# Maximum Power Point Tracking for Small Scale Wind Turbine Using Multilayer Perceptron Neural Network Implementation without Mechanical Sensor

Piyangkun Kukutapan, Siridech Boonsang



***Abstract*—**The article proposes maximum power point tracking without mechanical sensor using Multilayer Perceptron Neural Network (MLPNN). The aim of article is to reduce the cost and complexity but still retain efficiency. The experimental is that duty cycle is generated maximum power, if it has suitable qualification. The measured data from DC generator, voltage (V), current (I), power (P), turnover rate of power (dP), and turnover rate of voltage (dV) are used as input for MLPNN model. The output of this model is duty cycle for driving the converter. The experiment implemented using Arduino Uno board. This diagram is compared to MPPT using MLPNN and P&O control (Perturbation and Observation control). The experimental results show that the proposed MLPNN based approach is more efficiency than P&O algorithm for this application.

***Keywords*—**Maximum power point tracking, multilayer perceptron neural network, optimal duty cycle.

## I. Introduction

RENEWABLE energy has grown enormous. The wind energy conversion system is decade as one of renewable energy sources due to high cost and environment impact from the current energy source. Wind energy is one choice because it is no pollution and inexhaustible.

In wind energy system, wind turbine converts wind energy to mechanical energy then it runs a generator to create electrical energy. Power from turbine depends on wind velocity and pitch angle [1]. To take advantage of wind turbine characteristic, Maximum power point tracking is necessary variable to obtain maximum power.

In recent year, Maximum Power Point Tracking(MPPT) algorithms [2] such as Optimal torque control (OTC), Perturb and Observe (P&O) and Incremental method [3] have been proposed. The advantage of OTC and P&O are high efficiency and simplicity respectively.

Main drawbacks of P&O algorithm are low efficiency and difficulty in determining step size of duty cycle. However, maximum power point tracking using multilayer perceptron neural network (MLPNN) can overcome these problems by optimize efficiency and reduce step size determining.

A mechanical sensor is necessary for maximum power point tracking using artificial neural network to optimize efficiency at each wind velocity [4]. A mechanical sensor with neural network is used in [5], [6]. The preceding MPPTs have to know the wind velocity and rotor speed that increase complexity and cost.

This article presents Maximum power point tracking using multilayer perceptron neural network (MLPNN) to predict optimal duty cycle without mechanical sensor. The objective of article is to simplify, reduce cost and optimize efficiency of output power. Maximum power point tracking using MLPNN was implemented using Arduino to drive dc converter. The performance of article was compared with P&O algorithm in wind tunnel with height of 0.6 m width of 0.6 m, length of 1.6 m, and 0.785 m$^2$ cross section area

## II. Wind Turbine System Overview

In wind power system, wind power is converted into shaft power by wind turbine, and the shaft power is converted into electrical power. The structure of wind turbine system is given in Fig. 1. Wind turbine system consist of wind turbine, dc generator, buck converter, and resistive load.

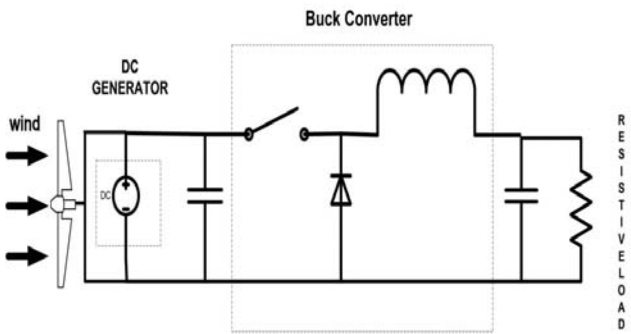


Fig. 1 Structure of wind power system

The output power of wind turbine is a function of wind velocity cubed described by (1).

$$Pm = \frac{1}{2}\rho\pi A V_{wind}{}^{3} C_p(\lambda, \beta) \tag{1}$$

where P is power (watt) $\rho$ is air density (kg/m$^3$) R is radius of wind turbine (m) $V$ is wind speed (m/s), $C_p$ is power coefficient and A is rotor swept area (m$^2$) [7], [8].

In the experiment, initial duty cycle was 0%. and duty cycle was in each round. The output power in each round is recorded for analyzing the relation between power and duty cycle. The experimental results found that each wind speed

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corresponds to one optimal duty cycle which generates the maximum output power.

Fig. 2 shows that, optimal duty cycle are 50, 55 and 70 percents, and maximum output power are 2.81, 4.53 and 7.57 watt at wind speed 5 (blue line with square), 6 (green dash line) and 8.3 (red solid line) m/s respectively.

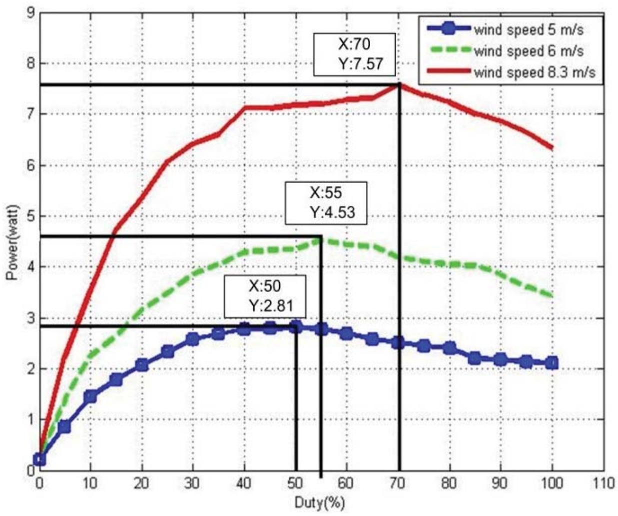



Fig. 2 Relationship between output power and duty cycle (x is duty cycle (%) and y is output power (w))

## III. Design of MPPT Control

### A. Multilayer Perceptron Neural Network

Neural network is an artificial intelligent. The principle of neural network is to imitating function of human brain, the output signal is determined by activation function [9].

Neural Network with at least hidden 1 layers is called multilayer neural network. If a network has hidden layer more than one layer and its activation function is sigmoid it can estimate continuous function [10].

Architecture of proposed Multilayer Perceptron Neural Network (MLPNN) is shown in Fig. 3. The network consists of one hidden layer with n nodes, input layer with three nodes, and output layer with n nodes.

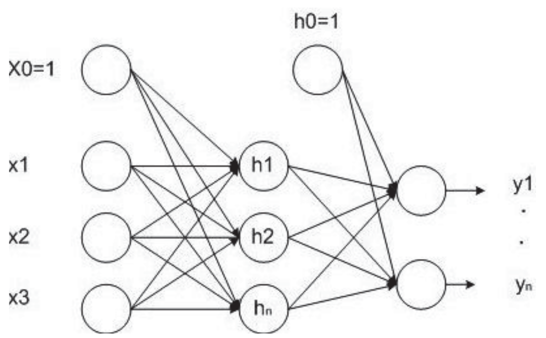



Fig. 3 Architecture of multilayer perceptron neural network: $X_1$, $X_2$ and $X_3$ is input nodes, $X_0$ is hidden layer bias, and $h_0$ is output layer bias

Architecture of Maximum Power Point Tracking using MLPNN is shown in Fig. 4, in which the predicted duty cycle can be obtained by five inputs and one output node where inputs are voltage, current, power, turnover rate of power, and turnover rate of voltage. The output is predicted duty cycle.

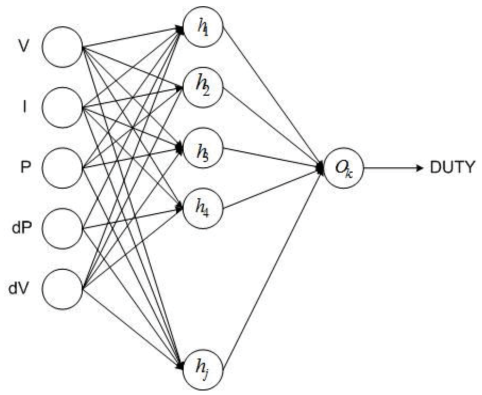



Fig. 4 Architecture of MPPT using MLPNN without mechanical sensor

Block diagram of maximum power point tracking using MLPNN is given in Fig. 5, in which the predicted optimal duty cycle is output from multilayer perceptron neural network used to drive the converter. The controller receives voltage and current from the electrical sensor. Input are calculated by controller. The predicted duty cycle from MLPNN is controlling value to drive the buck converter. Predicted duty cycle is calculated by (2)-(5).

$$X_i = [V, I, P, dP, dV, dI]$$

where V is voltage, I is current, P is power, dP is turnover rate of power and dV is turnover rate of voltage.

$$s_j = \sum_{i=1}^{d} w^{(1)}{}_{ij} X_i + \sum_{i=1}^{j} b^{(1)}{}_i w_i \tag{2}$$

$$z_j = h(s_j) = \frac{1}{1+\exp(-s_j)} \tag{3}$$

$$a_k = \sum_{j=1}^{M} w_{kj}^{(2)} z_j + \sum_{v=1}^{o} b_v w_v \tag{4}$$

$$y_k = O(a_k) = \frac{1}{1+\exp(-a_k)} \tag{5}$$

where $s_j$ is activate function, $z_j$ is output from hidden layer, $a_k$ is activation from hidden layer, $y_k$ is output from MLPNN.

### *B. Perturbation and Observation Control*

Perturbation and Observation control is mathematical technique. This technique is perturbing control variable and observing target. The algorithm perturbs step size of control variable until turnover rate of target is zero and then stop. The operations of perturbation and observation method is shown in Fig. 6. If operation point is on the left of maximum point (slope is positive), the controller perturbs control variable to move observing target to the right side of operation point. On the other hand, if operation point is on the right side, the controller moves the observing target to the left to be close to maximum point. The advantage of perturbation and observation technique is that it does not require knowledge of wind turbine characteristic curve. This technique is simple and flexible. However, it fails to obtain the maximum power point because it is difficult to choose appropriate step size. The large step size cause fast response with large oscillation around maximum point. The small step size is more provides efficiency but reduces the response.

Maximum power point tracking using P&O method block diagram is shown in Fig. 7. The voltage and current signals are sent to controller to calculate the power. The target and control variable are power and duty cycle respectively. Controller perturb control variable and observe slope of target variable. The controller perturbs duty cycle until differential of power is zero. In this study, control variable used step size of duty cycle 0.5 percent.

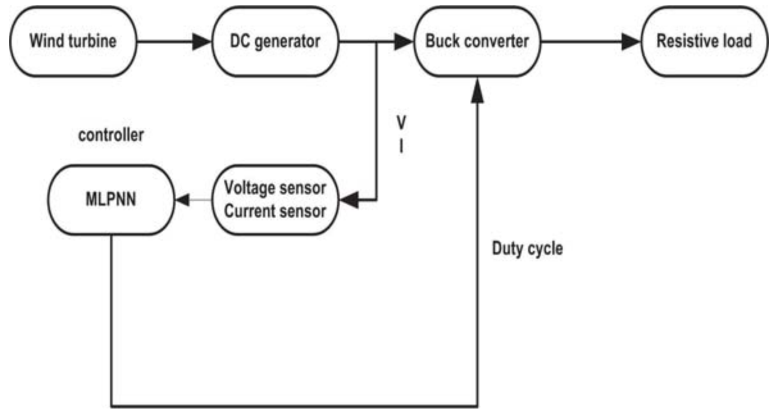



Fig. 5 Block diagram of Maximum power point tracking using MLPNN

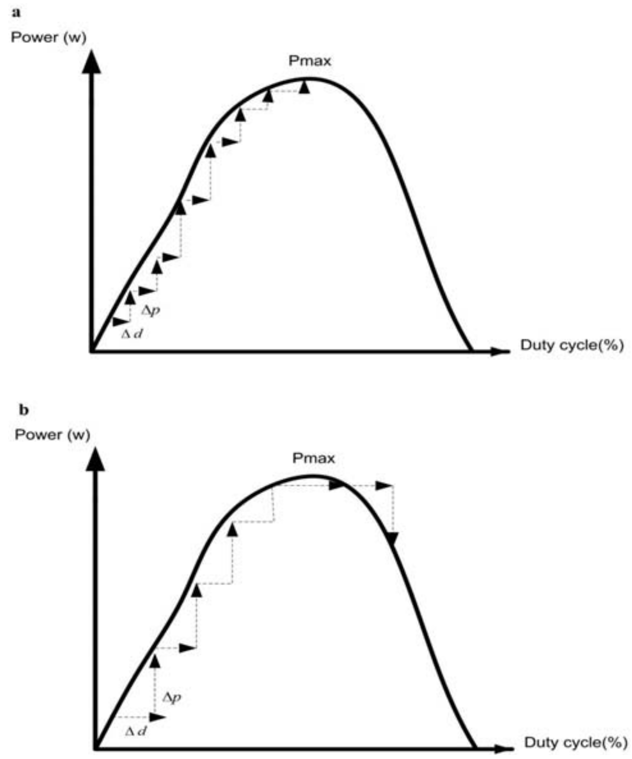



Fig. 6 Perturbation and Observation operation (a) small step size (b) large step size [2]

## IV. Experimental Result

The equipment used to track maximum power by artificial neural network without mechanical sensor is shown in Fig. 8 (a) control circuit with ARDUINO UNO processing that obtains current and voltage from current and voltage sensor. INA 146 gain difference amplifier is used in current and voltage sensors. (b) Overview of wind tunnel used in the experiment, which size 0.6 meters of height, 0.6 meters of wide, 1.6 meter of long and 0.785 m2 cross-sectional area (c) operational part will be used in the test. Operational part is composed of DC generator and multiple blade wind turbine with diameter of 0.45m, blade width 10cm and 16cm in length. The experiment took place at wind speed of 5, 6, and 8.3m/s.

The relation between output power and duty cycle is aforementioned in Fig. 2 revealing that at wind speed 5 m/s, duty cycle the maximum power (2.81watt) is 50 percent and at wind speed 6 m/s, duty cycle the maximum power (4.53watt) is 55 percent and at wind speed 8.3m/s, duty cycle the maximum power (7.57watt) is 70 percent. Thereby, the maximum power regarded as the expected value are 2.81, 4.53 and 7.57 watt for the specific wind speed (5,6 and 8.3 m/s).

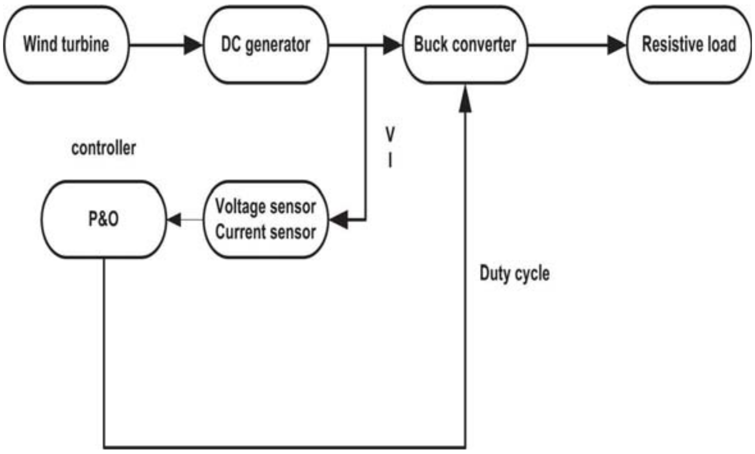
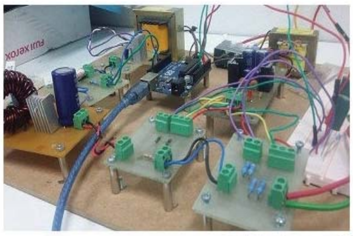
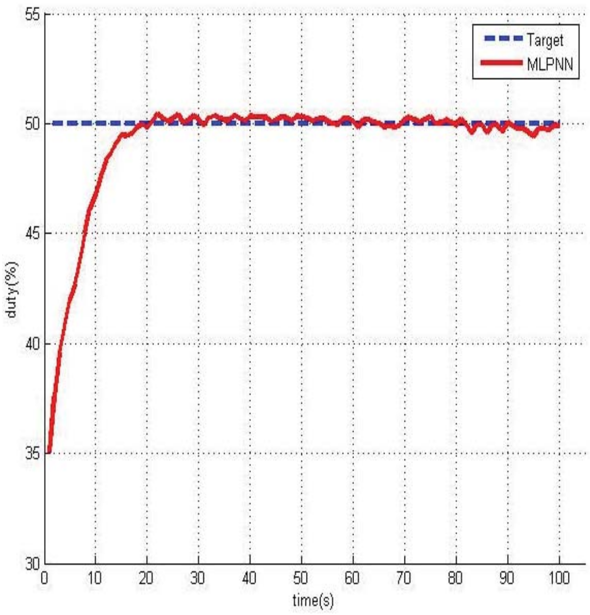



Fig. 7 Block diagram of Maximum power point tracking using P&O method

(a)  (b) 

(c) 

Fig. 8 Experimental equipment

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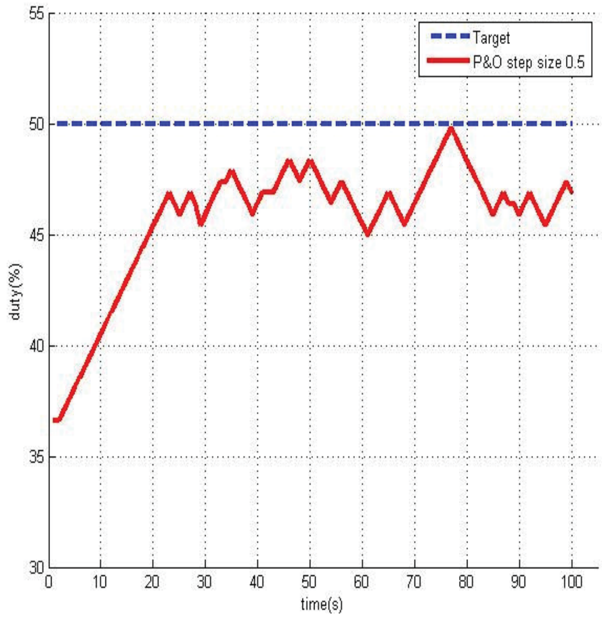
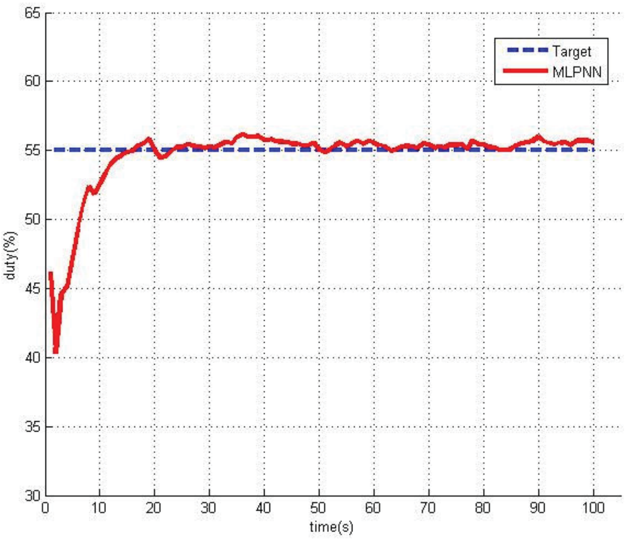
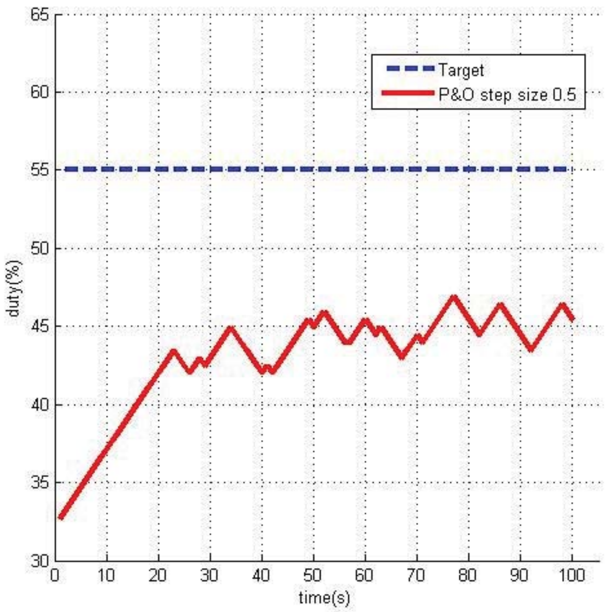



(b)

Fig. 9 Experiment of (a) MLPNN (b) P&O output duty cycle at wind speed 5 m/s




(a)

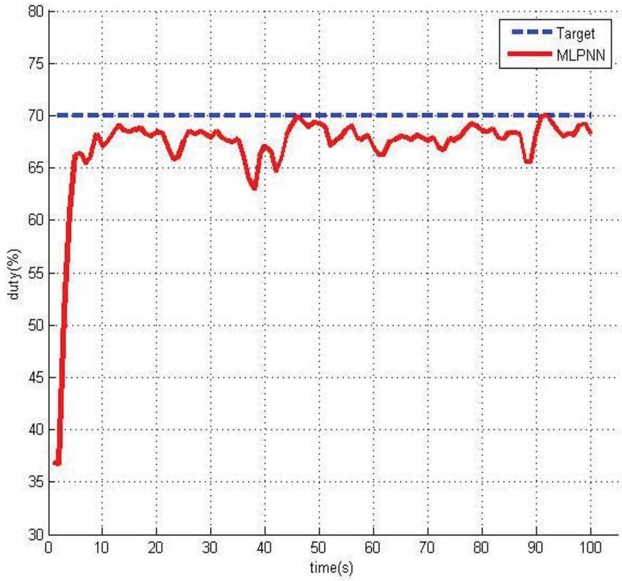



(b)

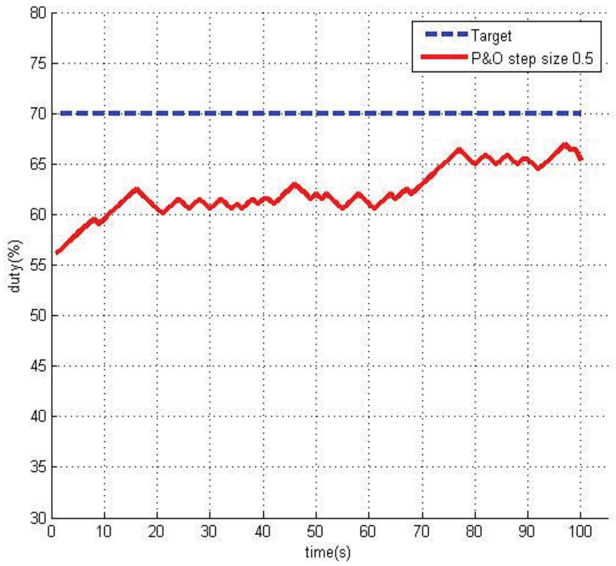
Fig. 10 Experiment of (a) MLPNN (b) P&O output duty cycle at wind speed 6 m/s

TABLE I
COMPARISON OF DUTY CYCLE

| Wind speed(m/s) | Output duty cycle (%) | | | Error (%) | |
|---|---|---|---|---|---|
| | MLPNN | Target | P&O | MLPNN | P&O |
| 5 | 49.98 | 50 | 46.88 | 0.04 | 6.24 |
| 6 | 55.40 | 55 | 44.95 | 0.72 | 10.1 |
| 8.3 | 68 | 70 | 63.86 | 2.85 | 8.77 |




(a)



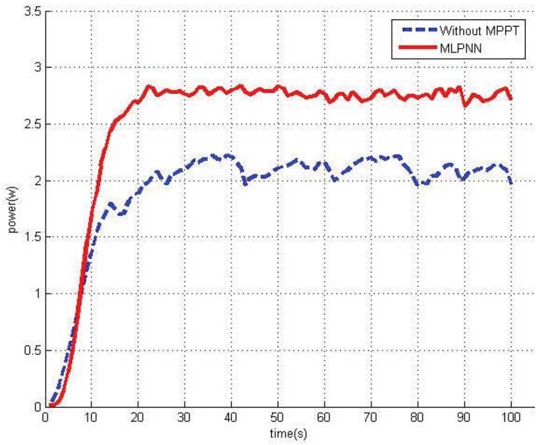

(b)

Fig. 11 Experiment of (a) MLPNN (b) P&O output duty cycle at wind speed 8.3 m/s

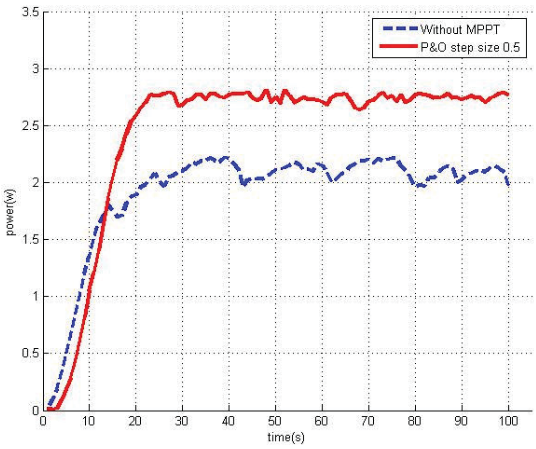
Fig. 9 represents the comparison of duty cycle between maximum power tracking with (at wind speed 5 m/s) (a) MLPNN and (b) P&O. Targeted duty cycle at maximum power (blue dash line) is 50 percent. From Fig. 9 (a), Maximum power tracking by MLPNN (red solid line) provides 49.98 percent duty cycle. From Fig. 9 (b) Maximum power tracking by mean of P&O step size 0.5% (red solid line) provides 46.88 percent duty cycle .

Fig. 10 represents the comparison of duty cycle between MLPNN and P&O at wind speed 6m/s .Targeted duty cycle at maximum power (blue dash line) is 55 percent. From Fig. 10 (a) Maximum power tracking by MLPNN (red solid line) provides 55.40 percent duty cycle. From Fig. 10 (b) Maximum power tracking by mean of P&O step size 0.5% (red solid line) provides 44.95 percent duty cycle

Fig. 11represents the comparison of duty cycle between MLPNN and P&O at wind speed 8.3m/s .Targeted duty cycle at maximum power (red solid line) is 70 percent. From Fig. 11 (a) Maximum power tracking by MLPNN (red solid line) provides 68 percent duty cycle. From Fig. 11 (b) Maximum power tracking by mean of P&O step size 0.5% (red solid line) provides 63.86 percent duty cycle. The experimental results are recorded in Table I.




(a)

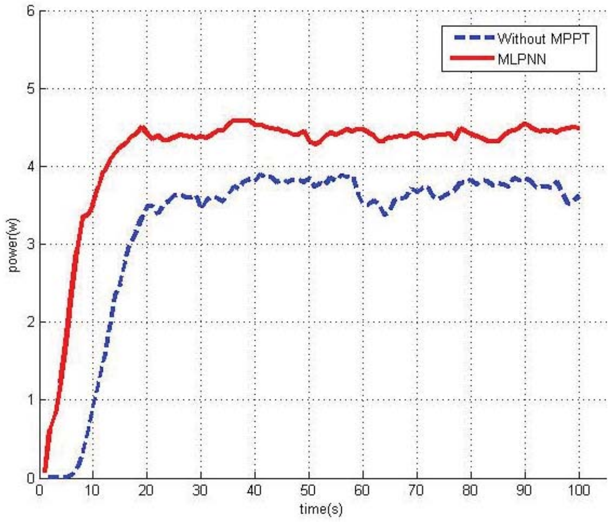



(b)

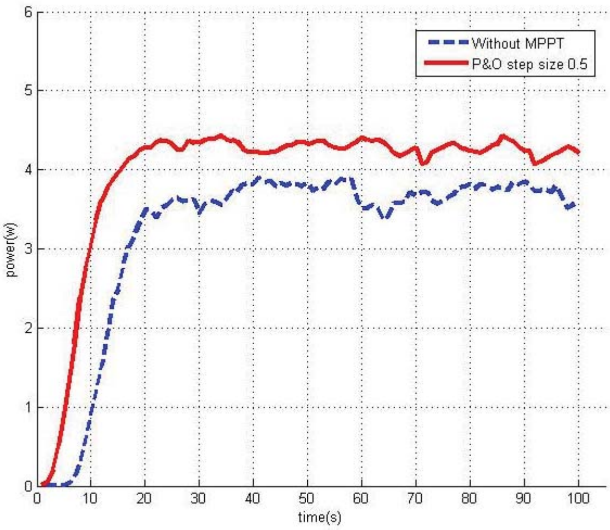
Fig. 12 Experiment of (a) MLPNN (b) P&O output power at wind speed 5 m/s

Fig. 12 represents the comparison of obtained power with and without the use of maximum power tracking. Fig. 12 at wind speed 5m/sec, obtained power without maximum power point tracking is equal to 2.1 watt. From Fig. 12 (a) maximum power tracking by MLPNN (red solid line), the power is 2.75 watt. From Fig. 12 (b) maximum power tracking by P&O at step size 0.5% (red solid line), the power is 2.74 watt.

Fig. 13 represents the comparison of obtained power with and without the use of maximum power tracking. Fig. 13 (a) at wind speed 6 m/sec, obtained power without maximum power point tracking is equal to 3.42 watt. From Fig. 13 (a) maximum power tracking by MLPNN (red solid line,( the power is 4.41 watt. From Fig. 12 (b) maximum power tracking by P&O at step size 0.5% (red solid line), the power is 4.27 watt.




(a)

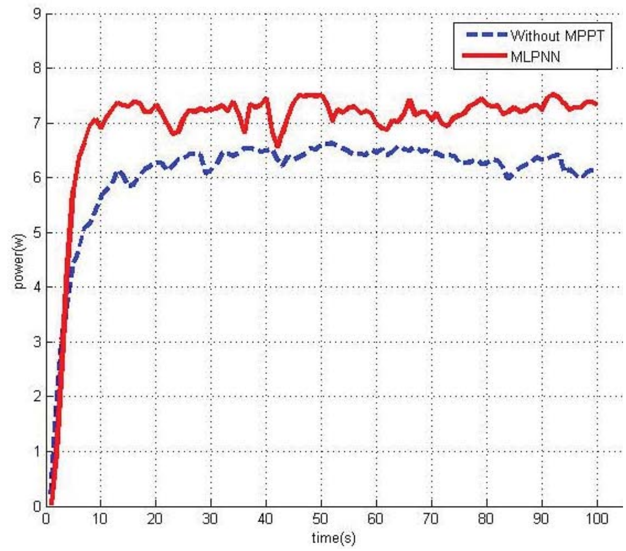



(b)

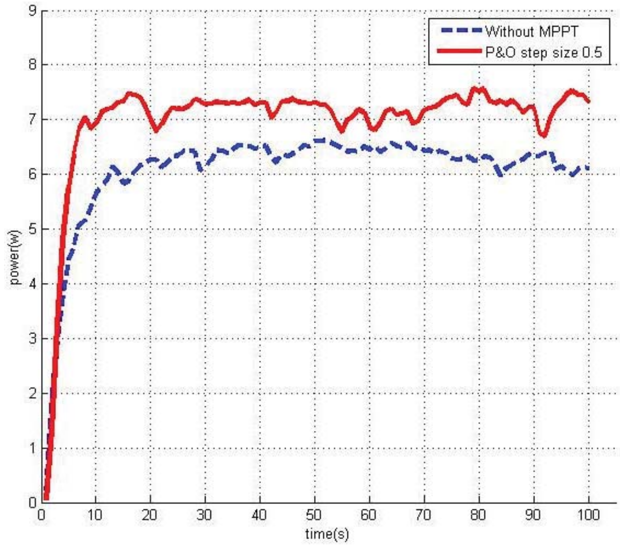
Fig. 13 Experiment of (a) MLPNN (b) P&O output power at wind speed 6 m/s

Fig. 14 represents the comparison of obtained power with and without the use of maximum power tracking. Fig. 14 at wind speed 8.3 m/sec, obtained power without maximum power point tracking is equal to 6.18 watt. From Fig. 14 (a) maximum power tracking by MLPNN (red solid line), the power is 7.23 watt. From Fig. 14 (b) maximum power tracking by P&O at step size 0.5% (red solid line), the power is 7.20 watt. The output power from generator corresponding wind speed (5,6 and 8.3 m/s) are recorded in Table II where mean square absolute error indicates the error between output and expected output power.

As shown in Figs. 12-14 maximum power tracking by MLPN, it can be seen that the fluctuation of power is less, since duty cycle from control system is less fluctuate. This is different from P&O, which fluctuation of power is higher, since duty cycle from control system directly affects the mechanical system of small wind turbine. Thus, obtained power is fluctuate leading to errors in duty cycle.




(a)




(b)

Fig. 14 Experiment of (a) MLPNN (b) P&O output power at wind speed 8.3 m/s

TABLE II
COMPARISON OF OUTPUT POWER

| Wind speed(m/s) | Output power(w) | | | | Error(%) | |
|---|---|---|---|---|---|---|
| | MLPNN | Target | P&O | Without MPPT | MLPNN | P&O |
| 5 | 2.75 | 2.81 | 2.74 | 2.1 | 2.13 | 2.49 |
| 6 | 4.41 | 4.53 | 4.27 | 3.42 | 2.64 | 5.74 |
| 8.3 | 7.23 | 7.57 | 7.20 | 6.18 | 4.49 | 4.88 |

According to Figs. 9-11 Maximum power tracking by MLPNN at 0-13 second, obtained duty cycle is quite different from targeted duty cycle ,because rate of change in power and voltage is too different from training data ,thus overfitting was made in the training of MLPNN. For P&O step size 0.5%, it is appropriated step size for this application. Although this step size improves it reduces the convergence speed to track target.

In Tables I and II, the comparison results are shown. The results show that the proposed Maximum power point tracking using MLPNN is supereminent.

## V. CONCLUSION

This article proposes the maximum power point tracking without mechanical sensor using MLPNN. The control system with the approach can predicts duty cycle. For achieving the maximum power, MLPNN model plays a role in generate and controlling the optimal duty cycle. The experimental results show that the proposed approach can obtain better the optimal duty cycle and maximum power estimation than P&O algorithm. In summary, MLPNN model without using mechanical sensor not only reduces system cost but also it can optimize output power for wind energy conversion system.

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