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Power Quality Improvement of Thyristor Controlled Reactor using Harmonic Filters

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***Abstract:* -** The modern power grid operations encompass huge transmission network comprising of many transmission lines which are operating in scenarios of large load variations. This demands the application of various Flexible AC Transmission Systems (FACTS) devices which includes the Static Var Compensator (SVC) and the Thyristor Controlled Reactor (TCR) is a basic component of SVC, which injects the harmonics into the system. This article focuses on the power quality improvement of the system, which includes the TCR. The TCR injects the current harmonics into the grid which further leads to the voltage harmonics. This article focussed on the Total Harmonic Distortion (THD) analysis of the grid and TCR both of voltage and current harmonics. This article presents the simulation results of the test system with harmonic filters for three sections with variation in the firing angle of TCR. The simulation results proven that the grid voltage and current harmonics have been minimized significantly with the application of the harmonic filters to a great extent and THD content is very minimal and highly accepted according to IEEE Standards.

Keywords: Harmonic Filters, TCR, THD analysis, FFT Analysis, Power Quality, Harmonic mitigation, Voltage Harmonics, Current Harmonics.

I. INTRODUCTION

The modern power system consists of huge transmission interconnection in which the load on it is continuously varying with time and many of these lines are operating at either on no load or lightly loaded conditions [1] to [5]. This article focussed on the harmonic analysis and power quality improvement of the grid with Flexible AC Transmission Systems (FACTS) devices which includes the Static Var Compensator (SVC) and the Thyristor Controlled Reactor (TCR) is a basic component of SVC, which injects the harmonics into the system [6] to [9]. The Fast Fourier Transform (FFT) analysis has been performed on the grid with TCR alone and with TCR and Power Quality Compensators. The voltage and current harmonics have been increased with the application of TCR and these harmonics are harmful to the performance of the system, hence these harmonics are eliminated by the application of power quality equipment into the system such as the harmonic filters [10] to [16]. These two cases, one is system harmonics analysis including voltage and current harmonics with TCR and the second case is with TCR and power quality compensation equipment. The both of these results were presented in this article with MATLAB Simulations [6] to [16].

II. MATERIALS AND METHODS

2.1. Power Transmission Systems

The different abnormal conditions have made to enhance new technology replacing out dated technology for better operation of the power system. FACTS (Flexible AC Transmission System) technology has been introduced which belongs to power electronic based devices to improve the stability and reliability of the system. There are different types of FACTS controllers i.e., shunt, series and hybrid controllers used for mitigating different abnormal effects in the power system. Among different shunt devices, STATCOM is chosen for reducing Ferranti Effect due to its best control strategies in order to improve the system voltage stability by compensating reactive power [1] to [6].

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The Ferranti effect has been observed in both medium and long transmission lines, the line is considered as medium transmission line if the line length is less than or equal to 200 km and these lines can be analysed using Nominal-T and Nominal-Π configurations [7] to [10].

2.2. Nominal-T Configuration

In Nominal-T configuration as illustrated in Fig.1, the total shunt capacitance of line is lumped at the midpoint of the transmission line and the line inductance is divided into two equal halves, each is concentrated at both sending and receiving ends [1] to [4].

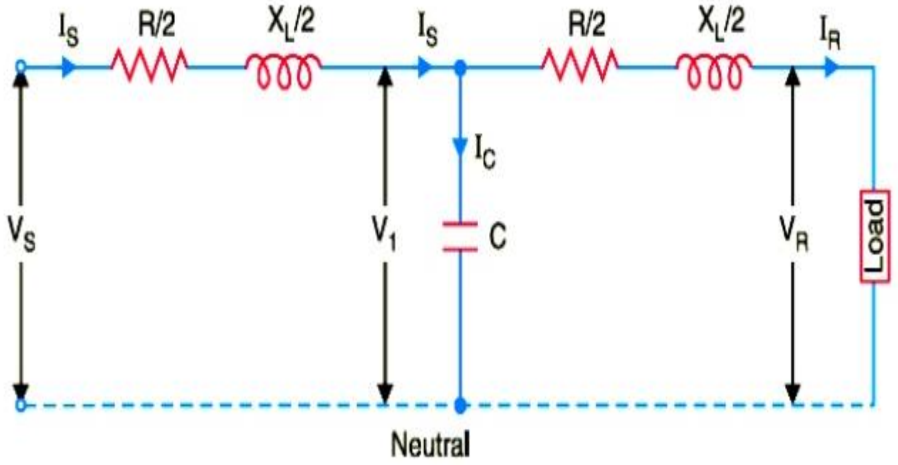

Fig.1. Equivalent circuit of Nominal-T method

2.3. Nominal- Π Configuration

In Nominal-Π configuration as illustrated in Fig.2, each total line capacitance is sub divided into two equal halves, concentrated at both the ends and the total impedance is placed at middle of the transmission line [1] to [5].

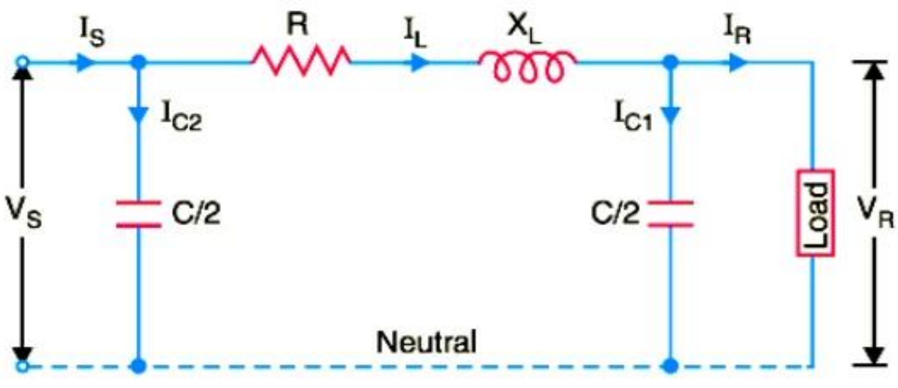

Fig. 2. Equivalent circuit of Nominal- Π method

If the length of the line exceeds 200 km, then that line is considered to be long transmission line where the line parameters are distributed over entire transmission line. Ferranti effect is predominant in long lines than in medium lines.

2.4. Equivalent T and Π Configurations

The equivalent circuit of long transmission line represented by equivalent-T as depicted in Fig.3, and equivalent-Π as depicted in Fig.4, networks with equivalent impedance and admittances and are expressed in the following equations (1), (2), (3) and (4) respectively [1] to [5].

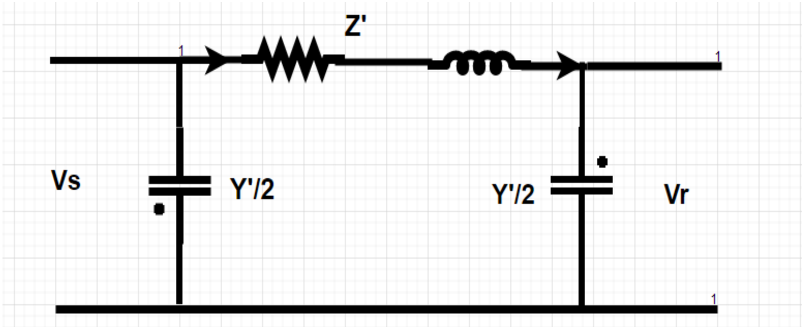

Fig. 3. Equivalent- Π network

$$Z' = Zsinh(\gamma l)/\gamma l \quad (1)$$

$$Y' = 2\frac{Ytanh\left(\frac{\gamma l}{2}\right)}{\gamma l} \quad (2)$$

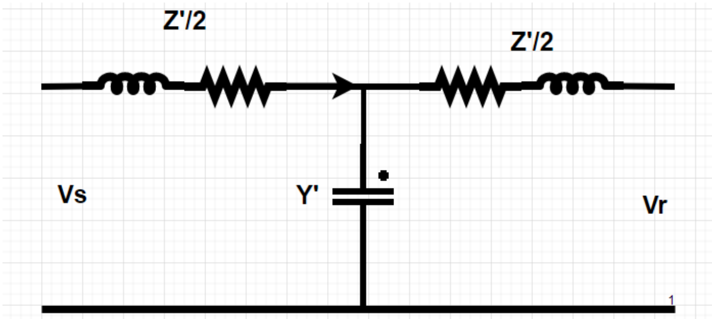

Fig. 4. Equivalent- T network

$$Y' = Ysinh(\gamma l)/\gamma l \quad (3)$$

$$Z' = 2\frac{Ztanh\left(\frac{\gamma l}{2}\right)}{\gamma l} \quad (4)$$

III. Transmission System with TCR and Harmonic Filters

3. 1. Test System with TCR

The power transmission system with the Thyristor Controlled Reactor (TCR) as illustrated in Fig.5 below, which comprised of Generator connected to the sending end and feeding the load with a transmission interconnection and at receiving end the TCR is connected in shunt for the compensation against Ferranti Effect. The TCR is used to control the current injection at receiving end may lead to change in reactive power injection for compensating Ferranti Effect. This injected current of TCR may pump the harmonics into the system of both voltage and current harmonics.

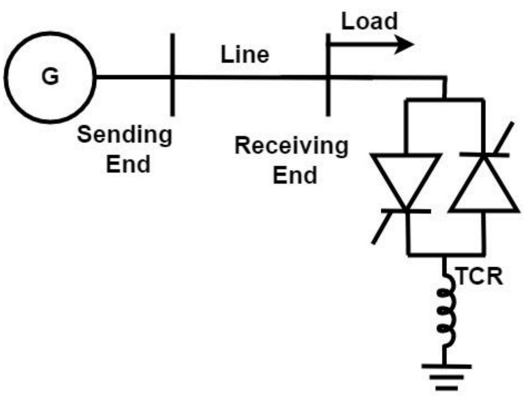

Fig.5 Power Transmission System with TCR

3. 2. Test System with TCR and harmonic filters

The test system is developed without harmonic filters and with harmonic filters and the Fig.6 depicts the Power Transmission System with TCR and Harmonic Filter for mitigation of both voltage as well as current harmonics. The effectiveness of this harmonic filter on the mitigation of both voltage and current harmonics has been presented in the subsequent section.

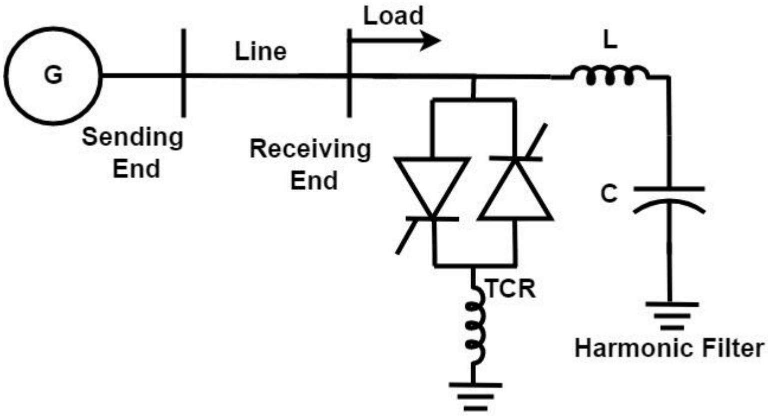

Fig.6 Power Transmission System with TCR and Harmonic Filter

3. 3. Thyristor Controlled Reactor (TCR)

TCR is an important FACTS device used for mitigation of Ferranti effect in power transmission and it is an important component of the Static Var Compensator (SVC), which is used widely in interconnected power systems for the reactive power control to ensure power system security. TCR injects the harmonics into the power system leading to adverse effects due to both current harmonics and subsequently voltage harmonics. The TCR is constituted with the reactor connected with the anti-parallel combination of the Thyristors as depicted in the below Fig.7 and equations from (5) to (7) describes the mathematical modelling of TCR.

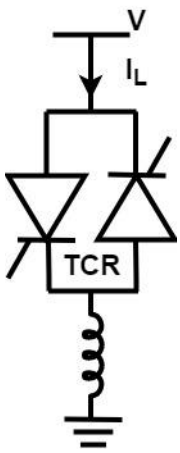

Fig. 7 Thyristor Controlled Reactor Schematic Circuit

$$B_{TCR}(\alpha) = B_{Lmax}\ [1 - \frac{2\alpha}{\pi} - \frac{1}{\pi}\sin 2\alpha] \tag{5}$$

$$I_{TCR}(\alpha) = \frac{V}{\omega L}[1 - \frac{2\alpha}{\pi} - \frac{1}{\pi}\sin 2\alpha] \tag{6}$$

$$I_{TCRh}(\alpha) = \frac{V}{\omega L}\frac{4}{\pi}\{\frac{sin\alpha\cos(n\alpha) - ncos\alpha\, cos(n\alpha)}{n(n^2-1)}\} \tag{7}$$

IV. CASE STUDY AND SIMULATION RESULTS

The power transmission test system is built with a grid feeding the load through a transmission system with a TCR as illustrated in the Simulink diagram as depicted in below Fig.8. In Case 2, the test system is designed with a harmonic passive filter for mitigation of both voltage and current harmonics in the grid and simulation diagram as illustrated in Fig.9 below.

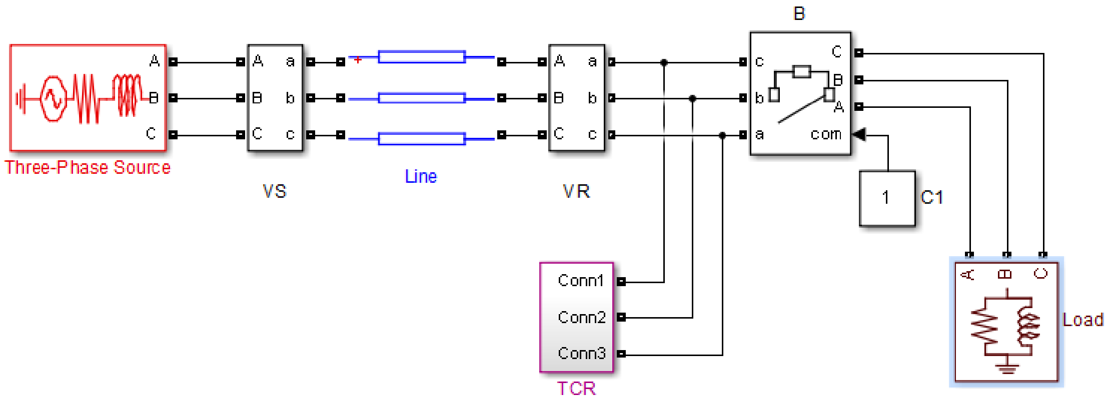

Fig.8 Simulink model of Grid and Transmission System with TCR

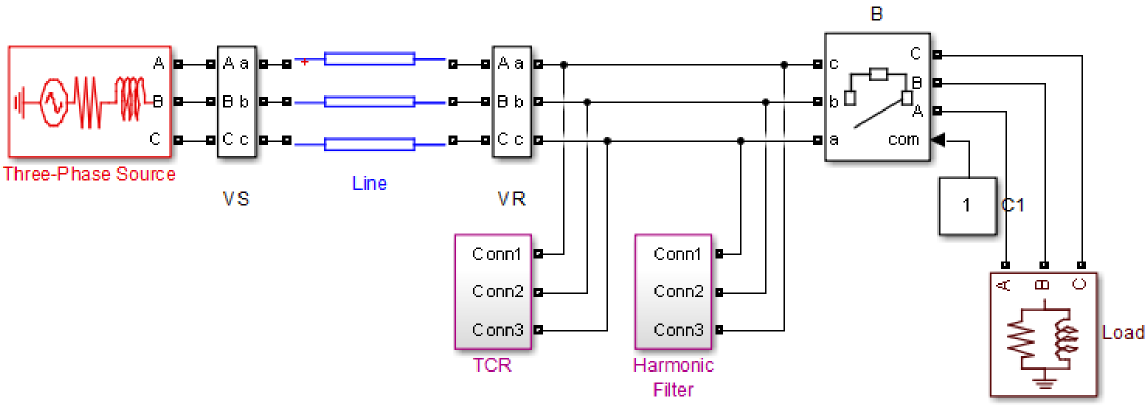

Fig.9 Simulink model of Grid and Transmission System with TCR and Harmonic Filter

The power transmission test system is simulated and presented in three sections viz. section 1 is with the test system with a firing angle of 100°, section 2 is with the test system with a firing angle of 130° and section 3 is with the test system with a firing angle of 160°. Each section is described the FFT Analysis of both TCR and grid.

4. 1. Section 1: test system with a firing angle of 100°

This section describes the FFT analysis and Total Harmonic Distortion (THD) of the TCR current, grid voltage and grid current with harmonic filters. The firing angle of the TCR is adjusted to 100°. Fig.10 illustrates the TCR Current FFT Analysis for firing angle of 100°, Fig.11depicts the Grid Voltage FFT Analysis for firing angle of 100° and Fig.12 shows the Grid Current FFT Analysis for firing angle of 100°. This analysis shows the THD of TCR injected current is of very high value of 47.45%, which is highly unacceptable and the grid side voltage and current harmonics have been minimized to a low value of 2.19% and 4.18% as illustrated in Fig.11 and Fig.12 respectively with the application of harmonic filters, which is highly acceptable according to IEEE standards. The design of harmonic filters have been carried out with the help of the reactive power based design.

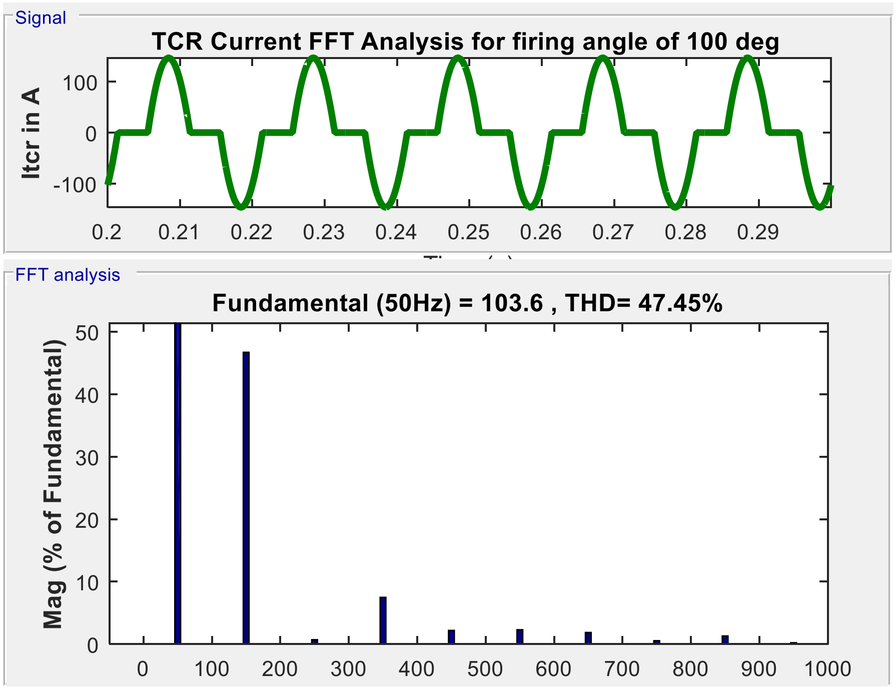

Fig.10 TCR Current FFT Analysis for firing angle of 100 °

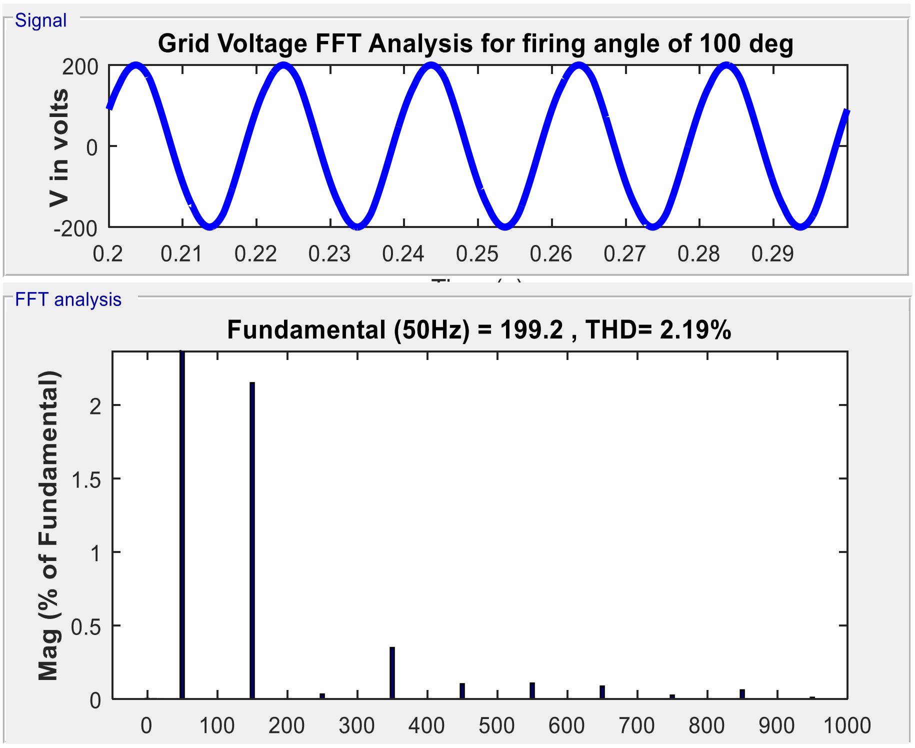

Fig.11 Grid Voltage FFT Analysis for firing angle of 100 °

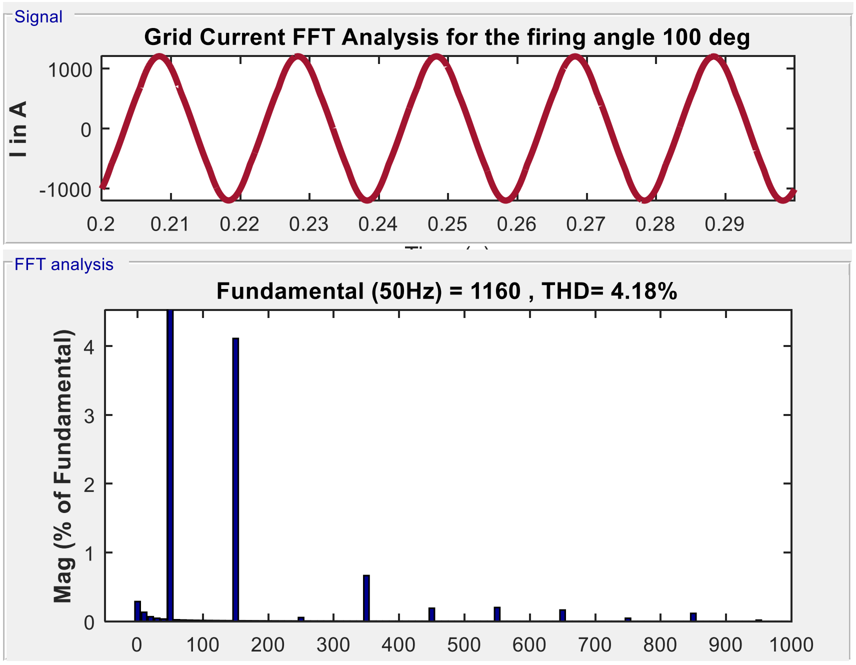

Fig.12 Grid Current FFT Analysis for firing angle of 100 º

4. 2. Section 2: test system with a firing angle of 130 º

This section describes the FFT analysis and Total Harmonic Distortion (THD) of the TCR current, grid voltage and grid current with harmonic filters. The firing angle of the TCR is adjusted to 100º. Fig.13 illustrates the TCR Current FFT Analysis for firing angle of 130º , Fig.14 depicts the Grid Voltage FFT Analysis for firing angle of 100º and Fig.15 shows the Grid Current FFT Analysis for firing angle of 130º . This analysis shows the THD of TCR injected current is of very high value of 87.22%, which is highly unacceptable and the grid side voltage and current harmonics have been minimized to a low value of 1.11% and 3.67% as illustrated in Fig.14 and Fig.15 respectively with the application of harmonic filters, which is highly acceptable according to IEEE standards. The design of harmonic filters has been carried out with the help of the reactive power-based design.

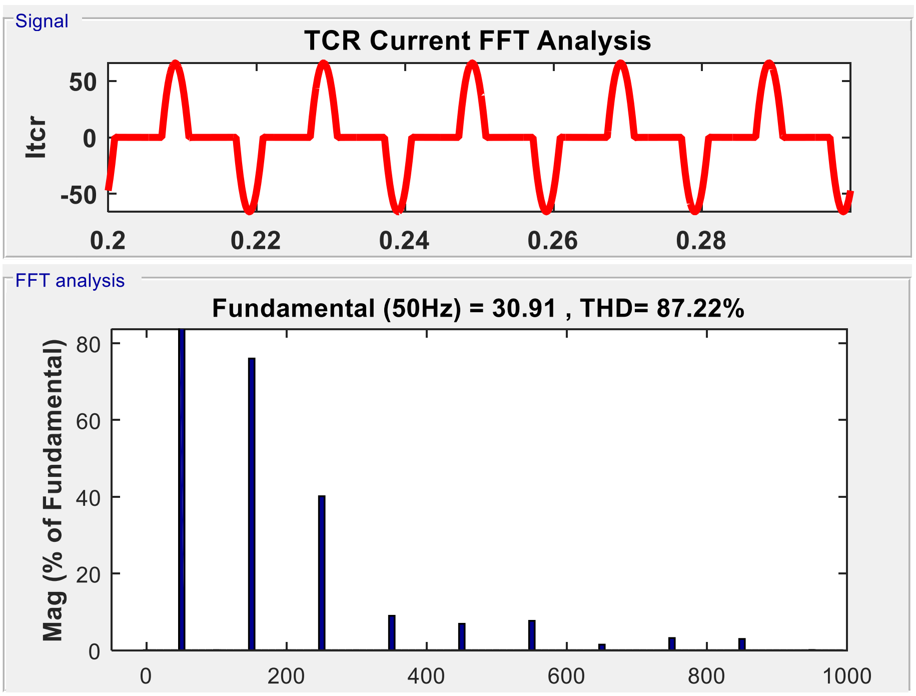

Fig.13 TCR Current FFT Analysis for firing angle of 130 º

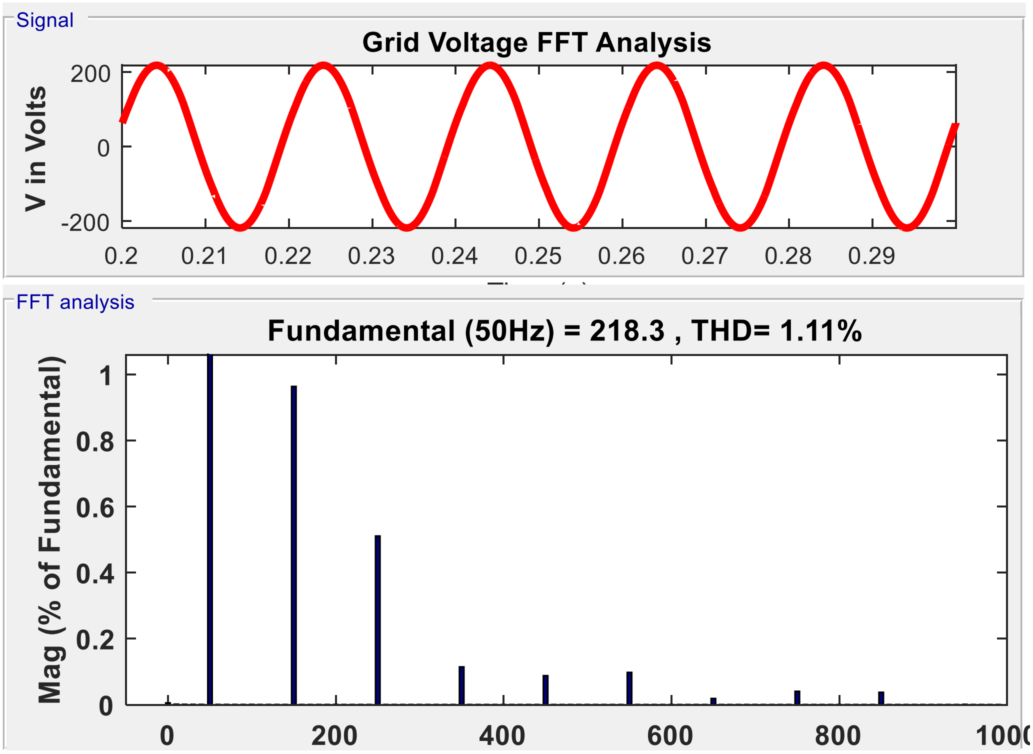

Fig.14 Grid Voltage FFT Analysis for firing angle of 130 º

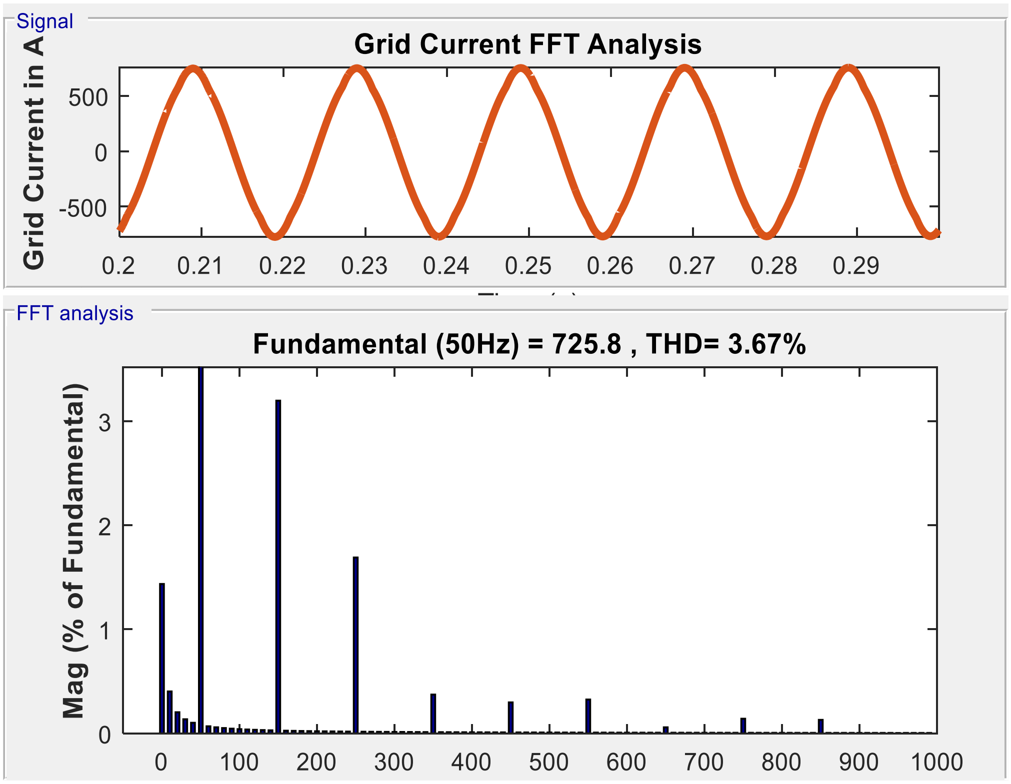

Fig.15 Grid Current FFT Analysis for firing angle of 130 º

4. 3. Section 3: test system with a firing angle of 160º

This section describes the FFT analysis and Total Harmonic Distortion (THD) of the TCR current, grid voltage and grid current with harmonic filters. The firing angle of the TCR is adjusted to 100º. Fig.16 illustrates the TCR Current FFT Analysis for firing angle of 130º, Fig.17 depicts the Grid Voltage FFT Analysis for firing angle of 100º and Fig.18 shows the Grid Current FFT Analysis for firing angle of 130º. This analysis shows the THD of TCR injected current is of very high value of 238.51%, which is highly unacceptable and the grid side voltage and current harmonics have been minimized to a low value of 0.06% and 0.34% as illustrated in Fig.17 and Fig.18 respectively with the application of harmonic filters, which is highly acceptable according to IEEE standards. The design of harmonic filters has been carried out with the help of the reactive power-based design.

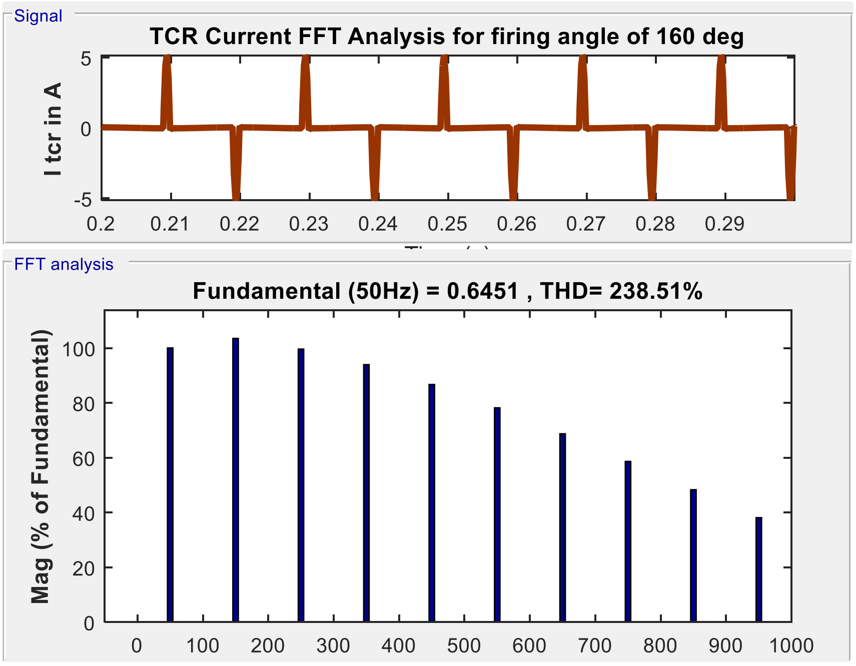

Fig.16 TCR Current FFT Analysis for firing angle of 160 º

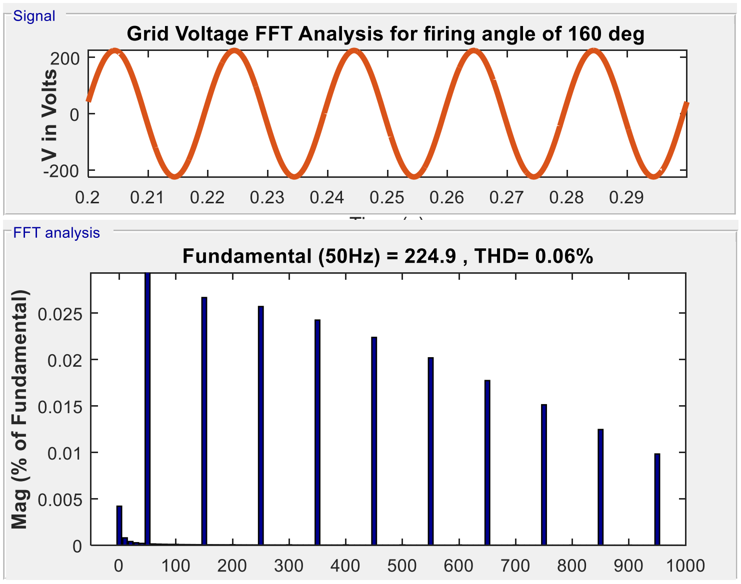

Fig.17 Grid Voltage FFT Analysis for firing angle of 160º

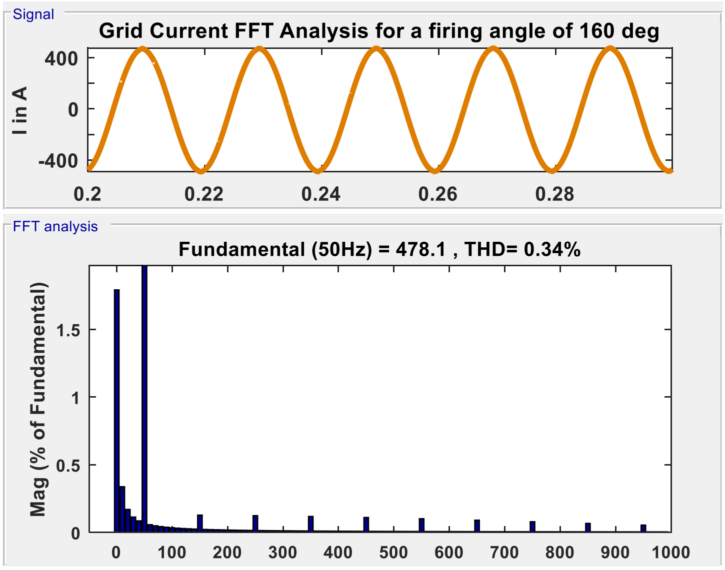

Fig.18 Grid Current FFT Analysis for firing angle of 160°

V. Conclusions

This article focuses on the power quality improvement of the system, which includes the TCR. The TCR injects the current harmonics into the grid which further leads to the voltage harmonics. This article focussed on the Total Harmonic Distortion (THD) analysis of the grid and TCR both of voltage and current harmonics. This article presents the simulation results of the test system with harmonic filters for three sections with variation in the firing angle of TCR. The simulation results proven that the grid voltage and current harmonics have been minimized significantly with the application of the harmonic filters to a great extent and THD content is very minimal and highly acceptable according to IEEE Standards.

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