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Variable Speed Controller of Wind Generation System using Model predictive Control and NARMA Controller

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Abstract
This paper applied an artificial intelligence technique to control Variable Speed in a wind generator system. One of these techniques is an offline Artificial Neural Network (ANN-based system identification methodology, and applied conventional proportional-integral-derivative (PID) controller). ANN-based model predictive (MPC) and remarks linearization (NARMA-L2) controllers are designed, and employed to manipulate Variable Speed in the wind technological knowledge system. All parameters of controllers are set up by the necessities of the controller's design. The effects show a neural local (NARMA-L2) can attribute even higher than PID. The settling time, upward jab time, and most overshoot of the response of NARMA-L2 is a notable deal an awful lot less than the corresponding factors for the accepted PID controller. The conclusion from this paper can be to utilize synthetic neural networks of industrial elements and sturdy manageable to be viewed as a dependable desire to normal modeling, simulation, and manipulation methodologies. The model developed in this paper can be used offline to structure and manufacturing points of conditions monitoring, faults detection, and troubles shooting for wind generation systems.

KEYWORDS: Wind generation, PID, NARMA, MPC

I. Introduction

For the preceding few periods, desires of power have been growing steadily, electrical power and environmental troubles in precise and this has extend to be a hard problem for the world. Besides, Pollution is many cases growing parallel to electricity demand, at the equal time as surprisingly every day electricity sources such as fossil fuels are depleting. This led to the discovering of large than a few preferences for renewable energies to generate Electric current [1]. Clean energy is recognized be successful of generate from one-of-a-kind environmental furnish such as photovoltaic radiation, wind movement, water waft and herbal waste. However, such electrical power is about low fee and reachable with no clear environmental pollutant. The electrical energy generated by means of the usage of capability of wind being soundly discern out upon of these produced by every day fuels and in addition has no influences on world warming. Furthermore, such electricity is produce by way of the usage of viable of transferring kinetic electricity to electric powered form with the useful resource of possible of way of the utilization of the use of pinnacle designed turbines [2].

II. Principal of Wind Energy Conversion System (WECS)

WECS consists of the following :Mechanical System,Electrical System and Control System:
The wind energy capture turbine enhancement using two controls as pitch and stall controls. The first check power output of turbine utilize electronic controller.When wind speed is high of operational limit, Because send signal to the blade pitch mechanism .Turbine with mechanism type control is known a pitch control of Wind Turbine (WT)[3-4] that show compound of WT in Fig. (1).
Many researchers are study control of wind turbine such as : Y. Qi .et.al. (2012)[5] presented apply PID to control generator speed and blade angle. It gives a result that can make the generator run at maximum power. Civelek , et.al. (2016)[6] Use P, I, and D to tuning the rotational speed, and using IGA algorithm for the PID parameter to modify the blade controller settings L. Suganthi, et.al.

(2015) [7]: A fuzzy logical control application to enhance control of wind turbines. The results that obscure models have been widely used in recent years for site evaluation.

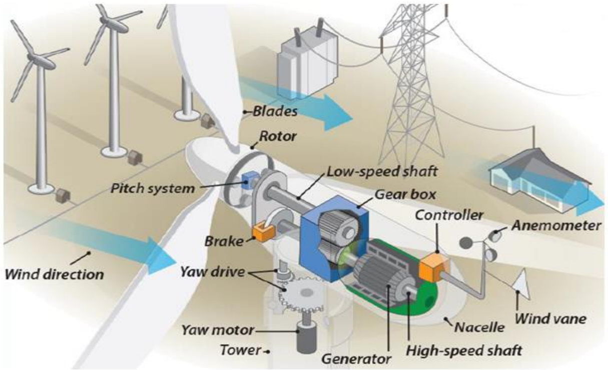


Fig. (1) Component of a wind turbine

The main purposes of this paper is applied intelligent controllers (PID,NARMA,MPC) of Variable Speed in wind generation System and Comparison between them of time specifications .

III. Aerodynamic Model of Wind Turbine

Wind turbines generated an electrical energy through extracting wind energy to trigger electric generator. Turbine blades extract kinetic energy from the wind, creating a lift force and using rotary force. Inside the nest, the blades rotate the WT column, and then activate the rotation force. The rotary blades raise the rotational speed to an appropriate speed for the generator. Then, the magnetic fields of the generator produce electrical energy from the rotary energy. The power generated to feed the transformer, in order to raise the generator voltage from approximately 700 volts to the appropriate value of the power collection system, is normally 33 kV Aerodynamic model of WT optimizes the withdrawal of power through the rotor; provide the mechanical torque by affect flow air at blades. The speed of wind turbine is measured as average value occurrence speed on the blades swept area. The goals are to evaluate low speed axis average torque[10]Wind velocity feeding to WT as a parameter speed with value time and adjust pitch angle (β) at 0 to get maximum coefficient power (Cp). The sweep area of blade take out the energy kinetic from wind according of formula (1) and generate a moving air power (Pair) as formula (5)[9-10].

$$E = 1/2\, mv^2 \quad (1)$$

Where $m{=}\rho Av$ and ρ is air particles density (1.225 kg/m^3), and A the blades swept as:

$$A = \pi R^2 \quad (2)$$

The moving air power is equal to

$$Pair = dE/dt \quad (3)$$

$$Pair = 1/\,2\,.\dot{m}\,.v^2 \quad (4)$$

$$Pair = 1\,/2\,\rho\,\pi R^2\, v^3 \quad (5)$$

The wind power is highly depending on wind speed therefore comparative power to the cube wind speed. P_{air} indicates energy which obtainable in wind although energy essentially motivate to rotor of the wind turbine ($P_{wind\ turbine}$) is reduce by Cp according to formulas (6), (7).

$$Cp = Pwind\ turbine\ /Pair \quad (6)$$

$$Pwind\ turbine = 1/\,2\,\rho\,\pi R^2\, v^3 * Cp \quad (7)$$

Where Cp: wind power coefficient, optimal rate coefficient wind power is 59.3% but experimental is approximation (0.25-0.45) rotor WT.
The power and torque coefficient correspond analytical expression connected to ratio of tip speed (λ) and pitch angle (β). The frequently expressions apply with enhanced many WT, by formula (8).

$$(\lambda,\beta) = c1(\frac{c2}{\lambda i} - c3\,\beta - c4)exp - (C5/\,\lambda i) + c6\,\lambda \quad (8)$$

Where: c1 to c6 are equal to 0.517, 116, 0.4, 5, 21 and 0.0068 respectively for HAWT with a changeable speed of wind [8] and (λ_i) is given from the formula:

$$\lambda i = \frac{1}{\frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1}} \quad (9)$$

The tip speed ratio is determined as formula

$$\lambda = \omega\, R/v \quad (10)$$

Cp and λ dimensionless and apply to essential the exploit of rotor of WT at different sizes. Maximum Cp is attain just at exclusive single tip speed ratio and for constant rotating speed of WT, it happens at a single wind speed. Later, one reason to operate WT at variable rotational speed to operate at maximum Cp over a different wind speed [9].
Cp depends on geothermal parameter and manufacturers, naturally Cp is introduce creature associated with two limit ratio of (λ) and (β).
Figure 2 shows a relationship of Cp $(\lambda,)$ at many number of pitch angles. It represent so as to, every pitch angle and of tip speed ratio Cp it maximum value, for example, Cp gets the maximum at β=0°.
Therefore, to cutting as possible as maximum energy from the wind. It is essential to situate β and λ to obtain optimal Cp .The energy of wind turbine is defined at different speeds of the wind as expected by the energy curve shown in Fig. (2).

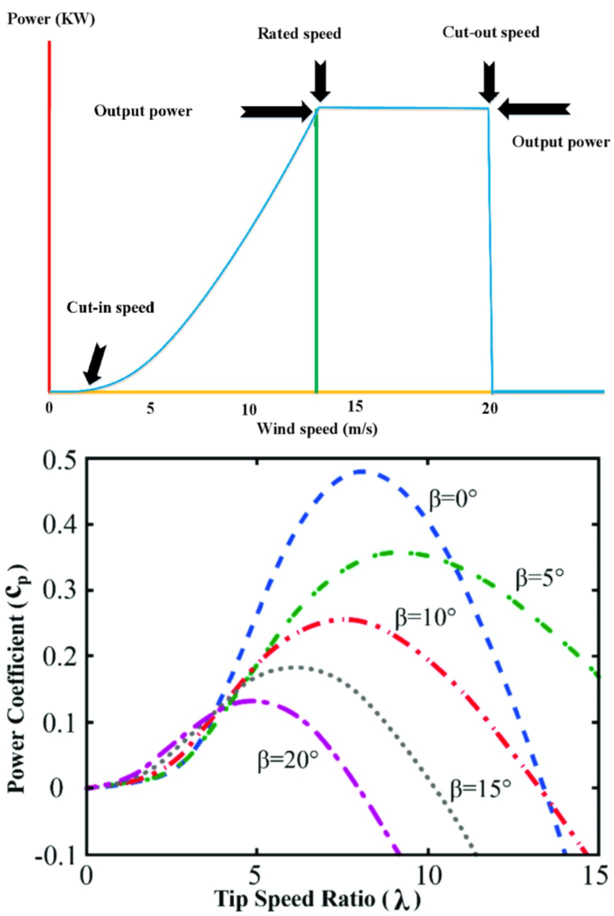


Fig. (2): The coefficient of power Cp (λ, β) and curve of WT power

The resulting electric power is displayed in a stable state of wind speed at elevation of axis and measure the application of the average information for 20 minutes. Initial spot of this curve illustrated the cut-in speed that smallest wind speed cause the machine deliver practical power. Next point is rating wind speed which energy rated is get (best output power of electrical generator). Finally, point is Cutout wind speed, which is higher speed of WT that allow transmitting power [9].
The WT rotor produce a torque as formula:

$$Tw = Pwind\ turbine / \omega \qquad (11)$$

IV. Neural Network Modeling

Artificial neural networks (ANN) are really barring a doubt honestly beneficial in many fields of science, archives and technology. They furnish a desire approach to the simulation of complicated system, [11, 12, 13]. The most crucial wondering of ANN is to resemble the human genius for treatment challenging troubles in a differ of scientific areas such as engineering, psychology, linguistics, philosophy, economics, neuroscience, etc. ANN is described as a computing gadget, which is made up of a sum of straight previously, in unique interconnected processing elements (neurons) that geared up in layers as input, hidden layer and output layer [14]. ANN learns with the advocated beneficial useful resource of the use of instructing. Each enter into the neuron its very private connected weight. Weights are adaptable number that determined in route of the instructing process. Figure (3) suggests structure of ANN with inputs, outputs and one hidden layer.

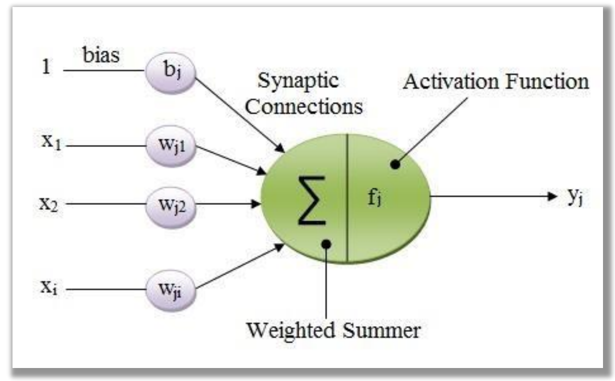


Fig. (3): A simple structure of ANN

Figure (3) suggests a reachable single-input neuron with its input, output, and factors consisting of the sum and attribute blocks. p, w, b, f, and a, are input, weight, bias, activation function, and output respectively [15]. The neuron output is determined with the useful resource of performance of way of way of way of formula:

$$a = (w * p + b) \qquad (12)$$

In ANN -based Model Predictive Control (MPC), neural nearby characterize in the previous nonlinear dynamics of the plant has been typically used in a wide-ranging of approach plant existence of the world. The most fundamental profit of MPC that made it worthwhile of industrial elements embody functionality of managing structural change, non-minimal vicinity and unstable strategies because genuine as multi-variable manipulate troubles. Figure (4) suggests a on hand shape of MPC. As it can be seen from this figure, the mannequin predicts output of the device in popular particularly pretty based totally on future inputs, preceding input, and preceding output. Output is in distinction to a reference cost and the massive distinction (error) go to optimizer that determine future input of model. Optimization manner takes nearby on base of mainframe constraint(s) and a predefined fee function [16].

For Design Model Predictive Control

MPC block shown in Fig. (4). This block previously carried out in Simulink /MATLAB. Design of ANN- fairly based in reality MPC in MATLAB surroundings consists of one-of-a-kind tiers. The first step in MPC diagram laptop is computing system identification, the plant mannequin is use the controller for predict future each day performance [17]. NN is educated the utilization of the NN instructing sign which is the prediction fault between the plant output and the neural network output. Previous enter and outputs are utilized via the use of the NN plant model to predict future values for plant output.

System Identification

System identification manner select to be carried out and the neural shut by means of plant model have to be developed. The optimization algorithm employs these prediction for decide out the manipulate inputs that optimize future performance. Figure (3) indicates the block shape of plant identification for Wind technological facts laptop computer pc with all adjusted parameters for producing data, and instructing neural network mannequin of system, the manipulate horizons N2,Nu have been tuned at 7and two respectively.

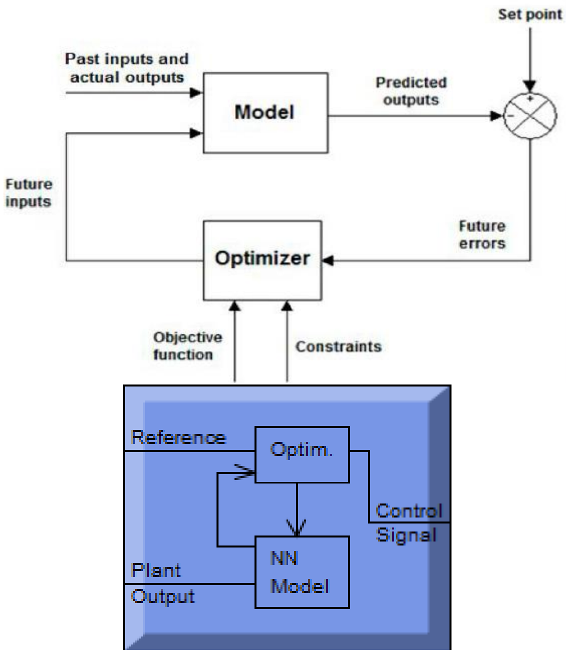


Fig. (4): A basic MPC structure [16].

As it can be regarded from Fig. (5), minimal and most values for the plant enter and output are 14, 0, inf, 0 respectively. Minimum and most interval values as 1 and 5 seconds respectively. These archives have been generated the utilization of "Data Generate Training" option. Dimension for hidden layer is 5 and differ of delayed plant inputs and outputs had been adjusted at three and two seconds respectively. The interval sampling used to be every day at 1 second. The instructing proceeds in accordance to the chosen educating attribute (trainlm). When the teaching complete, response of ensuing plant mannequin is displayed, as its show in of training, validation data and performance of MPC in Fig. (5).

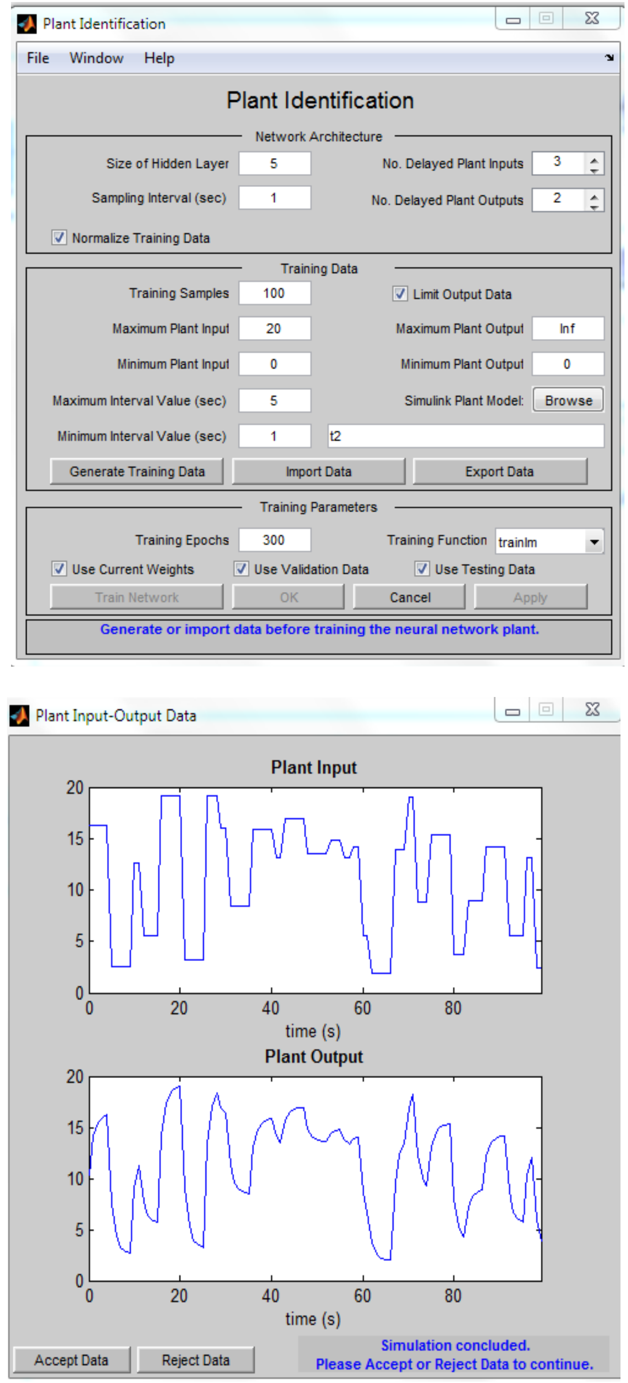


Fig. (5): Block diagram of system identification MPC.

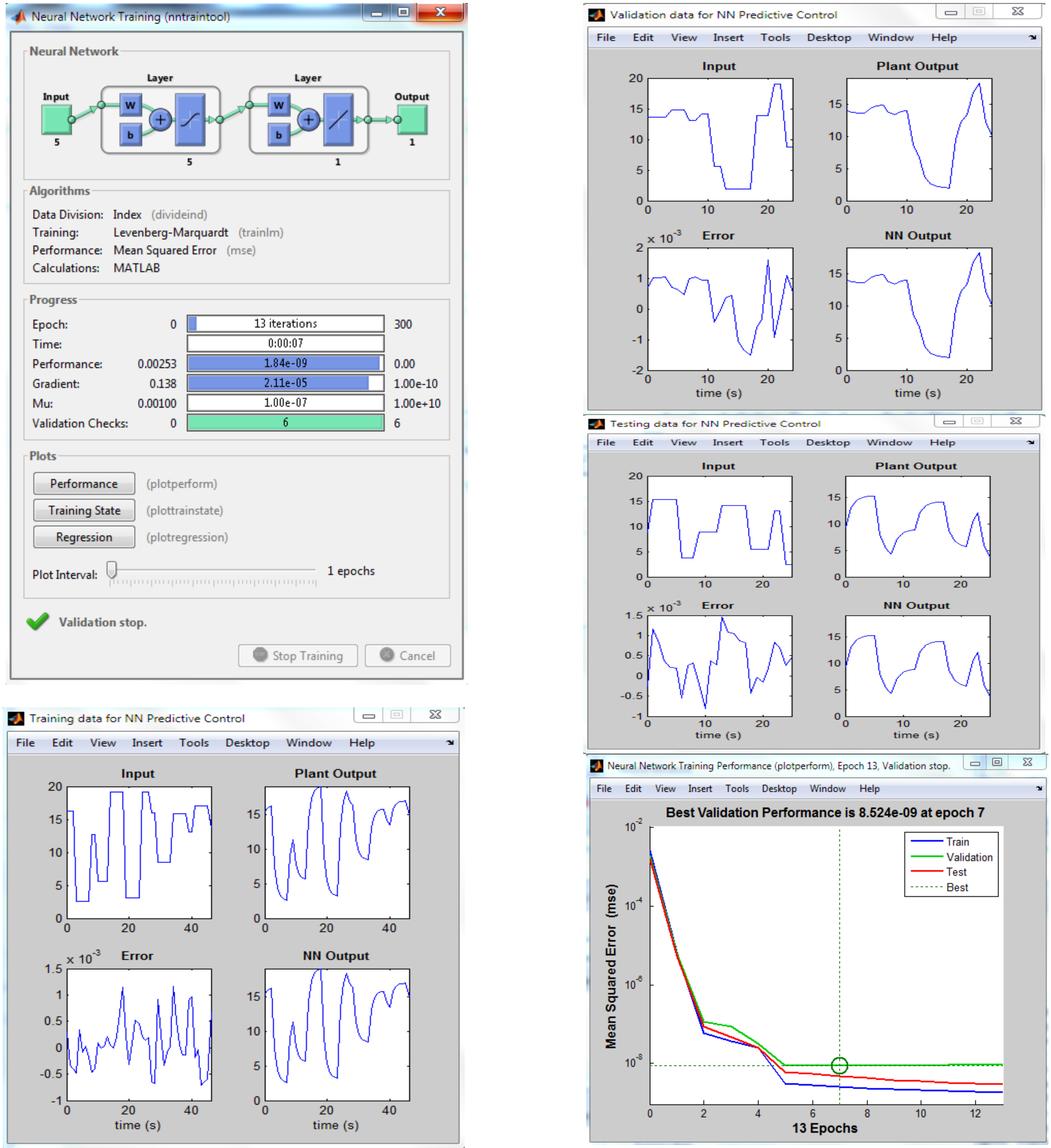


Fig. (5): Continued.

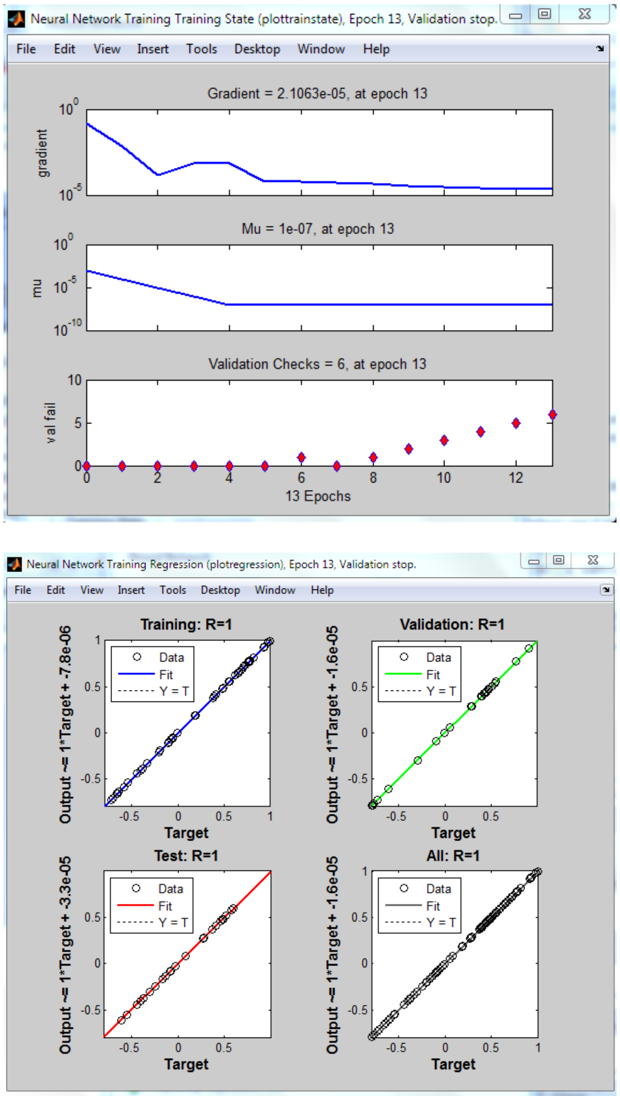


Fig. (5): Continued.

Feedback Linearization Control (NARMA-L2)

NARMA is the nonlinear autoregressive moving average model.is standard model is apply to represent behavior of input-output of nonlinear system. The NARMA model represent as:

$$y(k+d) = Nf[y(k), y(k-1), \dots y(k-n+1), u(k), u(k-1), \dots u(k-n+1)] \quad (13)$$

Where: u(k) is the system input, and y(k) is system output. A neural nearby have to be specialist to approximate the nonlinear attribute Nf for the gadget identification stage. Fig.(6) suggests a block diagram of NARMA-L2 controller with factors f and g, and the time delays TDL, all put in stress in the NARMA-L2 manipulate block. Controller is multi-layer neural shut by using way of achievable of that has been effectively utilized in the identification and manipulate of dynamic constructions [17] [18]. The quintessential questioning in the hinder as soon as greater of the NARMA-L2 is redesigning nonlinear laptop computer pc laptop dynamics into linear dynamics

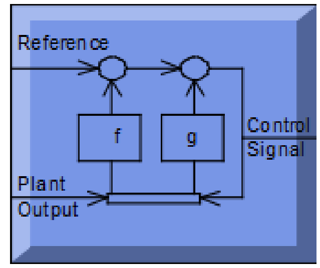


Fig. (6) Block diagram of NARMA-L2 controller [16]

Design of NARMA

The diagram closed loop for controlling of variable speed in wind generation system with the NARMA controllers have been applied in Simulink\Matlab. There are most important step for using NARMA-L2 include identification system and control design. In identification system state, a model of neural network is developed of plant. Fig. (7) shown the NARMA controller block. Fig. (7) show block diagram of identification plant of variable speed in wind generation system of NARMA controller with all the adjusted parameter to generate data, and neural network train mode l for system ,testing , validation and training performance.

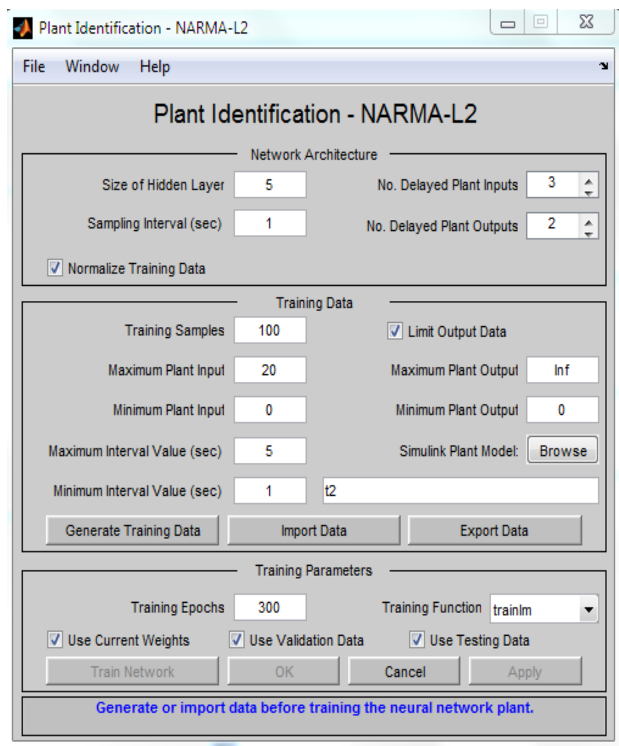


Fig. (7): Plant identification of and Generate training data of Variable Speed in Wind Generation System of NARMA control.

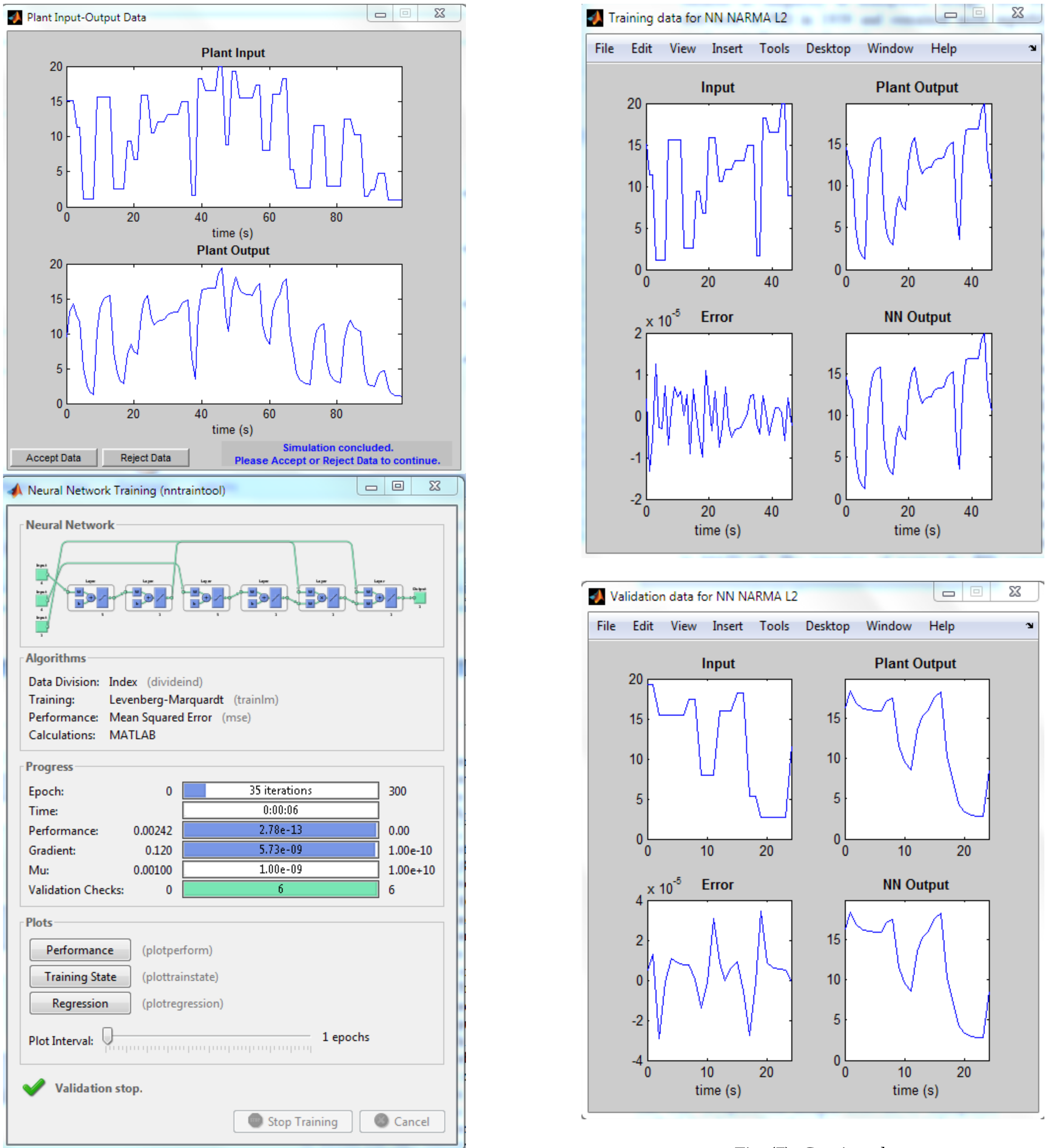
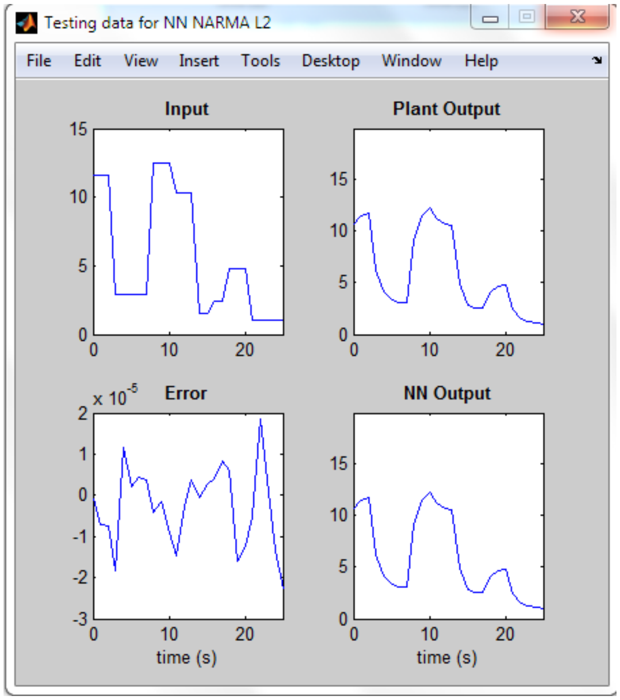
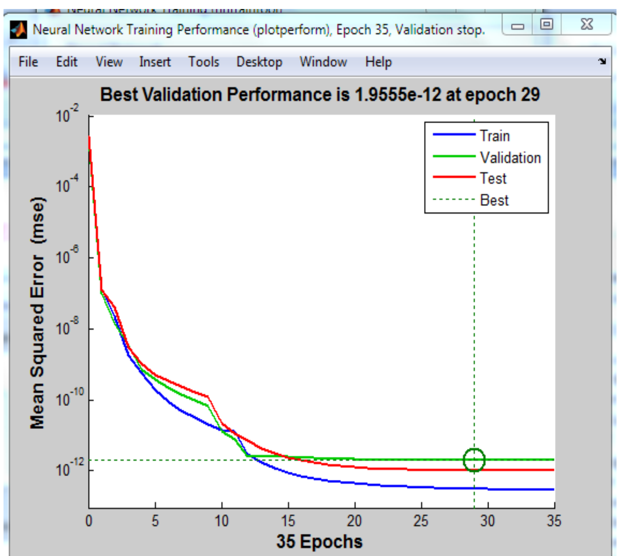
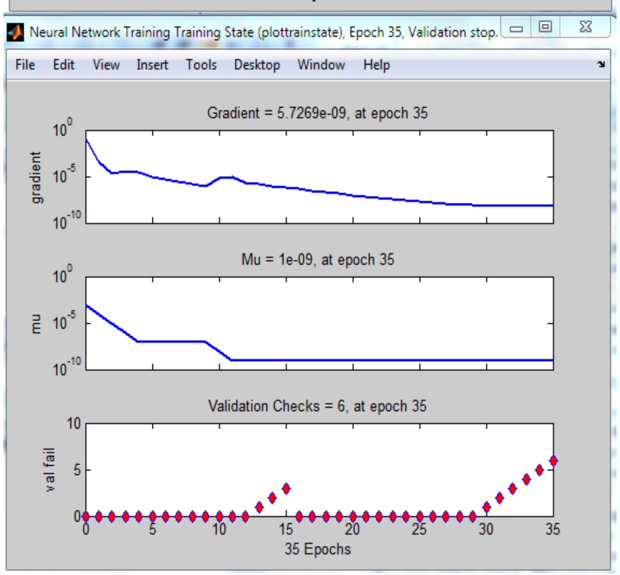


Fig. (7): Continued.







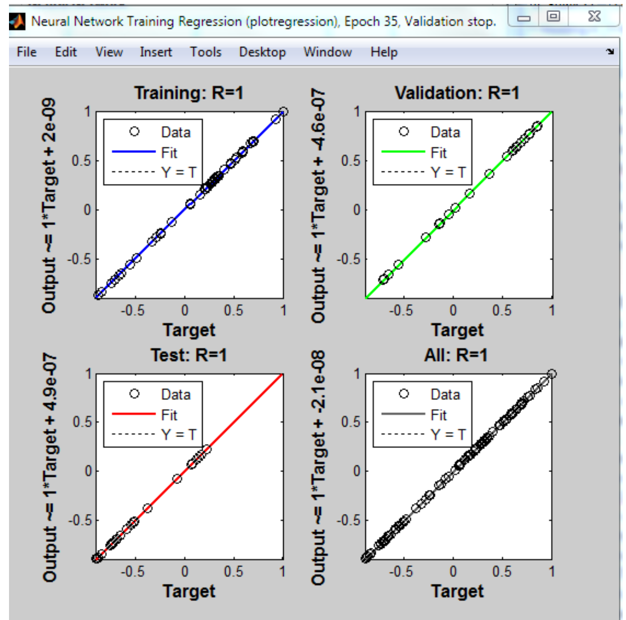


Fig. (7): Continued.

As well as from these figures , maximum and minimum values of plant input speed is 0,20plant output maximum and minimum values are 0,inf and interval values minimum and maximum are1,5sec.

PID CONTROL

The PID (Proportional-Integral-Derivative) manipulate method has been placed to be a promising information due to its low cost, straight beforehand to maintain as suitable as simplicity in manipulate design. first off delivered of PID in 1939 and remained most superbly used controller in industrials manage constructions till these days [19] Basically the PID controller variables consist of three separate variables: proportionality (kp), quintessential (ki) and spinoff values (kd). A pinnacle notch inserting of these variables will decorate the dynamic response of system, keep away from overshoot, avoid ordinary kingdom error and extend steadiness of the system .The swap attribute of a PID controller is [20-22].

$$U_C(s) = \left[K_P + \frac{K_I}{s} + K_D s\right] E(s) \quad (14)$$

The imperative constriction of a PID manipulate computer is set up in Fig. (8).The set thing is change, and the error is decided between the set bother and proper output. The error signal, E(s), is utilized to generate the proportional, integral, and spinoff actions, with the ensuing warning symptoms and signs and symptoms weighted and summed to shape the manipulate signal, U_C (s), employed to the excellent model. In addition, show case off a new output signal. This new relevant signal will be launch to the controller, and once more, the error sign will be determined. New manipulate signal, U_C (s), pick to be dispatched to the plant. This enchantment select to be run continuously till every and each day – United States – error raise to be zero. PID controller block has been put in pressure in Simulink-MATLAB and its elements are tune in a attribute each manually or automatically in accordance to the PID tuning algorithm in MATLAB. The intention of tuning the PID correct factors is to reap an exquisite steadiness between everyday usual universal overall performance and robustness, even as conserving the closed-loop stability.

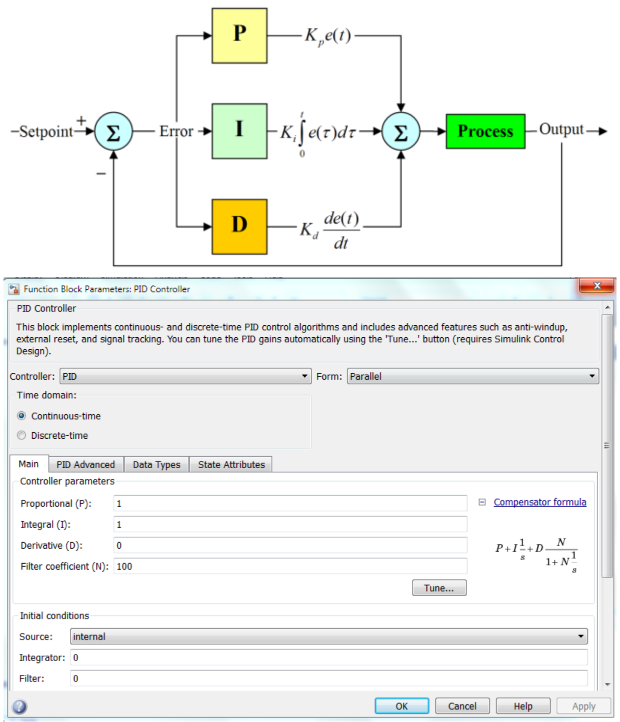


Fig. (8): PID control system.

V. Results and Conclusions

This paper apply technique of artificial neural networks for control of Variable Speed in Wind generation System to design and manufacturing of more efficient, reliable for optimization that shown in Table (1) and figs (9), (10) Simulink model of control of speed of wind generation system and response of MPC,NARMA,PID as:

1- In this paper using PID with ANN-based (MPC and NARMA-L2) controllers. The results show NARMA controllers is better than PID controllers.

2- ANNs gave an excessive and sturdy manageable to be regarded for reliability desire to state-of -art model, simulations and manipulate methodologies.

3- ANN can be used to exceptional enhancement in method of industrial computing device model and control.

4- Levenberg-Marquardt instructing algorithm (trainlm) had a closing each day usual performance in big difference to each of one-of-a-kind algorithm.

5- The settling time, upward shove time and most overshoot of NARMA-L2 response is a superb deal lots much less than for MPC and PID.

6- ANN controller offline instructing to furnish a existence like diploma of information about the laptop pc dynamics.

7- The neural regional form chosen with 5 hidden neurons and training algorithm for 300 epochs.

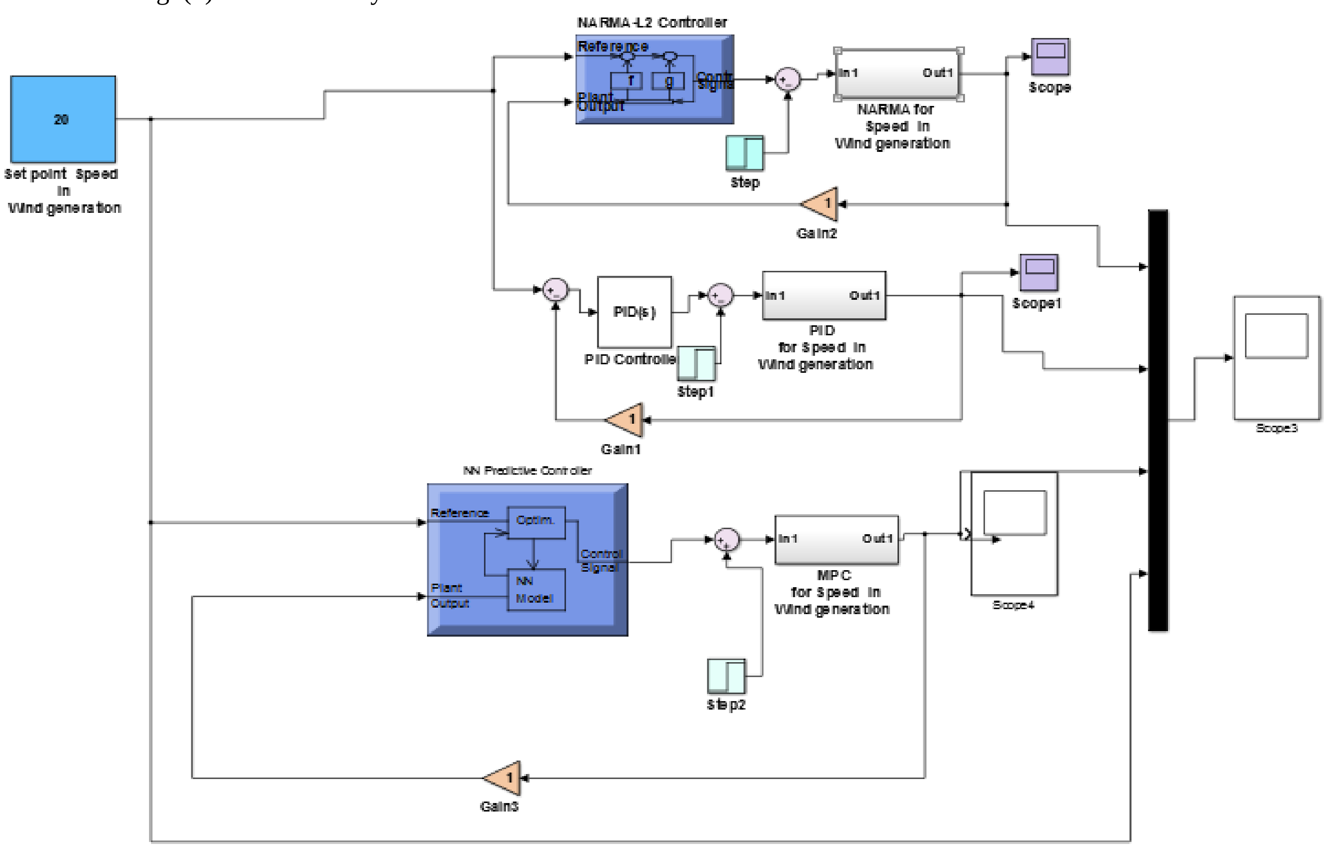


Fig. (9) Simulink model of Variable Speed in Wind generation System.

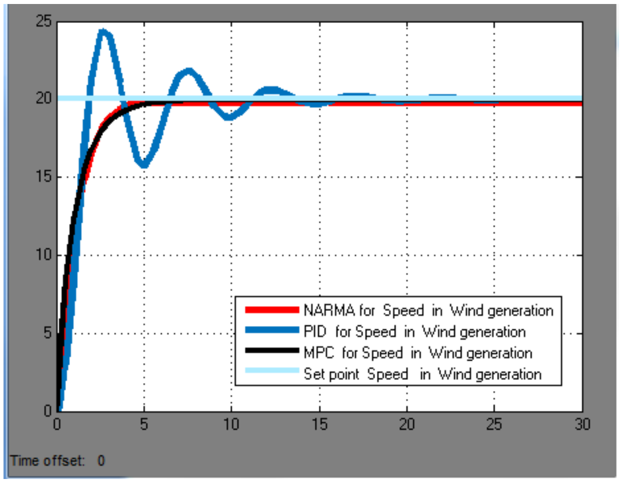


Fig. (10): Response of MPC, NARMA, PID of Variable Speed in Wind generation System.

TABLE 1
Comparison Time Domain Specification For Speed Input With Pid, Mpc And Narma Controller

Parameter Speed	**Rise Time**	**Settling Time**	**Peak Value**	**Overshoot**
NARMA	0	4.3	20	0
MPC	0	5	20	0
PID	3	17	24	0.25

Conflict of Interest

The authors have no conflict of relevant interest to this article.

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