Harmonic Distortion Analysis by Artificial Intelligence Technique

Bhagat Singh Tomar
Assistant Professor ,
Electrical Engineering Department
Laxmi Devi Institute of Engineering & Technology
Alwar ,Rajasthan (India)

Apeksha Rajput
Electrical Engineering Department
J.En –I
Rajasthan Rajya Vidhyut Prasaran Nigam limited
Bhiwadi ,Alwar ,Rajasthan (India)

***Abstract*— Harmonic distortion in power systems is an old problem which continues to grow in importance due to the proliferation of non-linear loads and of sensitive electronic devices. Thus, the need of standards to limit such distortion is required. Due to the time-varying nature of the distortion more advanced techniques are required to properly quantify their impact.**

***Index Terms*— Non-Linear Loads, Harmonic Distortion, Sensitive Electronic Devices, Losses, Sources, Resonance, Voltage Levels, Fuzzy Logic.**

I.INTRODUCTION

Harmonics in electrical power system is becoming a major concern for electric utility company and consumers. It is produced by power electronics and other equipments which are called non-linear loads. Examples of nonlinear loads are computers; fluorescent lamp and television in residential while variable speed drives, inverters and arc furnaces are mostly common in industrial areas. Increasing numbers of these loads in electrical system for the purpose of, such as improving energy efficiency, has caused an increase in harmonics pollution. These loads draw non-sinusoidal current from the system. The waveform is normally periodic according to supply frequency which is either 50Hz or 60Hz depending on the country.

Research, in general, on harmonic distortion aims at characterizing the distortion, the behavior of the loads and the power system. Also the effects the distortion has on loads, the system and the environment are studied. The research presented in this thesis concerns the sources of distortion (loads) and the interaction between those and the propagation of the distortion in the power system. Effects on the power system are also studied, e.g. additional losses, harmonic resonance and related financial costs. Further, mechanisms affecting the harmonic active power flow, in a certain point, are shown. A new mechanism concerning harmonic current interaction in high voltage transmission systems, due to a difference in the fundamental voltage phase angle between two nodes, is addressed.

II. SOURCES OF HARMONIC DISTORTION

Non-linear equipment or components in the power system cause distortion of the current and to a lesser extent of the voltage. These sources of distortion can be divided in three groups:

(a) Loads
(b) The power system itself (HVDC, SVC, Transformers, etc)
(c) The generation stage (Synchronous Generators)

Subdivision can also be made regarding the connection at different voltage levels. In general, loads can be considered connected at lower voltage levels, the power system exists at all voltage levels and the generation stage at low and medium voltage levels.

Electronic equipment, supplied from the low voltage power system, rectifies the ac power to dc power for internal use at different dc voltage levels. This is done, either with or without an ac step down transformer, and a diode rectifier.. The power range for each device is small, from a few W up to some kW. The total harmonic distortion, THD, of the line current is often over 100 % and consists of all odd multiples of the fundamental component. In some case the THD can be nearly 150%, mainly depending on the design of the DC-link and the crest factor of the supply voltage.

Harmonic producing equipments are found in varied locations from offices to manufacturing plants and they are becoming inevitable in daily life. Various harmonic producing equipments are:

(a) Personal computers
(b) Electronic lighting ballasts
(c)Variable and adjustable speed drives
(d) Industrial process controls
(e) Electronic test equipment
(f) Solid state controls
(g)UPS systems
(h) Medical equipment

III.HOW NON-LINEAR LOADS CREATE VOLTAGE DISTORTION

By far the majority of the voltage distortion found in today's distribution systems is produced by the loads themselves, not the supply. Much of today's electrical load is non-linear, meaning they consume current in a non-sinusoidal manner. Since, by definition, a no sinusoidal waveform is composed of harmonic currents; non -linear loads are considered to be harmonic current sources. In other words, by consuming current in a non-sinusoidal manner, these non-linear loads produce harmonic currents that circulate through the power

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distribution system. Most voltage distortion is the result of the interaction of these harmonic currents with the impedance of the electrical distribution system. As the harmonic currents pass through the system's impedance, they produce voltage drops at each harmonic frequency in relation to ohm's Law - $v_h = I_h \times Z_h$. The voltage drops appear as harmonic voltages and the accumulation of these voltages at all the harmonic frequencies produces the voltage distortion.

The relationship is:

$$V_{TH} = (v_1^2 + v_2^2 + v_3^2 + v_4^2 + \ldots v_h^2)\, 0.5 \qquad (1.1)$$

where , V_{THD} =Total harmonic distortion of voltage.

V_h =Voltage at harmonic h.

V_1 =Fundamental voltage.

Distortion levels can be quite high when system impedance is high. A fatal combination is high densities of non-linear loads in systems with high impedance or low fault level. This situation is common when weak sources, such as UPS system or diesel generators, are used to service electronic equipment. The problem is magnified further when the equipment is serviced by long cable runs.

IV. SIMULATION

A The Harmonic Distortion Fuzzy Model

The fuzzy model for the harmonic distortion diagnostic was implemented in MATLAB using the fuzzy logic toolbox. This toolbox allows for the creation of input membership functions, fuzzy control rules, and output membership functions. To implement this system in Simulink the system will need to have two different inputs: the harmonic voltage and the temperature. These two inputs will then be processed by a fuzzy logic controller that will output a degree of caution. This degree of caution is then decoded into one of four possible outputs: No problem, Caution, Possible Problem, and Imminent Problem. A simple (two-variable example) diagnostic system was created as shown in Figure 1.

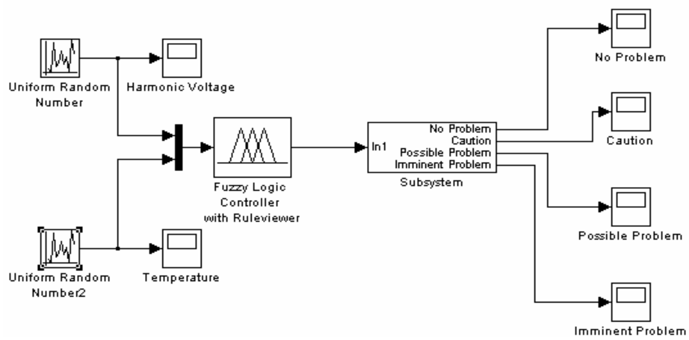

Figure 1 Harmonic Distortion Diagnostic Simulink Model

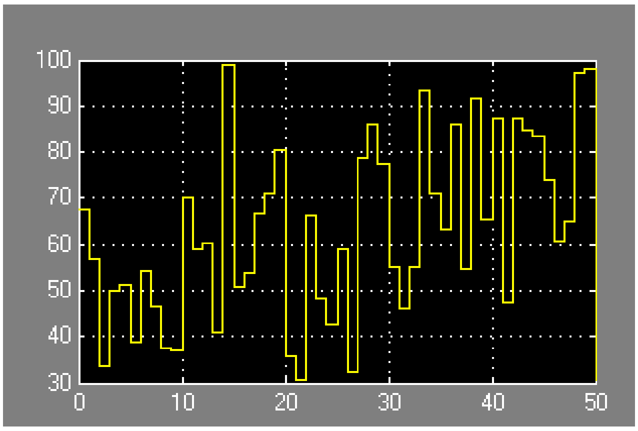

Figure 2 System Temperature Input

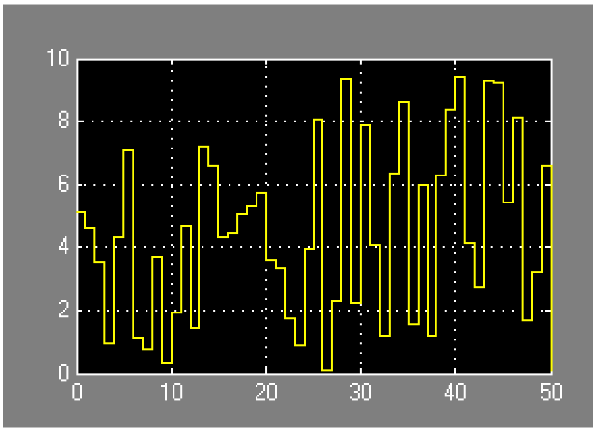

Figure 3 Harmonic Voltage Input

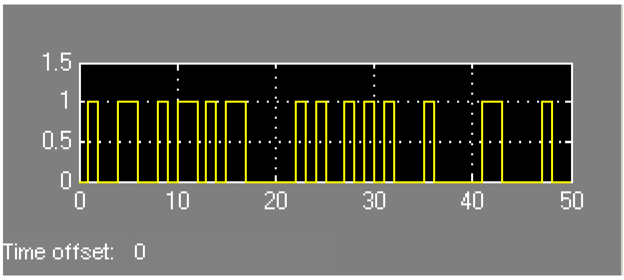

Figure 4 No Problem Output

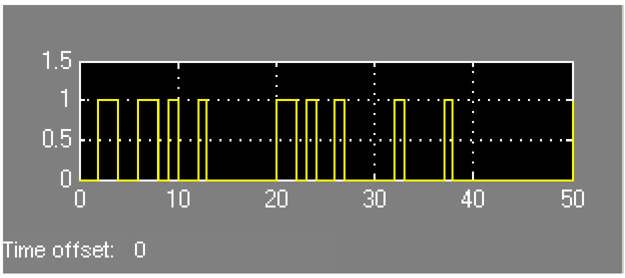

Figure 5 Caution Output

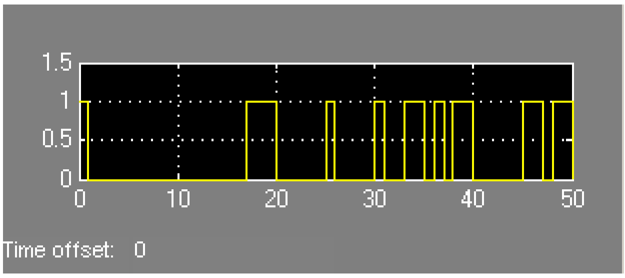

Figure 6 Possible Problem Output

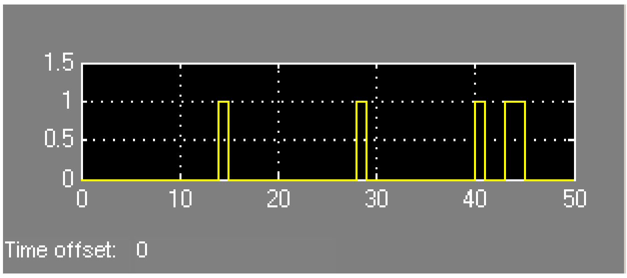

Figure 7 Imminent Problem Output

Table I. Membership Rules

If Harmonic Voltage is	And the temperature is	Then the Output is
very_low	Below normal	no _problem
very_low	normal	no _problem
very_low	over_heating	no _problem
very_low	very_hot	caution
low	Below_normal	no _problem
low	normal	no _problem
low	over_heating	caution
low	very_hot	Possible _problem
medium	Below_normal	no _problem
medium	normal	caution
medium	over_heating	Possible_problem
medium	very_hot	Possible_problem
high	Below_normal	caution
high	normal	Possible_problem
high	over_heating	Possible_problem
high	very_hot	Imminent_problem
very_high	Below_normal	Possible_problem
very_high	normal	Possible_problem
very_high	over_heating	Imminent problem
very_high	very_hot	Imminent_problem

The inputs for this example system have been shown before; they are randomly generated data within a valid range. The system can be simulated using this data. The output signals generated are shown in Figure 5.3 through Figure 5.6. The Fundamental and the harmonics will have uniform random function generators as inputs. These function generators will generate a uniform distribution of inputs within the variances . The total harmonic distortion will be calculated depending on these inputs and so it will be in the range of 1% to 13%, these are the best and worst case scenarios. The temperature variation will remain the same as in the previous case. Using this input data and the basic model developed in the first case a Simulink model can be developed that processes all the input data and gives an appropriate indication for each harmonic, the fundamental, and THD. These indications will remain the same as in the previous case. Each indicator will have a fuzzy logic controller that implements one of three control topologies, one for the fundamental, THD, and the harmonics. The final Simulink model can be seen in Figure

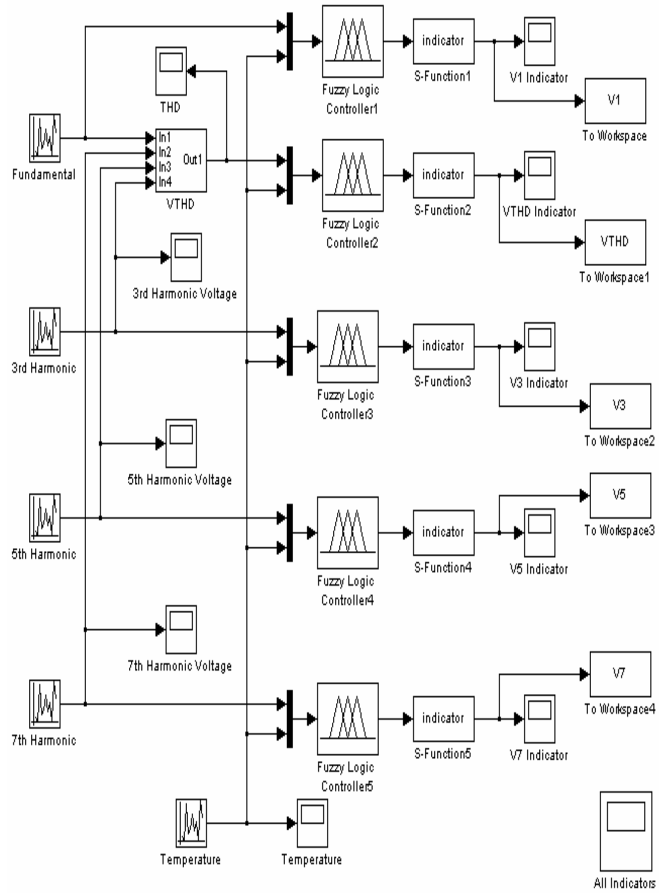

Figure 8 Final Simulink Model

B . Results

The inputs for this example system have been shown before; they are randomly generated data within a valid range. The system can be simulated using this data. The output signals generated are shown in Figure 5.3 through Figure 5.6. The Fundamental and the harmonics will have uniform random function generators as inputs. These function generators will generate a uniform distribution of inputs within the variances given in Table 2. The total harmonic distortion will be calculated depending on these inputs and so it will be in the range of 1% to 13%, these are the best and worst case scenarios. The temperature variation will remain the same as in the previous case. Using this input data and the basic model developed in the first case a Simulink model can be developed that processes all the input data and gives an appropriate indication for each harmonic, the fundamental, and THD. These indications will remain the same as in the previous case. Each indicator will have a fuzzy logic controller that implements one of three control topologies, one for the fundamental, THD, and the harmonics. The final Simulink model can be seen in Figure.

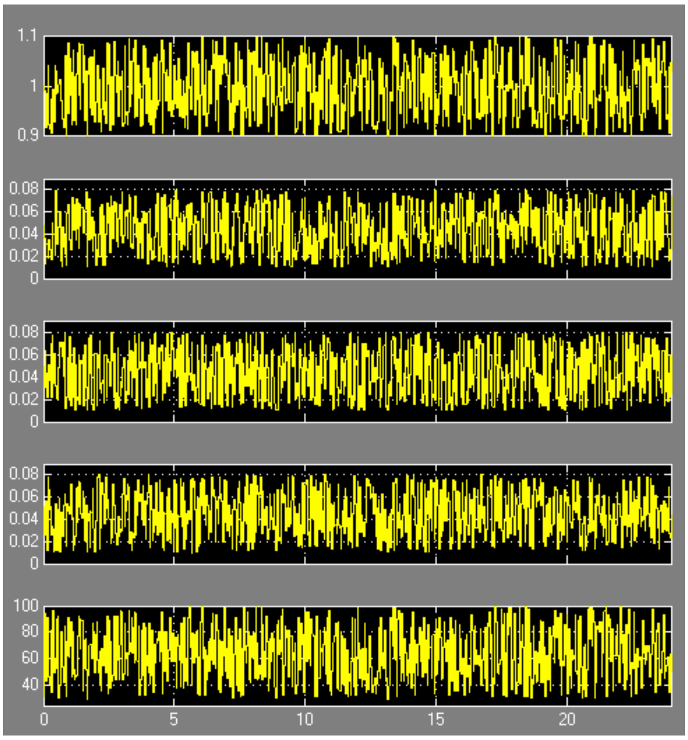

Figure.9 All System Inputs (top down): Fundamental, Third, Fifth, Seventh Harmonics and Temperature

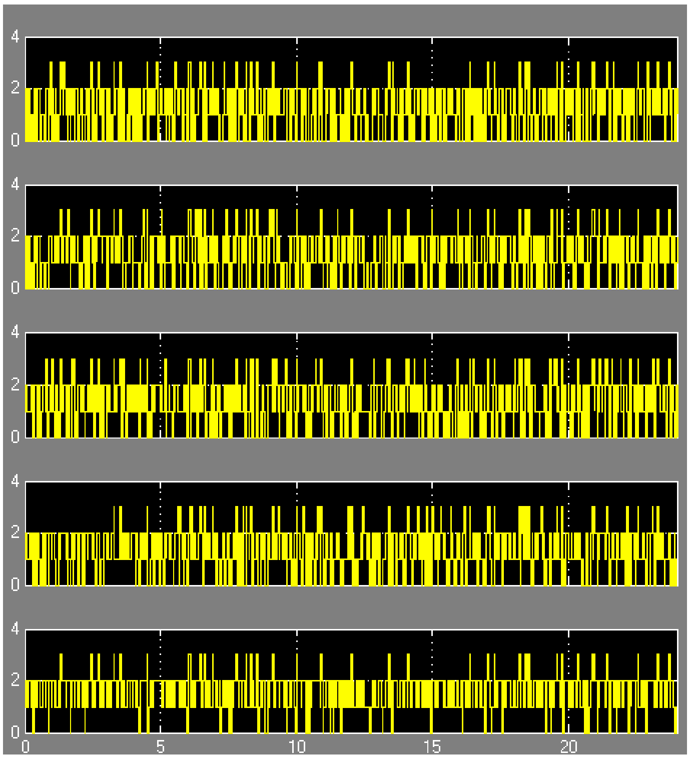

Figure 10 Output Indicators (Top down): Fundamental, Third, Fifth, Seventh Harmonics and THD.

V.CONCLUSION

The conclusions are that non-linear loads generate current distortion up to 200 % THD. The tendency for modern loads is a reduction of the lower order harmonics, below 1 kHz, and an increase of higher frequency components, up to 100 kHz. The current distortion decreases at higher voltage levels, around 5 % THD, mainly due to mixing with passive loads but also due to current interaction between single and three phase non-linear loads. The voltage distortion is also highest at low voltage levels, mostly below 6 % THD, and decreases down below 2 % at higher voltage levels. A dominating source of distortion, at all public voltage levels, is the use of television receivers at evening time with dominating 5:th and 7:th harmonics, up to 0.5 % of the fundamental component at 132 kV and 400 kV levels.

In this study harmonics modeling of office equipments is realized for harmonic analysis of modeled systems in Simulink with the help of measured real data, voltage-current values and harmonic current spectrums; proposed Simulink nonlinear resistance model and harmonics current injection model. According to Fig.6 and Fig.7 line current values acquired from nonlinear circuit (time domain) and harmonic current injection circuit (frequency domain) are very close and better than expected tolerances (<%0.1)

THD value of neutral current observed from Fig.7 and Fig. 8 is greater than %200, thus some harmonic mitigation options, such as oversizing conductors (especially neutral in three-phase circuits with shared neutrals), applying passive or active harmonic filters, must be carried out and detailed neutral harmonic analysis is needed for circuits mainly consisting of office equipments.

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