Harmonics Analysis Due to Connecting an Electrical Traction to A 3-phase Power Supply System Through V/V Transformer

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Abstract- The wide application and usage of electrical traction system presents utilities with planning and operation challenges. Electric railways impose several power quality problems to the utility grid. Such as generated large negative sequence components (NSCs), undesirable harmonics, cause system voltage and current unbalance. Harmonics and unbalanced voltage also may cause negative effects on the components of the power system such as: overheating the transformers and the transmission lines, vibration and cause torque reduction of rotating machines, additional losses of lines and transformers, interference with communication systems, malfunctions of protection relays, measuring instrument error. All these problems have become more and more significant. This paper is an attempt to quantify and assess the impact of electrical traction on the grid side through a V/V transformer. Firstly in this paper, the typical utility power grid and traction power supply system model are designed. Then, the traction system is integrated with the power supply system through a V/V transformer. Two cases of the connection are considered. The first case, when the traction system is connected to one side of transformer. The second case, when there is a balance traction load on the both transformer side. Finally, PSCAD simulation is used to analyze the power system quality and to estimate the harmonics that are generated in the traction and power supply system sides due to this integration. The simulation results show that, in the both cases, high levels of voltage and current harmonics are generated in the traction side. These harmonics are generated only on the phases that the traction is connected to them, while the other phase will not be affected. Also, it is observed that, the generated harmonics at the traction load side have also been transferred to the power supply system side though the transformer.

Key words ***Electric traction, Negative sequence components, Harmonics, Power quality, V/V transformer, PSCAD Simulation.***

المستخلص– إن التطبيق الواسع وإستخدام القطارات الكهربائية وتغذيتها من الشبكة القومية يعتبر تحدياً كبيراً لمهندسي التشغيل ويتطلب التخطيط المسبق والمحكم لإستيعاب هذا النوع من الأحمال. تتسبب السكك الحديدية الكهربائية في ظهور العديد من مشكلات جودة طاقة شبكة الكهرباء العامة. ومن هذه المشاكل ظهورمركبات التتابع السالب وبالتالي ظهور التوافقيات غير المرغوب فيها ، والتي تتسبب في عدم تولزن الاحمال. وقد يؤدي الجهد التوافقي وغير المتوازن أيضاً إلى تأثيرات سلبية على مكونات نظام القدرة مثل: ارتفاع درجة حرارة المحولات وخطوط النقل ، والاهتزاز ، ويؤدي إلى تقليل عزم الدوران للآلات الدوارة ، وزيادة المفاقيد الكهربائية في خطوط والمحولات ، والتداخل مع أنظمة الاتصالات ، وعمل مرحلات الحماية بطريقة خاطئة ، كنتيجة للقراءات الخاطئة لأجهزة القياس الموصلة مع هذه المرحلات. كل هذه المشاكل أصبحت موضع إهتمام وجديرة بالبحث والتحليل العميقين. هذه الورقة هي محاولة لقياس وتقييم تأثير القطارات الكهربائية على أنظمة القدرة الكهربائية متمثلة في الشبكة القومية للطاقة من خلال محولV / V . أولاً في هذه الورقة ، تم تصميم كل من نظام القدرة والقطار الكهربائي. ثم ، تم دمج القطار الكهربائي مع نظام القدرة من خلال محول V / V . تم الأخذ في الإعتبار حالتين من التشغيل. الحالة الأولى عندما يكون هنالك قطار كهربائي موصل بجانب واحد من جوانب، الحالة الثانية، عندما يكون كل من جانبي المحول موصل بهما قطار كهربائي. بعدها ، تم استخدام برنامج محاكاة يسمي PSCAD لتحليل جودة نظام الطاقة وتحليل التوافقيات المتولدة في جانبي المحول نتيجة لتوصيل هذا النوع من الأحمال بنظام القدرة. أظهرتالنتائج أنه ، في كلتا الحالتين، تولدت مستويات عالية من توافقيات الجهد والتيار في جانب القطار. ولوحظ أن هذه التوافقيات المتولدة قد إنتقلت عن طريق المحول إلى جانب نظام القدرة المغذي. هذه التوافقيات تظهر فقط علي الأطوار التي يتصل بها القطار الكهربائي. أما باقي الإطوار فإنها لم تتأثر بهذه التوافقيات إطلاقا.

INTRODUCTION

Nowadays, with rapid growth of the population over the world, the need for a reliable and fast transportation system has been increasing significantly. Among all the different typs of the transporation systems, the electrical trains have been acquiring momentum and special concern and importance. They have been a preferred option due to their high performance, low maintenance cost, and lack of greenhouse-gas emissions. However, the traction system has a negative impact on the power system and may cause problems in the utility grid. These problems are including: large negative sequence components (NSCs), undesirable harmonics and low power factor, more system losses, overheating the rotating machines, malfunction of protection relays and measuring instruments [1] [2].

Moreover, the electric traction is changing its position continuously, therefore, it is considered as a dynamic load due to the non linearity feature. According to that, the power demands is varying with the time and it is controlled by the operating conditions, such as starting, accelerating, decelerating and breaking the traction, Also, the absorbed power from the utility side is a function of the railroad profile due to ascent and descent grades, curvature radius and rolling resistance.

In addition to that, the number of the passengers and the weight of the traction are affecting significantly on the consumption of power, and since the train is committed to travel with different speeds in every section in order to be maintained in the railways. Thus the voltage and current are varying continuously with the time [3].

In the AC traction system, the unbalanced voltage is the main problem, whereas the harmonic generation must be taken into account for the DC system. These harmonics are produced due to the converter systems which are connected with the substations. Unbalanced voltage and current could have a large effect on the power system and the other components connected to it. This effect has a different forms such as: reducing the torque of rotating machines, vibration, overheating the transformers the transmission lines and increase their losses, interference and overlapping with adjacent communication systems, raising electric and magnetic field (EMF) to humans near the transmission lines [4]. The generated harmonics may cause maloperation or miss the lock of the protection relays because it is injecting (NSCs) or composite voltage components. This will cause malfunction of phase-difference High-frequency protection system, and sometimes the high level of some individual harmonics might trigger system inductors, capacitors resonance, amplified the resonant and threat the power grid [5].

The power electronics devices are essential part of the electrical traction system. They are representing the connection ring between the power supply system and the traction side. Because they are rectifying the alternative current in to direct current. However they are affecting negatively in the power system quality. The main components of the rectifiers that are used in the recertification circuits are powerelectronics. The rectifier that are common used either 6 or 12 pulse rectifier, and in most cases it produces odd harmonics only [6].

The major problems caused by the electric traction are the voltage unbalance and the harmonics. These problems are representing big challenge for the utility; because they will affect negatively on the whole power system. The unbalance of the voltage occurres because the single traction system is connected between two lines and the harmonics produced due to the rectifier circuits which are used to rectify the AC current [7].

Also, the nonlinearity nature of the traction load produces large amount of harmonics at the load side and then these harmonics will be proppagated to the grid side. Many countries over the world have adopted the electrical train as the main transportation sustem. Therefore, they conducted intensive researches on the impact of these trains on the the power supply system and their impact on the power quality. However, China is the most country that has developed a model of an electrical train. Thus, a Chinese experience will be discussed in the following section [9].

China is the biggest country in terms of the population and the result of that it was necessary to develop the transport system in order to meet this challenge. It has been adopting the metro-transit system to be the main transport system in China. Recently electrified railway has developed rapidly, particularly with the opening of the

Beijing-Tianjin inter-city train and the advancement of the Beijing-shanghai high-speed railway construction, of the traction load in power system load proportion is more and more big [10] [14].

The traction system in China composes of AC-DC and AC-DC-AC traction which is affecting adversely on the network. The major problem of the DC traction is the harmonics that produced by the traction. These harmonics are injected in to the utility side which have a large influence on the power quality of the utility power system network. Also, in china a single phase AC voltage about 25 KV is considerd the main feeder to the electrical traction system. This causes a sever unbalance in the 3-phase power supply system [15] [17].

The authors in Ref.[18], discussed the impact of a high speed railway (HSR) with speed of 350 km/h on the utility grid. To analyze the effect of electric traction on utility voltage wave, the adopted model called CRH2C. This model uses rectifier and inverter. Both of them have been design with diode base. A typical Chinese model of High Speed Rail (HSR) connected to a power supply system, is presented in Ref. [19]. In this model, the efficiency of AC-DC-AC transformation determines the amount of absorbed current from the power supply system, when the traction needs to speed down, it transfers to the breaking mode, and in that case, the traction motors will act as generators, while the converters work as inverters. Most of the frequent methods that are used to present the traction load have represented the traction load by an equivalent admittance.

This is called constant impedance model or by an equivalent impedance which is called constant current model. However, these models are not valid to represent a dynamic activity of a system, which is the actual situation for the electric traction during its journey. Furthermore, the parameters of the system are vulnerable and can be affected by the other tractions connected to the same power supply [19].

In Ref. [20] [21], another Chinese model has been developed. In this model, the authors have adopted a real time simulation in large-scale power grid by using Advanced Digital Power system Simulator (ADPSS). It gives more accurate results than the previous studies. Authors in Ref [20] mentioned that, some dynamic conditions such as the slope of the road and the friction force have not considered. Autotransformer has been used to step-down the voltage from 25 KV to 1.5 KV. The secondary side of the transformer connected with a thyristor based converter circuit in order to rectify the current from AC to DC.

From the previous literatures, it is clearly seen that, most of studies have demonstrated measurements and utilized recorded data for assessing Power Quality (PQ) problems. Of course, the outcome results from field test are more accurate than the results that come from model-based simulation and reflect the real PQ issues and actual physical situation. However, model-based simulation is compulsary for the prediction process; it gives an overview about prospective conditions in future by simulating unrealistic cases. Furthermore, model-based simulation is more effective in system planning and enables the utility to take the required precautions for expected abnormal cinerios.

The Objectives

The objectives of this paper can be concluded as follows:

Conducting an intensive literature survey on the electrical train and its impact on the power system quality. Then, designing an electrin model for the DC type, this model will be represented by DC motors connecting to an AC/DC converter. After that, power supply system will be installed by obtaining Thevivnin equivalent for the network.

The most important part of the paper is to integrate the electric train model with power supply system on the PSCAD. This integration will be accomplished through a special type of transformer which is a V/V transformer. This will enable us to analyze the voltage and current waves of the power supply system in both cases. The first case, when there is only one traction connected at one of the V/V transformer terminals which is representing the unbalance case. The second case when there is a balance load on the two transformer terminals.

Total harmonic distortion of the voltage and current waves will be analyzed on the traction side and the power supply side to study the impact of such kind of load on the power system quality.

Proposed Model and Research Methodology

The electric traction is considered as a dynamic load because it is varying its position all the time during the journey. The power electronics elements in particular the thyristor and IGBT are playing a very important role in the controlling process of the traction speed.

The PSCAD Software has been adopted to establish the simulation model of the electric traction. Then this model has been used to analyze and study the behavior of the traction and its impact on power quality of the power system supply through a V/V transformer. Fig. 1 shows a schematic diagram of a traction system connected to a power supply system through a V/V transformer.

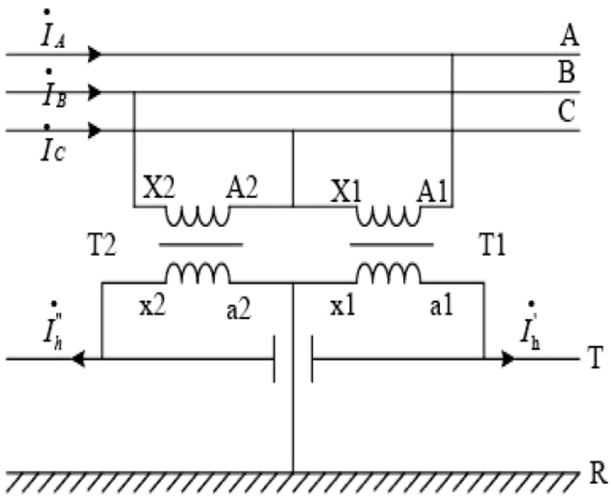

Fig. 1. The wiring diagram of three-phase V/V transformer.

To study the impact of the electric traction on power system an electric railway system model has been developed by using PSCAD. Then, this model has connected to 110 KV/ 25 KV power supply system through V/V transformer as shown in Figure 2.

The proposed model consists of two parts:

The first part, is the utility grid which is represented by Thevinin equivalent of the network connected to a transmission substation which is stepping down the voltage from 110 KV to 25 KV through V/V transformer.

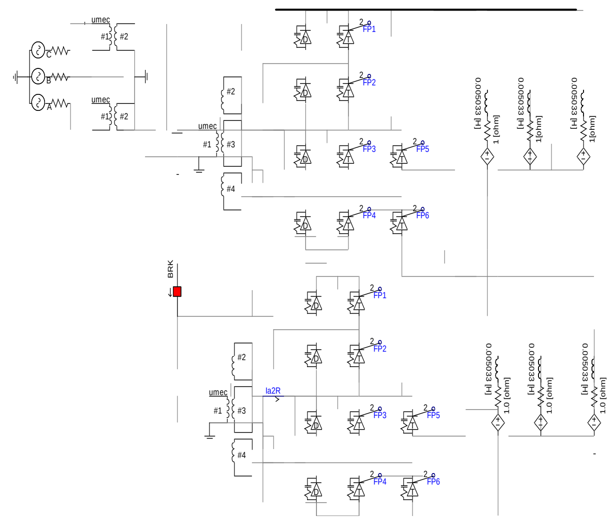

Fig. 2. The PSCAD model of electric railway system connected to V/V transformer.

The second part, is the electric traction system, which is consisting of the contact line system and rails connected to the V/V transformer which is reducing the voltage from 110 KV to 25 KV. This voltage will be applied to the rectifier circuit which is built of resistances connected in series with the diode and the parallel RC elements. The traction model is represented by a 6 DC motors. Each 3 of them are connected in parallel, these motors are represented by the back electromotive force (e.m.f), the main field inductance and armature resistance.

Simulation Results and Discussion

When the circuit breaker (CB) in Figure 2 is opened, the electric traction system will be connected only to the left arm of the transformer, while the right arm will be unloaded. This represents unbalanced loading condition of the transformer. Thus the harmonics will flow only through the phases that the traction is connected with, which are phase B and phase C, while phase A will not be affected. The voltage and current waves at the DC rectifier side is shown in Figures 3 and 4 respectively.

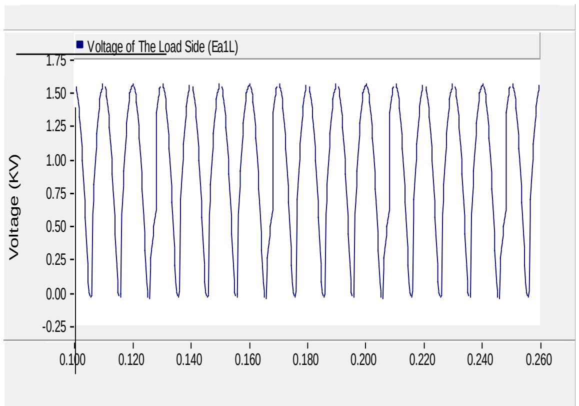

Fig. 3. Voltage waveform on 110 kV side of traction substation transformer.

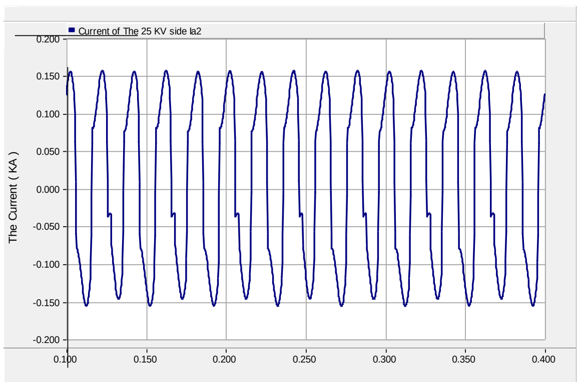

Fig. 4. Current waveform on 110 kV side of traction substation transformer.

The current wave at PCC has been analyzed. The harmonics spectrum of the total current at 110 KV side has been plotted as shown in Figure 5.

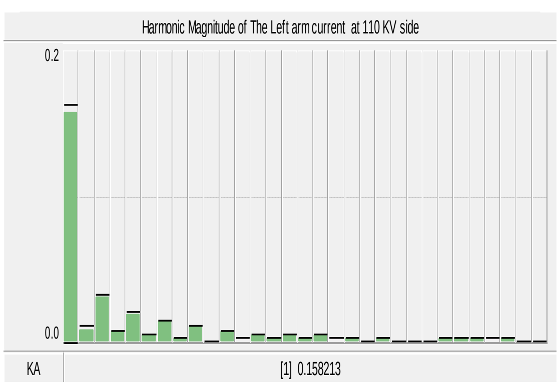

Fig. 5. Harmonics of the total current at 110 KV side.

The individual harmonics at 110 KV side for phase A, B and C are shown in Figures 6, 7 and 8 respectively.

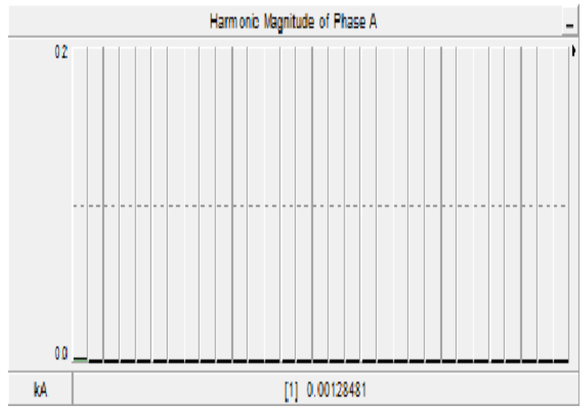

Fig. 6. The current harmonics of phase A on 110 KV side.

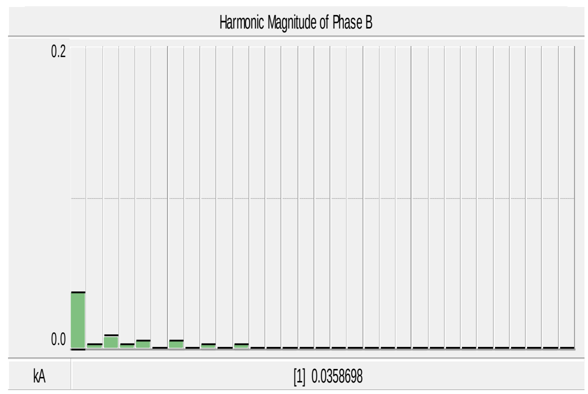

Figure 7. The current harmonics of phase B on 110 KV side.

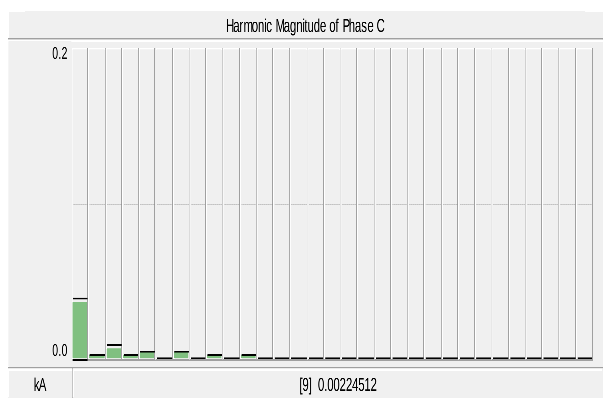

Figure 8. The current harmonics of phase C on 110 KV side.

From the harmonic current wave spectrum in Figure 5, it is obvious that at the PCC the lower odd harmonics are the dominant (3^{rd}, 5^{th}, 7^{th}, 9^{th} and 11^{th}).
From Figures 7 and 8, it is very clear that phase B current is substantially equal to phase C current. In this case the imbalance is 100% because the

current will flow only through the left arm on 25 KV side of the transformer and a large amount of (NSCs) have been generated due to the unsymmetrical load on the both sides of the transformer and this affected each of phase B and phase C and polluted the power system by injecting a large amount of harmonics into the system where phase A has a very little effect as shown in Figure 6. Because there was no flow of the current through it at the secondary side of the transformer.

The second condition when the traction load is symmetrical on the both side of the V/V transformer. This condition can be satisfied by closing the (CB) in Figure 2. The system became balanced and the harmonic spectrum on 110 KV side is plotted as shown in Figure 9.

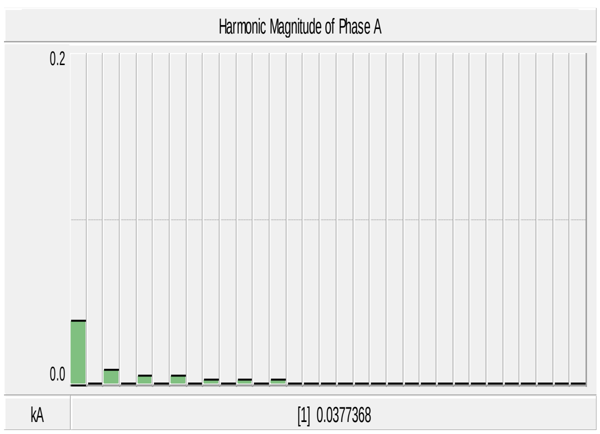

Fig. 9. The current harmonics of phase A on 110 KV side.

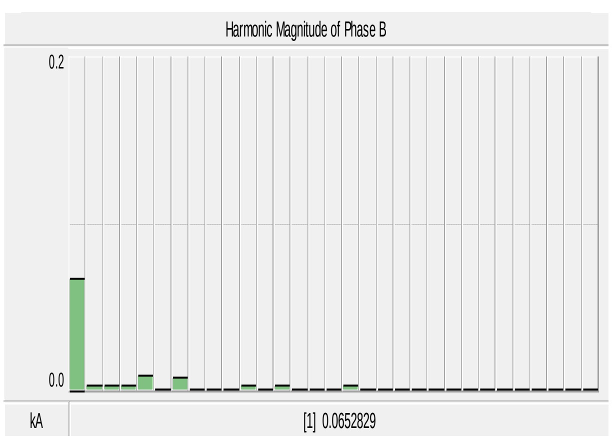

Fig. 10. The current harmonics of phase B on 110 KV side.

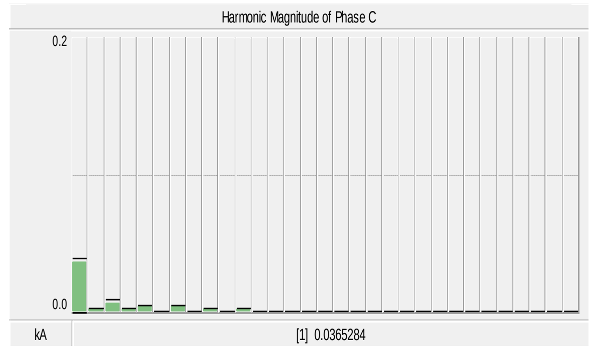

Fig. 11. The current harmonics of phase C on 110 KV side.

Figures 9, 10 and 11 show clearly that, when the load is symmetrical on the both sides of the transformer the harmonic spectrum is substantially equal on each of phase B and phase C, and the harmonic of phase A which is the common between the two sides of the transformer has a greater value than the other two phases.

Figures 12 and 13 show that the total current harmonics on both sides of the transformer was equally due to the symmetry of the load.

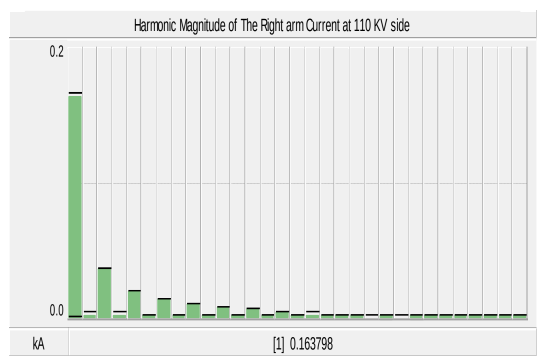

Fig. 12. The current harmonics of the right arm current on 25 KV side.

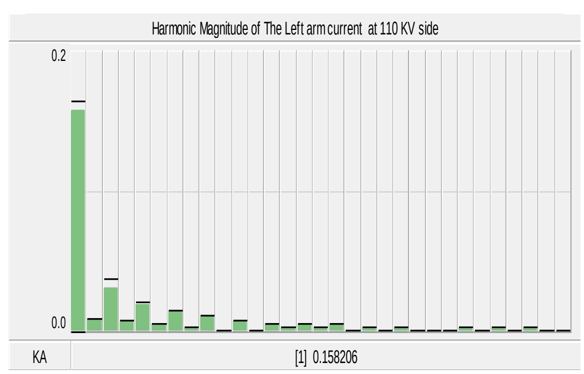

Fig. 13. The current harmonics of the left arm current on 25 KV side.

The rms value of the current for each of phase A abd B has measured and it found equal 107 for both of them.

It can be clearly seen that in the both cases of the loading conitions, a large amount of harmonics have been injected to the primary side of the substation transformer. But the distribution of this harmonics depends upon the load condition.

CONCLUSION

The fast development and the wide of the electrical traction over the world has envolved the electrical power system with new type of loads. These loads have high power ratings and un predictable due to the nature of its operation. Electrical trains are nonlinear load which means that it absorbes variable amount of current and thereby power from the utility side. Unconstant absorbtion of power leads to presence of many power quality issues in the network. Therefore, these type of loads should be subjected for an intensive study and analysis.

This paper shows that the electric traction system has a large impact on the electric power system. The traction system has a nonlinearity nature because it is moving continously from one point to another and it is varying its position continously.

The syudy shows also that, the connection of a traction to a power supply system is generating a large amount of harmonics on the phases that the traction is connected to them, while the other phase will not be affected. Also, the study shows that the harmonics that are genertaed at the traction load side will be transferred to the utility side throgh the transformer. So, any other load connected at the utility side will be affected as well.

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