Study Of DC Railway Traction Substation On Rectifier Loading Variations

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Abstract. This research focuses on studying harmonic disturbance conditions that have the potential to arise at DC traction substations caused by non-linear loads, namely rectifiers. In the DC railway traction substation system there is a rectifier component whose function is to convert AC power to DC. The aim of this research is to determine the system power quality when varying loads occur on the rectifier. The method used is to simulate a DC traction substation system model and measure its power quality parameters such as voltage, power factor, and total harmonic distortion index under several loading conditions. The results show changes in the total harmonic distortion (THD) value linearly with the rectifier loading. THD values that exceed the standard are at loads above 80%.

Keywords: power quality, DC railway traction, loading, rectifier.

1 Introduction

Load fluctuations can have significant effects on the power quality of a traction substation [1], which is a critical component of an electrified railway system. Train operations produce load fluctuations ranging from the lowest load to the highest. These fluctuations are caused by dynamic train operation patterns [2] starting from acceleration, deceleration, train start stop and the operation of more than 1 train in the traction substation service area. Power quality refers to the characteristics of the electrical supply, including voltage and frequency, and how well it meets the requirements of the equipment and systems it powers. Here are some of the key effects of load fluctuations on power quality in a traction substation such as the acceleration and deceleration of an electric train in a DC railway electrification system with a 12-pulse uncontrolled rectifier can have various effects on power quality [3]. The impact of acceleration operations, including Voltage Sag. During the acceleration phase, the electric train might draw a significant amount of current from the DC power supply. This sudden increase in current can result in a voltage sag, causing a temporary drop in voltage levels. This can affect other equipment connected to the same DC supply. The acceleration also can cause harmonic distortion. The 12-pulse uncontrolled rectifier itself can introduce harmonics into the system. When the train accelerates, it draws non-sinusoidal currents from the rectifier, potentially exacerbating harmonic distortion in the system. Harmonic distortion can affect power quality by causing voltage distortion and overheating of equipment. Beside that, Deceleration can cause electric regeneration. When the electric train decelerates, it can act as a generator, feeding power back into the DC supply if using regenerative breaking on the braking system. This regeneration can cause voltage spikes, which can damage the rectifier and other equipment if not properly managed. Voltage spikes can negatively impact power quality by causing voltage transients. The regenerated power can lead to overvoltage issues in the DC electrification system, potentially causing equipment failure and other power quality problems.

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To mitigate these power quality issues during acceleration and deceleration of electric trains in a DC railway electrification system with a 12-pulse uncontrolled rectifier, various measures can be taken. One of the solutions is by using harmonic filters. Installing harmonic filters can mitigate harmonic distortion caused by the rectifier and the train's non-sinusoidal current draw during acceleration. These filters can help maintain a cleaner power supply. in research [4] applied HPF to reduce harmonics and was able to increase performance efficiency and life span of the equipment. Another solution can apply the controlled rectification: In some cases, replacing uncontrolled rectifiers with controlled rectifiers can provide better control over the current draw and voltage levels, reducing the impact on power quality {Citation}. Several studies have also carried out measurements of electrical power parameters at traction substations [5].

The specific measures taken will depend on the requirements of the railway electrification system, the characteristics of the trains, and the available budget for power quality improvements. Proper engineering and design are essential to address power quality issues effectively in such systems. This research focuses on discussing about power quality especially harmonic distortion occurs on the DC railway traction substation when the load has changes from no load until maximum load.

2 Method

The method used in this study is system modeling and simulation. DC railway traction substation is modeled using the equipment model listed in the software library by entering the parameters that will be studied. The single line diagram of DC railway traction substation include high voltage circuit breaker, transformer, rectifier and DC circuit breaker are shown in figure 1. The parameters of the traction transformer is shown in table 1 and the parameters of the rectifier is shown in table 2. The substation model is simulated by varying the load from zero to maximum with step 20%. In this simulation, data taken from the simulation results include the input and output voltage of the transformer, the power factor on the primary and secondary side of the transformer as well as the THD index on the input and output side of the transformer. This research was also carried out by comparing the THD measurement results at each load with the applicable THD standards. The IEEE 519-2014 limit standard states that for systems with voltages of less than 1 kV there is a harmonic limit of 5%. More than 1kV and less than equal to 69kV ($1 \text{ kV} < V \leq 69 \text{ kV}$) has a harmonic limit of 8%.

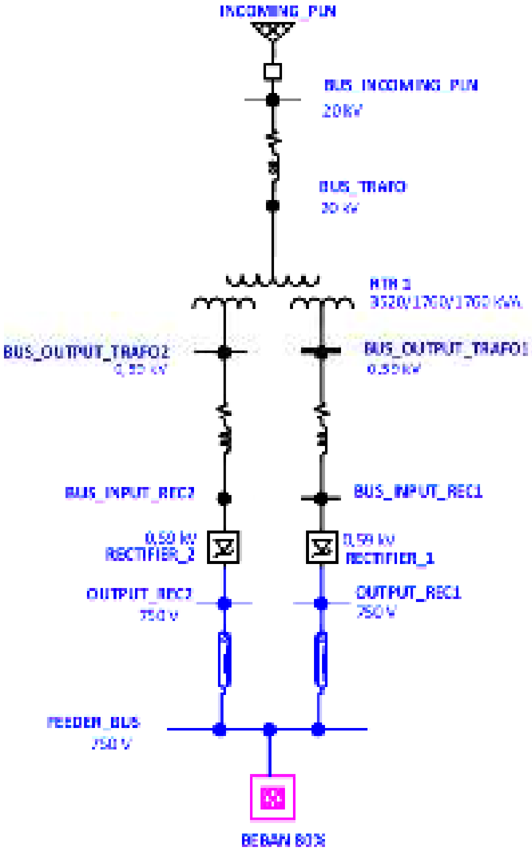

Fig. 1. Single line diagram of DC Railway traction substation

Table 1. Transformer parameters.

Parameters	Value
Primary Voltage	20Kv
Secondary Voltage	590
Power Rating	3520/1760/1760 kVA
Type	Cast oil dry
Cooling	AN/AF
Class	C2/E2/F1
Temperature	50/40/30
Impedance	7%
Connection	Delta - Y solid

Table 2. Rectifier parameters.

Parameter	Value
Type	12 pulse, parallel
Power	3000 kVA
input Voltage	590 VAC
Frequency	50
Output Voltage	750-795 VDC
Power Factor	0.90
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3 Result and Discussion

From the simulation results, several parameters were observed, including nominal voltage, power factor and THD index. The loading is varied from 0% to 100% with steps of 20%. Observation results on the transformer input side (20 kV level) can be seen in table 3.

Table 3. Observation Results on the input side of the transformer (20 kV).

Rectifier Loading (%)	Nominal Voltage (kV)	Power Factor	THD Index (%)
0	20	90	0
20	20	89,61	0,497
40	20	89,2	1
60	20	88,75	1,56
80	20	88,35	2,05
100	20	87,91	2,69

Table 4. Observation Results on the output side of the transformer (590 Volt)

Rectifier Loading (%)	Nominal Voltage (kV)	Power Factor	THD Index (%)
0	0,59	90	0
20	0,588	89,99	2,4
40	0,585	89,975	4,85
60	0,582	89,96	7,51
80	0,579	89,947	9,95
100	0,576	89,93	10,67

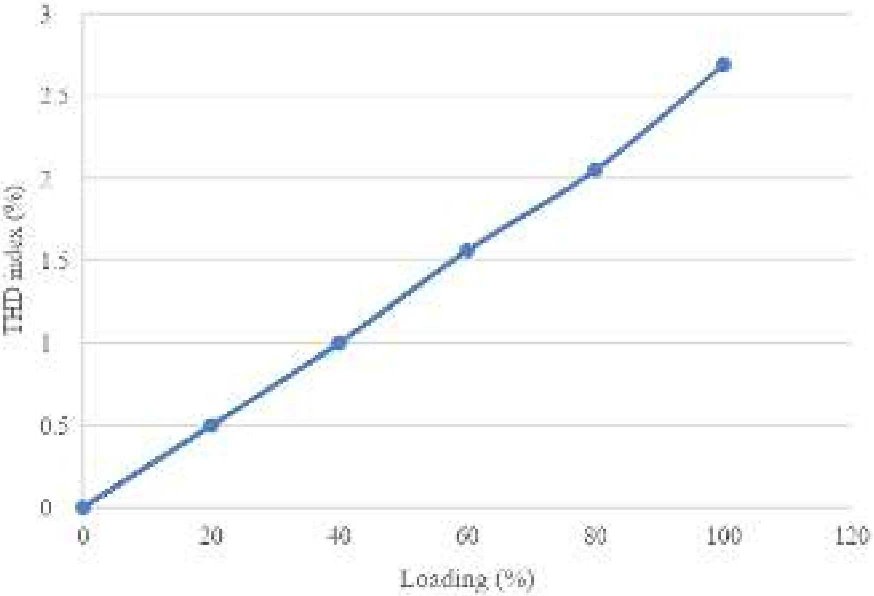

Fig. 2. THD response on the input side of transformer

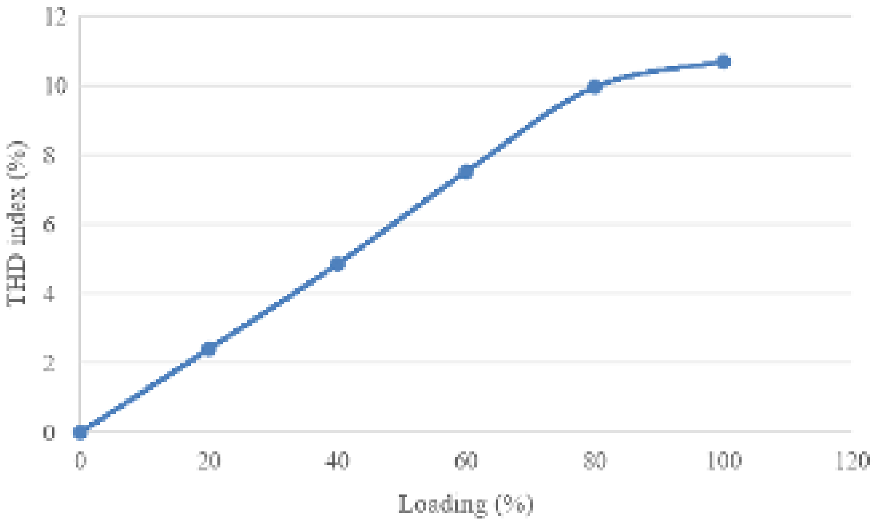

Fig. 3. THD response on the output side of transformer

From fig. 2 it can be seen that on the transformer input side (20 kV level) the greater the load on the rectifier, the THD index increases. The level of increase in the THD index at maximum rectifier loading is considered to be within safe limits (< 5%). In Figure 3 it can be seen that on the output side of the transformer (level 590 V), the greater the rectifier loading, the THD index also increases, but significantly. The THD index at maximum rectifier loading (100%) reached the level of 10.67%, this level is considered to have exceeded the safe limit (> 8%). From these observations it can be seen that the maximum allowable rectifier loading limit is 65%.

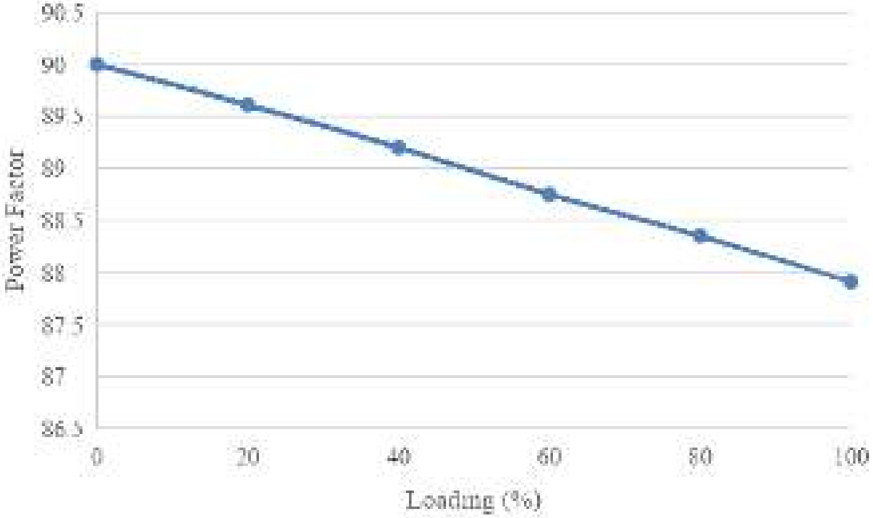

Fig. 4. Power factor changes on the input side of transformer

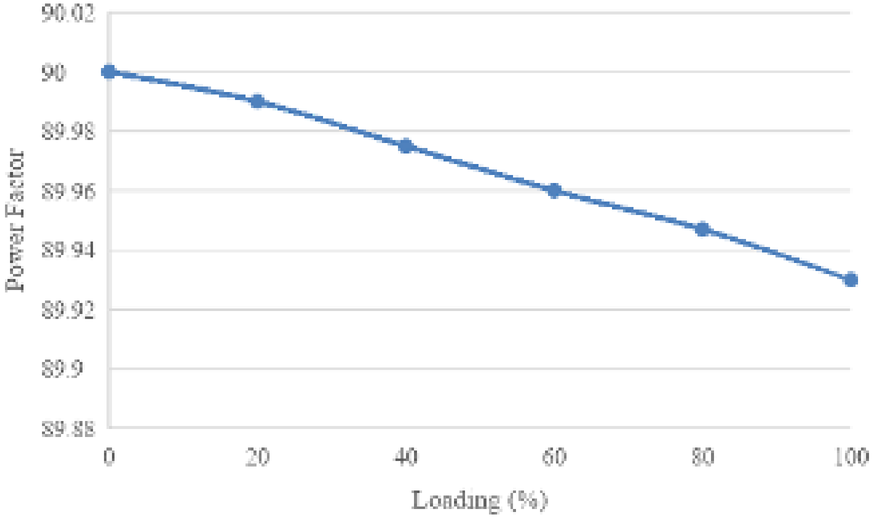

Fig. 5. Power factor changes on the output side of transformer

From fig. 4 it can be seen that on the input side of the transformer (20 kV level) the greater the load on the rectifier, the power factor decreases. The level of power factor reduction at minimum to maximum rectifier loading is only 2.09%. The power factor value at maximum rectifier loading is 87.91%. The level of power factor reduction is considered still within safe limits (> 85%). in fig. 5 it can be seen that on the output side of the transformer (level 590 V), the greater the rectifier loading, the power factor decreases, but it is not significant. The decrease in the power factor value for rectifier loading only has a range of 0.07. When the maximum load (100%) is at the level of 89.93%. this level is considered to be within the permitted limits (> 85%). From these observations it can be seen that the rectifier loading does not have a significant impact on reducing the power factor.

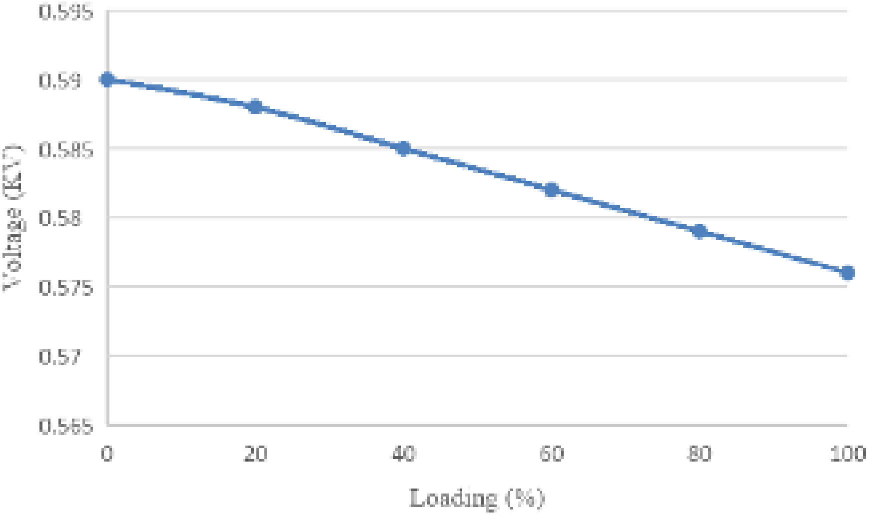

Fig. 6. Voltage level on the output side of transformer

4 Conclusion

Changes in rectifier loading do not have a significant impact on the system power factor and voltage but have a significant impact on changes in the THD value on the output side of the transformer. The THD value on the output side of the transformer reaches 10.67% when the rectifier loading is 100%. From these data it is known that the maximum load is 65%. These results show the importance of overcoming or reducing the THD index value to be able to maximize the use of traction substation component equipment up to 100% loading.

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