FD2.5-300W consumes less than this power rating only(ie less than 12W)

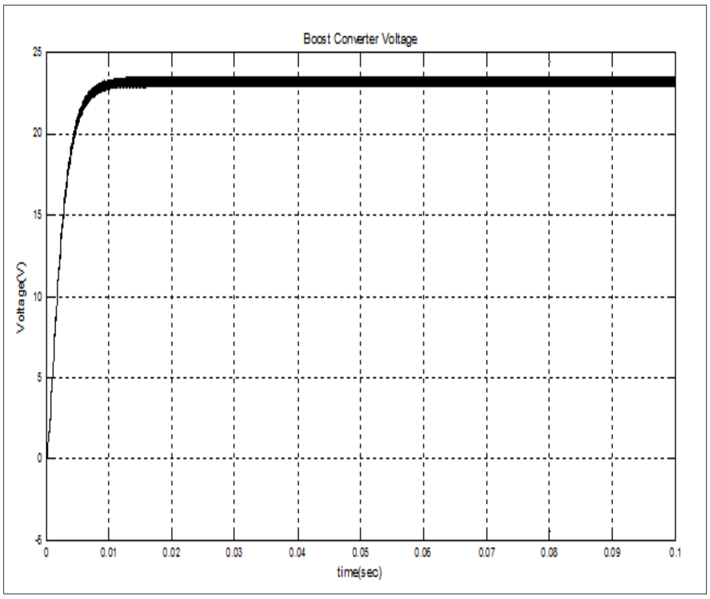

Figure 13 Voltage with respect to time

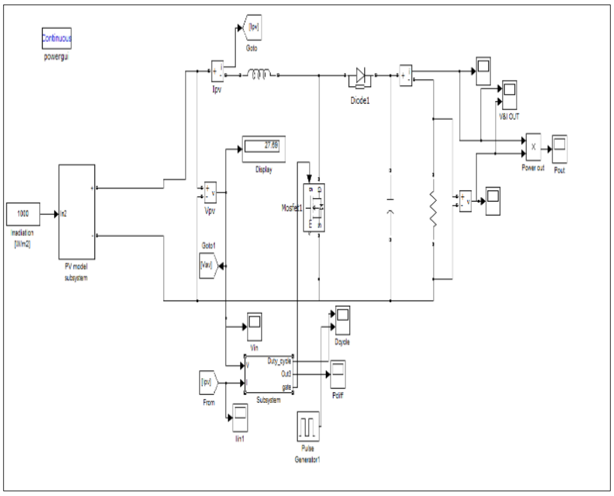

Figure 14 Overall PV model with converter and MPPT algorithm

Hence the above figure shows the solar panel with boost converter along with MPPT algorithm simulation implemented for to provide supply for the stepper motor

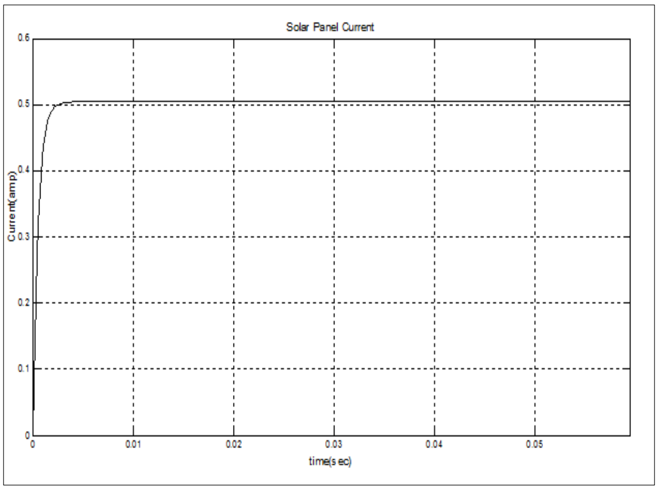

Figure 15 Solar panel Current vs time

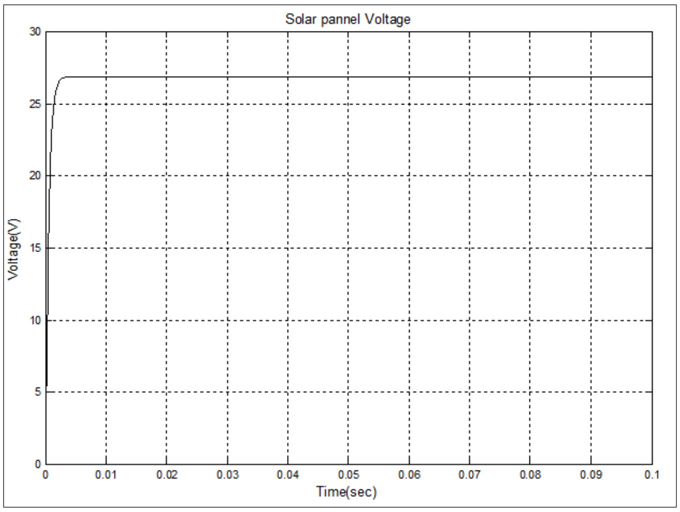

Figure 16 Solar Voltage vs time

5.5. Algorithm/assumptions for proposed system

- In the above model, wind turbine 200W(FD 2.1-200-8) gets simulated with rotational speed as 30rpm,diameter of the turbine is 2.2m
- Disturbance at 20-40sec
- Stepper motor should check whether the wind speed should be greater than or equal to cut-in speed and also it should check whether the output mechanical power is zero then it should run for to provide initial torque to the turbine

5.6. Flow chart for the proposed system

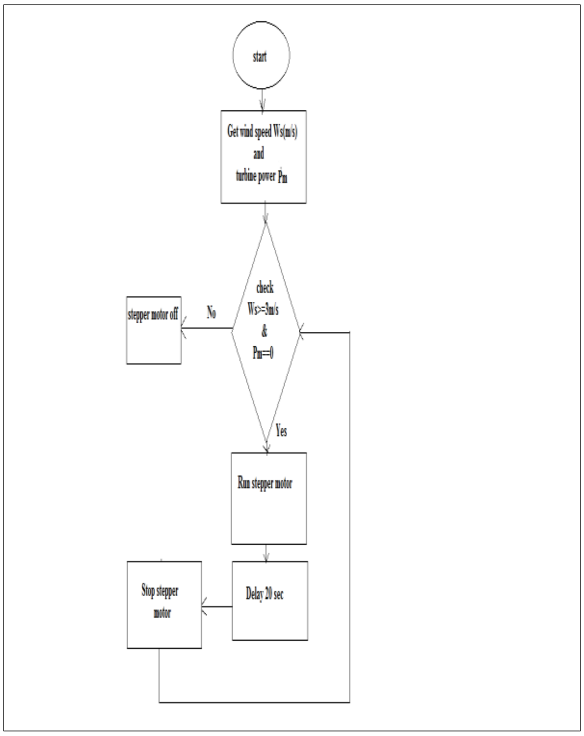

Figure 17 Flow Chart for the proposed system

Step 1:Check whether the wind speed is greater than cut-in wind speed and also whether the output power of the turbine is greater than zero.

Step 2:If the step 1 condition fails to prevail start the stepper motor and made it run for 20 seconds and again check the system output power and wind speed.

Step 3:If it starts to rotate (ie power extract from turbine starts) then stop the stepper motor and keep monitoring the system

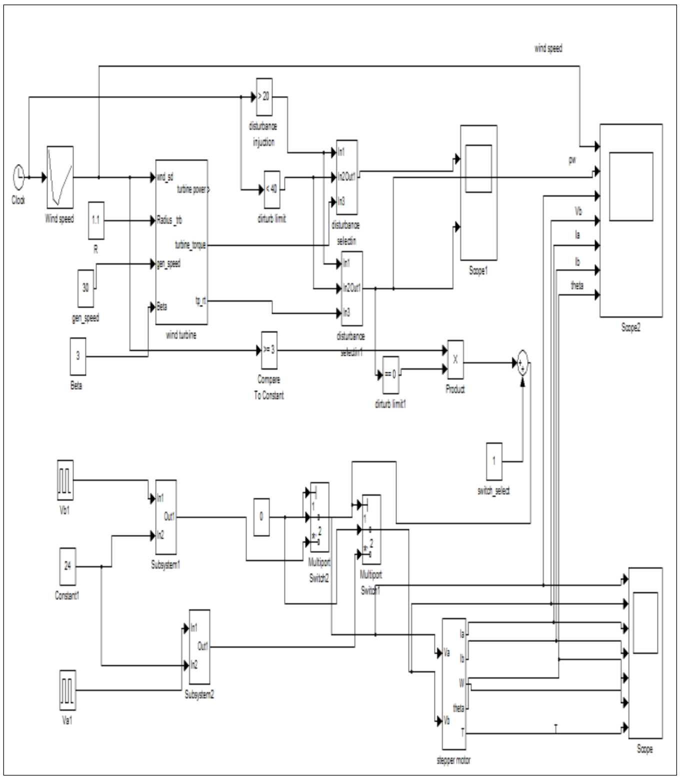

Figure 18 Overall system model

Fig 18 shows the Simulink model of wind turbine with stepper motor setup including Po zero at 20-40 sec

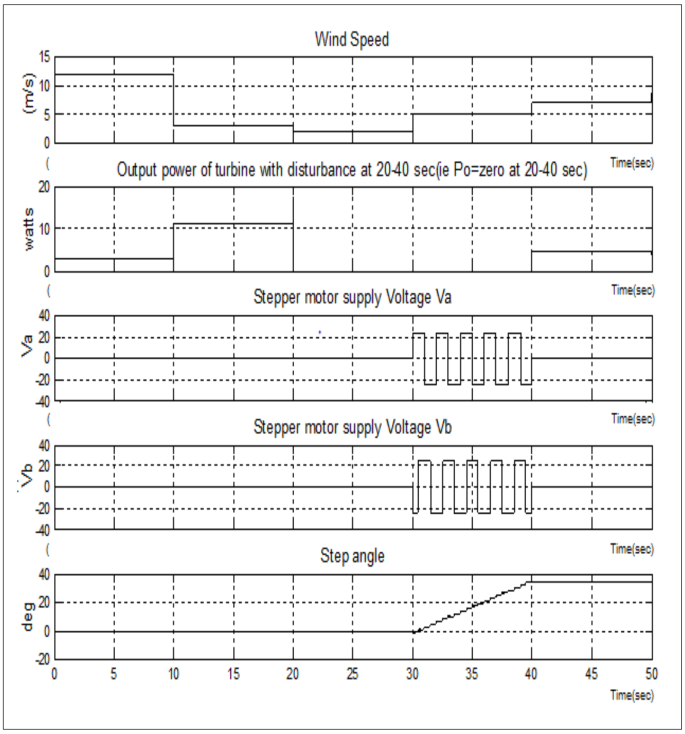

Figure 19 Simulation result of proposed system

Simulation result shows motor operates at disturbance period(ie turbine output power zero period)

5.7. Torque requirement for different wind turbines based on spec

5.7.1. Sheet at cut-in wind speed

Where pitch angle=3deg

The torque requirement for stepper motor to rotate the turbine at 30rad/sec is calculated by taking speed of the turbine as 30rad/sec and speed of the wind in turbine as 3m/s.

The calculated value is tabulated as follows from the respective formula in the section 5

Table 3 Different turbine ratings

Wind turbine model	Start up Wind speed	Cut-in speed	Rated wind speed	Rotor diameter	Pitch angle (deg)	Torque(Nm)
200W [FD2.1-200-8]	2.5m/s	3m/s	6m/s	2.2m	3	-0.05753
300W [FD2.5-300]	2.5m/s	3m/s	12m/s	2.5m	3	-0.09059
500W [FD2.7-500-10]	2.5m/s	3m/s	8m/s	2.7m	3	-0.1183
1KW [FD-1K-10]	2.5m/s	3m/s	9m/s	3.9m	3	-0.1512
2KW [FD3.6-2K-10]	2.5m/s	3m/s	9m/s	3.2m	3	-0.2108
5KW [FD6.4-5K-16]	2.5m/s	3m/s	10m/s	6.4m	3	-1.986
10KW [FD8.0-10K-20]	2.5m/s	3m/s	10m/s	8m	3	-4.001

Table 4 Stepper motor selection table

Wind turbine Model [Renewable energy house]	Cut-in speed	Torque(Nm) required for to rotate the turbine in 30rad/sec	Stepper motor selection(i.e. 10% above the require torque level for the turbine to rotate at 30m/s) [Mine bee] [MMB-MAT]	Torque range of the motor(obtained from the torque-speed spec sheet of the motor)
200W [FD2.1-200-8]	3m/s	-0.05753	17PY-Z249U [MMB-MAT]	(90-0)mNm (step angle=0.9deg) (Supply v=24v)
300W [FD2.5-300]	3m/s	-0.09059	17PY-Z264U	(120-0)mNm (step angle=0.9deg) (Supply v=24v)
500W [FD2.7-500-10]	3m/s	-0.1183	17PY-Z342U	(230-0)mNm (step angle=0.9deg)

				(Supply v=24v)
1KW [FD-1K-10]	3m/s	-0.1512	17PY-Z349U	(250-0)mNm (step angle=0.9deg) (Supply v=24v)
2KW [FD3.6-2K-10]	3m/s	-0.2108	17PY-Z442U	(350-0)mNm (step angle=0.9deg) (Supply V=24V)
5KW [FD6.4-5K-16]	3m/s	-1.986	34K-K006U	(2.8-0.5)Nm (step angle=1.8deg) (Supply v=24v)
10KW [FD8.0-10K-20]	3m/s	-4.001	34KM-K206U	(7-0.7)Nm (step angle=1.8deg) (Supply v=24v)

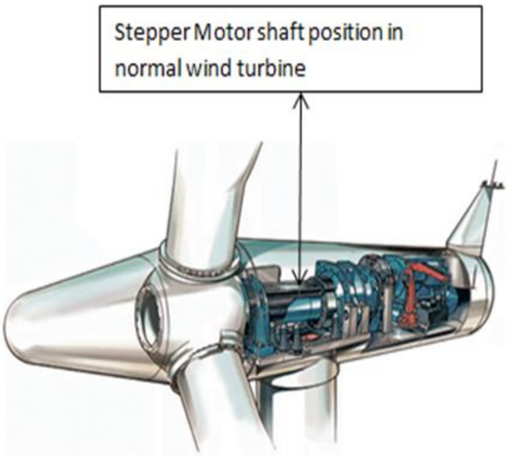

Figure 20 Stepper motor placing space on turbine

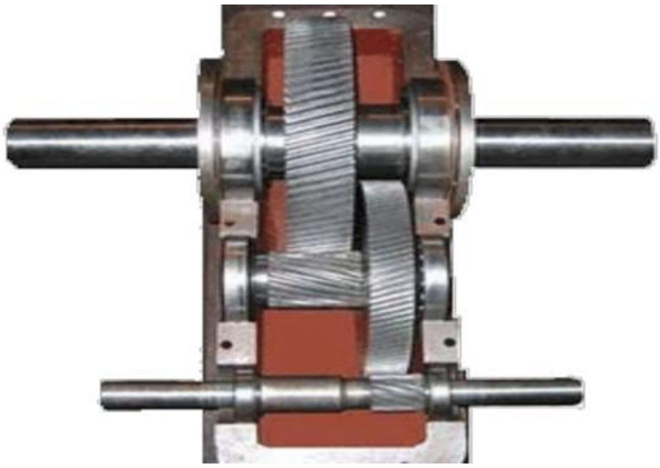

Figure 21 Shaft arrangement to place stepper motor

Parallel shaft helical gearbox for stepper motor arrangement in shaft of the turbine

6. Conclusion

In which

- Torque requires for different wind turbine to rotate at some constant speed on Cut-in wind speed has been calculated.
- Different stepper motor ratings have been analyzed.
- Simulation model for the proposed system has been done.
- Solar panel modeling with mppt has been done
- Proper matching of the stepper motor to the torque requirement has been done.
- Also available rating of wind turbines and stepper motor in the market has been studied.

A control strategy for a direct-drive stand-alone variable speed wind turbine with a PMSG has been presented in this paper. A simple control strategy for the generator-side converter to extract maximum power is discussed and implemented using Simpower dynamic-system simulation software. The controller is capable of maximizing output of the variable-speed wind turbine under fluctuating wind. The generating system with the proposed control strategy is suitable for a small-scale stand-alone variable-speed wind-turbine installation for remote-area power supply.

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