RECOGNITION AND CALCULATION OF HARMONIC POLLUTION FOR DISTRIBUTION SYSTEMS

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ABSTRACT: The focus of this paper is to recognize and to calculate the harmonics and develop a simulation method to investigate this concept in an interconnected power system containing nonlinear loads with resistive, inductive, and capacitive impedances. The IEEE 519 recommended practice provides indices to determine distortion as well as recommending limits within which systems containing harmonics should operate. Difficulty in solving harmonics problems is, as a renowned truth, initiated with the complexity to illuminate source and consequence between harmonic source and utility power systems. If we could measure harmonic current of inflow to load side from convenience power network and outflow to efficacy power network from load side, the harmonic problem will be effortlessly resolved and prohibited. Several varieties of harmonic instruments are being used, still, no realistic technology has been presented so far. We have developed the entire harmonic power (THP) methodology is one amongst the strategies planned within the literature for this purpose. This paper tries to indicate that the source of harmonic pollution is downstream with respect to the nodes (i.e., the load is the source of harmonic pollution). Then, a modification to the strategy is planned to generalize its application to non-radial systems.

KEYWORDS: Harmonics, total harmonic power, nonlinear load, resistive, inductive and capacitive.

INTRODUCTION

I present electrical circumstances; harmonic distortions have become an important concern for utility companies. Two schemes have been planned for restricting the amount of harmonic pollution nearby in a distribution system. The first proposal occupies the concern of confines on the amount of harmonic voltages and currents created by customers and utilities. Power systems are intended to function within the limits. This method has been extensively established in industry. The 519 IEEE Standard [1] and the IEC 1000-3 [2] are good examples. A major problem with this regulation-based system is that if the limits are go beyond by a customer, the only enforcement power the efficacy has is to cut off the customer, which is not attractive. As a consequence, an incentive-based scheme has been proposed recently. This scheme, inspired by the eminent power factor management practice, is to charge harmonic generators an amount corresponding with their harmonic pollution level when the limits are surpass. A revolutionary work in this area was described in [3]. The incentive scheme is considered by many as an ideal solution to control harmonic generations from disturbing loads. Unfortunately, the scheme faces two key technological challenges. One dispute is the need to split the harmonic involvement of a customer from that of the supply system. The other is to separate the effect of usefulness impedance deviation on customer's harmonic injection levels. Since the publication of [3], a lot of research efforts have been directed to these problems [4]–[7]. However, there are still no satisfactory solutions.

The total harmonic power (THP) method [10] is a simple method that uses the sign of the THP at a specific node to decide on whether the source of harmonic pollution is upstream or downstream from this node. Despite its simplicity, this method suffers from two main drawbacks: 1) the concept of upstream and downstream cannot be applied to non radial networks. 2) the sign of the THP depends on the phase shifts between the voltages and currents at different harmonic orders. Hence, any error in calculating these phase shifts affects the reliability of the method. Such a problem becomes serious for higher harmonic orders when the system has an inductive nature and the phase shifts approach 90

[12]. The capability of the THP method in identifying the source of harmonic pollution correctly has been questioned by some researchers. The results were not similar for some cases and, thus, the THP method was assumed to fail in these cases. However, using an index that is entirely designed for the method proposed in [6], as a basis for the comparison, seems unreasonable. Accordingly, the THP method was assumed to be unsuitable for some cases as it cannot accommodate this concept. However, this idea is questionable, because it assumes that a load that will increase the ability loss within the system as a result of the generation of harmonic powers will still be outlined as not a problematic load that is certainly not a sensible assumption.

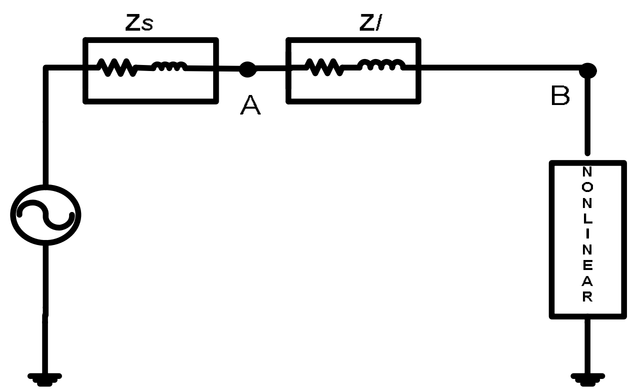

Figure 1. Simple network with a nonlinear load connected to a sinusoidal supply

TOTAL HARMONIC POWER METHOD

The fundamentals of the THP technique are often illustrated by using the circuit shown in Fig. 1. a perfect sinusoidal voltage source is connected to a nonlinear load through the system impedance. The nonlinear load generates harmonic currents that flow within the system inflicting voltage distortion at PCC. This voltage distortion depends on each the harmonic currents and the system electrical phenomenon at harmonic frequencies. The distorted voltage and current at PCC are often expressed by Fourier series as

$$v_{pcc}(t) = V_0 + \sum_{h=1}^{\infty} \sqrt{2Vh \sin(h\omega 1t + \theta hV)} \quad (1)$$
$$i_{pcc}(t) = V_0 + \sum_{h=1}^{\infty} \sqrt{2Ih \sin(h\omega 1t + \theta hI)} \quad (2)$$

where Vpcc(t) and ipcc(t) are the instantaneous voltage and current at point pcc, h is the harmonic order, $\boldsymbol{\omega}_1$ is the fundamental angular frequency of the supply, V_0 and I_0 are the magnitudes of dc components of the voltage and current, V_h and I_h are the rms values of the voltage and current at frequency h$\boldsymbol{\omega}$1, and $\boldsymbol{\theta}_{hv}$ and $\boldsymbol{\theta}_{hI}$ are the phase shifts of the *h*th harmonic voltage and current with respect to a common reference.
The instantaneous power at any point in the system is defined as

$$p(t)=v(t).i(t) \quad (3)$$

The average power at point pcc is

$$P_{pcc} = \frac{1}{T}\int_0^T pb(t)dt \quad (4)$$
$$\therefore P_{pcc}=V_0I_0 + \sum_{h=1}^{\infty} VhIh\, cos\Phi h \quad (5)$$

The average power at point pcc can be decomposed into: 1) power due to dc components P_0; 2) fundamental active power P_1; and 3) total harmonic active power P_H

$$P_{pcc}=P_0+P_1+P_H \quad (6)$$
$$P_0=V_0I_0 \quad (7)$$
$$P_1=V_1I_1 cos\Phi 1 \quad (8)$$
$$P_H= \sum_{h=2}^{\infty} VhIh\, cos\Phi h \quad (9)$$

Consider the voltage at point A as a reference, hence

$$v_A(t)=\sqrt{2}V_{A1}\sin(\omega 1t) \quad (10)$$

Applying the procedure outlined before to point A, the average power at A can be given by

$$P_{A1}=V_{A1}I_{B1}\cos\Phi 1 \qquad (11)$$

Equation (11) demonstrates the well-known fact that a sinusoidal source delivers power only at the fundamental frequency. Some of this power is dissipated in the resistance of the system impedance and the rest flows to the load side. The nonlinear load is the only source of distortion in this case that generates harmonic currents at different frequencies. Thus, harmonic powers, with a total value of P_H flow from the load side to the supply side and are dissipated in the resistance of the system impedance [18]. As a conclusion, the nonlinear load converts power at the fundamental frequency to powers at the fundamental and harmonic frequencies. The THP method suggests that the THP at a certain node is an indication for the existence of a polluting load. Moreover, the sign of this power can be used to identify the location of the polluting load in radial systems as follows.

If P_H positive at a certain point in the system, then a harmonic source exists upstream of this point and the harmonic power is received from the source side. If P_H is negative, then a harmonic source exists downstream of the node under study, and the harmonic power is received from the load side.

SYSTEM CONFIGURATION

Case 1: THP method for nonlinear loads with resistive load of 100 Ω, input 230-Vrms, 50-Hz sinusoidal supply with an internal impedance of Zs=1+*j6.28* Ω is connected to Node A of the circuit shown in Fig. 2. The line impedance is Zl= 2+*j*12.56 Ω and the load is a phase-controlled bridge rectifier with a firing angle of $\alpha=30^o$ and 60^o.

1) The fundamental power P_1 is positive at nodes A and B and decreases from A to B. This indicates that the supply is delivering fundamental power to the load and some of this power is lost in the line resistance.

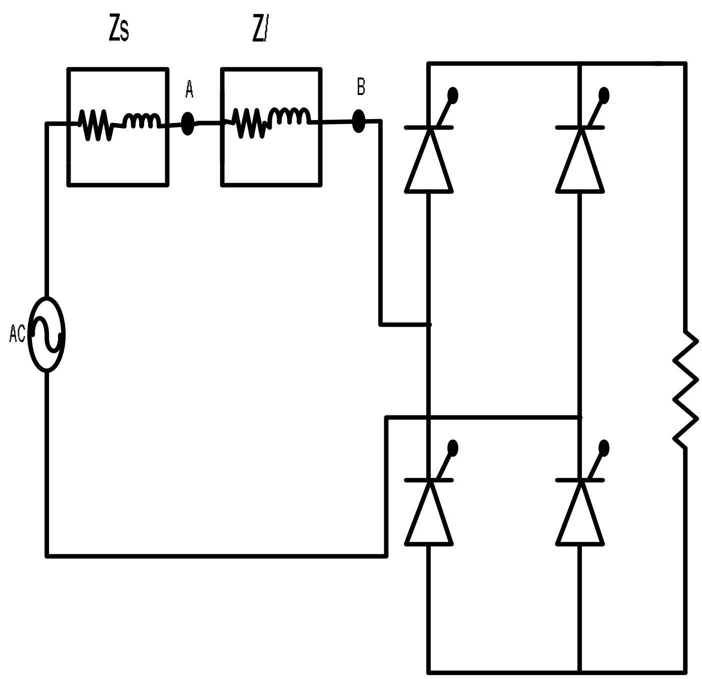

Figure 2. Nonlinear load with R load connected to a AC supply

Case 2: THP method for nonlinear loads with inductive load of 0.2H input voltage of 230-Vrms, 50-Hz sinusoidal supply with an internal impedance of Zs=1+*j6.28* Ω is connected to Node A of the circuit shown in Fig. 3. The line impedance is Zl= 2+*j*12.56 Ω and the load is a phase-controlled bridge rectifier with a firing angle of $\alpha=30^o$ and 60^o.

Case 3: THP method for nonlinear loads with capacitive load of 0.7µF with input supply of 230-Vrms, 50-Hz sinusoidal supply with an internal impedance of Zs=1+*j6.28* Ω is connected to Node A of the circuit shown in Fig. 4. The line impedance is Zl= 2+*j*12.56 Ω and the load is a phase-controlled bridge rectifier with a firing angle of $\alpha=30^o$ and 60^o.

For the above proposed three cases, the THP and each individual harmonic power are all negative at nodes A and B. This indicates that the source of harmonic pollution is downstream with respect to these nodes (i.e., the load is the source of harmonic pollution). The harmonic pollutions of these proposed concepts can has been simulated and shown in tables.

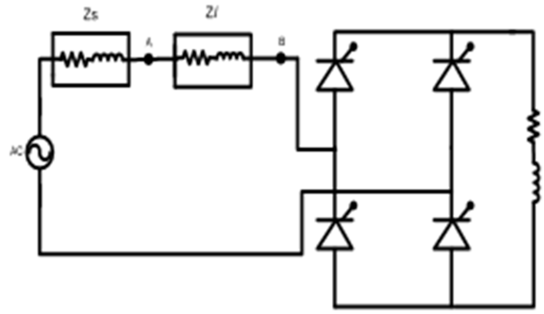

Figure .3. Nonlinear load with RL load connected to a AC supply

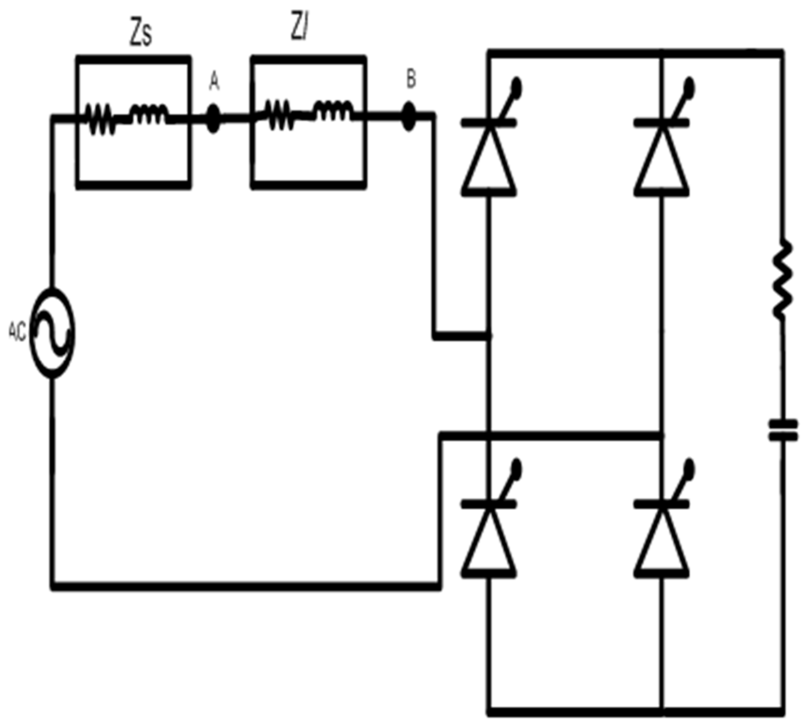

Figure .4. Nonlinear load with RC load connected to a AC supply

MATLAB/SIMULINK OUTPUTS

Case I: Simulation analysis for Resistive load based Non linear load linear load at $\alpha=30^0$ and 60^0

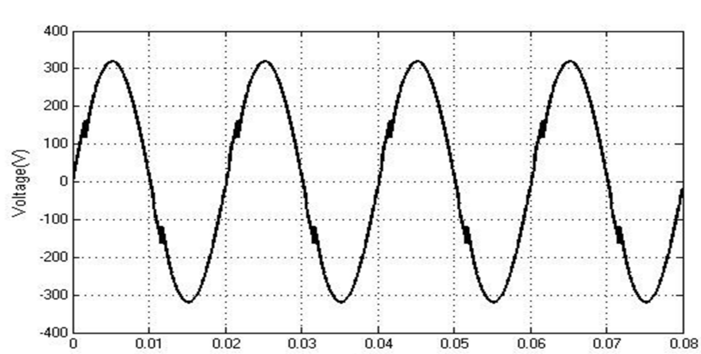

Figure .5. Simulated Voltage wave form at Node 1 with α=30 controlled R load

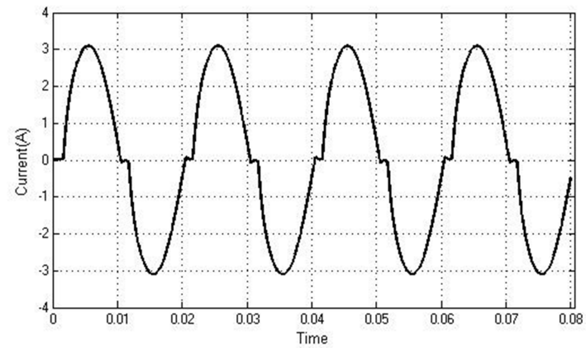

Figure .6. Simulated Current wave form at Node 1 with α=30 controlled R load

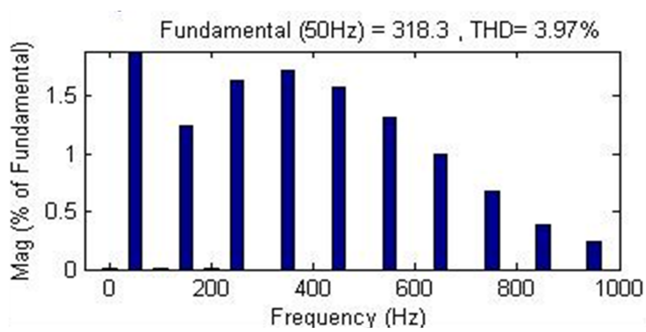

Figure .7. Total Harmonic Distortion of Voltage at Node 1 shows 3.97% with α=30 controlled R load

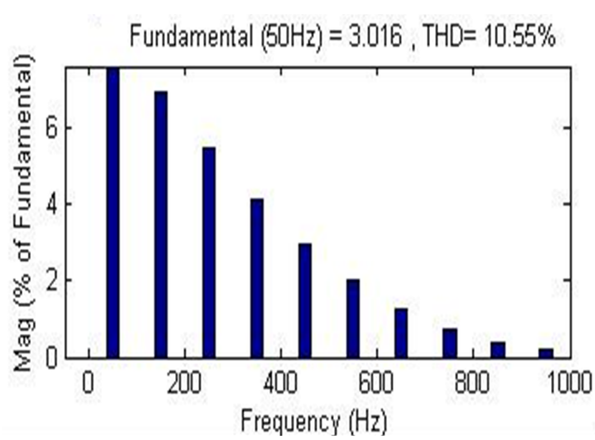

Figure .8. Total Harmonic Distortion of Current at Node 1 shows 10.55% with α=30 controlled R load

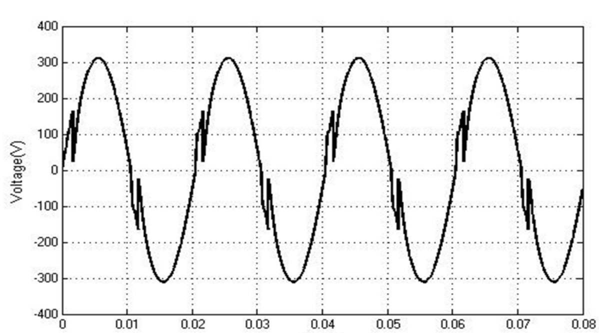

Figure .9. Simulated Voltage wave form at Node 2 with α=30 controlled R load

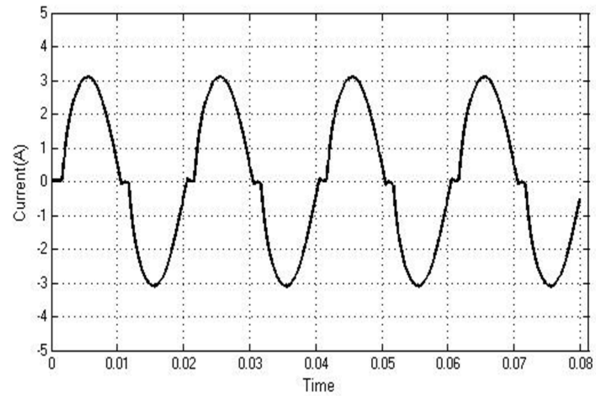

Figure .10. Simulated Current wave form at Node 2 with α=30 controlled R load

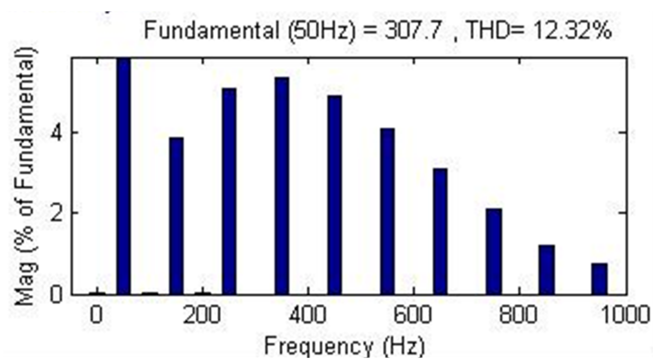

Figure .11. Total Harmonic Distortion of Voltage at Node 1 shows 12.32% with α=30 controlled R load

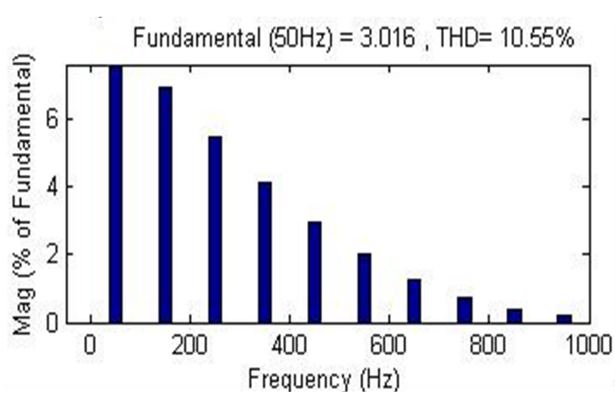

Figure .12. Total Harmonic Distortion of Current at Node 2 shows 10.55% with α=30 controlled R load

Table 1. Harmonic Voltages controlled Currents with Rectifier Controlled R-Load

Harmonics in	*Resistive load at α=30*		*Resistive load at α=60*	
	Node 1	*Node 2*	*Node 1*	*Node 2*
V	**3.97%**	**12.32%**	**7.23%**	**22.85%**
I	**10.55%**	**10.55%**	**30.96%**	**30.86%**

Table 2. Harmonic Power with Rectifier Controlled R-Load

POWER (W)	*Resistive load at α=30*		*Resistive load at α=60*	
	Node 1	*Node 2*	*Node 1*	*Node 2*
P1	**472.1**	**463.1**	**376.5**	**369.5**
P3	**-0.02428**	**-0.0728**	**-0.174**	**-0.5221**
P5	**-0.01569**	**-0.0470**	**-0.0391**	**-0.1173**
P7	**-0.00912**	**-0.0273**	**0.00692**	**0.00207**

Case II: Simulation analysis for Inductive load based Non linear load linear load at $\alpha=30^0$ and 60^0

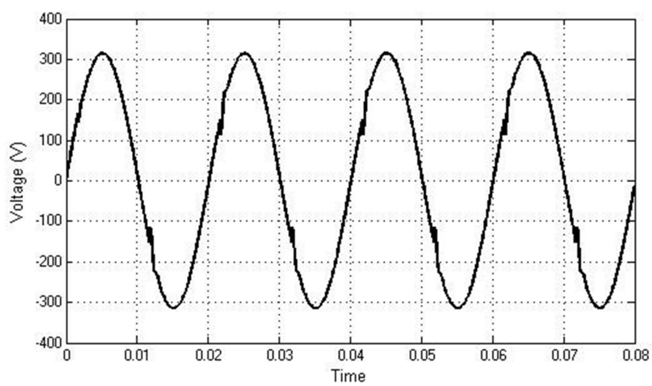

Figure .13. Simulated Voltage wave form at Node 1 with α=30 controlled RL load

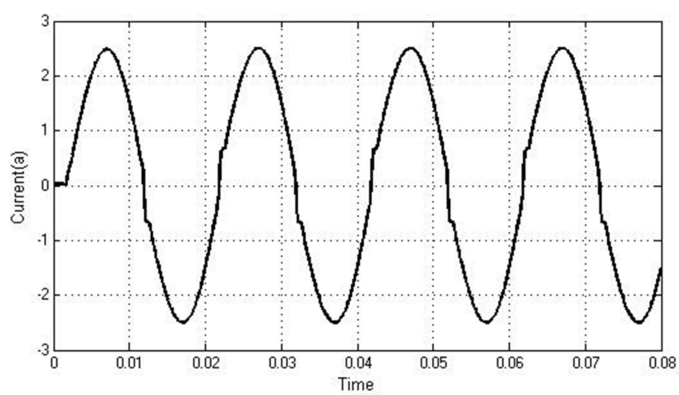

Figure .14. Simulated Current wave form at Node 1 with α=30 controlled RL load

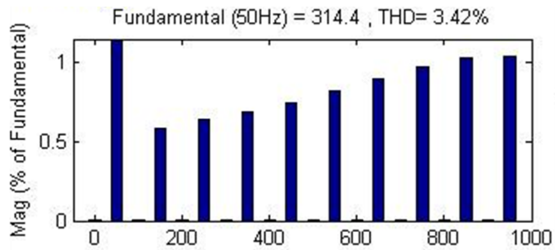

Figure .15. Total Harmonic Distortion of Voltage at Node 1 shows 3.42% with α=30 controlled RL load

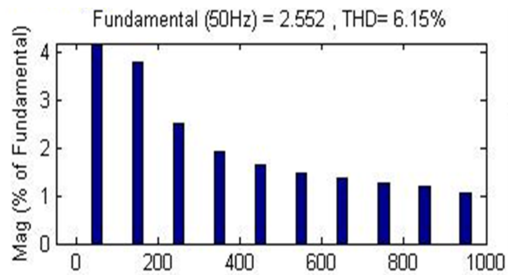

Figure .16. Total Harmonic Distortion of Current at Node 1 shows 6.15% with α=30 controlled RL load

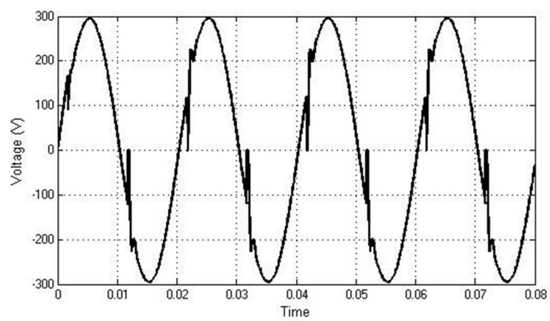

Figure .17 Simulated Voltage wave form at Node 2 with α=30 controlled RL load

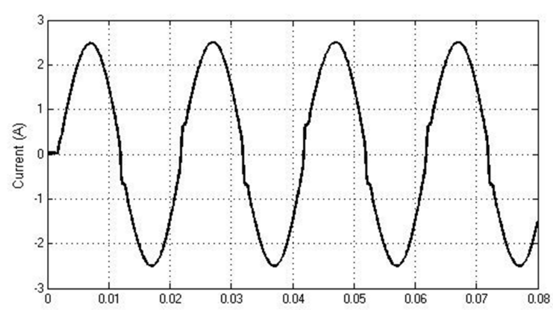

Figure .18 Simulated Current wave form at Node 2 with α=30 controlled RL load

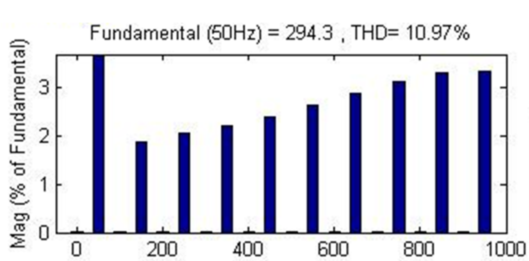

Figure .19 Total Harmonic Distortion of Voltage at Node 1 shows 12.32% with α=30 controlled RL load

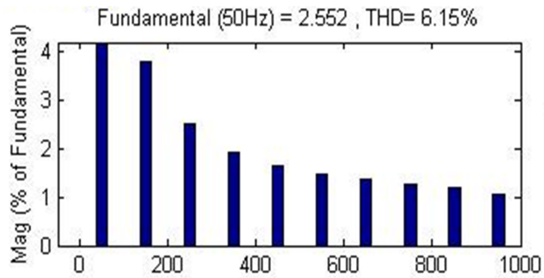

Figure .20.Total Harmonic Distortion of Current at Node 2 shows 10.55% with α=30 controlled RL load

Table 3. Harmonic Voltages controlled Currents with Rectifier Controlled RL-Load

Harmonics in	*RL load at α=30*		*RL load at α=60*	
	Node 1	*Node 2*	*Node 1*	*Node 2*
V	**3.42%**	**10.97%**	**2.94%**	**9.44%**
I	**6.15%**	**6.15%**	**12.66%**	**12.66%**

Table 4. Harmonic Power with Rectifier Controlled RL-Load

POWER (W)	RL load at α=30		RL load at α=60	
P1	Node 1	Node 2	Node 1	Node 2
	342	335.5	238.5	234
P3	-0.0046	-0.0140	-0.0237	-0.071
P5	-0.0020	-0.0061	-0.0073	-0.0219
P7	-0.0012	-0.0036	-0.0026	-0.0078

Case III: Simulation analysis for Capacitive load based Non linear load at α=30^0 and 60^0
Due to page limitations simulated output wave forms of RC loading condition has not displayed

Table 5. Hence Table of RC loading condition is shown with Harmonic Voltages controlled Currents with Rectifier Controlled RC-Load

Harmonics in	*RC load at α=30*		*RC load at α=60*	
	Node 1	*Node 2*	*Node 1*	*Node 2*
V	12.68%	43.53%	18.80%	71.34%
I	14.51%	14.51%	26.11%	26.11%

Table 6. Harmonic Power with Rectifier Controlled RC-Load

POWER (W)	RC load at α=30		RC load at α=60	
	Node 1	Node 2	Node 1	Node 2
P_1	**1392**	**1286**	**1108**	**1023**
P_3	**-0.9393**	**-2.818**	**-2.605**	**-7.815**
P_5	**-0.1172**	**-0.3515**	**-0.2679**	**-0.8036**
P_7	**-0.0316**	**-0.0949**	**-0.0204**	**-0.0612**

CONCLUSION

In this paper it has been studied the recognition of harmonic pollution caused due to resistive, inductive and capacitive based non-linear loads. The harmonic analysis has done with non linear load controlled with $\alpha=30^0$ and 60^0. The harmonic caused due these non radial loads has been efficiently recognized and calculated with Total Harmonic Power method. From the simulation analysis it is proved that for a certain node in the system, the sign of the fundamental power can be used as a reference, while the signs of the harmonic powers are compared to this reference sign to specify the responsibility of the load connected to this node to the harmonic pollution. The new modification was applied to several case studies and proved to be successful. Moreover, to eliminate the possible errors associated with measuring the harmonic powers due to calculating the phase shifts between harmonics.

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