Design a Position Control of the Blade Pitch Angle for Variable Speed Wind Turbine Generators

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Abstract

Variable speed wind turbine generators are more powerful than constant speed turbines. However the unstable wind speed causes the variable speed machine to have variable voltage and frequency.

The quality of power can be improved if a suitable control technique is used in the system, the fluctuating wind generator output needs to be controlled, for this reason one needs to study the dynamic characteristics of the combined wind generator system.

Better control design can be designed for more dynamic performance. Blade pitch control of the fan is discussed here in this research by using rotary potentiometers for position control and some tests is done in control laboratory as a simulation of the position control.

Keywords: position control, variable wind turbine generator

تصميم دائرة سيطرة على زاوية تثبيت ريشة مروحة مولدات الطاقة الكهربائية من الرياح ذو السرع المتغيرة

الخلاصة

أن مولدات الطاقة الكهربائية من الرياح ذات السرع المتغيرة يمكن أن تعطينا قدره وكفاءة أكثر من مولدات الطاقة الكهربائية بواسطة الرياح ذات السرع الثابتة, وبما إن الرياح تهب وتتغير بصوره غير نظاميه من ناحية السرعة والاتجاه فأن مولدات الطاقة الكهربائية بواسطة الرياح ذات السرع المختلفة سوف تكون الفولتيه الخارجة والتردد أيضا متغيرة.

لذلك لابد من وجود نظام سيطرة على تلك القيم الخارجة لجعلها مستقره ولأجل التوصل إلى أحسن اختيار وتصميم لمنظومة السيطرة المستخدمة يجب دراسة الخصائص الديناميكية لتلك المولدات.

إحدى هذه الطرق هي طريقه السيطرة على زاوية تثبيت ريشه المروحة، في هذا البحث استخدمنا مقاومة متغيرة دائرية الشكل(بوتنشوميتر) وقد تم أجراء بعض التجارب ألمختبريه في مختبر السيطرة على هذه الطريقة للسيطرة على الزاوية(زاوية تثبيت الريشة).

Introduction:

Wind energy is the most viable renewable energy options in renewable energy systems. Quality and reliability of power are most vulnerable issue.

The disadvantage of fixed speed systems is that the wind turbine are coupled to the system bus through a gearbox and induction generator so the induction generators require reactive power from the grid or capacitor bank to meet the reactive power demand.

It would be advantage to operate the wind turbine at variable speed because the fixed speed systems run at constant speed and frequency while the wind speed is changing. The variable speed wind turbine allows capturing more energy from the wind.

The variable speed wind generator output needs to be controlled, so we need to study the dynamic characteristics of the system so one can assess the transient performance.

The behavior of wind is study and a large amount of data is collected so it makes the design much easier.

There are many ways of control but in this research the position control by using DC rotary potentiometers is used to control the pitch angle of the blade is discussed as shown in figure 1 and many laboratory tests is done[1].

System:

In the system under study, a variable speed wind turbine generator (WTG) used to investigate the power quality. Based on the power curve of the wind turbine, the tip speed ratio and power coefficient (Cp) has been inferred.

The wind turbine consists of a permanent magnet type generator, which is connected to the AC load bus through suitable interfacing equipment (converter/inverter). This help in isolating the variable voltage, variable frequency output of the continuously varying output of the wind generator, it can not be directed connected to the consumer load bus, because in the case of high wind speeds, the output power may exceed the actual load demand. This may lead to instability because of perturbations in voltage and frequency [1].

The variable speed wind turbine generates variable voltage and variable frequency for a given fluctuating wind speed, which can vary on random basis. And this cause the output to became unstable and cannot connect directly to the system bus because of its poor power quality, so a suitable interface is needed.

A simple block diagram is shown in figure 2.

Pitch control strategy:

The output of variable wind speed turbine generator is change according to the wind speed, so the output voltage and frequency is change too and this is very bad when it is connected to weak networks.

The variable speed wind generator output needs to be controlled to make it suitable for feeding the customer load, In places, where higher wind speeds are not frequent, it might be better to run the wind turbine at constant speed at the higher wind speeds (> rated wind speed).

The excess power available at the higher wind speeds can be discarded by the turbine rotor to prevent the turbine overloading. This is generally achieved by pitch control method.

For a variable speed wind turbine with a pitch control system, which regulates the effective rotor blade angle, optimum power can be obtained using appropriate control method.

The blade pitch control has been used in practice to reduce the overloading of wind turbine when higher wind speeds are available. In active pitch control, the blade pitch angle is continuously adjusted based on the measured parameters to generate the required power output. In some cases, it has been observed that the active pitch regulation sometimes can make the system unstable during highly variable wind conditions and later in this research we will show experimentally how we can improve this case.

The pitch angle required can be generated based on the power error. This control signal can be also being produced based on the error between actual shaft speed and the desired shaft speed [2,3].

Simulation results:

The simulation is divided into two parts the first one is by using Matlab simulink (Software) to simulate the wind turbine generator, wind speed and the pitch control system used while the second one is by using a test (Hardware) in control laboratory for the blade pitch angle position control.

Matlab simulink:

Figure 5 shows the complete block diagram of the dynamic model of variable speed wind turbine with permanent magnet synchronous generator connected to an AC bus, the load is fed through an interfacing device, initially the wind generator is running at a wind speed close to 10.5 m/sec (rated wind speed) for soft starting so that the initial transients of the models settle down. At t=25 sec, the wind turbine generator (WTG) is connected to the consumer load bus in such a manner that the wind generator is feeding a 20 Kw constant load. Any extra power produced by the wind turbines is dumped to the dump load [4].

Uncontrolled wind generator output:

A randomly varying wind speed from 9 to 18 m/sec has been applied to the wind generator model. Before implementing the control strategies the dynamic model of the wind generator system was run with no control on the output the rotor speed and the output voltage follow the wind speed variations. The results are shown in figure (6) [4].

Pitch control results:

In this case, the wind generator is directly connected to the load bus without any power electronics interface and the active pitch control has been applied to the uncontrolled wind turbine. The error signal has been used to control the blade pitch angle.

The rotor speed and voltage are plotted in figure (7) [4].

Experimental test and results of the pitch angle position control:

Figure 4 shows the complete circuit diagram for the position control system used in this test, the components used are [6]: Rotary Input potentiometer: used as the reference input voltage (set value)it is consist of rotary potentiometers that can rotate about 300 degree, the 2 terminals is supplied with +15 and-15 volt because it can rotate clockwise and counterclockwise. The clockwise and counterclockwise movement of the potentiometer because the pitch angle of the fan can rotate in both directions. Operation amplifier: We used three input op-amp as summer that make the algebraic summation for the input signal and the feedback signal with gain equal to one. Potentiometer: We used two potentiometers as forward and feedback attenuation. Pre amplifier: A preamplifier is used in our experiment so it can sense the error signal if it is positive or negative voltage so the motor can rotate clockwise and counterclockwise. DC servo motor with gearbox: a DC servo motor used

so it can rotate in both directions and it has high speed shaft and low speed shaft with ratio 1:30, it also contain tacho generator so one can get voltage proportional to the speed of rotation of the motor and we can used it as transducer so we convert the motion into voltage. Output rotary potentiometer: It is similar to the rotary input potentiometer but it is connected to the low speed shaft of the motor so the output signal from this potentiometer is according to the direction and rotation of the motor.
The idea of this research is to move the blade fixing angle clockwise or counterclockwise by using suitable position control system in order to get constant output however the wind speed is.

So by moving the blade of the fan little degrees clockwise or counterclockwise this will cause to change the surface area of the blade that been hitting by the wind, that's mean when the wind is high the control system will reduce the surface of the blade that been hitting by the wind in order to reduce the speed of the rotor till we reach the set value and when the wind speed is slow the control system increase the surface of the blade that been hitting by the wind in order to increase the speed of the rotor till it reach the set value, this explanation is shown in figure 3. In order to do this experiment practically we connect the circuit shown in figure 4, in the beginning of our test we connect the circuit with position feedback only and adjust the

input potentiometer to a certain value such as (1) volt for example which is represent the set value that the output voltage must be the same.
The set value is represent the blade fixing angle, and this value is obtained from data of wind speed of the area that wind turbine is build in, the output potentiometer is connect to the motor low speed shaft through a gear box and its ratio is about 1:30, if the set value of the input potentiometer is (1) volt then the output potentiometer must be (1) volt too.
Any difference in the output potentiometer than input potentiometer will cause an error signal at the output of the operational amplifier which acts as comparator this operational amplifier output represents the algebraic sum of the input signals (set value and feedbacks).

The pre amplifier sense this error signal if it is larger or smaller than the set value (positive or negative) in order to give suitable signal to the motor to rotate clockwise or counterclockwise, rotation of the motor cause the output potentiometer rotate too till the error signal is zero and the motor will stop.
The error signal is due to the variation of wind speed that cause the rotor of the wind turbine to rotate in variable speed, so the output voltage of the output potentiometer (simulator of the rotor wind turbine) is differs than the input potentiometer.
During the test we change the gain of the system in order to get better specification so we get faster response and less steady state error but higher overshoot and long settling time (settling time is the time needed to reach 5% of the final value) also when

the gain is too large the system is oscillate and become out of control.
In order to improve the system dynamic characteristic the second feedback is connected (velocity feedback) by connecting the tacho generator, which convert signal from the motor speed to electric signal and fed to the operational amplifier (comparator), it is called velocity feedback because the feedback signal value is depend on the velocity of the rotor. This feedback acts as a damper that reduces the overshoot and makes the steady state error less. The output can be drawn by many ways such as XY recorder or storage oscilloscope or by using suitable interface card with PC.
Different step response tests for different gain is done in order to get the best response as shown in figures (8,9,10,11,12,13), the experiment is done in control lab of control and system engineering department in the university of technology, the wiring diagram is shown in figure 14 [5].

Analysis of simple position control:

For any closed-loop system, the error signal is used to operate the forward path, the error being the difference between the input and output shaft angels,

$$E = J_i - J_o \quad \text{……………….(1)}$$

Assuming that the error, which will be in radians is converted to a voltage and subsequently amplified so that one radian gives Kg volts, than

$$V_s = E.K_g \quad \text{…………..(2)}$$

Where V_s is applied voltage If the frequency response of the system is being considered, and using the relation previously obtained for the motor shaft angle, than

$$J_m = \frac{K_g.K_s}{Jw(1+Jwt_m)}E \quad \text{……..(3)}$$

Where J_m is total motor shaft angle and K_s is speed constant, if there is a gear reduction 1:N to the output shaft, then

$$J_o = \frac{J_m}{N} \quad \text{…………….(4)}$$

Leading to

$$J_m = \frac{K_g.K_s/N}{Jw(1+Jwt_m)}E \quad \text{……..(5)}$$

This may be substitute into the error relation to give finally the very important result

$$\frac{J_o}{J_i}(Jw) = \frac{\frac{K_v}{Jw(1+Jwt_m)}}{1+\frac{K_v}{Jw(1+Jwt_m)}} = \frac{K_v}{Jw(1+Jwt_m)+K_v} \quad \text{……(6)}$$

Where Kv=Kg.Ks/N. The factor Kv determines how fast the output shaft rotates for a constant error and is called the 'velocity error constant', and is an important parameter in controlling the steady state following accuracy of the system. Although the closed-loop expression has been developed in terms of frequency response it is also possible to establish a differential equation relating the input and output under closed-loop conditions. The differential equation governing the motor speed is

$$t_m\frac{dS}{dt} + S = K_sV_s \quad \text{……………(7)}$$

Where S is the motor speed, but since speed is the differential of position, hence

$S = \frac{Nd J_o}{dt}$ and $\frac{dS}{dt} = \frac{Nd^2 J_o}{dt^2}$ …….(8)

Where θo is the output shaft angle, and N reduction ratio. Also

$V_s = K_e K_{amp}$ ……………(9)

Where K_{amp} is the Amplifier gain and these may be substituted into the motor equation to give

$t_m \frac{d^2 J_o}{dt^2} + \frac{d J_o}{dt} = K_v E$ ……..(10)

Where t_m is the Motor time constant Since Kv=(KeKampKs)/N and from equation (1) the equation may be written as

$t_m \frac{d^2 J_o}{dt^2} + \frac{d J_o}{dt} + K_v J_o = K_v J_i$ ..(11)

This is a second order differential equation. If this equation is compared with the 'normalized' form of a second order equation

$\frac{d^2 y}{dt^2} + 2zw_n \frac{dy}{dt} + w_n^2 y = w_n^2 x$ ..(12)

It can be seen that the parameters ωn, the undamped natural frequency, and ξ, the damped factor are given by

$w_n = \sqrt{\frac{K_v}{t_m}}$;

$z = \frac{1}{2\sqrt{K_v t_m}}$

The frequency response corresponding with the normalized equation given by

$\frac{y}{x}(Jw) = \frac{1}{(J\frac{w}{w_n})^2 + 2z\frac{Jw}{w_n} + 1}$ …(13)

And a phase shift of 90o occurs when ω=ωn. The factor ζ controls the general form of frequency and transient response, and plots of these responses with ζ as a parameter are available in many books.

In practical system it is often required that the motor should put a shaft in a given position, such would be termed a POSITION CONTROL SYSTEM.

In a position control system a common requirement is for a motor to rotate an output shaft to the same angle as an input shaft. The general form of the block diagram for such a system is as in figure 15, but for a position control the input and the output transducers must measure input and output shaft angles and produce a control signal (or error) proportional to the angle between the shafts.

In this case a simple form of 'error channel' is to mount a potentiometer onto each shaft and then add together the voltages from the potentiometers sliders with an operational amplifier as in figure 16. Then if the two shaft angels θi and θo are equal, the two slider voltages are equal and opposite and cancel at the amplifier output. Any misalignment will give an error signal proportional to the misalignment (θi - θo) which can operate the forward path.

If the input potentiometer is displaced an error will be produced, the motor will drive the output potentiometer in a direction to reduce the error and the system will come to rest in the new position.

Unfortunately with such an arrangement the error can only be zero when the two potentiometers are aligned. Due to the inertia of the motor and any load attached to it the system often overshoots the point of alignment, this means the error reverses, the motor reverses and may overshoot the alignment point on return and the system takes some time to settle.

This situation can be improved if the error signal can be reduced to zero before the point of alignment is reached and the motor will then be slowed down as it approaches alignment. To reduce the actual error signal and output can be taken from the tacho of such polarity to oppose the error signal, and so will reduce any overshoots.

An alternative method of preventing these overshoots would be to add a load to the motor proportional to its speed which will slow down the response and so limit the amount of overshoot. The magnetic brake assembly will provide such a loading [7].

Conclusions:

It has been shown that the dynamic model developed in this research can be used to simulate variable pitch wind turbines, and a suitable position control is applied to investigate the system behavior. It is evident from the results that active pitch angle position control reduces the wind turbine generator output fluctuations. The second feedback (velocity feedback) can smooth the voltage and power output to make it suitable for the network connection.

References:

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[2] W.E. Leithead. S.A. De La Salle and D. Reardon,"Classical control of active pitch regulation of constant speed horizontal axis wind turbines", Int. journal control,pp8455876,Vol.55,no4,1992.

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[6] "Rugged miniature position transducer solution guide", published by Space age control, www.spaceagecontrol.com.

[7] Book3,"DC, Synchro, & AC Advanced Experiments", by Feedback company for education instruments, modular servo system MS150MkII, 1984.

The following table shows the dynamic characteristics of the results obtained from the experiments for the case when no velocity feedback was connected:

Gain	t_d (Sec)	t_r (Sec)	t_p (Sec)	t_s (Sec)	M_p (Volt)	e_{ss} (Volt)
1	0.55	1.1	2.25	15	0.76	0.05
5	0.35	0.7	1.5	20	1.38	0.33
10	0.2	0.4	1	23	1.6	0.4

The following table shows the dynamic characteristics of the results obtained from the experiments for the case when velocity feedback is connected:

Gain	t_d (Sec)	t_r (Sec)	t_p (Sec)	t_s (Sec)	M_p (Volt)	e_{ss} (Volt)
1	0.875	1.75	2.6	4	0.56	0.01
5	0.3	0.6	1.4	6.5	1.12	0.3
10	0.15	0.3	1.1	6	1.31	0.38

Where:
td = delay time
tr = rise time
tp = peak time
ts = settling time
Mp = maximum peak overshoot
es.s = steady state error

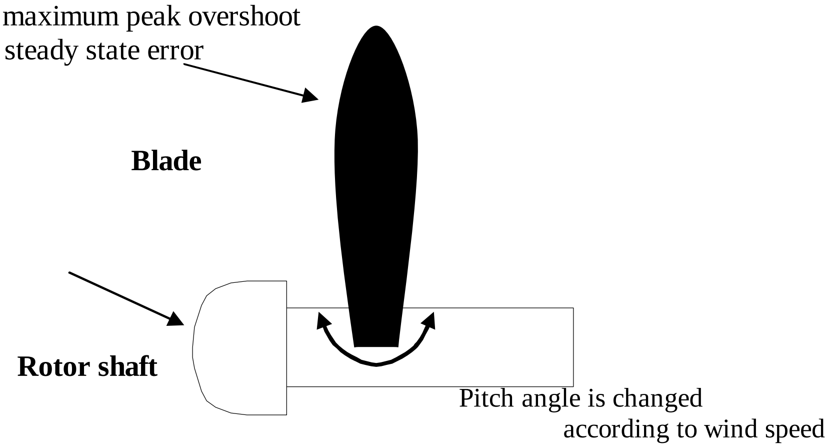

Figure (1) Side view of turbine blade

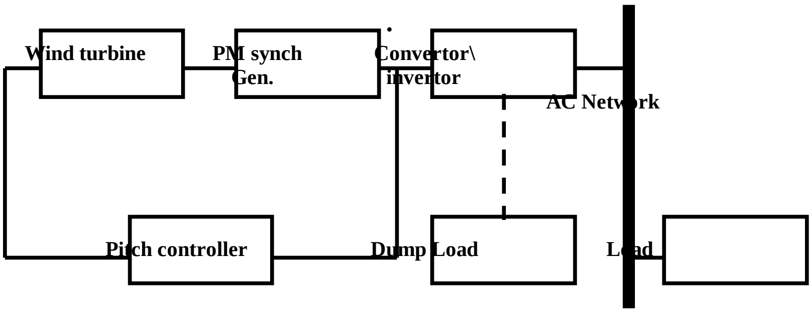

Figure (2) Block diagram of standard variable speed wind generator based system

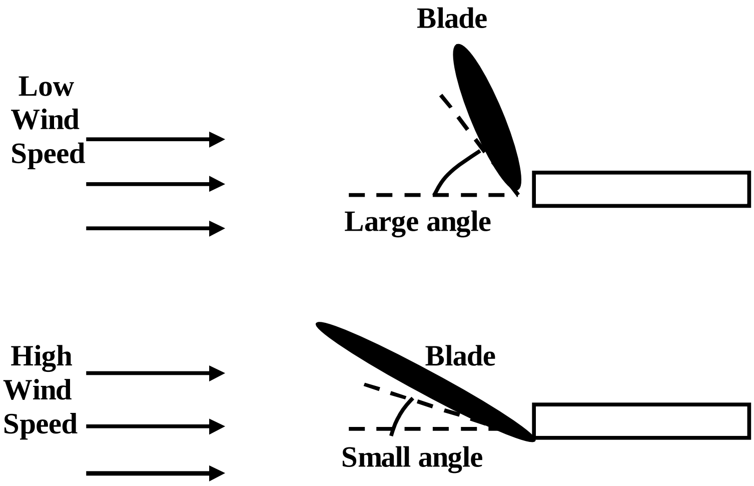

Figure (3) the idea of research

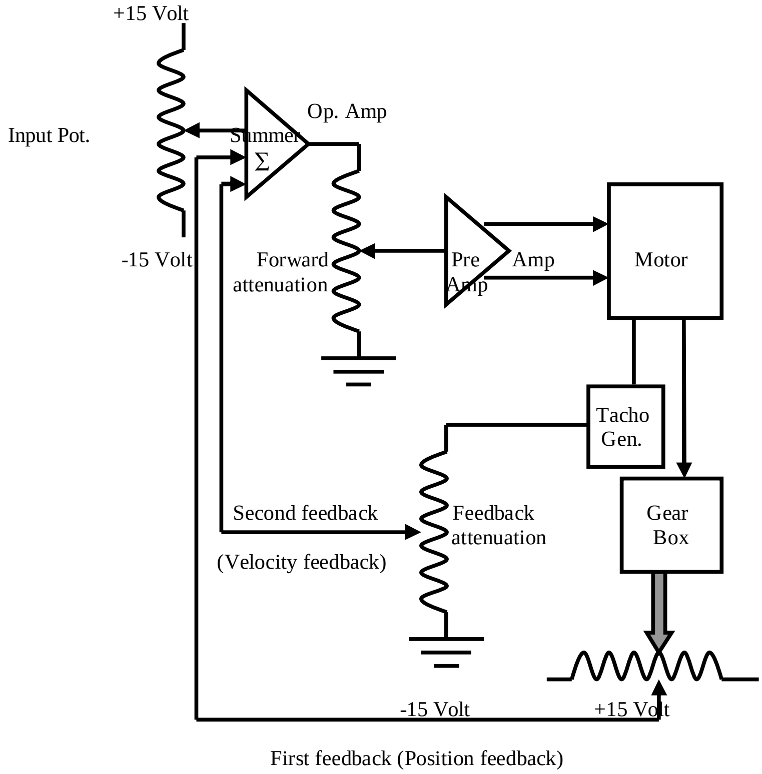

Figure (4) Circuit diagram for position control system

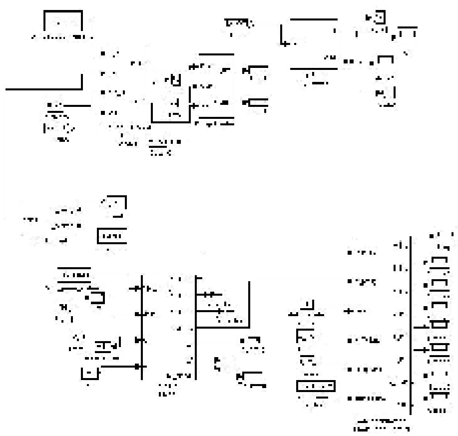

Figure (5) Block diagram of variable speed wind generator system in Matlab

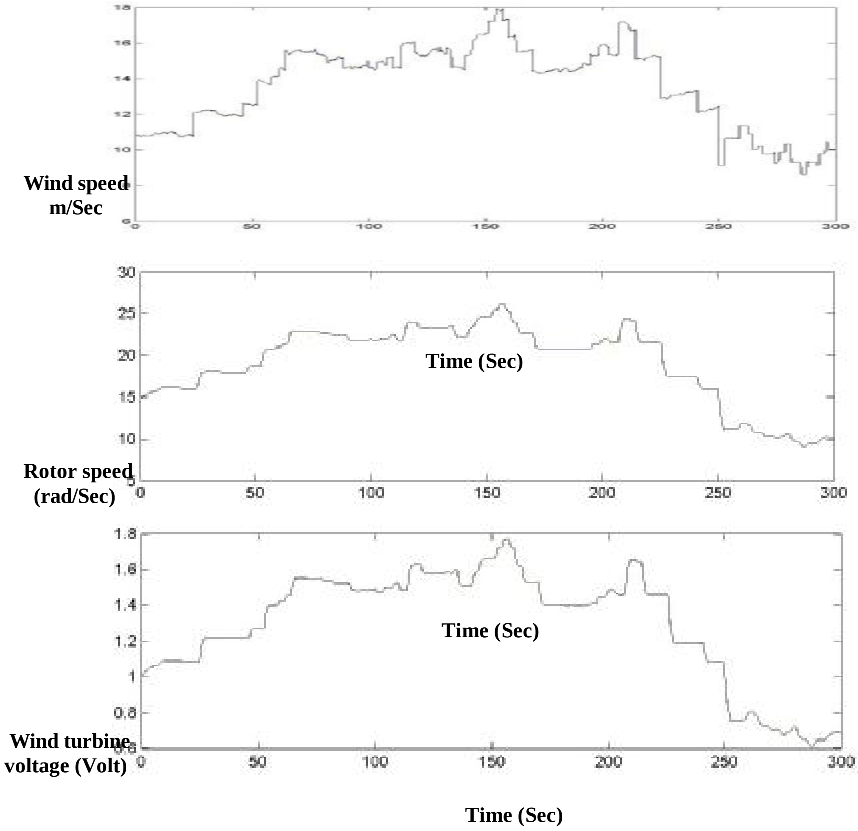

Figure (6) Wind speed, rotor speed and output voltage (uncontrolled)

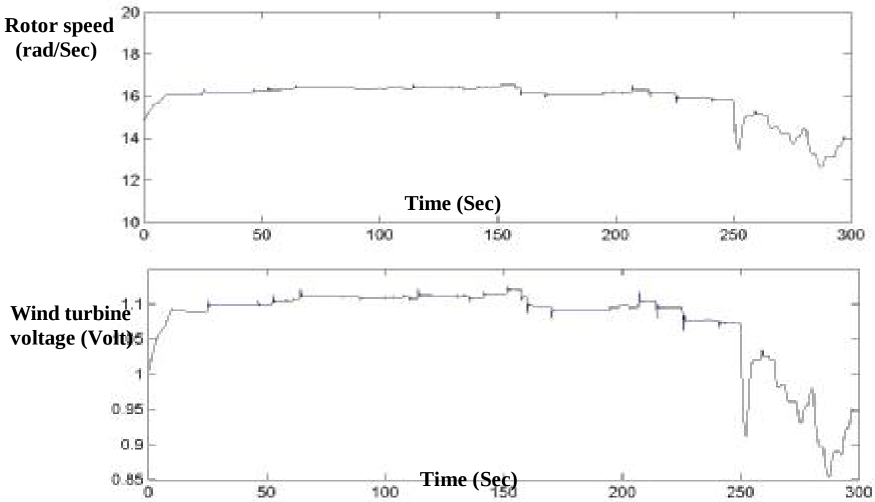

Figure (7) Rotor speed and output voltage(Controlled)

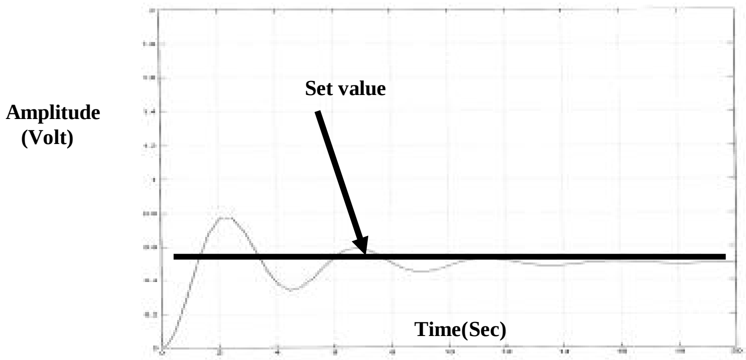

Figure (8) Step response when gain=1 and set value=0.5 without velocity feedback

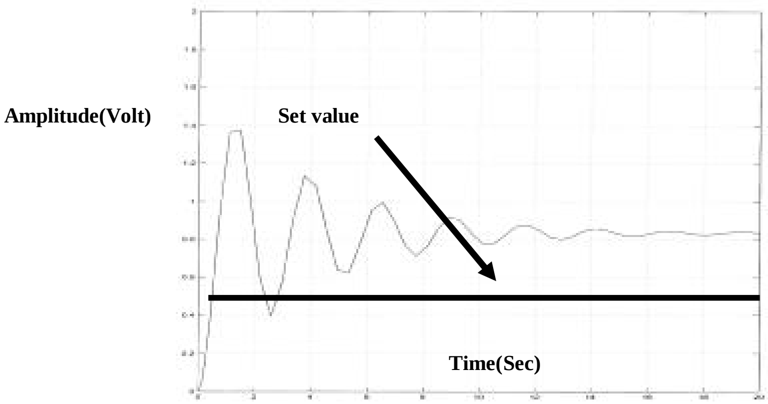

Figure (9) Step response when gain=5 and set value=0.5 without velocity feedback

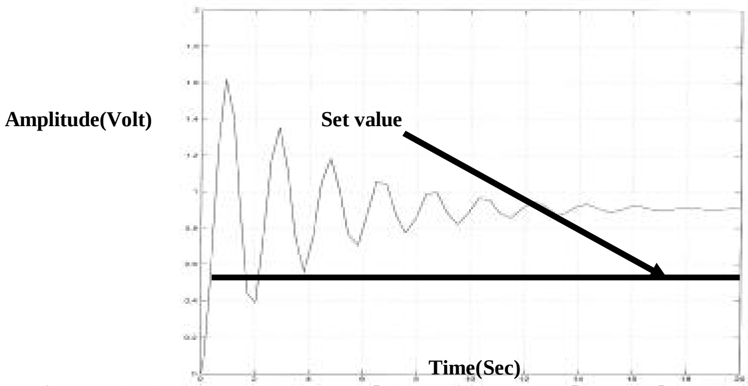

Figure (10) Step response when gain=10 and set value=0.5 without velocity feedback

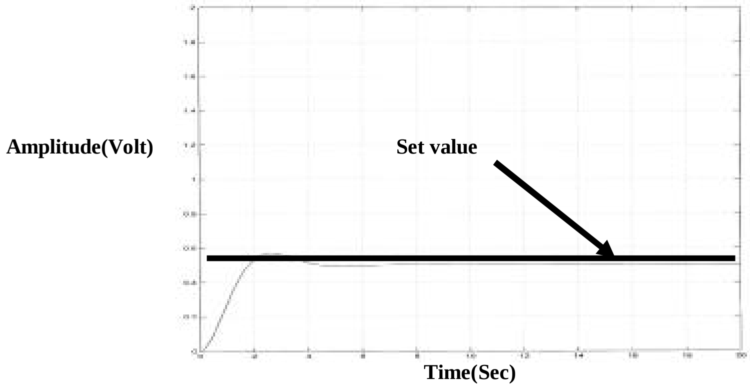

Figure (11) Step response when gain=1 and set value=0.5 with velocity feedback

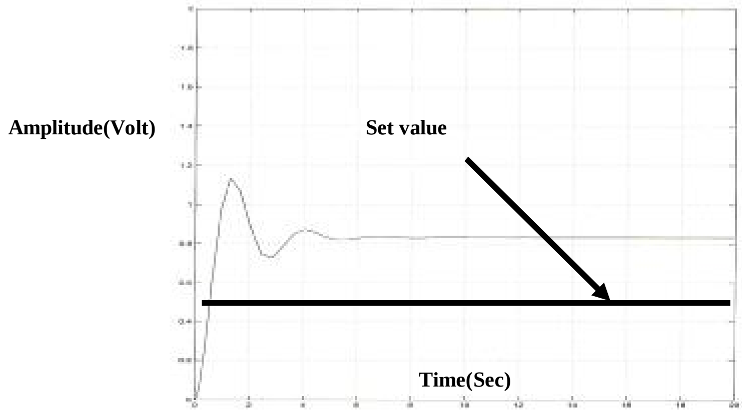

Figure (12) Step response when gain=5 and set value=0.5 with velocity feedback

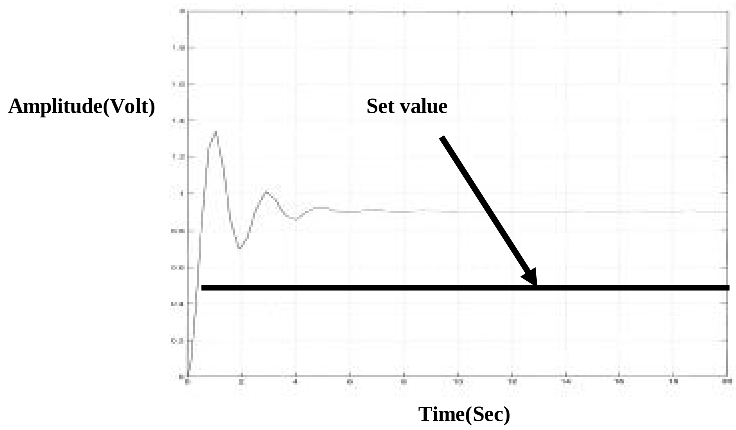

Figure (13) Step response when gain=10 and set value=0.5 with velocity feedback

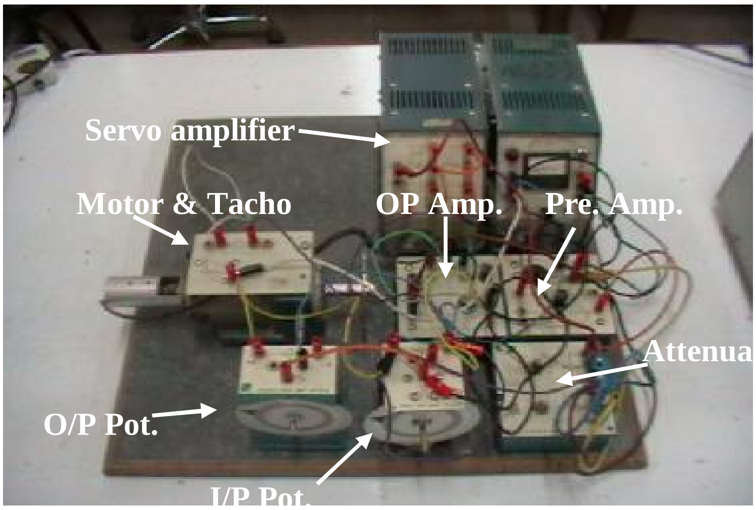

Figure (14) wiring diagram of the position control system

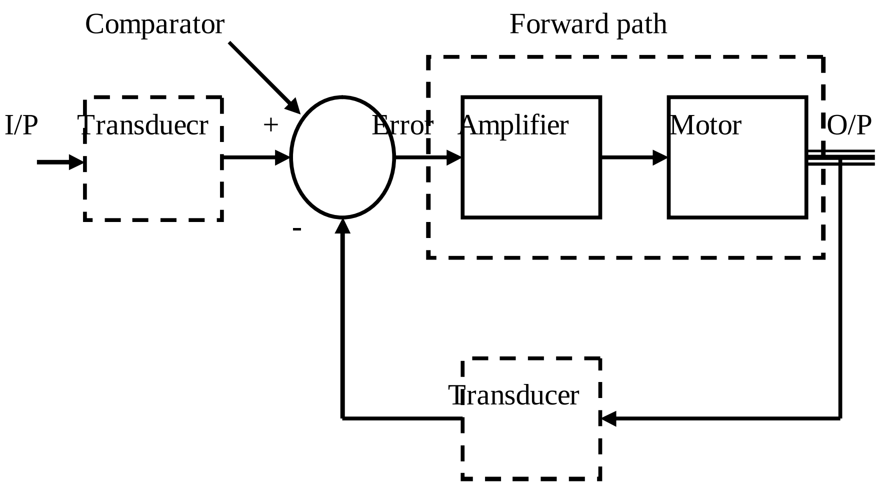

Figure (15) Elements of a closed-loop system

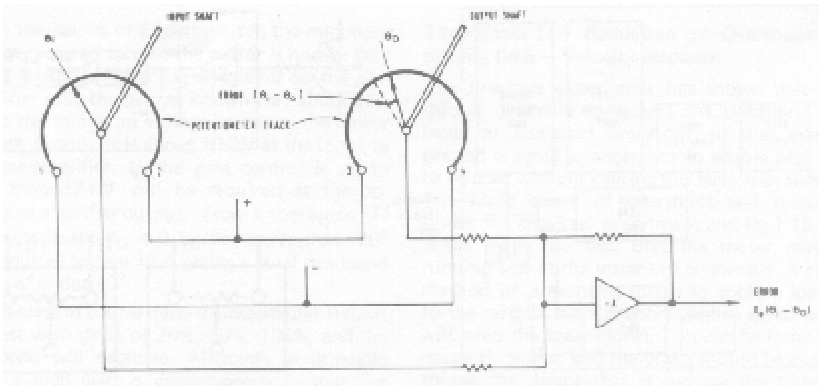

Figure (16) Simple error channel