# Fault Impedance Calculation as Autotransformer Tab Change in Traction Power Supply System

Joorak Kim Moonseob Han Sang-Hoon Chang
Department of Electric Power Supply
Korea Railroad Research Institute
Uiwang City, Korea
jrkim@krri.re.kr

*Abstract*—**AC traction power supply system has adopted autotransformer (AT) feeding method. This system has an advantage as long feeding distance. However, the countermeasure for voltage drop should be considered, because load capacity grows larger and headway grows shorter in recent electric railway system. This paper proposes the improved system configuration to enhance voltage drop in ac railway system without additional power electronic device and investigates fault analysis as autotransformer tap change.**

***Keywords-electric power supply system; autotransformer; tap changer***

## I. INTRODUCTION

The method to be supplied electricity in electric railway system has two ways which are DC feeding and AC feeding method. And AC feeding method comprises approximately 60% globally. Korean interurban railway system also has been adopted this AC feeding system. AC feeding system is two schemes, the one is the scheme using AT(autotransformer) and the other is by BT(booster transformer). AT fed system has a few advantages about voltage drop, EMI, and so on. So, most of AC electric railway system has been adopted this system recently.

Train which is the electric load in electric railway system has some features. Train is mobility and large capacity, for example, Korean high speed train has 15MVAof capacity. If a couple of train enter a feeding section of traction power supply system, a lot of power is consumed in system. The demand for railway is increased because of environment-friendly and headway between trains grows shorter. Because of large capacity train and increasing demand for railway, the load in electric railway system grows larger so, voltage drop grows larger. If voltage drop is severe in railway system, input voltage of traction motor in train is lower and efficiency is also lower.

The power electronics technology as static var compensator has been adopted in electric railway system for the solution to improve voltage. The application, however, for this facility is not simple problem because consumed power in electric train is fast fluctuation [1,2]. This paper presents novel solution to improve voltage in railway system. The proposed solution is the alternation of AT's turn ratio equipped in SSP(sub sectioning post) and SP(sectioning post). AT equipped in electric railway system is connected to contact wire, feeder and rail. AT's turn ratio is 1:1. In other words, nominal voltage between contact wire and rail is equal to the one between contact wire and rail. This paper proposes larger turn ratio of between contact wire and rail than between rail and feeder to improve input voltage to train. This configuration changes the system characteristic, that is short current, fault impedance, and its R/X ratio. This feature should be considered.

## II. CONVENTIONAL FEEDING SYSTEM

AT fed railway system in Korea consists to SS(substation), SSP and SP. AT is equipped there.

### A. *Configuration of AT fed system*

The configuration of AT fed railway system in Korea is shown in figure 1. Three phase power is supplied from utility to railway substation. Scott transformer changes the three phase power to the one phase power. This one phase power is supplied to train through AT and catenary system.

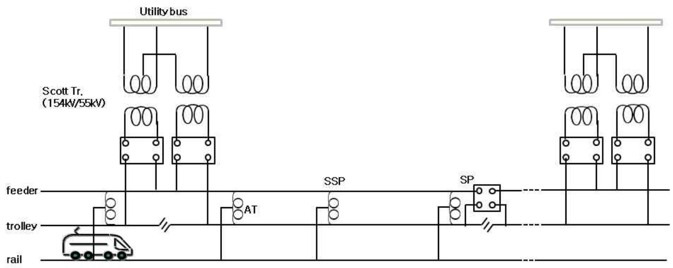



Figure 1. Configuration of AT fed system

### B. *Conventional Configuration of AT*

AT is equipped at SS, SSP and SP of AC fed system, and AT is allowed to reduce influence of voltage drop and EMI as compared with any other system.

Figure 2 indicates the equivalent circuit SSP's AT. The neutral point of AT is connected to rail (R) and other two points is connected to contact wire (TF) and feeder (AF) respectively. The turn ratio between TF and R is equal to between AF and R. So, nominal voltage of TF-R and AF-R is same.

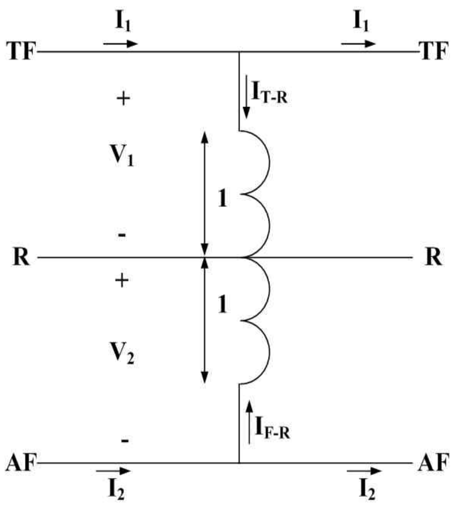



Figure 2. Equivalent circuit of AT

Electric power is supplied to train between TF and R in AT fed system. So, to increase input voltage of train is same to increase voltage between TF and R.

## III. PROPOSED CONFIGURATION OF AT FED SYSTEM

This paper proposes the configuration of AT in railway system to improve input voltage in train. The proposed configuration is considered to change turn ratio of AT equipped at SSP and SP.

### *A. Configuration of proposed System*

The proposed solution to increase train voltage is AT with tap changer. Turn ratio between TF and R could be larger than between AF and R to change neutral point of AT and then voltage between TF and R would be increased.

The proposed AT's configuration is shown as figure 3. Left AT of figure 3 conventional AT with turn ratio 1:1 between TF-R and AF-R. So, nominal voltage of TF-R and AF-R is same as 25kV. The right AT of figure 3 is proposed AT and it has the different turn ratio between TF-R and AF-R. That is N : 1 and neutral point is changeable. Turn ratio and nominal voltage of TF-R is larger than AF-R (N > 1) as AT has this configuration,.

### *B. Tap Chageable A*

As above mentioned, proposed AT's configuration is tap changeable AT. Turn ratio of TF-R change $N_1 = N_2$ to $N_1 > N_2$ and then train voltage can be larger. Figure 4 indicates proposed configuration of AT in SSP and SP. In figure 4 turn ratio of TF-R and AF-R is N : 1.

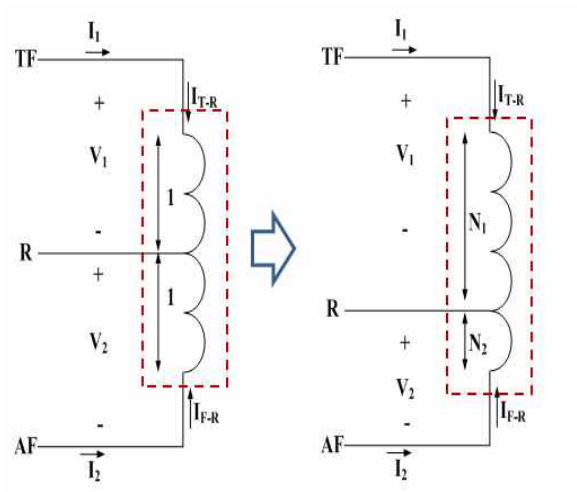
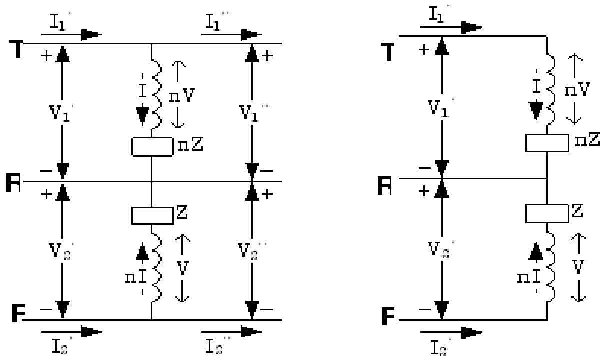



Figure 3. Proposed autotransformer at SP




(a) AT in SSP (b) AT in SP

Figure 4. Equivalent circuit for proposed autotransformer

Equations about voltage and current at terminal of AT shown in figure 4 are following as (1) ~ (8)

$$V_1^{'} = V_1^{''} \tag{1}$$

$$V_2^{'} = V_2^{''} \tag{2}$$

$$I_1^{'} = \frac{1}{2(1+n)} V_1^{''} - \frac{1}{2(1+n)} V_2^{''} + I_1^{''} \tag{3}$$

$$I_2^{'} = \frac{1}{2(1+n)} V_1^{''} - \frac{1}{2(1+n)} V_2^{''} + I_2^{''} \tag{4}$$

Where,

$V_1^{'}$ : Voltage of TF-R at input terminal of SSP [V]

$V_1^{''}$ : Voltage of TF-R at output terminal of SSP [V]

$V_2^{'}$ : Voltage of ATF-R at input terminal of SSP [V]

$V_2^{''}$ : Voltage of AF-R at output terminal of SSP [V]

$I_1^{'}$ : Current of TF-R at input terminal of SSP [A]

$I_1^{''}$ : Current of TF-R at output terminal of SSP [A]

$I_2^{'}$ : Current of ATF-R at input terminal of SSP [A]

$I_2^{''}$ : Current of AF-R at output terminal of SSP [A]

n : Turn ratio of TF-R

Equation (1) ~ (4) indicates relation with voltage and current of figure 4 (a).

$$V_1^{'} = V + 2nZ_{at}I \quad (1)$$

$$V_2^{'} = V - 2nZ_{at}I \quad (2)$$

$$I_1^{'} = I \quad (3)$$

$$I_2^{'} = I \quad (4)$$

Where,

$V_1^{'}$ : Voltage of TF-R at input terminal of SP [V]

$V_2^{'}$ : Voltage of AF-R at input terminal of SP [V]

$V$ : Voltage at output terminal of SP [V]

$I_1^{'}$ : Current of TF-R at input terminal of SP [A]

$I_2^{'}$ : Current of AF-R at input terminal of SP [A]

$I$ : Current at output terminal of SP [A]

Equation (5) ~ (8) indicates relation with voltage and current of figure 4 (b).

## IV. SIMULATION

To verify the proposed system configuration, simulation about some items is performed. The performed simulation items are voltage drop, short current, fault impedance and its R/X ratio.

### A. *Conditions for simulation*

To perform the simulation, this paper select an AT fed substation of Kyung-Bu high speed railway line. The length of section of target substation is about 30km. The capacity of selected substation is considered as 45/60MVA. Table 1 shows impedance data of selected substation.

TABLE I. IMPEDNACE DATA OF THE SELECTED SUBSTATION

| Item | | % Impedance | Ω Impedance | |
|---|---|---|---|---|
| | | | *154kV* | *55kV* |
| Utility bus | | 0.079+ j0.955 | 0.187+j2.265 | 0.0239+j0.289 |
| Transmission line | | 0.357+ j1.982 | 0.847+j4.701 | 0.108+j0.600 |
| Scott Tr. | M | j9.58 | | j6.440 |
| | T | j9.48 | | j6.373 |

To simulate voltage drop, short current, fault impedance and its R/X ratio of AT fed system, the system configuration is considered as figure 5. The considered system includes SS, two of SSP and SP. Turn ratio of AT equipped in SP is considered as 1:1, 1.2:1, and 1.5:1. All simulation is performed using PSCAD/EMTDC.

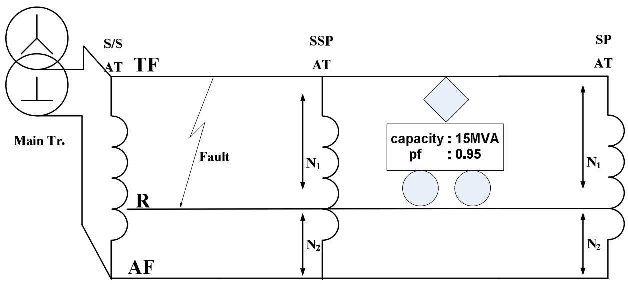



Figure 5. Diagram for simulation

### B. *Voltage drop simulation*

To verify improvement voltage drop according to tap change of AT, simulation is performed as following that

- The load, train, is located at 3km from SP.
- its capacity 15MVA.
- And its power factor is 0.95.

The results of simulation performed as above conditions are shown in table 2.

When turn ratio is 1:1, the voltage between TF and R of AT is 24.327kV because of power consumption in train as a shown table 2. However, voltage of TF-R can be 26.327kV according to increasing of turn ratio to 1.2:1 and it is increased to 26.689kV when turn ratio is 1.5:1. The rate of increase is 5.973% and 7.430% respectively. Figure 6 indicates voltage drop calculation result in the system as shown figure 5.

TABLE II. TRAIN VOLTAGE COMPARISOM RELATED TO TURN RATIO

| Item / Turn ratio | Max. instantaneous value [kV] | RMS value [kV] | Rate of increase [%] |
|---|---|---|---|

| Item / Turn ratio | Max. instantaneous value [kV] | RMS value [kV] | Rate of increase [%] |
| --- | --- | --- | --- |
| 1 : 1 | 35.189 | 24.843 | - |
| 1.2 : 1 | 37.286 | 26.327 | 5.973 |
| 1.5 : 1 | 37.791 | 26.689 | 7.430 |

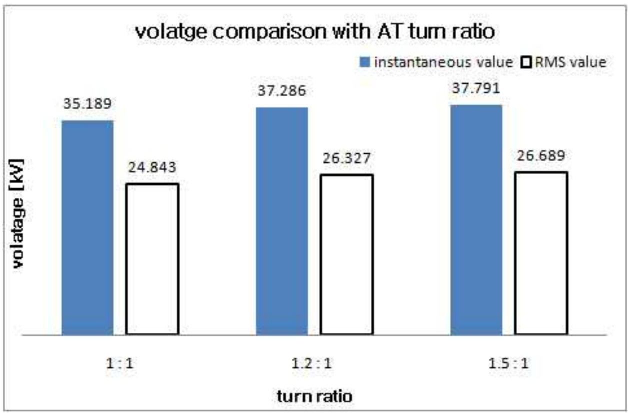



Figure 6. Voltage comparison with AT turn ratio

*C. Short current simulation*

Short current simulation is performed to investigate the effect of AT's tap change. The following that is the assumption for short current simulation

- Turn ratio of AT is identical when voltage drop simulation
- There is no load in system.
- It is assumed that short between TF and R is occurred every 1km in system

Figure 7 is shown the supplied current in SS according to short point. This figure is shown there is no severe difference between the results of current according AT's turn ratio, because tap change is only occurred in SP which is located at 30km from SS and the end point of system. The tap change of end point of system cannot cause much the change of system and then protective facilities in AT fed system can be used with conventional setting value about over current.


Figure 7. Supplied current from SS at fault between TF and R

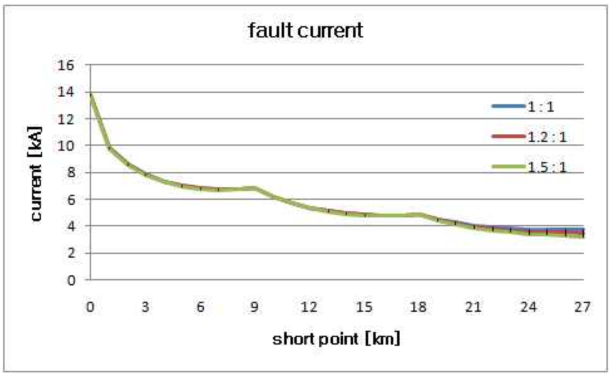



Figure 8. Fault current from SS at fault between TF and R

Figure 8 indicates fault current calculation result between TF and R according to turn ratio of AT. Fault current at fault point is also similar to the supplied current result as shown figure 7. The difference, however, between results according to turn ratio is larger than the result of supplied current because fault current is calculated at fault point. The maximum difference between calculated results is approximately 200A.

*D. Fault Impedance simulation*

Fault Impedance simulation is performed with short current simulation simultaneously. This should be investigated for relay setting.

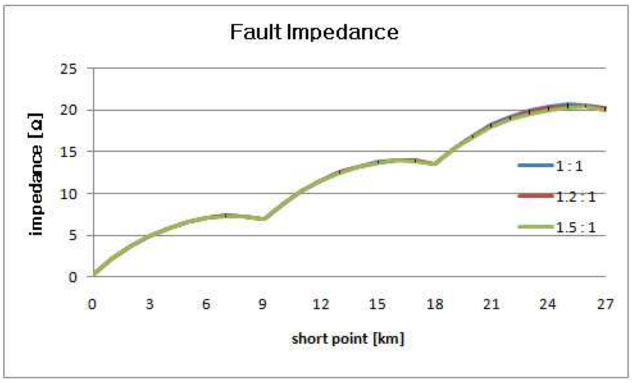



Figure 9. Fault impedance at 55kV side

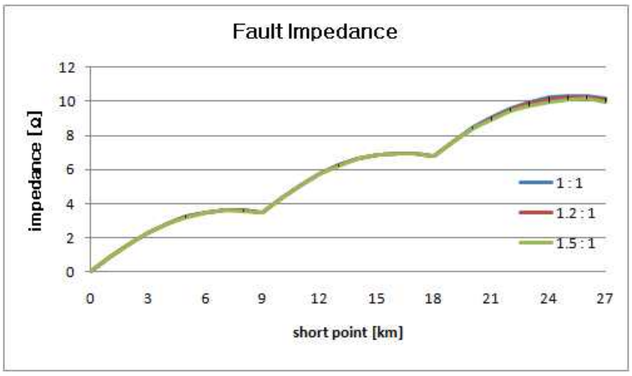



Figure 10. Fault Impedance at 27.5kV side

Figure 9 and 10 indicate the calculation result of fault impedance according tap change of AT. Figure 9 is shown the result of fault impedance at 55kV side (between TF and AF at SS, that is 1st side of AT in SS), and figure 10 is shown the one at 27.5kV side (between TF and R at SS, that is 2nd side of AT in SS). The maximum difference between calculated results is approximately 0.35Ω.

Figure 11 is the result of ratio between resistance and reactance of fault impedance at 55kV side. The degree between resistance and reactance of fault impedance is about 71° to 73°. Likewise, the calculation result is 73° to 74° when turn ratio is 1.5:1.

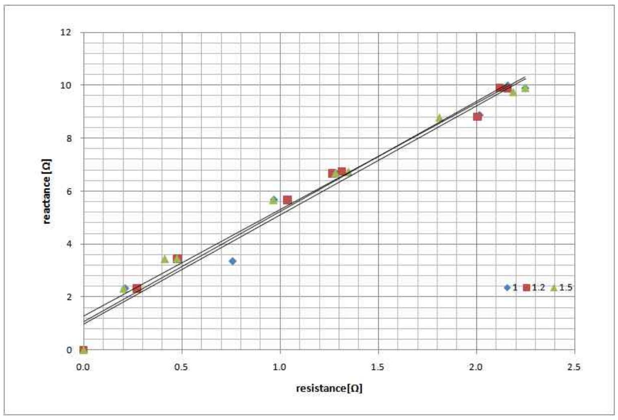


Figure 11.R/X ratio of fault impedance at 55kV side

## V. CONCLUSIONS

This paper investigates the effect system when tap changer is applied to AT in electric railway system. The investigated items are short current, fault impedance, and its R/X ratio. The main result of this paper is following that;

- Improvement of voltage for tap change of AT is 5.9% at turn ratio 1.2:1, and 7.4% at turn ratio 1.5:1.
- The maximum difference between system conditions is approximately 200A according to short current calculation result.
- The maximum difference between system conditions is approximately 0.35Ω according to fault impedance calculation result.
- The angle between resistance and reactance of impedance at fault condition is calculated as 73° to 74°.

If the tap changer of AT is adopted in AT fed system of electric railway system, the system impact is not severe. So, the proposed tap changer of AT is available to be adopted in system

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