Optimization of Alternating Current Power Flow Analysis in Railway Electrical System: A Brief Review

Santi Triwijaya[1(✉)], Andri Pradipta[1], and Trisna Wati[2]

[1] Indonesian Railway Polytechnic, Madiun 63132, Indonesia
{santi,andri}@ppi.ac.id
[2] Institut Teknologi Adhi Tama Surabaya, Surabaya 60117, Indonesia
trisnaw@itats.ac.id

Abstract. The technical requirements for minimum rail gauge and platform clearance at station emplacements are one of the important aspects to support railway operations, given the large number of train accidents caused by rail gauge and platform clearance that are not following applicable regulatory standards. This IoT-based Gauge Hybrid platform is used to make it easier to test rail gauge and platform clearance on station emplacements. The process of testing the gauge of the rail and platform clearance in this study was carried out by utilizing a rotary encoder to detect the dilation and narrowing of the width of the railway track. The VL53l1X lidar sensor detects the distance and height of the platform clearance on the station emplacement. The platform gauge hybrid control system is to use an Arduino Uno microcontroller that is connected to a web application on a laptop by utilizing the Wemos D1 Mini for sending data from sensor readings. Detection of path widening through the rotary encoder is by integrating linear block bearings with a spring system. The Platform Gauge Hybrid is designed to be operated on a 1067 wide R54 rail with a measurement accuracy rate of 99.29%.

Keywords: Railway · Load flow · Step Descent Algorithm · optimalisation

1 Introduction

The electric rail train or KRL is one of the public's favorite modes of transportation. KRL has several advantages, including being able to carry large numbers of passengers large, has a strategic location of the station in the center of community activities and avoid congestion problems that can occur when using other means of transportation such as buses and cars. Railway electrification system (RES) supplied by DC and AC voltage. The standard DC voltages between 600 V to 3000 V. The standard AC Voltages between 11 kV and 25 kV. The frequency is 25,50 and 60 Hz. With these several advantages and growth very fast area, causing the number of KRL passengers to experience increase every year, so the number of KRL fleets operating must also be added. This increase in the number of KRL must be balanced with the addition of power capacity traction substation that serves to supply electric power to KRL In supplying electrical power, we

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need to analyze the power flow first. By analyzing the power flow, we can determine the capacity of the circuit breaker, the size of the cable cross-section, the voltage drop, and power losses. Calculation of power flow in electric trains is very complex because of the type of train, long routes, power consumption, delivery schedules and track systems and electricity supply [1]. One of the methods used to calculate power flow in a distribution system is backward forward reverse [2]. Calculation of power flow in electric rail train needs to consider several factors. Probabilistic load flow calculation using simple simulation with AC supply using autotransformer system. The Monte Carlo simulation method is used in calculating the probabilistic load. This is done because the position of the train is a primary random variable, the probability distribution function of the position of the train is determined before being used as a further random sample in the calculation of the load flow [3]. The DC electric distribution system has been integrated into the existing industrial power system. One example of an ac/dc or multi-system electrical system, is an electric train. Electric trains can run on either AC or DC overhead power. In this system, the upstream electricity uses AC power and DC motor traction. The electric current flows through the upstream electricity, passes through the CB then goes to the transformer. Transformers are needed because usually overhead electricity uses high voltage electricity so that the losses generated when distribution are small. Usually use 25 kVA. Electricity enters the transformer and then the voltage is lowered. After that the electricity goes to the AC-DC Converter (rectifier), from the AC power rectifier it is converted to DC. After that, DC electricity will enter the DC-AC Motor Converter (VVVF) which then supplies the traction motor and enters the DC-AC Auxiliary Converter (SIV) which then supplies the auxiliary load. The current flow is the same, that is, electricity then returns to the supply substation via the rail. Whereas in the AC overflow electrical system that uses a DC motor, it is almost the same. The difference is only DC – AC Motor Converter is changed to DC-DC Converter. The converter can also supply an induction motor driven by an inverter burden. The main tools used in designing this system are load flow program. Load flow analysis technique developed to date which is suitable for the analysis of ac/dc power systems it is always assumed that direct current the commutation resistance product (I_{drc}) is small compared to ac system voltage [4, 5]. Load Flow Calculation Under 3 phase operation and balanced load conditions. In general, load flow studies are carried out for power system planning, operation and control. Load flow also used for contingency analysis, blackout security, as well as for shipping and alphabet. The problem of load flow has received more attention than all other power system problems. However, the classical power flow load model the voltage function has been used in the production class program for the study of load flow for many years. The effect of voltage depends on load on performance. Study the effect of voltage depends load on the performance of the 5-bus system. This study shows that the load flow as the solution obtained by the Newton-Raphson method for voltage-sensitive constant current and constant impedance load is more accurate than constant power. The load flow can be calculated for each case of system data and the final value of the voltage [6–8].

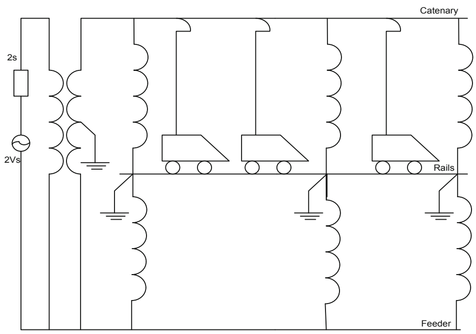

Fig. 1. AT fees system

2 Load Flow Analysis

Load flow analysis needs to consider supply and system layout, and loading. On AC system trains, transformer substations are located along the track. Meanwhile, direct connection of secondary transformer to catenaries and rails is not uncommon for AC trains. The booster transformer (BT) or autotransformer (AT) is placed in the feeding section. To improve the efficiency of AC and rail transmission systems, reduce rail-to-ground, earth voltage and current and suppress electromagnetic interference. Figure 1 shows a typical AT feeding arrangement [9, 10].

The drag force on the load depends on the speed and mode of operation of the train operating in turns, which of course is determined by the characteristics of the traction equipment, train weight, aerodynamics, track geometry and train control strategy, and so on. So, power demand can vary significantly over a short period of time. Calculation of power flow in a conventional power system that is different from the rail supply system. The number of trains is also important to take into account as they may travel at different speeds, thus having different effects on the supply system. The value of the separation between trains needs to be considered and must follow the schedule or train delivery schedule [11, 12],

Load condition is one of the parameters in power flow analysis. At the load of conventional power systems, the value of MVA is constant. Traction equipment characteristic values such as parameters, traction power, efficiency, and power factor to speed, both real power and reactive power can be calculated directly from the train speed. The position of the train is used as the main parameter in calculating the load flow using the Monte Carlo method [3, 13].

One method for calculating the probabilistic load flow is the Monte Carlo. Where input parameters are obtained from pseudorandom values and large values from load flow cases which are processed probabilistically. The probability density function of the power and voltage at the selected point on the electricity network is the final result. This method is very flexible with many possibilities of success. However, it requires substantial computation. To reduce the number of computations, we can assume a simplified distribution of flow computations. The Monte Carlo method is adopted for a faster and

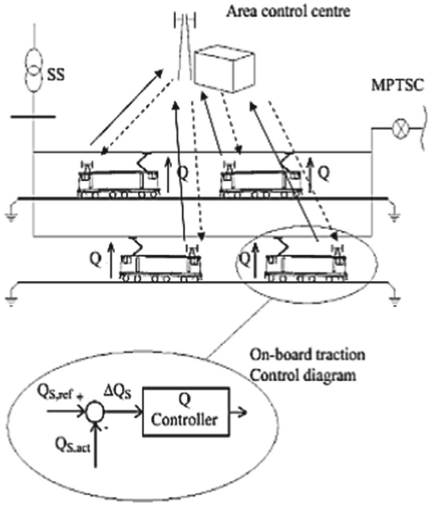

Fig. 2. Area Control system of AC locomotive powers

more reliable calculation to achieve a probabilistic density function that needs to be determined to match it [14].

3 Optimal AC Railway Power Flow

The Impedance in the overhead catenary feeding system and the load on the train causes the AC train power supply to be not optimal. For example, voltage drop across feeder lines, current harmonics caused by power full trains operating under poor power factor conditions (usually 0.5–0.85). Although some electric trains can operate under the pantograph voltage range (16.5 kV – 27 kV, which is specified for normal operation in a 25 kV system), traction performance and power supply conditions should be better at nominal voltage. In general, it operates at low voltage levels, thereby causing a large amount of reactive power from the supply. This can cause the system to be overloaded with reactive power, thus the operation of the power supply is not safe in the feeding system. Thus, compensating for excessive reactive power consumption by installing an external reactive power source has become one of the possible solutions for power supply instability. The main objective of this paper is to introduce and illustrate a new alternative method of reactive power compensation. However, for comparison, standard track-side reactive power compensation techniques are reviewed and discussed [15, 16].

Reactive power in the control area can improve system performance. One such control system can be used in Fig. 2. on the coordinating board in such a way as to achieve total performance for the substation system on the overhead supply line and rail. Suitability of purpose reduces transmission loss or improves voltage profile. These goals are not actually independent. And both can be used as objective functions, then can be optimized with constraint variables such as reactive power on each train. Several things are assumed to implement this control system. For example, bidirectional between the

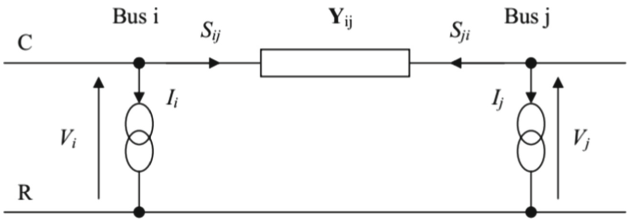

Fig. 3. Circuit representation of a feeder portion

carriage and the central control as shown in Fig. 2. The instantaneous values of the position and strength of the train are fed back to the central controller. Each central controller performs optimization [17], thus reactive power will be sent to each PWM locomotive and used as a reference signal to the loop controller. In this case it can be assumed as follows [1]:

1. Area control system for one feeding section is developed
2. Only steady-state operation is taken into account
3. High-frequency harmonics drawn by the all locomotives are neglected
4. Two-way wireless communication between any locomotive and the control center is available
5. All PWM locomotives are specially designed to supply a sufficient amount of reactive power as required by the central controller within certain reactive power limits.

Step Method for solving optimization problems

To get the power loss, it can be done by adjusting the reactive power of the controlled PWM locomotive which functions as a dynamic reactive power compensator. It is assumed that a given AC railway system contains N buses and M PWM locomotives. In addition, each PWM locomotive is capable of providing reactive power within the reactive power limit range. Thus, the system formulation can be expressed in the general form of an optimization problem as follows:

$$Minimize\ q^{min} \le q \le q^{max}\ \mathrm{f(q)} \tag{1}$$

where:

q: denotes the reactive power of the PWM locomotives.

q^{min}: denotes the lower bound of the PWM locomotive reactive powers.

q^{max}: denotes the upper bound of the PWM locomotive reactive powers.

f (q): denotes the total power losses.

the power losses caused by power flowing through feeder sub-section calculated. The first compute the complex conjugate of power flowing through a feeder sub-sections connected between bus i and bus j, S^*_{ij}, and similarly in the reverse direction, S^*_{ij}. Secondly, the power loss, P_{loss}, of any feeder sub-section is defined by the real part the summation of these two complex power as shown in Eq. (2)-(4) Fig. 3.

$$S^*_{ij} = Y_{ij} V^*_i \left(V_i - V_j\right) \tag{2}$$

$$S_{ji}^{*} = Y_{ij} V_{j}^{*} \left(V_{j} - V_{i} \right) \tag{3}$$

$$P_{Loss} = Re\left\{ S_{ij}^{*} + S_{ji}^{*} \right\} = Re\left\{ Y_{ij} \left(|V_{i}|^{2} + \left| V_{j} \right|^{2} - V_{i}^{*} V_{j} - V_{j}^{*} V_{i} \right) \right\} \tag{4}$$

Total of L feeder portions, and total power loss function, f(q), of the entire system shown as Eq. (5)

$$f(q) = \sum_{k=1}^{L} P_{Loss,k} \tag{5}$$

Method for solving optimization problems

The optimal solution for the centralized reactive power control problem, an appropriate method has to be chosen. Method of the Steepest Descent Algorithm (SDA) has been applied [18, 19]. The general form of an unconstrained optimization problem as follows:

$$Minimize x \in \Re^{n} \mathrm{f}(x) \tag{6}$$

where:

x: vector of control variables.

f(x): continuously differentiable objective function on bounded sets.

$\Re^{n}$: set of n-dimensional real numbers.

The simplest gradient search technique is SDA. It involves finding a minimum with the search direction defined by its gradient. Steps of this method following bellow:

Step 0: initialization. Given an initial $x_0 \in \Re^n$ and the counter i = 0.

Step 1: compute the search direction $p_I = -\nabla f(x_i)$, terminate if $\nabla f(x_i) < \varepsilon$.

Step 2: compute the step-length λ_i by solving the following sub problem

$$Minimize\, \lambda_i > 0 \qquad F(\lambda_i) = f(x_i + \lambda_i p_i) \tag{7}$$

Step 3: update the current solution $x_{I+1} = x_i + \lambda_i p_i$ and the counter i = i + 1

Step 4: repeat step 1.

Where,

p_i: the search direction.

λ_i: the step length.

ε: maximum error allowance of the objective function.

The step optimization problem solved for the reactive power commands to the PWM [20] locomotives in order to minimize the power loss function. In its application, the central computer will perform numerical calculations in real time based on the input data received from all locomotives providing power consumption. So to evaluate the real time control performance that will be applied from locomotive reactive powers, a multi-train simulator is used to simulate the movement of trains and the power according to consumption. This simulation is used to generate realistic real time (train position and power) as input signal to the locomotive control center, thereby testing the control system to be used. In general, the optimal control area can be shown in Fig. 4.

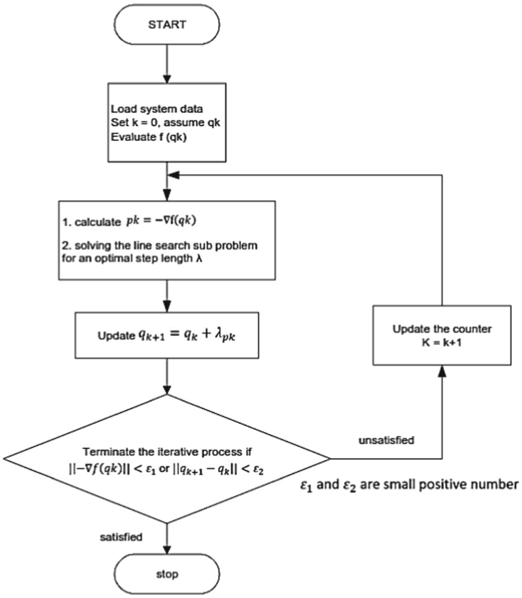

Fig. 4. Flowchart diagram for the AC railway power solution.

4 Summary

Even though the optimization load flow methods for electricity railway systems it still has specific features which can be explored. It is discussed about All moving loads in this chapter are assumed to be fixed in position. However, in the real world, the running trains change their position at every second. Hence, a full hour operation of train services is required to investigate the effectiveness of the optimal AC railway power flow control via the area control system. The simulation will be carried out in the next paper.

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