Power Quality Issues and Harmonics Performance Analysis for Non Linear Load in Power Distribution System

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***Abstract*— This paper presents the power quality issues and their effects on utility, harmonics performance of nonlinear load in distribution power system network. Power electronics based applications used in power systems which causes harmonics and deteriorated the quality of electrical power. Non-linear (NL) loads are widely utilized in industrial which draw reactive power and generates the harmonics or harmonic currents in additional to fundamental frequency. Harmonics flow from load to source and distorted the utility current source. Voltage source at point of common coupling (PCC) at terminal voltage and before connecting the NL is rarely a purely sinusoidal. Efficiency of supply system is low due to nonlinear connected load and has poor power factor in power supply lines are reduced and return of current through neutral wire and increases sharply although system is balanced. It damages and failure of other equipment because of extreme stresses due to harmonics. In this paper diode bridge rectifier is chosen as non-linear load for study analysis and there significant effect and performance on power system. NL loads such as semiconductor based electronic devices, electric and induction furnaces and welding machines. According to IEEE-519 standard Total Harmonics Distortion (THD) should be less than five percent, waveform is approximately sinusoidal. A detailed steady state and dynamic performance of the non-linear load is presented by Simulink model through MATLAB Software.**

Keywords—power quality, harmonics, THD, nonlinear load

I. INTRODUCTION

Electric Power quality is the main concern in power system to maintain the electric supply on transmission line and to utility in pure sinusoidal shape waveform at rated voltage, magnitude and frequency [1]. The generally terms which describes the power quality (PQ) issues are voltage sag, swell, interruptions [2], voltage variations, noise, notching, voltage flicker, transients, frequency variations, blackouts, brownouts, electromagnetic interference and waveform distortion [3]. The increased use of power electronic based devices in industrial is the main reason of production of harmonic distortion in power system network in recent years. NL loads daily inflict disruption on the systems that create deviations from ideal power supply. NL loads affected supply source voltage and current, produce non-sinusoidal waveform, such types load as the semiconductor based devices, electrical furnaces, induction furnaces and welding devices introduces the voltage and current harmonics [3]. NL consequences can over electric load to system, slowdown the system's efficiency and working performance [4], causes harmonics in additional to the rated frequency. The current waveform gets distorted leading to distortion of voltage waveform and affects the supply source [2-3]. The voltage distortion is the highest at the loads, since full system impedance terminates at that point [5].

With recent developments in the field of power electronics, widely used of electronic appliances for industrial purpose especially in automation industries, in commercial and consumer needs. In conversion dc to ac and vice-versa, rectifier, converter, semiconductor, thyristors are used in placed of diodes. Bridge rectifiers utilization at the back end of power stage [6]. Electric ccompressor, air compressive home and car cleaner, air conditioner, television, computer and switch mode power supply (SMPS) having indiscriminate NL attributes and power electronics based converters are not special case [7]. These type NL loads creates many problems within source and load supply at load connected terminal such as distorted voltage, voltage flicking, over heating of transformers damage the electric and electronic base sensitive equipment [8]. The extremely usage of power converters and NL type loads towards deterioration of PQ and induces serious concern processes and significant economic losses [9]. IEEE standard-519, IEC 1000-3-2, IEC 1000-3-3 and IEC-3-4 standards are used to limit and compensate the harmonics and power quality issues. According to IEEE standard -519 THD should be less than five percent to operate system without heat and damage [7], [10]. Power electronics based devices concentrating to improve power quality are known as "Custom-Power" [2]. In 1988, the concept of flexible alternating current system (FACTS) is proposed by the Hingorani. FACTS devices are power electronic based power quality improvement devices, used to improve quality of power, power capability, voltage profile and controllability of power system network. Distribution Static Compensator (DSTATCOM), Static Compensator (STATCOM), Dynamic Voltage Restorer (DVR), active, passive, hybrid filter are the solutions to compensate the power quality issues [1-5].

II. HARMONICS

Harmonics are numerous of rated fundamental (50Hz) frequency, it can be even or odd harmonics, a type of distortion and transposing the value of voltage, current waveform and rated frequency [11]. Harmonics caused by various nonlinear loads, magnetic core, variable speed drives, solid state switch devices, power semiconductor devices, fluorescent lamps and personal computers [12].

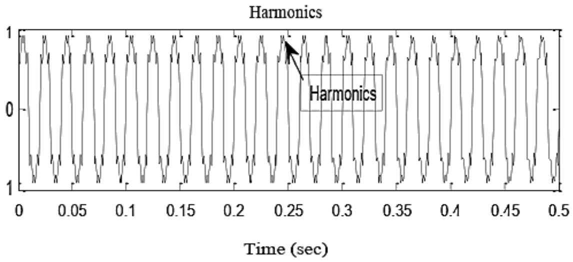


Fig. 2.1. Harmonics

The fundamental consequence of harmonics on the electronic device or system as heating of rotatory machines, transformers and cables, create various dangerous effect on system it can reduction the performance of device [13], causing so much damage, plant’s equipment fail to working normally, excessive heating, overloading and failure of machines, power transformers, ruinous of capacitors not outfitted within relevant string reduce the performance of inductor, faulty operation of digital controlled device, destruction of system equipment because of extended r.m.s. currents and voltages of capacitor, cogging and crawling appears in induction machine, acoustic noise from equipment and vibrations [14].

A. Inter harmonics

Inter harmonics terms belongs to those frequencies which are not integer-multiples of the fundamental. Inter harmonics that are under the fundamental frequency are also called subharmonics. Inter harmonics are often used for controlling the ripple (e.g. 175Hz or 317 Hz) [15]. Inter-harmonics is a waveform distortion kind that is normally end result of signal enforced on the rated deliver supply voltage by way of electrical device static frequency converters, arcing equipment and induction machine, cyclo-converters causes a number of the maximum enormous inter-harmonic power supply issues, this sort of devices transform the supply voltage in to ac voltage of decrease or at lower frequency [16-18].

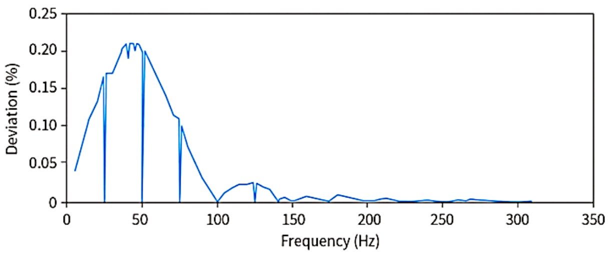
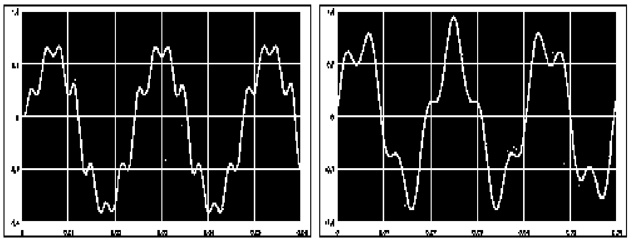


Fig. 2.2. Inter harmonics

Inter Harmonics caused by Magnetic saturation, arc furnaces, rectifiers, welding machines, NL loads such as SMPS and DC brush motors [19].

B. Sub-harmonics

Sub-harmonics term was introduced by Butler and Concordia. Harmonics which have non integer value within the frequency and lower than rated frequency are under concern. NL loads create harmonics current which cahnge the shape of wavefom are not necessarily sinusoidal [20], inductive type utility loads generates the harmonics that are multiples within fundamental frequency (e.g., 120Hz, 180Hz, 240Hz). A circuit which connecting in series with a resistive element, inductor and capacitor, voltage and current with frequency of lower than the fundamental frequency (e.g., 20Hz, 25Hz, 30Hz, etc.) will be produced, these are identified as sub harmonic frequencies [21]. It devlops the effects on induction generator, torque intensification, sub synchronous resonance, and saturated the transformer due to harmonics and heating. A sub-harmonic protection relay utilized to identify the sub-harmonic frequencies and consent the relay to proceeds counteractive action [22]. ERL invented modern S-PRO relay (sub-harmonic protection relay), Phase power technologies provides to the user a comprehensive sub-harmonic solution to protect the device from abnormal issues. S-PRO compromises 5-45Hz frequency protection, under-overvoltage protection, and overcurrent protection [22-26].



Harmonic waveform Interharmonics waveform

Fig 2.3. Waveform-shape difference between harmonics and inter harmonics

TABLE I. Comparison Between Harmonics, Interharmonics And Sub harmonics With Respect To Frequency and Harmonic order

Harmonic Type	Harmonics Frequency	Harmonic Order
Sub-harmonics	30	0.6
Harmonics	50	1st
Harmonics	150	3rd
Inter harmonics	175	3.5

Harmonics: sinusoidal component of periodic waveform shape within a frequency have an integral multiple of the 50 or 60 Hz frequency. For 60 Hz- fundamental, 120 Hz -2nd harmonic, 180 Hz-3rd harmonic, 240 Hz -4th harmonic and so on [11], [21].

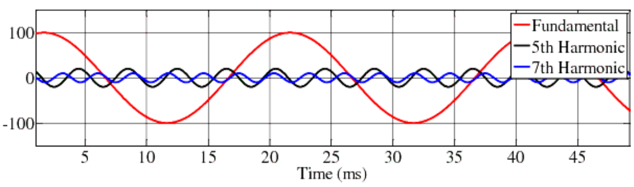


Fig 2.4. Waveform representation of different harmonics

Triplen Harmonics: Odd number multiplication of the 3rd order harmonics (3rd, 9th, 15th, 21st, etc.) [11], [16].

Harmonic Distortion: Ratio of harmonics to fundamental when a pure sine wave is reconstructed [11].

Total Harmonic Distortion (THD): The square root of the sum of square of all harmonic currents and voltage present in the load excluding the 60 Hz or 50 Hz fundamental. It is generally demonstrate as a percentage of the fundamental [4], [11].

III. Simulink Equivalent Model Methodology And Result Performance

Simulink model is design for non-linear load by the help of MATLAB software. Three phase voltage source is 230 V, 50 Hz which is represented by Vta Vtb and Vtc where Vt presents the terminal voltage and a,b,c, represent the phases and V_L represents the load voltage. NL load as a diode bridge rectifier is connected at the end of load point.

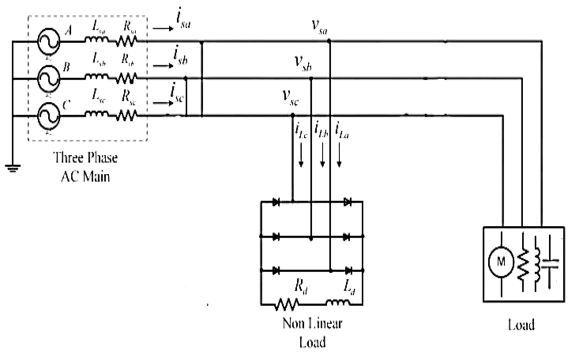


Fig 3.1. Model for nonlinear load

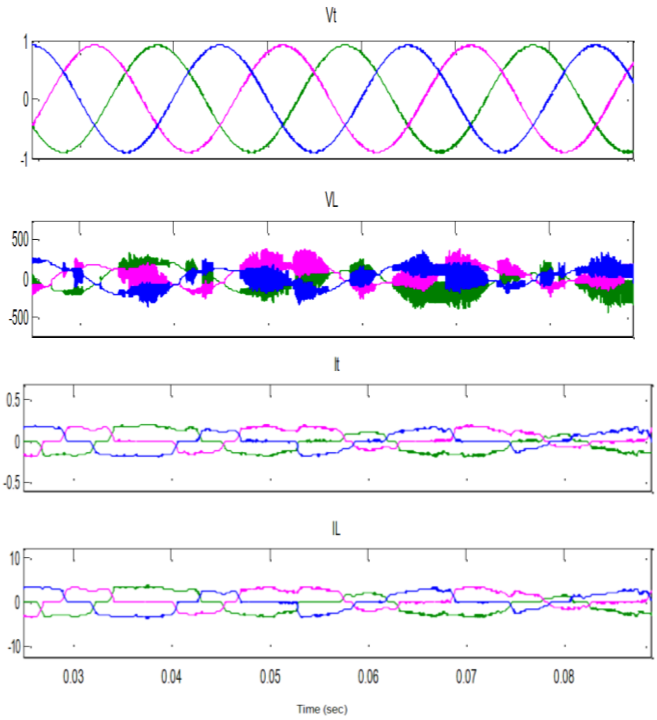


Fig. 3.2. Terminal voltage (Vt), load voltage (V_L), terminal current (I_t) and load current (I_L) performance

Fig 3.2 presents the performance of NL load which is connected at the end of terminal at load point. The terminal voltage (Vt) is pure sinusoidal and balanced that is there is no fluctuation and disturbances with supply voltage and no more harmonics. At the starting point time 0-0.1 sec. the waveform shape distorted due to magnetizing inrush current, suddenly a large voltage and current is required to operate inductive device. This waveform of supply voltage represent that there is no effect of non-linear load to supply voltage. Load voltage (VL) waveform is not sinusoidal due to non-linear load effects. Its shows that the NL load destroy the voltage and generate the harmonics much higher. Terminal current (It) contains more harmonics content at the power common coupling (PCC) point, while terminal current which is supply current source should be pure sinusoidal like as a voltage supply but it is not due to non-linear load because this type load generates the high rate harmonics. The reason is that harmonics which are generated by non-linear load are flow from load to source.

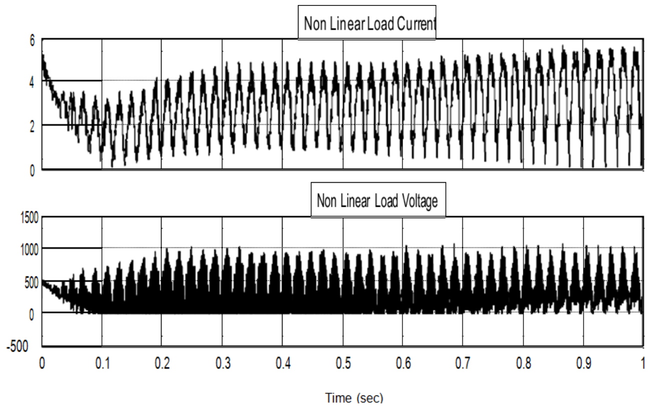


Fig 3.3 Non-linear load current and load voltage

Fig 3.3 presents the waveform shape of non-linear load, non- linear load voltage have low total harmonic distortion (THD) content compare than load current, it is clear that harmonics much affected the both terminal current and load current.

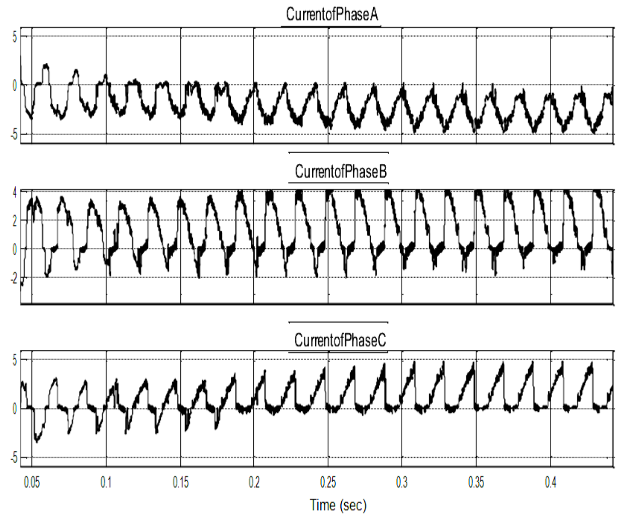


Fig 3.4 Non-linear load current of Phase A, B and Phase C

Fig 3.4 presents the current behavior of Phase A, B and phase C. Load current also have harmonics due to non-linear load and distorted waveform causes the heating problem with equipment which is utilized in industrial and commercial purpose.

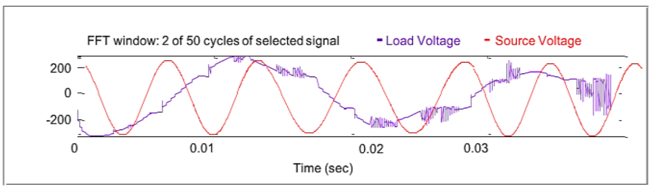


Fig.3.5. Non-linear load voltage and source voltage

Load voltage (VL) waveform is not sinusoidal due to non-linear load effects, it shows that the NL load destroy the voltage and generates the harmonics much higher. Load voltage have much higher THD than supply voltage, supply voltage THD is less than 5 percent which is negligible but load voltage THD is 20-25 percent.

IV. Fast Fourier Transform (FFT) Analysis For Total Harmonic Distortion (THD)

The maximum frequency evaluated by the FFT analysis. FFT analysis through Powergui sim power blocks which is given in MATLAB Power system library. FFT analyses done for find out the THD, fundamental frequency, harmonics order and waveform shape or signal details of the input and output constraints.

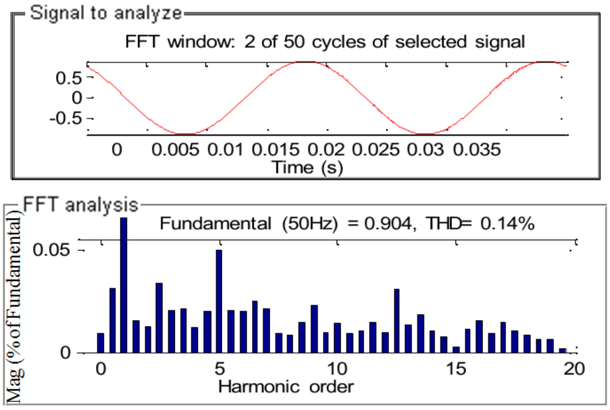


Fig.4.1. Terminal voltage at PCC along with harmonics spectrum

Fig 4.1 presents the THD spectrum for terminal voltage at PCC, which shows that fundamental magnitude value is 0.904 and THD is 0.14% which is negligible, results shows that waveform of power supply is sinusoidal and there is no distortion with Vt.

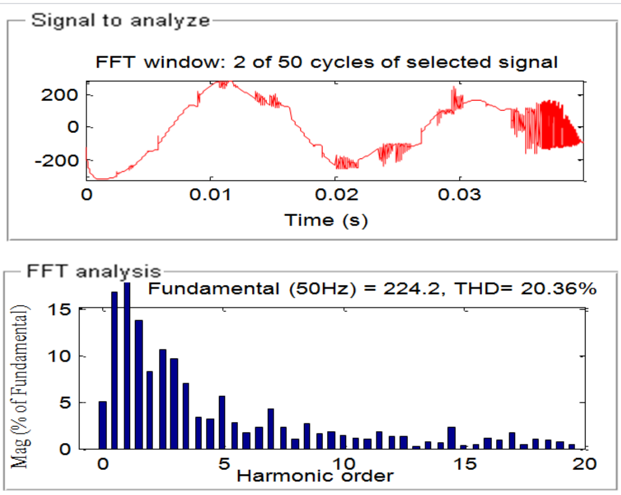


Fig. 4.2 Load voltage (VL) at PCC along with harmonics spectrum

Fig 4.2 presents the THD spectrum for load voltage at load terminal, which shows that fundamental value is 224.2 and THD is 20.36%, 3rd order harmonics which shows that waveform of power supply is non-sinusoidal and there is no high distortion with VL.

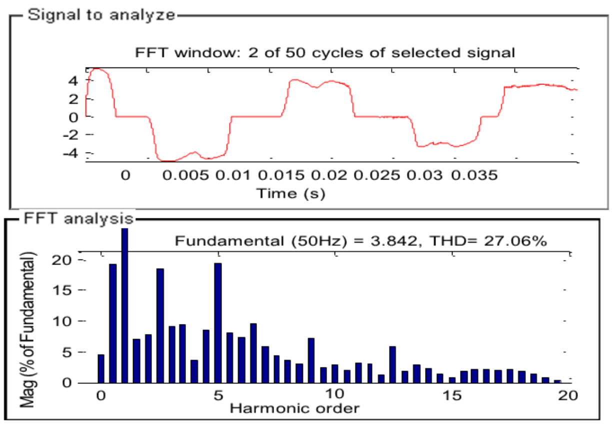


Fig. 4.3 Terminal and load current with harmonic spectrum

Fig 4.3 presents the THD for terminal current (It) and load current (IL), where fundamental (50 Hz) magnitude value is 3.842 and THD is 27.06%. The sinusoidal waveform is distorted, imbalance due to non-linear load.

TABLE II. Voltage Harmonics Limits Specified By IEEE-519 Standard

Voltage Distortion Limits		
Bus Voltage at PCC	***Individual Voltage Distortion (%)***	***Total Voltage Distortion THD (%)***
69kV and below	3	5.0
69.001 kV -161 kV	1.5	2.5
69.001 kV -161 kV	1	1.5

TABLE III. THD Result Comparison Between VT, VL, IT and IL

Bus Voltage at PCC	**Fundamental Frequency (50Hz)**	**THD%**
Vt	0.904	0.14
V_L	224.2	20.36
It	3.842	27.06
I_L	3.842	27.06

V. Conclusion

This paper conclude the performance of non-linear load as diode bridge rectifier, nature of waveform shape in modern power system and their source and effects on the equipment, power distribution system. When non-linear load is connected then current harmonics is generated by load, low power factor occurs and draw the reactive power and distorted the current and voltage waveform. The terminal current is distorted due to reactive power and flow of harmonics load to source. The terminal voltage THD is very low or negligible. Fundamental control strategy within Instantaneous Reactive Power Theory (IRPT) can be used to mitigation the harmonics. At PCC, THD voltage not much more 5% and individual harmonic distortion should in limit within 3% of the rated line voltage. Shunt Active Power Filter (SAPF), Passive Active Filter (PAF), Hybrid filter can be used for solve the power quality issues and mitigation of the harmonic currents due to nonlinear loads. Custom power device DVR, DSTATCOM, STATCOM, Unified Power

Quality Conditioner (UPQC) can be utilized within appropriate control techniques to satisfy IEEE-519 standards.

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