Regression Test on the Rotational Speed between Two Loads as the Preparation for Braking System

B S R. Purwanti 1, F Yusivar 2, I Garniwa M K 3
1 Student of Doctoral Program, University of Indonesia, Electrical Engineering Department
DTE-FTUI, INA
2, 3 University of Indonesia, Electrical Engineering Department, DTE-FTUI, INA

E-mail: bsrp_81@yahoo.co.id

Abstract. This paper is preparing the mathematical model of braking control, continuously of determination the error (e), delta error (de) of speed reduction [9]. Load-1 and Load-2 are driven by an electric motor located on the same shaft. Both loads are driven clockwise (CW), counter clockwise (CCW) by an asynchronous three-phase motor (M3). The mass of each load is also differentiated to simulate slip phenomena. Rotational speed of M3 is equal to Load-1, detected by Sensor-1, while speed rotation of Load-2 is detected by Sensor-2. The rotation for Load-1 and Load-2 can be adjusted on several position H j (j = 1, 2, 3). Once Load-1 and Load-2 reach a constant speed, current source will be disconnected. Speed reduction from (ω±1475 rpm) to stagnant (ω=0 rpm) on Load-1 and Load-2 is considered time function. Data collected from both load (ω(t)) known as e, de; on each position of H j. It uses covariance analysis to make sure that both loads are concurrent with each other against time difference. The objective of this research is to determine slip phenomena of speed reduction of each load. The expectations are to generate smoother braking and minimize the time needed when implemented with ANFIS.

1. Introduction
Braking is the process of reducing speed, usually performed in an attempt to avoid collision/crash. Reliability is critical in braking to avoid deadly collision and reducing incidents between vehicles. This research is aimed to develop a braking system that is appropriate to the customer’s demand and need. The implementations of braking system or speed reduction can be found everywhere, for example in industry, in the street, in buildings, even at home. Belt Conveyor (industries), elevator, escalator (buildings), blender, mixer, vacuum cleaner (household appliances), and many others. Reducing speed from high to naught (stagnant) by counteracting the momentum/force resulted from translation. Implementation of braking system has been studied by various methods. Simulation and testing of hydraulic antiskid braking system based Adhesion Creep Behaviour [1] has been implemented on a modern railway. Zuo Jianyong used the pneumatic method, sub model showed that the output data antiskid braking is graded; it is recommended to use Fuzzy Control Method.

Land vehicles demand a comfortable ride with reliable braking system, assuring safety from any accidents. The braking system has to adapt with various load/weight changes. The response time, velocity, and acceleration, which are generated by external loads cause waste in energy usage. In addition to external disturbances on the system, the characteristics, and behaviour of dynamic braking,
the energy savings can also be traced. This research will study the slip between two loads due to several load masses. The system is designed to get the slip value between two Loads due to differences in rotational speed. The results are statistically tested for reliability.

Antiskid braking concept known as ABS (Antilock Breaking System) is very interesting and unique. ABS system requires precise control and effectiveness in order to obtain braking perfection. Fuzzy intelligent control by Takagi-Sugeno in ABS system, minimize slip by regulating current-torque. FLC is claimed to optimize linguistic switching, thus generating better control. A good control system will include various aspects [2], such as energy conversion and energy balance. Yimin G, made a statement about energy conversion from electrical into kinetic energy to drive the railway. Reliable braking system ensures safety, comfort, and ultimately has smoother operation [3]. A smooth braking action designed to enhance passenger’s comfort can be achieved by minimizing slip due to dynamic force and friction between surfaces [4]. With bigger loads, the higher the speed, mean higher moment of inertia.

Driving force produced by Three Phases Induction Motor Asynhronous. Translational velocity is affected by the load (the car and its contents) and the coefficient of friction between the wheel-rail. Movers "railway" is a Induction Motor or Three Phase. Formed a separate cage induction motor with a local vector field (d, q) is [5, 6, 7].

Given the speed is influenced by driving force (electric motors), speed reduction can be done with disconnecting the current. This study will simulate slip between two rotating objects, Load-1 and Load-2. Both Loads are connected by a transmission and rotated by an Asynchronous Three-Phase Motor. The short-term objective of this research is to determine the differences in rotational speed between two Loads due power disruption. Slip value is very small but very important, ultimately to ensure the safety from any accidents. Statistical test is done to understand the ratio and the effect of rotational speed on Load-1 and Load-2. The difference in rotational speed between Load-1 and Load-2 caused slip in three different transition positions. This research will serve as the preparation for ANFIS based braking system for three-phase motor. The system will test the value of rotational speed covariant with two Loads. The long-term goal is to reduce the slip value due to weight (loading) to minimum.

2. Speed Reduction between Two Load for the Phenomenon of Slip

Speed reduction was smooth in the railway stabilize the braking system; the realization did not occur buffeting. Pounding in the braking process perceived as an inconvenience passengers. Significant speed reduction due to braking in the form of data on the curve visualization rail with wheel railway carriages loaded and its contents. Researcher [7] has said that the wheel speed will tend to be lower than the vehicle speed. The other opinion in [8] purpose a gain scheduling control structure base on slip and maximum frictions are not directly measurable but can estimated.

2.1. The Slip from difference of speed

The road adhesion coefficient (or coefficient of friction) [7] is the proportion of the road friction force to the normal load of the vehicle, and it is a nonlinear function of some physical variables; including wheel slip (1).

\[
V_s = \frac{V - \omega r}{V}
\]  

(1)

Where \( V_s \) is the slip value, \( r \) is the radius of wheel, \( \omega \) is the rotational speed of the wheel, and \( V \) is the longitudinal speed of the vehicle. Form the equation (1), \( V_{slide} \) is the speed slip and called the negative slip (2).

\[
V_{slide} = \omega r - V
\]

(2)

In general, equation (2) we can be stated as equation (3):
\[ \Delta v_{\text{slide}} = \Delta (\omega r - v) \]  

Researcher [7] has said that the wheel speed will tend to be lower than the vehicle speed. The other opinion in [8] purpose a gain scheduling control structure base on slip and maximum frictions are not directly measurable but can estimated.

2.2. Illustration of Railway
Redcing slip promoted smoother braking and improves railway safety and passenger’s comfort. The research will be conducted in four stages [9], currently this paper only covered the first phase (figure 1) shown the phenomenon of slip.

![Illustration of Railway](image1)

**Figure 1** Illustration of Railway [9]
Translational speed is affected by load (weight) and friction-force, where \( \mu_a \) coefficient of friction between the wheel and the track (rail).
The components of Braking Motion are:
- The wheels spin with particular thrust affects translational speed.
- Thrust is generated by Asynchronous Three-phase Induction Motor.

Real time observation for railway’s braking system is difficult to be done. Braking system simulator is required in order to obtain the phenomenon (figure 2). All wheels are driven by M3 with with certain torque (force) to achieve certain speed.

2.3. The Railway Illustration

![Block Diagram System](image2)

**Figure 2** Block Diagram System [9]
Actual design was activated so that rotational speed of both loads could be measured using optocoupler sensors. Optocoupler sensors determined rotational speed of Load-1 and Load-2. Once it reached a steady speed, current source was disconnected. The disconnection reduced the speed of the three-phase induction motor, which also reduced rotational speed of Load-1 and Load-2. The rotational speed of Load-1 and Load-2 were conditioned of in third positions different of clutch \( H_j \) with \( j = 1, 2, 3 \). The clutch positions \( H_j \) were conducted in clock wise (CW) and counter clock wise (CCW). Position of \( H_j \) conducted from \( G_4 \), it is part of the
fourth position of $G_i$ ($i=1, 2, 3, 4$). The $e$ values and $de$ values in all positions ($G_i$, $i=1, 2, 3, 4$) are minimum $0.00002 \leftrightarrow 0$, maximum $0.987 \leftrightarrow 1$ and applicable in CW and CCW [9].

2.4. Identity and Design of Simulation
Rotational speed of both loads can be determined (see figure 1), Load-1 and Load-2 are driven by three phase induction motor. In the event of braking, rotational Load-1 affects rotational speed Load-2 and vice versa. Illustration model for study any slips between two Loads (see figure 1) and Block Diagram in (see figure 2) is used to realize braking system with ANFIS based ICS. ANFIS requires $e$ and $de$ in interval $[0, 1]$, thus this research is aimed to determine the value of $e$ and $de$, similar to input-output on Fuzzy Control System.

Two optocoupler speed sensors (see figure 3a, figure 3b) are needed to detect the rotational speed of Load-1, Three-phase induction motor, and Load 2. Each sensor has acrylic-disc with 36 holes as trigger (see figure 3b). The value of $e$ and $de$ are very influential to the braking process with ICS. ANFIS based ICS is expected to prevent slip and buffeting occurred during braking process. Slip phenomenon generated by comparing the rotational speed of the two Loads as the result of current termination. Load-1, consists of solid cylinders. The transmission acts as a transition block, placed between Three-phase induction motor and Load-2, to allow the researcher change the clutch position. Three-phase induction motor is positioned on the same axle as Load-1. The connecting coupler for Load 2 is located on the different axle. Mass of Load 2 is designed to be adjustable, allowing the addition of weight to Load-2. Load 2 acts as an absorber for mechanical/electrical load.

3. Braking System Based on Intelligent Control
This research studies the mathematical model of braking system in actual plant (see figure 3). Actual plant is set of tools designed as braking system simulator on railway. Asynchronous Three-Phase Induction Motor drives Load-1 and Load 2. The objective of this study is to observe the speed reduction of Load-1 and Load 2 in Clock Wise (CW) and Counter Clock Wise (CCW). Then data between both Loads will be analyzed to estimate the effect of initial velocity against braking.
3.1. Methodologies
Smoother speed reduction in railway will stabilize braking system; the realization would be the absence of buffeting. Pounding in the braking process is considered as disturbance for the passengers. Especially in case of significant speed reduction due to braking in the form of graded data on the curve (mathematically). A model is made to simulate the rail-track and the wheels. Speed difference between the two Loads, the existence of friction force (see figure1), will generate slip.

3.2. Data Collection and Sampling and Result of Experiment

| Table 1 Data Sample of CW Rotation Speed |
|----------------------------------------|
| Load:       | CW1 | CW2 | CW3 |
| Second of:  | 1   | 2   | 1   | 2   | 1   | 2   |
| 1           | 0   | 0   | 0   | 0   | 0   | 0   |
| 2           | 0   | 0   | 0   | 0   | 0   | 0   |
| 3           | 10  | 8   | 191 | 190 | 16  | 16  |
| 4           | 845 | 845 | 1236| 1236| 860 | 860 |
| 5           | 1451| 1451| 1475| 1475| 1461| 1461|
| Some data have been hidden |
| 53          | 216 | 216 | 1   | 1   | 148 | 0   |
| 54          | 165 | 163 | 0   | 0   | 101 | 0   |
| 55          | 116 | 115 | 0   | 0   | 50  | 0   |
| 56          | 71  | 73  | 0   | 0   | 6   | 0   |

| Table 2 Data Sample of CCW Rotation Speed |
|------------------------------------------|
| Load:         | CW1 | CW2 | CW3 |
| Second of:    | 1   | 2   | 1   | 2   | 1   | 2   |
| 1             | 0   | 0   | 0   | 0   | 0   | 0   |
| 2             | 0   | 0   | 0   | 0   | 0   | 0   |
| 3             | 0   | 0   | 113 | 120 | 618 | 618 |
| 4             | 243 | 243 | 1143| 1143| 1431| 1433|
| 5             | 1285| 1285| 1475| 1475| 1476| 1476|
| Some data have been hidden |
| 58            | 158 | 158 | 6   | 0   | 941 | 81  |
| 59            | 110 | 111 | 0   | 0   | 878 | 55  |
| 60            | 66  | 68  | 0   | 0   | 815 | 35  |
| 61            | 31  | 41  | 0   | 0   | 751 | 21  |

The experimental results of the motor rotation speed from 0 to ± 1476 rpm (acceleration) and toward zero velocity (deceleration). Some sample data acceleration and load deceleration round two (see table 1, table 2). Braking process occur a reduction of speed, namely the speed of 1475 rpm ± towards zero, identical to deceleration events. Data selected special deceleration events at three positions transitions Gj, with j = 1, 2, 3, as the braking process variables.
3.3. Speed Rotation of the CW and CCW

The experimental results are to group become CW rotation (see figure 3, figure 4, and figure 5) and CCW rotation (see figure 6, figure 7, and figure 8). Regression equations for entire round of Load 1 and Load 2 Clock Wise (CW) rotation speed.

3.4. Regression of CW and CCW Speed Rotation
Regression Equations of Load 1, Load 2 with three conditions are CW-CCW1, CW-CCW2, and CW-CCW3 (see table 3). In accordance with the objectives research, analysis and testing of the data discussed specifically for section 3. 4. Processing data using with regression test to examine the relationship whether or not the correction of the measured variables, namely Load-1 to Load-2 with CW1, CW2, CW3 (see table 3).
Figure 3, figure 6 there was no difference, almost harmonious whole. Rated slip between Load-1 and Load-2, CW and CCW from zero. Figure 4 there was a slight difference, and different overall, rated slip between Load-1 and Load-2 small slip value CW and CCW large enough. Figure 5, figure 8 there was different overall, rated slip Load-1 and Load-2 large CW and CCW, value of regression (R) Load-1, Load-2 for CW and CCW ≥ 90%.

Table 3 Regression Equation of CW and CCW Speed Rotation Load 1 and Load 2

| Position of Transition | Regression and R | Load 1                                      | Load 2                                      |
|------------------------|-----------------|---------------------------------------------|---------------------------------------------|
| Clock Wise-1           |                 | \( y = -58.55x + 3450, R = 0.957 \)         | \( y = -58.49x + 3426, R = 0.958 \)         |
| Clock Wise 2           |                 | \( y = -54.64x + 2922, R = 0.960 \)         | \( y = -53.26x + 2853, R = 0.964 \)         |
| Clock Wise 3           |                 | \( y = -41.97x + 2451, R = 0.957 \)         | \( y = -28.44x + 1361, R = 0.637 \)         |
| Counter Clock Wise-1   |                 | \( y = -61.90x + 3824, R = 0.956 \)         | \( y = -61.95x + 3828, R = 0.955 \)         |
| Counter Clock Wise-2   |                 | \( y = -41.81x + 2630, R = 0.906 \)         | \( y = -45.17x + 2378, R = 0.897 \)         |
| Counter Clock Wise-3   |                 | \( y = -50.12x + 3798, R = 0.969 \)         | \( y = -39.92x + 2713, R = 0.757 \)         |

4. Conclusion
The slip phenomenon was founded in the CW and CCW rotation of the reduction speed, and then could be continued to experiment with to looking for the slip values. The deceleration system, Load-2 as the variable dependent to the power of Load-1 in CCW model, does not influence to the CW model.

5. References
[1]. Yu Zhang; Zhenhua Jiang; Xunwei Yu. Indirect Field-Oriented Control of Induction Machines Based on Synergetic Control Theory 2008 Proc. of the IEEE Int. Conf. on Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century 20-4 1-7
[2]. Yimin G. et al 2003 Electric Motor Flywheel/Characterization of Generator of Hybrid Vehicles. Proc. of the IEEE 58th Vehicular Technology Conference, IEEE Explore Press USA DOI: 10.1109/VETECF1286291 3321-25
[3]. Purwanti, B S R, Feri Y, Iwa G. 2011. COG FLC Implementation for Input-Output Value Calculation. Proc. of the 5th Int. Conf. Math and Natural Sci. (ICMNS 2010) ITB 1011-18
[4]. Yesim Oniz , Okyay Kaynak 2009 A Dynamic Method to Forecast the Wheel Slip for Antilock Braking System and Its Experimental Evaluation IEEE Transactions On Systems, Man, And Cybernetics—Part B: Cybernetics 39-2 551-60
[5]. Kais Jamoussi, M. Ouali., Haseen Charradi 2007 A Sliding Mode Speed Control of on Induction Motor. American J of Appl. Sci. 12-4 987-94
[6]. M. Ouali, M. B. A. Kamaoun 1997 Field Oriented Control Induction Machine and Control by Sliding Mode, Simulation Practice and Theory 5 121-36
[7]. A. Mansouri, M. Chenafa, A. Bouhenna, E. Efttien, 2004, Powerful Non Linier with Field Oriented Control of an Induction Motor Int. J. Appl. Math. Comp. Sci. 2-14 229-32
[8]. Solyom, S. and Rantzzer,A 2003 ABS A Design Model and Control Structure in Rolf Johansson and Anders Rantzzer (Ed). Nonlinear and Hybrid Control System
[9]. Purwanti, B. S. R. Yusivar, F. Garniwa, I. M. K. 2012. Determination the Error and Delta Error for Braking Control System of Three Phases Motor Proc. Int. Con. on Math. Stat and Its Applications (ICMSA) 2012, ITS AM3 29-38.