Sakon Nakhon Rajabhat University
Journal of Science and Technology
Journal home page: snrujst.snru.ac.th

An estimation of a rated motor for a multi-purpose shredder machine

Nattachai Pothi*

Department of Production Engineering Technology, Faculty of Industry Technology, Loei Rajabhat University, 234 Moo 11, Loei-Chiangkan Road, Mueang District, Loei, 42000, Thailand

* **Corresponding Author**: nattachai_me@hotmail.com

Received: 24 June 2015; **Revised:** 1 September 2015; **Accepted:** 18 December 2015; **Available online:** 20 April 2016

Paper selected from Sakon Nakhon Rajabhat University - International Conference 2015 (SNRU-IC 2015)

DOI: 10.14456/snrujst.2016.23

Abstract

This article presents an estimation of a rated motor for a multi-purpose shredding machine employed for transforming twigs or weeds for agricultural purposes. A three-phase induction motor is used as a power source to substitute for a diesel engine which incurs higher operating costs. Also, a digital signal processing unit is used to determine torque and power during experiment which can be calculated from current signal and voltage. A motor speed is measured by different types of sensors. The experimental results show that the estimation of power consumption of the motor for a multi-purpose shredding machine based on this method provided similar values to the actual ones derived from torque sensors. Furthermore, this method is employed in order to determine whether power consumption of the motor is suitable for shredding each type of material, and being appropriate selection of rated power of the motor that can help prevent unnecessary loss of power.

Keywords: Power Consumption, Shredder Machine, Torque and Power of Motor

1. Introduction

At present, twigs, coconut or palm leaf stalks, or other waste raw materials from production operated by community enterprises and factories are processed in many ways for agricultural uses. This not only helps reduce storage space, but also transforms garbage into value added products for community enterprises or business operators. For instance, a vast number of coconut shells left from sweet coconut patties production run by the community enterprise in Chiang Khan District, Loei province are shredded before being sold at approximately 2.5 Baht per kg., as shown in Fig. 1. However, a high priced multi-purpose shredding machine, accompanying by current escalating prices of fuel oil, may not be economic for such the process, when taking into account the operating costs incurred by the above factors.

Currently, electric motors has played a crucial role in all types of industry as they contribute to a cost reduction of production and maintenance, not to mention their environmental friendliness and a lower price, as compared to a diesel engine. Industrial works, thus, have increasingly employed a 3-phase induction motor. This is due to its significant features: low price, easy maintenance, and durability, as compared to other types of motor [1, 2]. Moreover, if an electric motor with suitable rated power can be used as a substitute for a diesel engine installed in a multi-purpose shredding machine, processing costs of wasted raw materials, in terms of both diesel engine and fuel oil price, will reduce considerably. Thus, a method to effectively determine rated power of a motor to be substituted for a diesel engine is crucial.

(a) (b)

Fig. 1 (a) Coconut shells and (b) Multi-shredding machine employing a diesel engine

As a result, this research was carried out with the aim of presenting an estimation of a rated motor, drawn upon electric power theories [1, 3, 4]. The estimation focused on rated motor for a multi-purpose shredding machine employing an induction motor as a power source. Together with this, a digital processor was also used to measure load, and calculated from electric current signals, voltage signals, and motor speed through various types of sensors.

2. Materials and Methods

Theories and Conceptual Framework

An estimation of the rated power was based on calculation of electric current (I) and voltage (V) using a digital signal processing unit to measure torque and power of the motor with load, as shown in Fig. 2.

Estimation of power and torque of a motor

This research employed vector principles to determine a power factor, as shown in Fig. 3, to estimate torque and rated motor as a substitute for a high priced torque meter. The power factor, equal to cos(ϕ), can be determined from a phase difference (ϕ), an angle between voltage and electric current, expressed in eq. (1). Rated power (P) and torque (T) can be estimated through measuring alternating current signals and alternating current voltage signals, as expressed in eq. (2) and eq. (3) respectively.

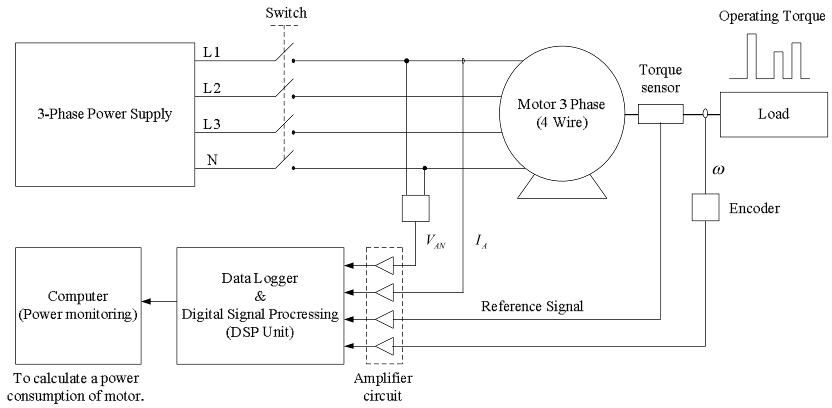

Fig. 2 Diagram of torque estimation

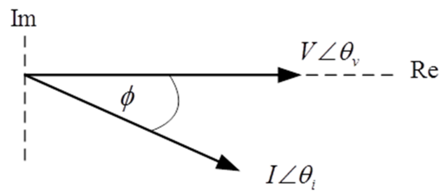

Fig. 3 Current vector and voltage vector

From $\mathrm{V} < \theta_v = \mathrm{I} < \theta_i \times \mathrm{Z} < \theta_L$

$$\phi = \theta_v - \theta_i \tag{1}$$

$$\mathrm{P} = 3 \cdot \mathrm{I_{rms}} \mathrm{V_{rms}} \cos\phi \tag{2}$$

$$\mathrm{T} = \frac{\mathrm{P}}{\omega} = \frac{3 \cdot \mathrm{I_{rms}} \mathrm{V_{rms}} \cos\phi}{\omega} \tag{3}$$

Calculation of the root mean square (rms) of electric current and of voltage was statistical quantitative measure of electric current and voltage, both alter constantly, and thus they can be determined using eq. (4) and eq. (5) as below.

$$\mathrm{I_{rms}} = \sqrt{\frac{1}{\mathrm{N}} \sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{I_i^2}} \tag{4}$$

$$\mathrm{V_{rms}} = \sqrt{\frac{1}{\mathrm{N}} \sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{V_i^2}} \tag{5}$$

where

N = a number of signals measured

$\mathrm{I_{rms}}$ = the root mean square of electric current

$\mathrm{V_{rms}}$ = the root mean square of voltage

Simulation results of three-phase induction motor drive

Fig. 4 as shown below illustrated the simulation results of the 3-phase induction motor driving system. The simulation considered a current waveform as well as voltage waveform in order to estimate a power factor for calculation of torque and motor power. This resulted in a method which can be substituted for a high priced torque meter. The simulation was conducted while driving constant load at 15 N·m.

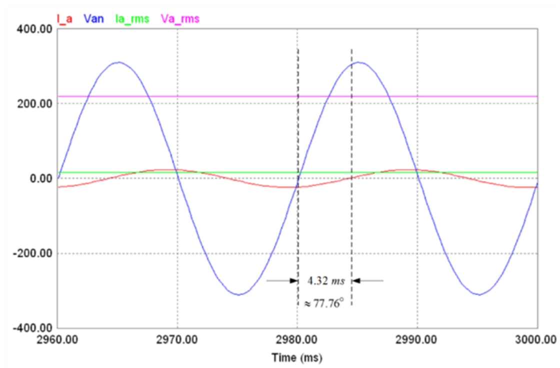

Fig. 4 Simulation results of power factor estimation derived from voltage and electric current waveforms

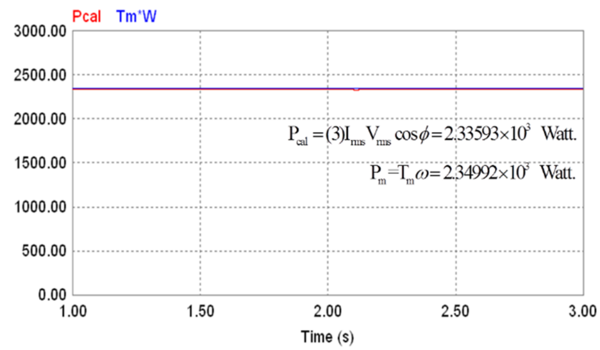

Fig. 5 Simulation results of motor power estimation (watt, W.)

From the simulation, the power factor was determined from a phase difference by measuring alternating current signals (I_a) and alternating current voltage signals (V_{an}). It was noticeable that while the motor was running and driving constant load (T_m) at 15 N·m, a phase difference between electric current and voltage was at 77.76°. This figure was then used for calculation of the power factor, the root mean square of electric current, the root mean square of voltage, and a motor speed were 0.212, 16.74 A., 219.39 V., and 156.66 radian per second, respectively. Then, the estimation of 3-phase electric power (P_{cal}) and torque (T_{cal}) were calculated using eq. (2) and eq. (3), and the simulation results are shown in Fig. 5 and Fig. 6, as shown below.

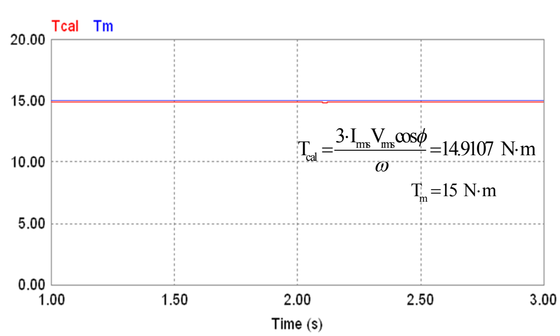

Fig. 6 Simulation results of torque estimation (N·m)

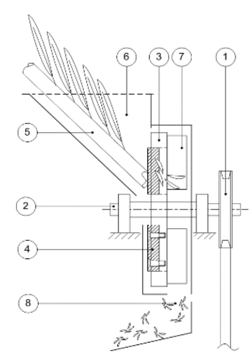

Fig. 7 Structure of the multi-purpose shredding machine

Fig. 5 demonstrated a comparison of electric power between that derived from estimation (P_{cal}), 2335.93 W. and that from the simulation (P_m), 2349.92 W. Also, torque (T_{cal}) was determined through a comparison between one derived from estimation, 14.9107 N·m, and one from the simulation (T_m) while driving constant load as shown in Fig. 6. From the simulation, the difference in results of power and torque obtained derived from the estimation was acceptable. The research, therefore, employed this method to conduct a test for estimation of power and torque of a motor for shredding coconut leaf stalks.

Diagram of a multi-purpose shredding machine

The structure and components of a multi-purpose shredding machine used for experiments in this research are shown in Fig. 7.

The components and the working principle of the shredder is as follows: an electric motor transfers power via a conveyor to drive pulley (No.1) which then creates rotation of an axel (No.2) fasted with a disc (No.3) attached with cutting blades (No.4). Then, twigs, coconut or palm leaf stalks, or other waste raw materials (No.5) are fed into a hopper (No.6) to be shred. After that a fan (No.7) will push shredded materials out through a discharge spout (No.8)

Test Results

The research conducted two experiments on power consumption of the motor for a multi-purpose shredder: one with no load and the other with load. Both experiments were conducted with coconut leaf stalks, as shown in Fig. 8.

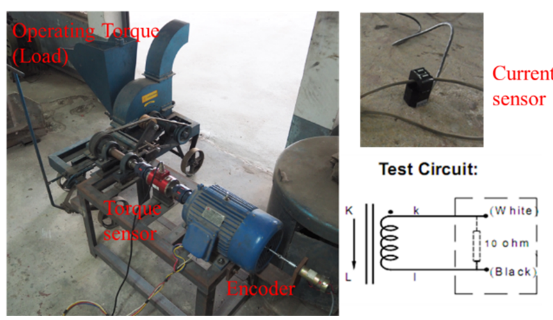

Fig. 8 Multi-purpose shredding machine used in experiments

Experimental results of electric power consumption of the motor (no -load)

This experiment employed an electrical motor to drive the mechanism of the shredder. In this experiment electric current and voltage were measured while coconut leaf stalks were not loaded into the machine. The results are shown in Fig. 9.

From the experiment, the results demonstrated that a power factor was 0.6613, while the root mean square of electric current and of voltage were 1.258 A. and 231 V., respectively. The power consumption was then calculated, and the result was 576.5 W. The electric power consumed to drive the mechanism of the multi-purpose shredder with no load.

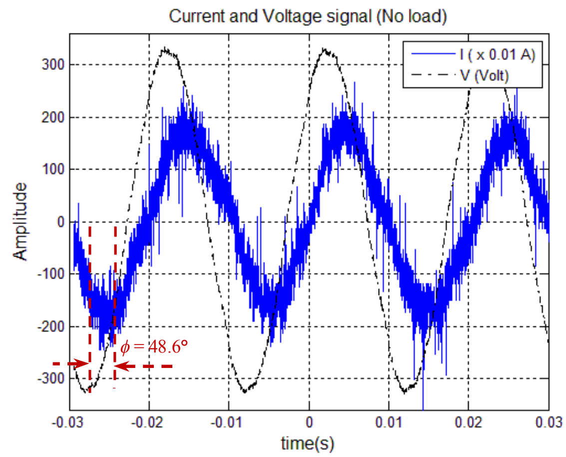

Fig. 9 Experimental results for estimation of electric current and voltage (no load)

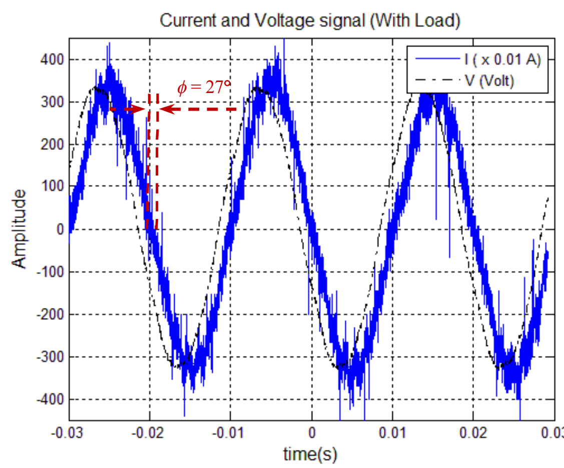

Fig. 10 Experimental results of estimation of electric power, torque, and electric current (with load)

Experimental results of power consumption of the motor with load (shredding coconut leaf stalks)

The multi-purpose shredder was tested while coconut leaf stalks were loaded for shredding to measure electric current and voltage in order for estimating power of the motor. The results are shown in Fig. 10. According to the experimental results, the power factor was 0.891, while the root mean square of electric current and voltage were 2.36 A. and 232 V., respectively, and the motor speed was at 146.6 radian per second. The 3-phase electric power suitable shredding coconut leaf stalks was 1463.5 W., where torque with load was 9.98 N•m.

3. Results and Discussion

An estimation of a rated motor in this research employed a 3-phase induction motor, with the purpose of substituting for a diesel engine which incurs higher operating costs, as a power source for a multi-purpose shredding machine. Power and torque of the motor can be measured from electric current signals, voltage signals, and a rotational speed using a various types of sensors instead of a higher priced torque sensor. From the simulation, the estimation of the rated motor with this approach can measure power and torque, and provide the results which are similar to actual values. Further, this method was employed for experiments to estimate the power and torque consumed for shredding coconut leaf stalks. The results of the experiments showed that the rated motor sufficiently suitable for shredding such material was at 1463.5 W. Moreover, this method can be employed to estimate the rated power and torque of the motor to be used for shredding a certain kind of material. Thus selection of the rated motor suitable for a particular material will help prevent unnecessary loss of power. In addition, a study by Natawut Ponsri [5] on fuel costs incurred by a range of diesel engines showed that Kubota ET 95 with 9.5 hp., employed as the power source for shredding waste agricultural materials, consumed fuel oil at a rate of 2.05 liters/hour. Based on an average diesel oil price at 28.69 Baht, surveyed by Shell Company of Thailand Limited between January and August, 2015, the fuel cost was 3528.60 Baht/60 hours/month. The experiment conducted with the power source generated by the motor for shredding coconut leaf stalks, showed that the maximum electric power used was 1463.5 watt, or 1.4635 unit/hour, and thus the electricity charge was 228.84 Baht/month, based on the progressive rate with the Ft of 0.4961 Baht/unit. As a result, the electric motor incurred less power consumption and operating costs than did the diesel engine.

4. Acknowledgements

The researcher would like to express sincere appreciation to Loei Rajabaht University for financial support from research funding of the year 2013, the Production Engineering Technology Program, Faculty of Industrial Technology, Loei Rajabhat University for providing tools and permission to grant location access for experiment in this research, and the Science Center, Loei Rajabaht University for a signal processing unit used in the research experiment.

5. References

[1] T. Juggrapong, Online Failure Detection of Electric Motors, J. KMUTNB. 22(2) (2012) 436-448.

[2] A.E. Fitzgerald, K.Jr. Charles, D.S. Umans, Electric Machinery, McGraw-Hill Companies, New York, 2003.

[3] M.E.H. Benbouzid, R. Beguenane, M. Dessoude, W. Hubbi, Energy Optimized Control Strategy for a Variable Input Voltage Three-Phase Induction Motor, Electric Machines and Drives Conference Record, IEEE International, Pages: MD2/5.1- MD2/5.3, 18-21 May 1997.

[4] P. Nattachai, An Estimation of Rated Motor for a Multi-Purpose Grinding Machine,The 27th ME-NETT Conference of the Mechanical Engineering Network of Thailand, Pattaya, 16-18 October 2013.

[5] N. Ponsri, A Comparative Study of Engine Performance on Modified Diesel Engine with Gasoline, LPG and Biogas Fuel, KKU Res J (GS). 11(1) (2011) 27-38.