Simulation and Analysis Effects of Non-Linear Loads in the Distribution Systems

Suad Ibrahim Shahl

Abstract— The more of nonlinear loads such as computers, printers and TVs has caused a significant increase in electromagnetic disturbances in power systems (voltage sags, voltage swells, harmonics, etc.). The presence of such troubles in power system causes a decrease in operating efficiency. The more nonlinear loads on distribution systems,, the higher the overall sum of harmonics. Harmonics can damage components like fuses and circuit breakers, and can cause the increase of waveform voltage and current supply deformations with the consequent poor in the power quality and as a result voltage and current waveforms are not sinusoidal waveforms. This paper presents two set of MATLAB/Simulink models used to simulate one of power quality disturbances. The models presented include nonlinear load models to simulate harmonic and voltage notching disturbances generated from the load side. The presented models are used to simulate voltage waveforms for power quality analysis as well as contribute to the studying one of power quality disturbance.

Index Terms— Non-Linear Loads, harmonics, power quality, voltage notching

1 Introduction

Electric power systems have today become polluted in industrial world with unwanted variations in voltage and current. Power quality are primarily issues due to continually increasing sources of disturbances that occur in interconnected power grids, which contain large numbers of power sources, transmission lines, transformers and loads, such systems are exposed to environmental disturbances like lightning strikes [1].

Electric Power quality is defined as the waveform of normal sinusoidal voltage or current source without any deviations. Usually the term power quality refers to maintaining the bus voltage waveform pure- sinusoidal at rated voltage and frequency. The waveform of electric power at the generating stage is purely sinusoidal and free from deformation. Many of the power consumption equipments are designed to function under pure sinusoidal voltage waveforms. Thus the power quality deals with the interaction of electrical power with electrical equipment and represents the quality of supply [2]. The most common power quality problem in industrial distribution systems are the voltage disturbances, which mainly encompasses the voltage sags, swells, harmonics, transients, unbalances, and flickers. These disturbances can cause the malfunction of voltage-sensitive loads in factories and buildings [3].

The measure of power quality depends upon the needs of the equipment that are being connected to the supply. If the equipment connected with the supply operates correctly and reliably without being damaged or stressed, then the supply is a good quality. On the other hand if the equipment is damaged during the normal usage, then the power quality is poor [4].

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However, there are many devices that distort the waveforms of the electric power supply. These deformations may propagate all over the electrical network. In recent years, there has been an increased use. Of nonlinear loads which has resulted in an increased fraction of non-sinusoidal current and voltage in electric networks. In order to evaluate the effects of harmonics in the network, first it is necessary to refer to their sources and define the real characteristics of harmonics produced by different load types [5]. This paper is aimed to study the effect of used types of non-linear loads.

2 PARAMETER DEFINITIONS

2.1 Linear Loads

When a sinusoidal voltage is applied to a certain type of load, the current drawn by the load is proportional to the voltage and impedance. Voltage and current follow each other without any deformation. These loads are referred to as linear loads. Examples of linear loads are resistive heaters, incandescent lamps, and constant speed induction and synchronous motors. A sinusoidal voltage source

$$v(t) = \sqrt{2}V_{rms}Sin(\omega t) \quad (1)$$

Supplying a linear load, will produce a sinusoidal current of

$$i(t) = \sqrt{2}I_{Rms}\sin(\omega t - \varphi) \quad \textbf{(2)}$$

where V_{RMS} is the RMS value of the voltage, I_{RMS} is the RMS value of the current, ω is the angular frequency, φ is the phase angle and t is the time[6] ,[7]. The instantaneous power is

$$P(t) = V(t).i(t) \quad (3)$$

and it can be represented as

$$P(t) = 2VV_{Rms}I_{Rms}\sin\omega t\,.\sin(\omega t - \varphi) \quad (4)$$

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2.2 Nonlinear loads

When there is a nonlinear load in the system, it operates in non-sinusoidal condition and use of well-known parameters such as power factor, defined as cosine of phase difference, does not describe system properly. In that case, traditional power system quantities such as effective value, power (active, reactive, apparent), and power factor need to be numerically calculated from sampled voltage and current sequences. The RMS value of some periodic physical entity *X* (voltage or current) is calculated according to the well-known formula.

$$X_{Rms} = \sqrt{\frac{1}{T}\int_{t0}^{t0+T}(x(t^2))dt} \quad (5)$$

where $x(t)$ represents time evolution, T is the period and t_0 is arbitrary time. For any periodic physical entity $x(t)$, we can give Fourier representation:

$$X(t) = a_0 + \sum_{k=1}^{+\infty}(a_k.\cos(k\omega t) + b_k.\sin(k\omega t)) \quad (6)$$

$$X(t) = c_0 + \sum_{k=1}^{\infty} c_k.\cos(k\omega t + \psi_k) \quad (7)$$

where $c_0 = a_0$ represents DC component $c_k = \sqrt{a_k^2 + b_k^2}$ magnitude of k^{th} harmonic, ψ_k= arctan ($\frac{v_k}{-}$) phase of k^{th} harmonic and ω =2π/T, angular frequency.

2.3 Harmonic Problem Power Quality

A growing concern of power quality is harmonics deformation that is caused by non- linearity of load. However, some loads cause the current to vary inexplicably with the voltage during each half cycle. These loads are classified as nonlinear loads. The current and voltage have waveforms that are non-sinusoidal, containing deformations. Current harmonic deformation is load sensitive devices that draw non-sinusoidal currents According to [8] IEEE Std. 519 reported in 1981, "A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency is defined as harmonic".

Most devices only produce odd harmonics but some devices have a fluctuating power consumption, for half cycle or shorter, which then generates odd, even and inter- harmonic currents. The current deformation for each device changes due to the consumption of active power, background voltage deformation and changes in the source impedance.

The most common harmonic index is the total harmonic deformation (THD), which is termed as the Root-Mean-Square (RMS) of the harmonics expressed as a percentage of the fundamental component. Thus by definition Total Harmonic Deformation (THD) is the percentage measurement of the deformation resulted in voltage or current waveforms due to harmonics [9] , [10].

Mathematically any periodic signal (waveform) can be described by a series of sine and cosine functions, also called Fourier series.

$$u(t) = U_{dc} + \int_{n=1}^{\infty}(U_{max}\sin(n\omega t) + U_{max}\cos(n\omega t)) \quad (8)$$

Where $u(t)$ is any periodic waveform
U_{dc} is the DC component of the periodic waveform $u(t)$

Hence, when a signal passes through a non-ideal, non-linear device, additional content is added at the harmonics of the original frequencies, these content are of the multiples of the fundamental frequency n_f , which actually destroy the signal.

$$THD = \frac{\sqrt{\sum_{h=2}^{n} I_h^2}}{I_1} \quad (9)$$

Where I_h is the single frequency R.M.S. current at harmonic h, n is the maximum harmonic order to be considered and I_1 is the fundamental line to neutral R.M.S current. THD is a measurement of the extent of the distoetion and is defined by equation given below

$$THD = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots V_\infty^2}}{V_1} \quad (10)$$

Hence, THD characterizes the ratio of all signal components of the multiple frequencies except the fundamental frequency, to the first signal component of the fundamental frequency.

3 SIMULATION RESULTS AND DISCUSSION

3.1 Single Phase Nonlinear Load Model

The single-phase, nonlinear model developed in MATLAB/SIMULINK is shown in Figure 1 . It is used to simulate triplen harmonic voltage disturbance caused by single-phase bridge rectifier with filter capacitor. The model consists of:

- 11 kV, 30 MVA, 50 Hz three-phase source block feeding,
-11 kV/0.4 kV, 1 MVA Δ/Y transformer,
- 1 MW resistive load,
-single-phase bridge with 2,000 μF capacitive filter and 10 Ω resistive load for each phase.

Figure 2 shows the harmonic waveforms at 11 kV and 0.4 kV bus. Harmonic deformations at 0.4 kV are still noticeable along 240° of each cycle waveform. However, at 11 kV bus harmonic deformation has be significantly suppressed by the delta/wye transformer,

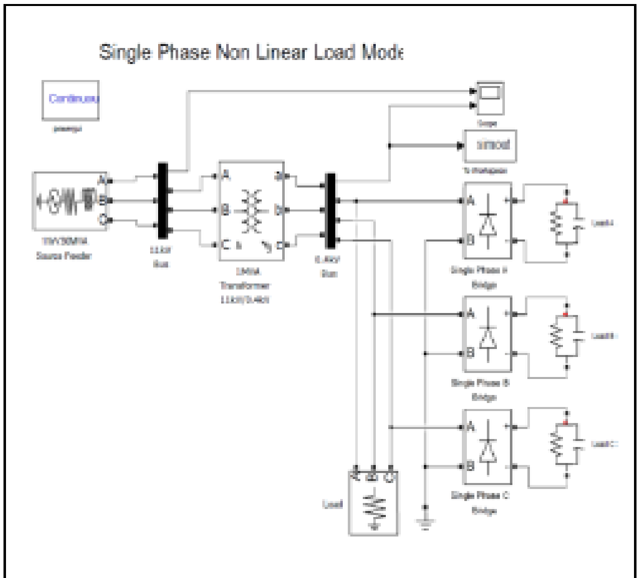

Fig. 1. Single-phase nonlinear load model.

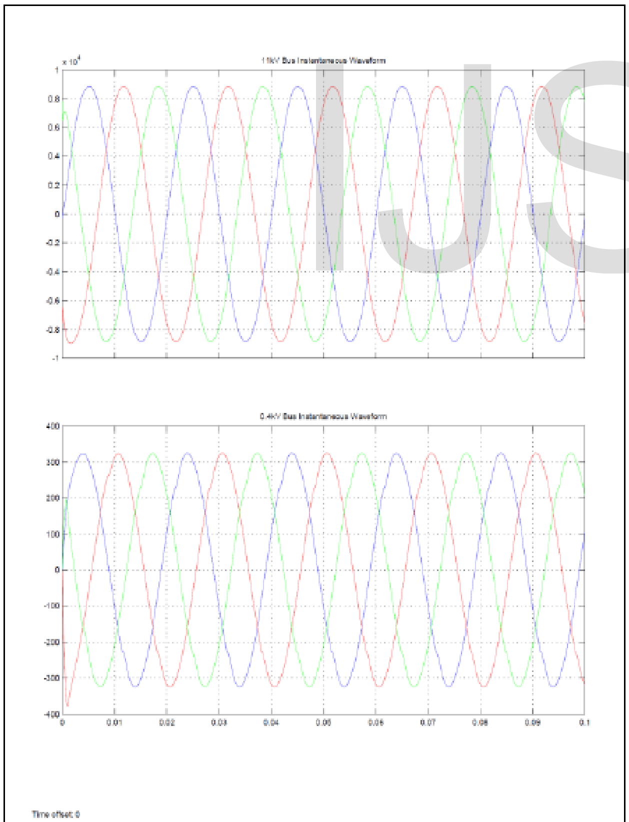

Fig. 2. Harmonic deformation waveforms at 11 kV bus and 0.4 kV bus.

To visualize the harmonic deformation, the simulation time is set at 0.2 second so that 10 cycles will be simulated. The power gui block is used to analyze the harmonic content with the setting of up to 2,000 Hz and 10 cycles window, Figure 3 clearly shows that at 0.4 kV, phase A consists of odd harmonic order with high 3rd order zero sequence harmonic, which is the unique characteristic of triplen harmonic generated by the single phase nonlinear load.

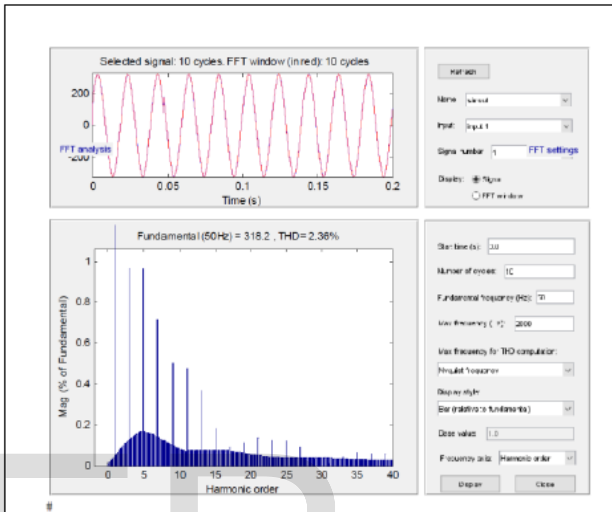

Fig. 3. Harmonic analysis of phase A harmonic deformation at 0.4 kV

3.2 Three Phase Nonlinear Load Model

The three-phase nonlinear load model developed in MATLAB/ SIMULINK is show in Figure 4. This nonlinear load model is used to simulate harmonic caused by a 6-pulse three-phase rectifier. The model consists of

-11 kV, 30 MVA, 50Hz three-phase source block feeding

- 11 kV/0.4 kV, 1MAV Δ/Y transformer

- 6-pulse controlled three-phase rectifier connected to a 600 V, 10 kW resistive and 1 kVA inductive load.

- 400 V, 10 kW resistive load connected in front of the three-phase rectifier

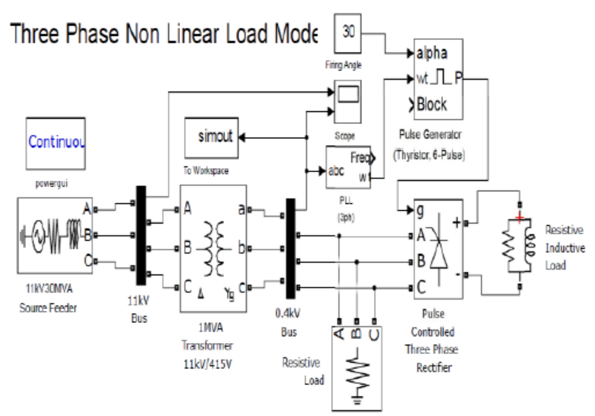

Fig. 4. Three--phase nonlinear load model

Figure 5 shows voltage notches caused by pulse controlled three-phase rectifier with pulse firing angle of 30°. The voltage notches for all three phase clearly visible across the sinusoidal waveform at 0.4 kV bus, again the voltage notches are significantly suppressed after it propagates upstream to 11 kV bus through the transformer.

To visualize the harmonic deformation, the power gui block is used to analyze the harmonic content. Figure 6 clearly shows that at 0.4 kV phase A consists of high 5th, 7th, 11th, 13th, 17th, 19th, 23rd, 25th, 29th, 31st, 35th, and 37th harmonic order, which is governed by a harmonic composite law in Equation (11), where H_o is the harmonic order, n is the natural number and q is the converter pulse number
.

$$H_0 = nq \pm 1 \tag{11}$$

4 Conclusion

Non-linear loads are most associated with modern electronic equipment that often relies on line-operated switch mode power supplies. These loads create harmonic deformation that can have adverse effects on your equipment. The non-linear loads may be either, single phase or a Three phase loads.The single-phase, nonlinear model developed in Matlab/Simulink is used to simulate triplen harmonic voltage disturbance caused by single-phase bridge rectifier with filter capacitor that is commonly found in domestic and commercial buildings. That all the triplen harmonics 3rd, 9th, 15th, and 21st generated from the single phase nonlinear load has been suppressed by the Δ/Y transformer.

The three-phase nonlinear load model developed in Matlab/Simulink is nonlinear load model is used to simulate voltage notches and harmonic caused by a 6-pulse three-phase rectifier. This three-phase nonlinear load model is capable to simulate voltage notches and negative sequence harmonic caused by the pulse-controlled, three-phase rectifier. The voltage notches for all three phase clearly visible across the sinusoidal waveform at 0.4 kV bus, again the voltage notches are significantly suppressed after it propagates upstream to 11 kV bus through the transformer.

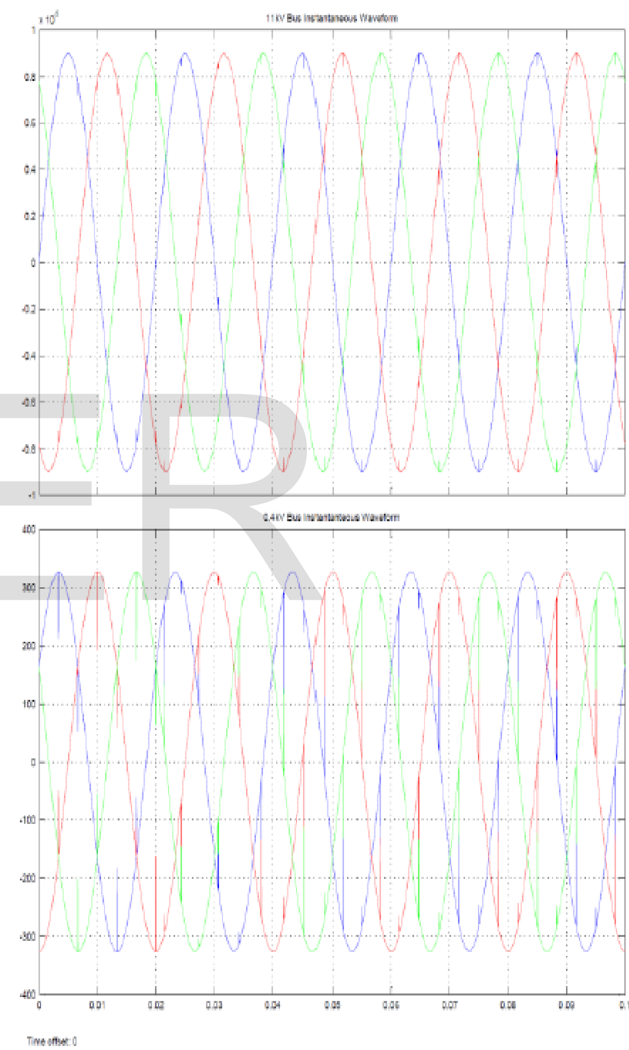

Fig. 5. Voltage notch waveforms at 11 kV bus and 0.4 kV bus

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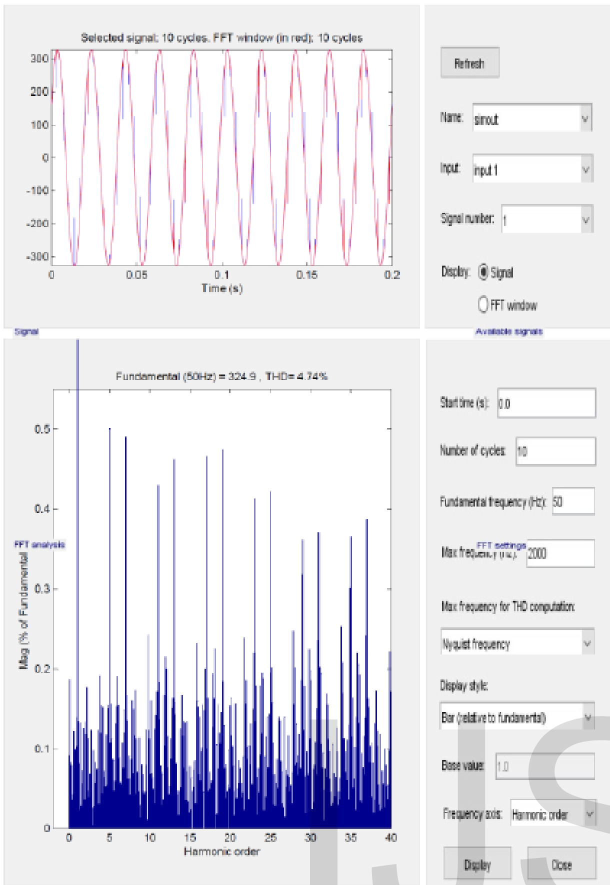

Fig. 6. Harmonic analysis of phase A voltage notch at 0.4 kV

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