Journal of Railway Transportation and Technology
Vol. 1 No. 2 (2022) 46-57
p-ISSN: 2830-0491 e-ISSN: 2830-6680
https://doi.org/10.37367/jrtt.v1i2.15

Harmonic Analysis of A DC Railway Traction with Uncontrolled 12 Pulse Rectifier

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Article Info

Article history:

Received 10 September, 2022
Revised 10 October, 2022
Accepted 29 November, 2022

Keywords:

Power Harmonic,
DC Railway Traction,
Analysis,
Uncontrolled 12 Pulse,
Rectifier

ABSTRACT

In the topology of the DC railway traction substation there is a rectifier component to convert AC power to DC. Among the several types of rectifiers used is the 12 pulse uncontrolled rectifier. In operation, the DC traction substation will be loaded with trains equipped with a variable speed drive (VSD). In the operation of the rectifier and the VSD load can cause harmonics on the AC input side so it needs to be anticipated. Therefore it is necessary to study the harmonics that appear in the DC traction substation to obtain a better quality of electric power. The purpose of this study was to determine the characteristics of the traction substation and measure system harmonics caused by the use of an uncontrolled rectifier with 12 pulses and a VSD load. To find out the characteristics of a 12 pulse uncontrolled rectifier, the traction substation will be loaded with a resistive load. This research was conducted by simulating a DC railway traction model with an uncontrolled rectifier with 12 pulses. The results of this study are the harmonic values of voltage and current.

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1. INTRODUCTION

So far, there are 2 topologies for traction substations for train power supply, namely traction substations with AC topology and traction substations with DC topology [1]–[3]. Currently, the DC traction system topology is more widely used as a power supply for urban trains such as light rail transit and mass rapid transit. Common DC traction voltages for train power supply systems include: 750 V. In Indonesia, for example, the

Jakarta LRT with the Pegangsaan Dua – Velodrome route, the Jabodebek LRT with the Jakarta, Bogor, Depok, Bekasi LRT route, which consists of three cross-services namely Cross-Service I Cawang-Harjamukti, Cross-Services II Cawang-Dukuh Atas, and Cross-Service III Cawang-Jatimulya); 1500 V is used by, for example, the commuter line for the Jakarta, Bogor, Depok, Tangerang, Bekasi, MRT Jakarta phase 1 route with the Lebak Bulus route - Bundaran HI [4].

The topology of the DC traction substation system is used for the conversion of the AC voltage system from the transmission-distribution grid network into DC voltage to be distributed to trains along the route. In the DC traction substation topology with a voltage level for 750 Volt traction, the traction substation converting 20 kV AC voltage to 750 V DC requires several main components. The main components of the traction substation are AC cubicles, DC cubicles, traction transformers, and rectifier panels. AC cubicles and DC cubicles are used for separators, breakers and at the same time protection systems. Traction transformer is used to reduce the voltage with an input voltage of 20 kV AC obtained from the grid. Then it is lowered to 590 V AC before entering the rectifier module on the rectifier panel which produces a voltage of 750 V DC.

Rectifiers used in traction substations are controlled and uncontrolled. its pulse number is determined by the winding of the traction transformer and the configuration of the static converter. Among the commonly used are 6-pulse rectifiers [5], 12-pulse rectifiers [6]–[8], and 18-pulse rectifiers [9]. An standart for uncontrolled rectifiers for traction substation applications up to 1500 V DC nominal output is published before [10].

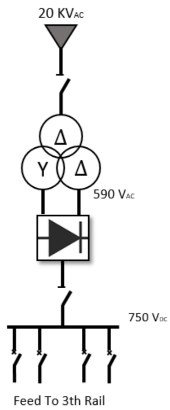

Figure 1. DC Railway Traction Studied

Several previous studies have discussed and investigated the use of 6 pulse and 12 pulse rectifiers [11]. the author considers the features of 6- and 12-pulse conversion units in terms of transient and steady-state short-circuit currents on zero fault impedance. Accurate determination of the transient dc short-circuit current is important for correct rating and tuning of protection devices and power equipment (high-speed circuit breakers, isolator switches, switchgears, dc-bus bars, etc.). The problem of the emergence of harmonics in the system has also been carried out by installing a filter [12]. That is why 12-pulse thyristor rectifiers with passive filters are typically used for these applications. Due to the large variation of load voltage and current, the reactive power at the input varies widely. Therefore, a passive filter alone cannot provide good power factor over the large load range [8]. Several studies have made improvements to the performance of the 12 pulse rectifier [6]. This research we know that, A parallel operation control scheme has two operating modes depending on the energy flow of trains. When the energy is less than the rated power of a converter, only one converter operates in a single operation mode. If the energy exceeds the rated power of a converter, the other converter is operated in parallel mode operation to distribute the excess energy. In another study, passive devices were also added [13]. this method is easy to be used in different 12-pulse rectifier topologies, and its conduction losses are far less than that of the conventional double-tapped IPR

Problems caused by the operation of the rectifier and the VSD converter load which makes the appearance of harmonics on the AC input side become interesting for further study. Therefore, it is necessary to conduct a study related to DC traction substations with this topology to obtain good electrical power quality. The purpose of this study was to determine the electrical power quality parameters of DC railway traction with the use of an uncontrolled 12 pulse rectifier and a VSD converter load. This research was conducted by simulating a DC railway traction model with certain parameters with a 12 pulse rectifier. In addition, the results can also be used to compare the power quality of the system when it is loaded with trains whose configuration uses a VSD converter. Comparison parameters will be taken using resistive load as a basic reference for the work system of this model traction substation. It is hoped that the results of this study can be used to develop a better traction system.

2. RESEARCH METHOD

Methodology of this research was conducted through a simulation model of the DC railway traction substation. The DC railway traction model is formed by assembling three phase AC input source components, three phase transformers, three phase uncontrolled rectifier 12 pulses and load. Three phase AC input source created by three phase sinusoidal voltage source, three phase transformer created by three phase three winding transformer with Δ-Δ-Y connections, three phase uncontrolled rectifier 12 pulse created by two of three phase diode bridge connected in parallel on the output side, and load model with detailed parameters as shown in tables 1 to 4.

To find out the characteristics of the DC railway traction with an uncontrolled 12-pulse rectifier, a resistive loading will be carried out. In this case the resistive load used is 19.3 ohm. In this condition, measurements of voltage and current will be carried out on the input side of the rectifier and measurements of voltage harmonic (THDv) and current harmonic (THDi). The results of measurements of voltage and current signals will then be carried out a Fourier analysis using the FFT method to determine the harmonic level in a certain frequency range. This FFT analysis can be performed using the FFT analysis feature in the PSIM software.

In fact, the train uses three-phase inverter technology to supply three-phase traction motors. The inverter switching control method uses a variable speed drive (VSD). In testing the DC traction substation, a load with 3 phase induction motor whose configuration uses a VSD converter is also carried out. Some of the electrical power supply equipment in the DC railway traction system that is simulated in this study include: three-phase voltage model from the grid, transformer, 12 pulse rectifier, connecting cable and load. Each of these components is modeled on the PSIM software and then all components are integrated according to the configuration of the DC railway traction system. Then the parameters will be measured including voltage, current, power, and harmonics of the system to determine the quality of the electrical power.

The transformer used for traction needs is a 3-phase transformer with several types, one of which is a dry-type transformer which has the advantage of being free of maintenance because it does not use transformer oil as its cooling system. This type of transformer uses only natural air circulation to cool the winding and body and does not require a tank as a container. To strengthen the air, the dry-type transformer is equipped with Cast Resin. The transformer is designed to work continuously at its rated power without exceeding the temperature rise limit of class F on high voltage windings and class F on low voltage windings. Transformers for traction generally use 3-phase transformers with 3 turns with the primary winding connected to the Delta connection, the secondary winding being connected to the Delta connection and the tertiary winding being connected to the Star connection. The use of transformers with these connections can reduce the effect of Harmonics [14], [15].

In DC railway traction with an output voltage level of 750 Volts, the input voltage on the primary side of the transformer is 20 kV AC. This 20 KV voltage is obtained from the grid network. By using a transformer, the voltage level is lowered to 590 V AC as the input voltage for the rectifier to produce a voltage of 750 V DC. The transformer winding connection used for the simulation is shown in figure 2. This model is developed with parameter shown in table 2.

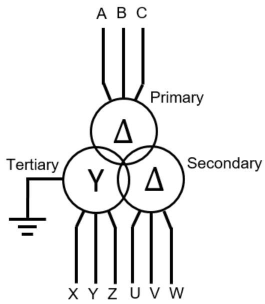

Figure 2. 3 phase, 3 winding transformer connection

A rectifier is a device used to convert an alternating current (AC) source into direct current (DC). The rectifier circuit is widely used for power supply which is combined with a step down transformer to be used in various loads with a certain working voltage level. Based on the number of diodes, the rectifier is divided into half wave rectifier and full wave rectifier. Of these two basic types of rectifiers can be configured into 3 pulse, 6 pulse and 12 pulse rectifiers.

In the DC traction substation system, the rectifier functions to convert the AC output voltage from the power transformer into DC voltage. The DC voltage is then channeled to the catenary / overhead electrification (OHE) network or to the power rail network along the train route to supply train operations. The most common type of rectifier used in DC railway traction is the 12 pulse rectifier. The configuration of a 12 pulse rectifier circuit consists of two full wave 3-phase rectifier circuits connected in parallel. If configured with a 3-winding transformer whose secondary and tertiary coils are connected by delta and star connections, it will produce a 30 degree phase shift between 2 full wave 3-phase rectifiers. The schematic of the 12 pulse rectifier circuit connected with 3 phase 3 winding transformer for DC railway traction system is shown in Figure 3. The 12 pulse rectifier model is developed with parameters shown in table 3.

Table 1. Three phase sinusoidal voltage source parameters

Parameters	**Value**
Interphase Voltage (Line Voltage)	20 KV
frequency	50 Hz

Table 2. Three phase three winding transformer parameters

Parameters	**Value**
Np (primary)	2000
Ns (secondary)	59
Nt (tertiary)	34
Connection (Primary, Secondary and Tertiary)	Δ, Δ, Y
Rp (primary)	512.614 mΩ
Rs (secondary)	420 uΩ
Rt (tertiary)	438 uΩ
Lp (pri. leakage)	10 uH
Ls (sec. leakage)	10 uH
Lt (ter. leakage)	10 uH
Lm (magnetizing)	50 mH

Table 3. 12 Pulse Rectifier parameters

Parameters	**Value**
Number of Diode	12
Diode threshold voltage	0,8 V
Diode resistance	165 uΩ

Table 4. 12 Cables Parameters

Resitor Inductor Branch from	**Value**
Supply voltage to transformers	1 mΩ, 1 uH
Transformer to rectifier	1 uΩ, 0.1 uH
Rectifier to third rail	10 mΩ, 10 uH

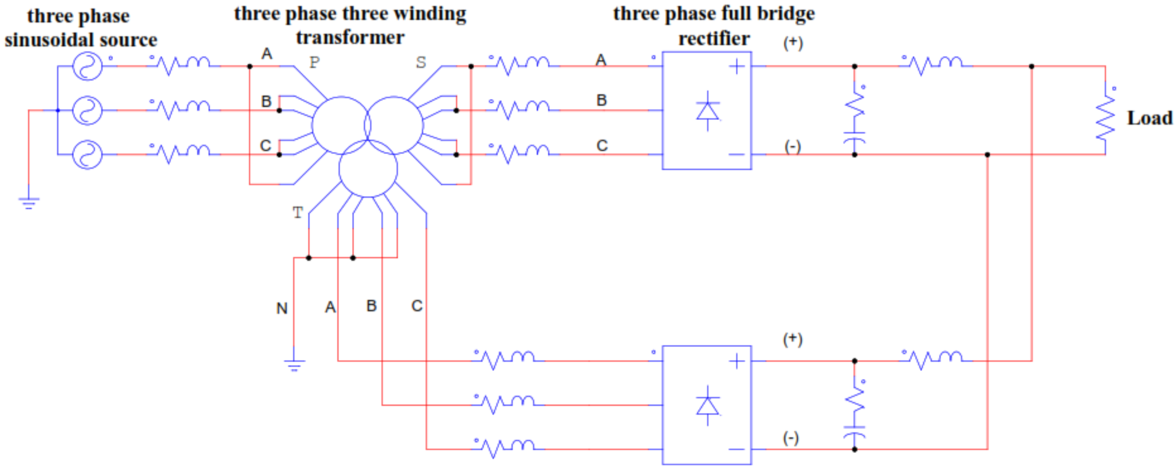

Figure 3. Schematic Modelling of DC Railway Traction System

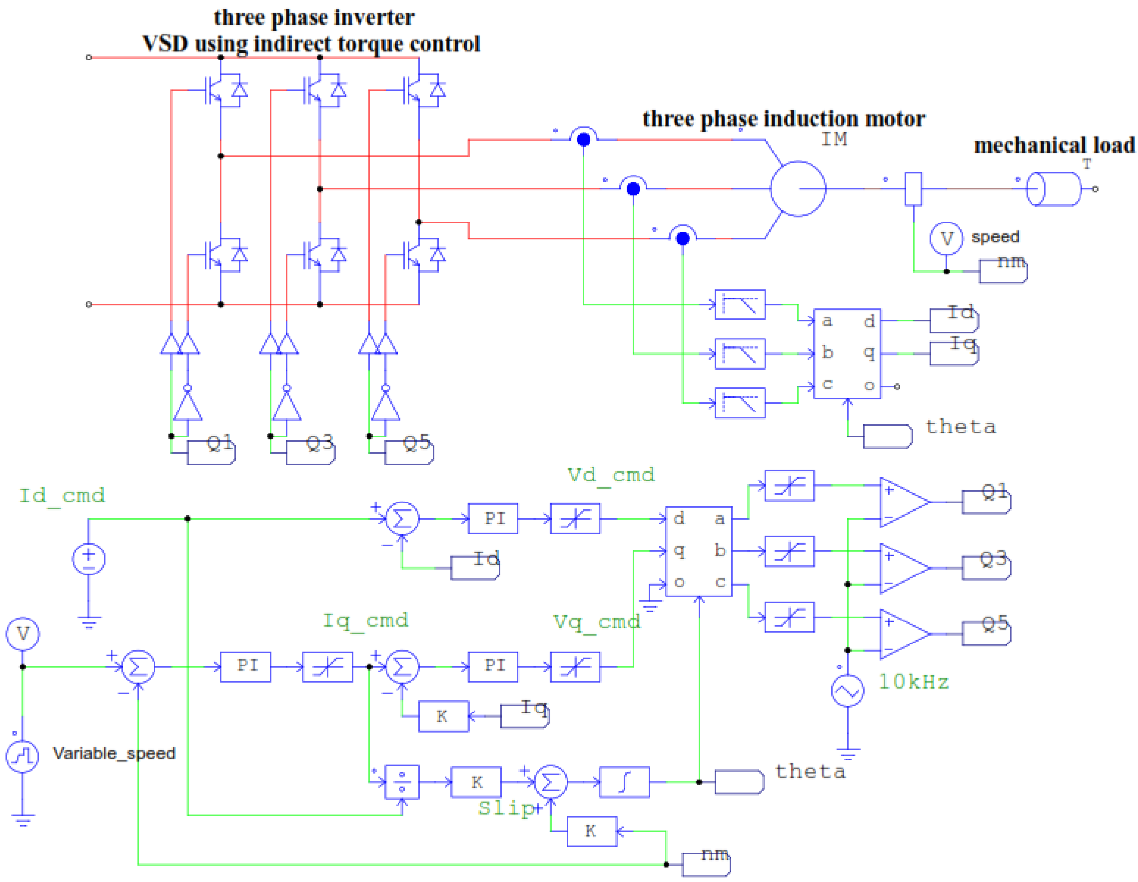

Figure 4. Schematic modelling of VSD and 3 phase induction motor with indirect torque control mode

3. RESULTS AND DISCUSSION

In this section, the power quality parameter such as voltage, current and harmonic is measured and explained the results of research. The comprehensive discussion also already discussed. The parameter is measured from the simulation result by PSIM software. The discussion devided in several sub-chapters below.

3.1. Voltage Profile Measurement

A DC railway traction simulation has been carried out with 2 conditions, namely resistif loading by testing with a 19.3 ohm resistor load and testing with a three-phase induction motor with VFD load. In testing with a load of three phase induction motor with VFD, voltage measurement is carried out on the primary, secondary and tertiary sides of the transformer and at the output terminal of the rectifier. The result show the operation of three phase induction motor with VFD does not affect the stability of the voltage in primary, secondary and tertiary of transformer side. The results of measuring these voltage parameters are shown in Figure 5.

Figure 5. Voltage Profile Measurement when 3 phase induction motor with VFD has been connected with varous speed operation

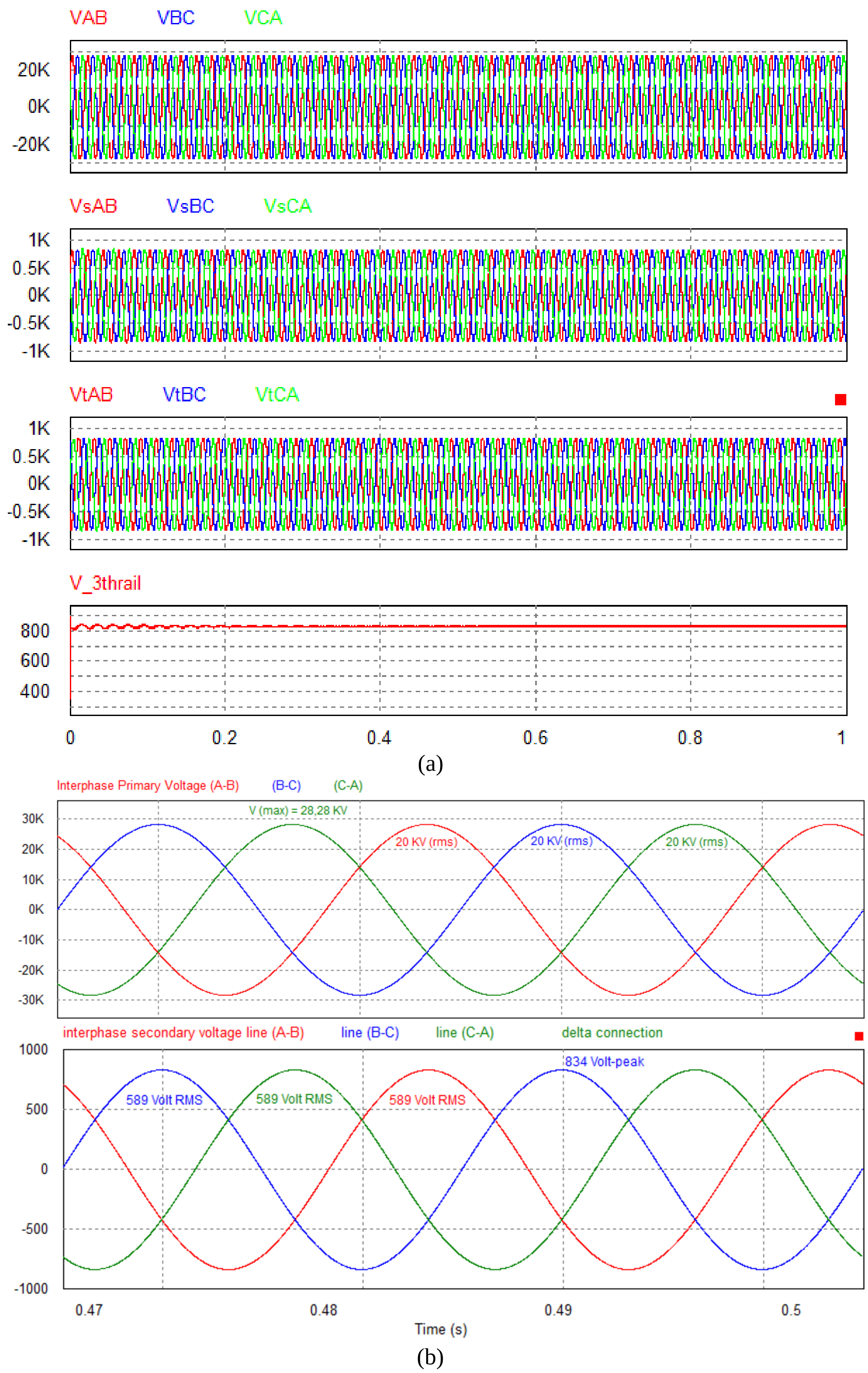

Figure 6. Voltage Profile Measurement when resistif load (19.3 ohm) has been connected; a.) 0-1s; b.) 0.465-0.505s

As a comparison, testing has been carried out with a 19.3 ohm load resistor connected to the output side of the rectifier. The test results with a 19.3 ohm load resistor are shown in Figure 6. These results show the characteristics of uncontrolled 12 pulse rectifier does not affect the stability of the voltage in primary, secondary and tertiary of transformer side.

3.2. Current Profile Measurement

In testing with a load of 3 phase induction motor with VFD has been connected with various speed operation, current measurement is carried out on the primary, secondary and tertiary sides of the transformer and at the output terminals of the rectifier. The results of the current parameter measurements are shown in Figure 7. As a comparison, testing has also been carried out with a 19.3 ohm load resistor. In testing with a 19.3 ohm resistor load, current measurements were also carried out on the primary, secondary and tertiary sides of the transformer and at the rectifier output terminals. The results of the current parameter measurements are shown in Figure 8.

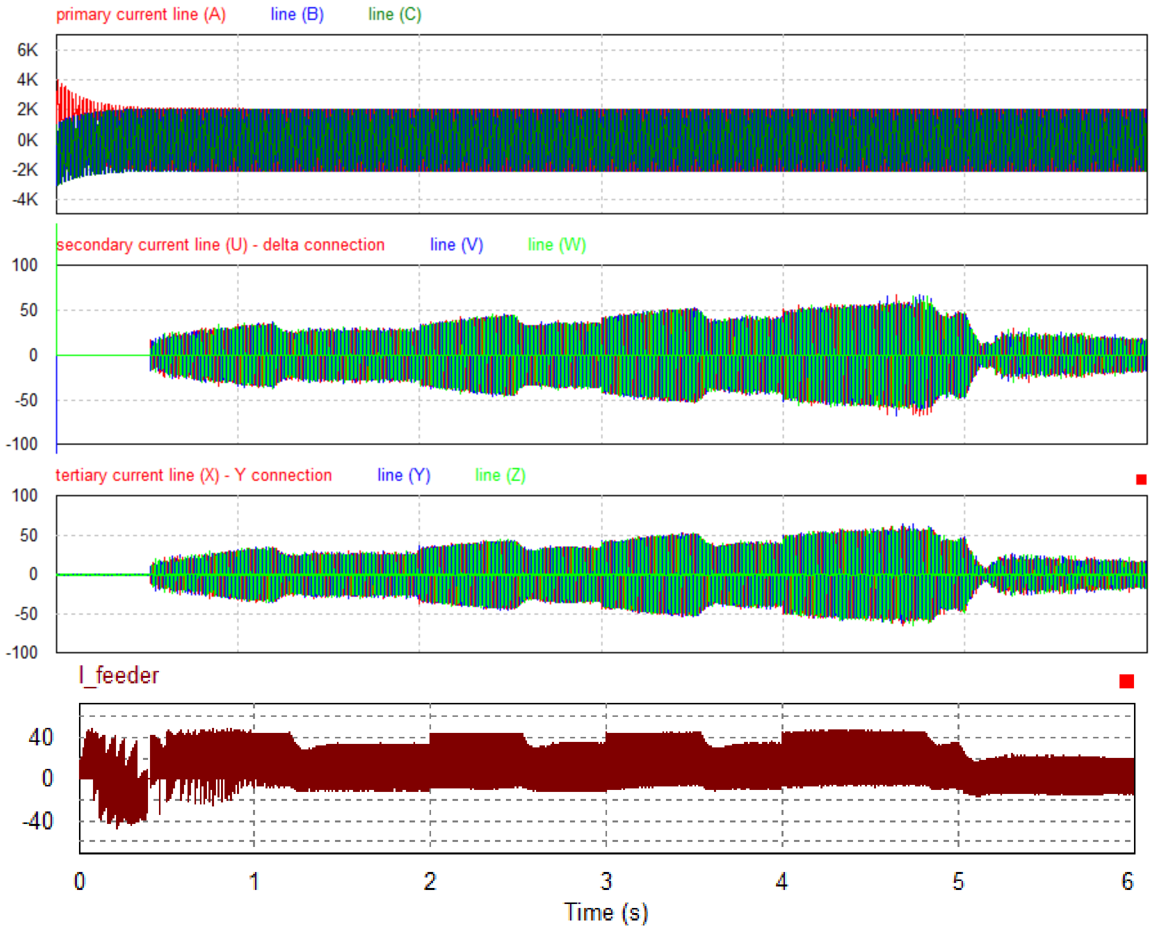

Figure 7. Current Profile Measurement when 3 phase induction motor with VFD has been connected with varous speed operation

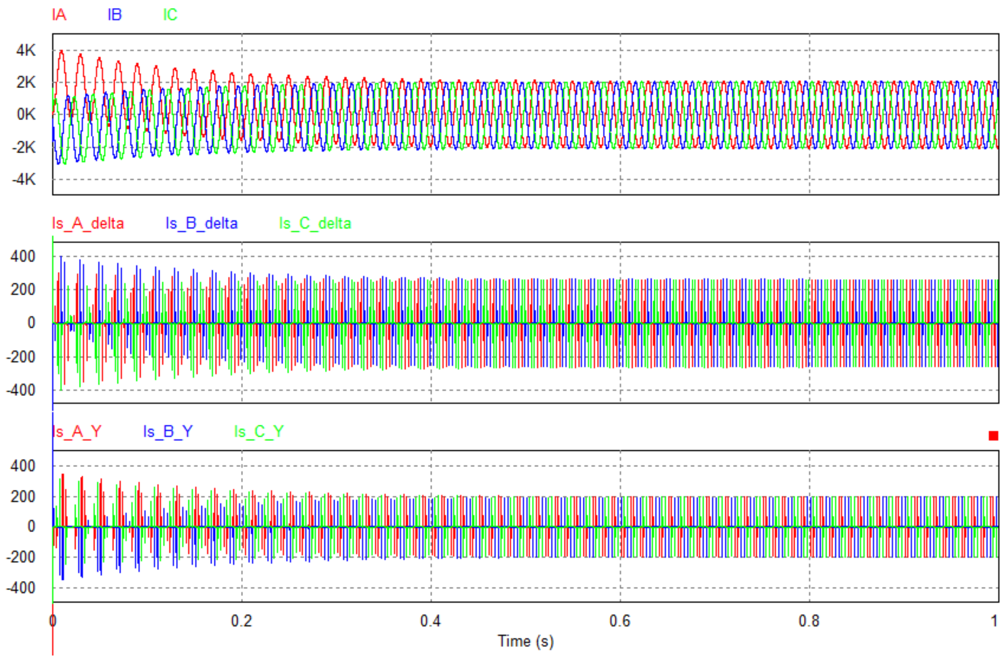

Figure 8. Current Profile Measurement when resistive load (19.3 ohm) has been connected

From the results of the Current Profile Measurement when resistive load (19.3 ohm) has been connected, a current profile has been obtained according to the number of pulses from the 12 pulse rectifier. Primary current transformer of each phase reach 1573 A, 1498 A, 1494 A on rms measurement. Secondary current transformer of each phase reach 24.9 A, 24.9 A, 24.8 A on rms measurement. Tertiary current transformers of each phase reach 24.6 A, 24.6 A, 24.4 A on rms measurement. From the current signal, an over current appears on the output side of the rectifier which occurs at the end of the period form some pulses. This has not been found in previous research.

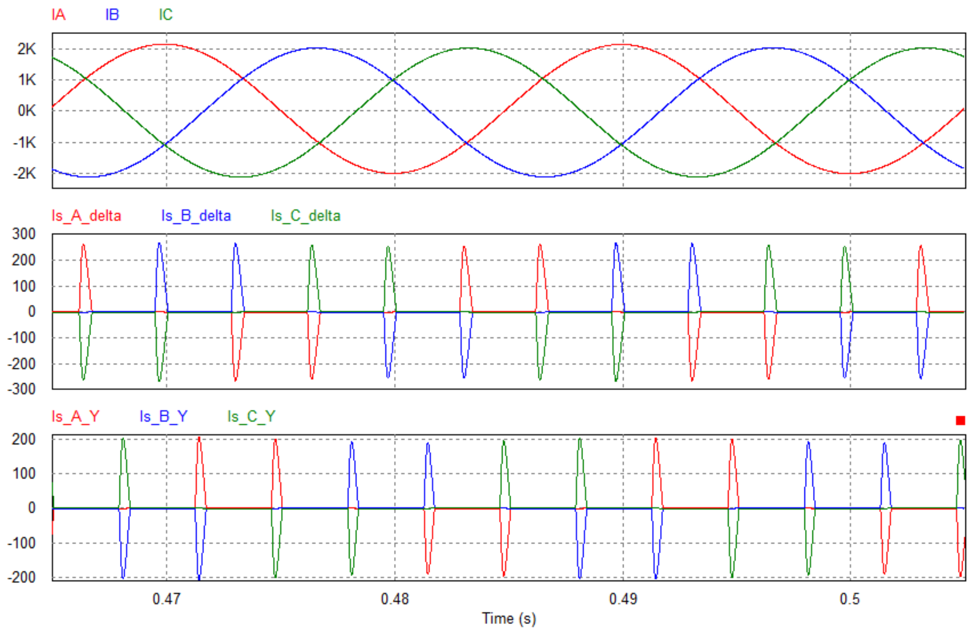

Figure 9. Primary, secondary and tertiary current of each phase when resistive load (19.3 ohm) has been connected

3.3. Power Harmonic Measurement

In the measurement using FFT, harmonic measurements have been carried out on the current and voltage sides at several terminals. Harmonic voltage measurement in primary, secondary and tertiary transformer when 3 phase induction motor with VFD has been connected shown in figure 15. Harmonic current measurement in primary, secondary and tertiary transformer when 3 phase induction motor with VFD has been connected shown in figure 16. This harmonic current also appears when connected to the resistive load. The result of harmonic current occur when resistive load was connected is shown in figure 17. This shows that operation of the 12 pulse uncontrolled rectifier only causes current harmonics to occur.

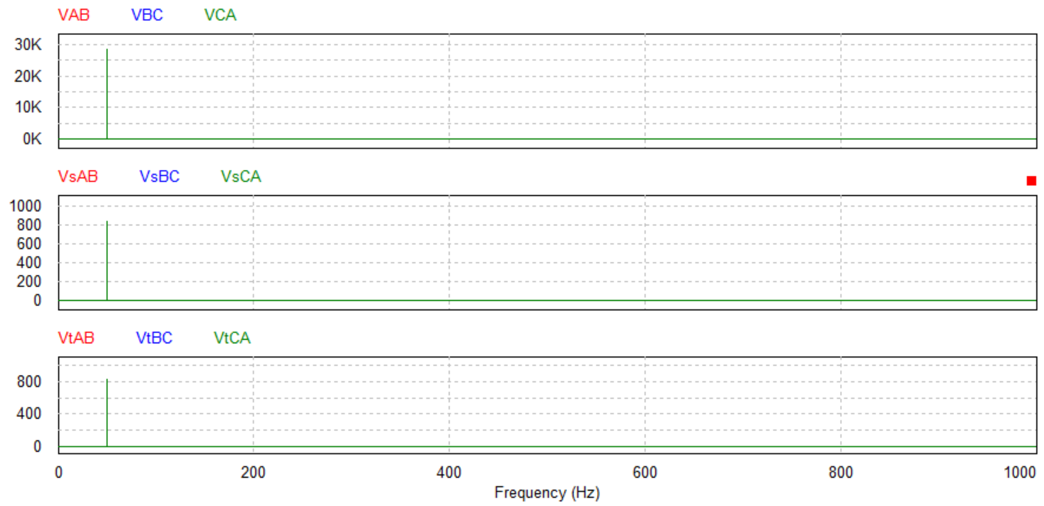

Figure 10. Harmonic voltage measurement in primary, secondary and tertiary transformer when 3 phase induction motor with VFD has been connected

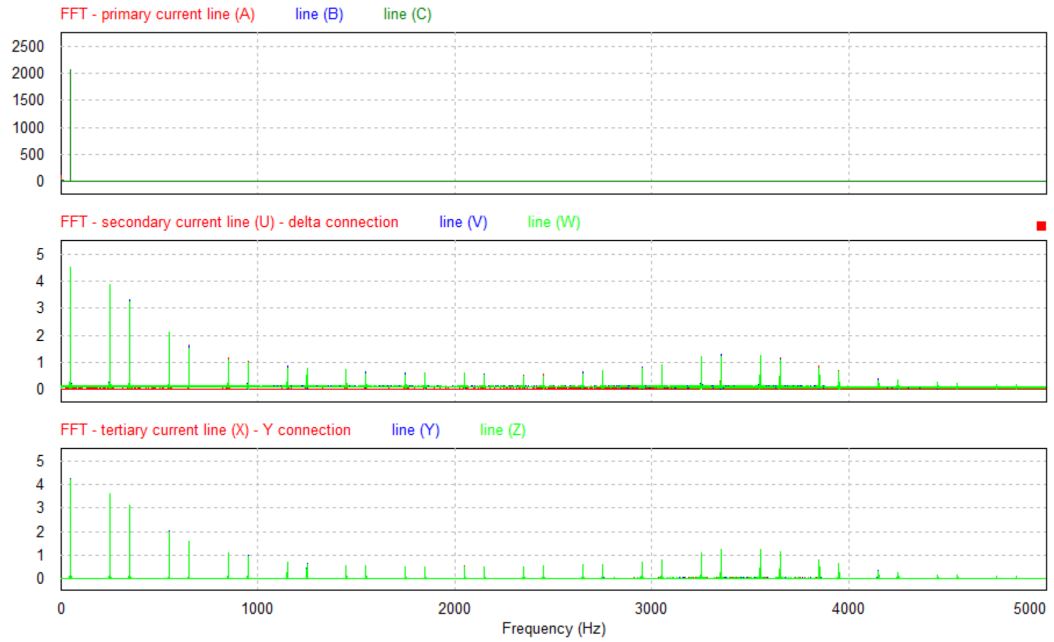

Figure 11. Harmonic current measurement in primary, secondary and tertiary transformer when 3 phase induction motor with VFD has been connected

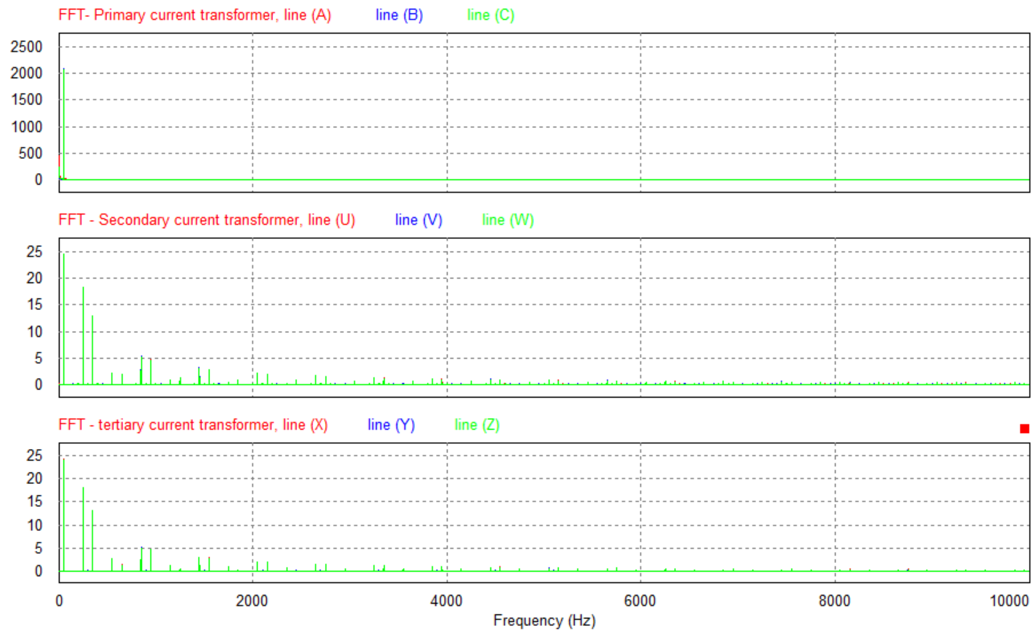

Figure 12. Harmonic current measurement in primary, secondary and tertiary transformer when resistor 19.3 ohm has been connected

FFT analysis results show that no current harmonic appear on the primary side but current harmonics appear on the secondary and tertiary sides of the transformer at frequencies of 250 hz, 350 hz, 550 hz, 650 hz, 850 hz, 950 hz, and so on or on the order of 5th, 7th, 11th, 13th, 17th, 19th etc for both resistive and three phase induction motor VSD load. But the current harmonic magnitude for multiple the order of 11th, 13th for VSD load is smaller than the resistive load.

4. CONCLUSION

Previous studies have shown the presence of harmonics in the rectifier on DC railway traction. This research has also shown the existence of harmonics, especially current harmonics on the secondary and tertiary side of the transformer. The simulation results show that the power quality of the primary side of the transformer is in good condition. There is no over and under voltage in each terminal. When the load is replaced with VSD with variations in the speed profile, current harmonics also appear on the secondary and tertiary sides of the transformer. While the voltage harmonics do not appear. The current harmonics appear on the secondary and tertiary sides of the transformer at frequencies of 250 hz, 350 hz, 550 hz, 650 hz, 850 hz, 950 hz, and so on for both resistive and three phase induction motor VSD load with the fundamental frequency is 50 hz.

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