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Electrical Power System Harmonics Analysis Using ETAP

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ABSTRACT

Power generation is normally produced at constant frequencies of 50 Hz or 60 Hz and the generators E.M.F can be considered practically sinusoidal. However, when a source of sinusoidal voltage is applied to a nonlinear device or load, the resulting current is not perfectly sinusoidal. Due to non-linear loads, distortions are produced in the sinusoidal waveform so filters are used to minimize these distortions. This paper aims to build a simulation model of a nine-bus ring system to evaluate characteristics of harmonics in different cases of study using electrical transient and analysis program (ETAP), which is considered one of the best tools to study harmonics in the power system, thus, the harmonic distortion is analyzed in ETAP. To generate harmonic distortion in the power network, a general load is modeled as a source of harmonics. A harmonic load flow analysis was carried out in order to determine the impact of harmonic current on a power network, and the THD% of all types of harmonic models on all the buses was checked and the typical IEEE model that has the highest THD% was chosen and compared with the model that contains low THD indices (one of the best models of IEEE manufacturer).

Keywords*:*

Non - Linear Loads; ETAP; Harmonics; THD; Typical IEEE.

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1. INTRODUCTION

Harmonics have been present in power networks for many years. The issue has recently gained new significance as a result of the convergence of two trends: the increased use of capacitor banks by electric utilities in an attempt to improve power factor, and the widespread use of power-electronic converters by industry to improve system reliability and efficiency [1].

The main intention of any electrical utility company is to deliver power with better quality. That's indicating to deliver a pure sinusoidal voltage or current waveform. This goal is complicated by the fact that there are loads on the system that produce harmonic currents, thus, the electrical power systems should be designed not only for the sinusoidal currents (which results in distorted voltages and currents that can badly impact the system performance [2]) and voltages but also for nonlinear and electronically switched loads. In recent years, there has been a surge in such loads, which can cause harmonic pollution, distort current and voltage waveforms, generate resonances, increase system losses, and shorten the useful life of electrical equipment.[3]

The deviation of the voltage and current waveforms from sinusoidal is described in terms of the waveform distortion, often expressed as harmonic distortion [5]. Power system harmonics is a real point of concern for electrical engineers. In power systems, non-linear loads are permanently connected, unlike transients and other distortions are produced [7]. Harmonics are components in electrical waveform which are integer multipliers of the fundamental frequency.

Non-linear loads or devices like personal computers, variable speed drives, static power converters, arc furnaces, fluorescent lights, cycloconverters etc., produce harmonics by consuming current in rapid short pulses, instead of smooth sinusoidal manner [4]. Harmonics can cause sensitive equipment to failure and other problems, as well as transformers overheating, degradation of the power factor and flow of additional current through power capacitors [7]. Industrial and commercial power incorporate power capacitors to improve the power factor. When the system includes sources of harmonic current, the capacitor may be used in power harmonic filter to minimize the harmonic voltage applied to the system load [9].

When harmonics are produced it is necessary to reduce it for better performance of the system. Harmonics have a variety of harmful impacts on power system components, which vary depending on the load type (or power source). The effects of harmonics can be classified into two basic categories: short-term effects and long- term effects. Short-term effects are usually the most noticeable and are related to excessive voltage distortion. On the other hand, long-term effects often go undetected and are usually related to increased resistive losses or voltage stresses [13][14]. The main effects of voltage and current harmonics within the power system are:

1) Degradation of the power factor.
2) Overheating of the phase and neutral conductors.
3) Efficiency of the generators is reduced day by day due to harmonics.
4) Eddy current and hysteresis losses in transformers.
5) Overheating of the system components e.g., generators, motors and transformers etc.
6) Flow of additional current through power capacitors [7].

There are many available methods to reduce harmonics of the system one of them is by using filters [8]. Harmonic filters are widely used to mitigate harmonic problems. Filters are of active; passive were assumed for the mitigation of harmonics. Passive filters are made up of resistor, inductor and capacitor elements. Active Power Filters (APF) are made up of power electronic devices. Since passive filters are simpler and cheaper when compared to active filters, Passive filters were considered for harmonic mitigation. Single tuned filter is the most commonly used passive filter it is very cheap and easy to design [6][8].

In this research, ETAP is being used to model a 9-bus 50Hz power network as shown in Fig. 1and perform harmonic analysis. First of all, a general load was modeled as a harmonic source, then harmonic load flow analysis was performed, to analyze the effect of harmonic current on the system. Load harmonics library contains several types of harmonic manufacturer and models. depending on the THD% indices, the appropriate type of harmonic model was selected. So, the THD% of all types of harmonic models on all the buses was checked and the type with the highest THDv% (the worst type) which is typical IEEE 6 pulse1 model was chosen and compared with typical IEEE 12 pulse 2 model that contain low THDv% indices.

In addition to this introduction, this paper contains four other sections. Section 2 presents the literature review. Classical model of a nine-bus system is explained in section 3. Harmonic Analysis using ETAP are included in section 4. Section 5 includes conclusion.

2. LITERATURE REVIEW

[1] M. T. Riaz [2021] Proposed the harmonic analysis in Industry using Fluke Energy Analyzer. The measured THD% values for the voltage and current will be used to model and analyze overall harmonics in the complete three-phase distribution system of Textile Plant through simulation using ETAP software. By taking measurements with the help of the Fluke Energy Analyzer, it was identified that 5th and 7th harmonic orders are most dominant in magnitude and are responsible for increased THD% levels. The results obtained from Fluke Energy Analyzer were used in ETAP for harmonic analysis of the overall plant. Resonance phenomenon was identified due to the conventional capacitor bank used for power factor improvement. Thus, a single tuned filter was designed, and Power Factor improvement bank was replaced with a Single tuned filter. The harmonic filter not only reduced the harmonic distortion levels but also provided power factor improvement [10].

[2] Guna [2020]aims to build a simulation model of gas cooling plant to evaluate characteristics of harmonics at different case studies with help of ETAP. Generally, harmonic analyzer in ETAP, studies the power network and is subjected to harmonic current injection and harmonic voltage at multiple frequencies. In this paper the 33kV system simulation model is built using ETAP. A 33kV bus is connected to utility grid via incoming feeder and VFDs and motors are connected to a bus and required single tuned filter bank are placed to mitigate harmonics injected by VFD.

In this project, the harmonic pollution is analyzed in ETAP and mitigation techniques are recommended which are that single tuned filters should be installed for worst case condition and simulation results of ETAP shows that harmonic voltage and current are well within the limit value as per IEEE 519 -2014 standard and provides theoretical lookout for the improvement of power quality in the power network [12].

3. CLASSICAL MODEL OF A NINE-BUS SYSTEM

In this work, we have designed an electrical circuit that works to suppress the electrical power system harmonics using ETAP because it is one of the best tools to study harmonics in the power system. We can use ETAP to study load flow in steady-state and transient conditions, harmonics analysis, and harmonics spectrum for higher and lower orders, as well as evaluate voltage, current, active and reactive power, and power factor for all buses by printing the complete system report under harmonics analysis conditions. The classical model is the most basic model used in power system dynamics studies, and it only requires a little quantity of data. As a result, such studies may be completed in a short amount of time and at a low cost. A classical study will be presented here on a nine-bus ring system that has three generators, three loads, six transmission lines and nine buses. A one-line impedance diagram for the system is given in Fig. 1[11].

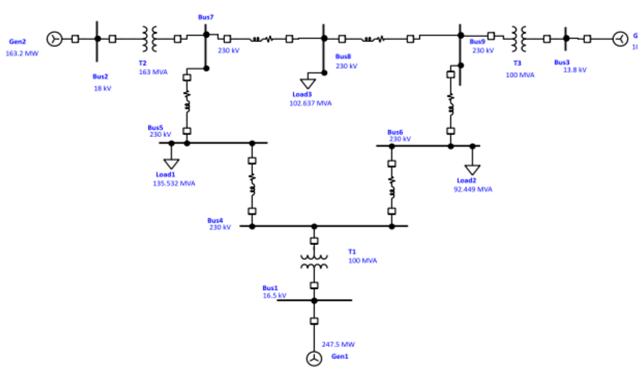

Fig. 1 Nine-bus system diagram.

3.1 Created 50Hz Nine Bus System

The nine-bus system in ETAP has a frequency equal to 60 Hz and it is shown in fig. 2, and in this paper the system frequency is equal to 50 Hz. To model a nine bus 50 Hz ring system that should have the same resultant active, reactive power and voltages as the nine-bus system of ETAP example. To model a 50 Hz nine bus system:

1. First, a 9-bus ring system with a frequency of 60Hz was created and the generators, transformers, loads and transmission lines data have the same values as data of the ETAP example component. Then run load flow analysis.
2. After running load flow analysis, we note that the resultant voltages, active and reactive power and values are the same as the nine-bus system of ETAP example. Fig. 3 shows load flow analysis results for the designed system.
3. The frequency is converted from 60Hz to 50Hz through the following steps:
   Project ⟹ standard ⟹ changing frequency from 60Hz to 50Hz.
4. After doing these steps, the impedance and admittance values of the transmission line have changed, as well as the speed and inertia of the generators, that means a new nine bus 50 Hz ring system has been created, and after running load flow analysis we noticed that there is a very slight difference in the voltages, active and reactive power values between the system of ETAP and the designed system and it's shown in fig. 4.

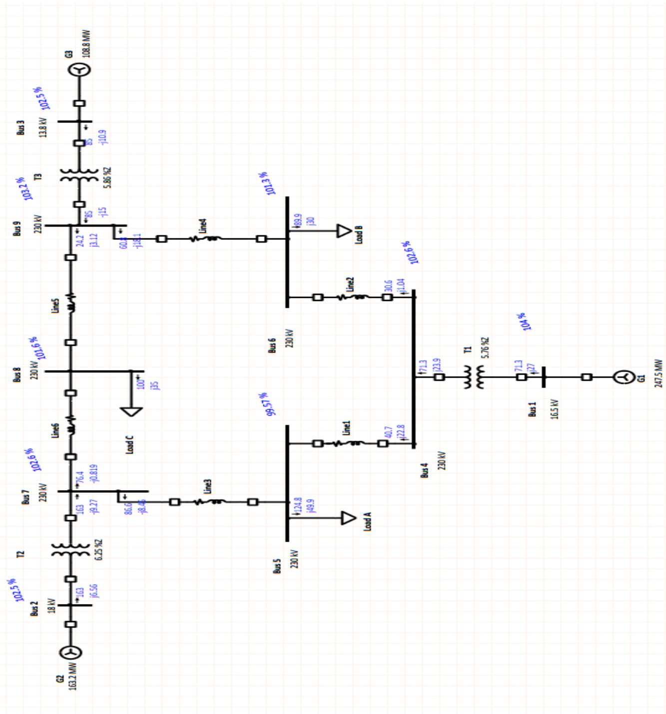

Fig. 2 A 60 Hz nine-bus system load-flow diagram from ETAP examples.

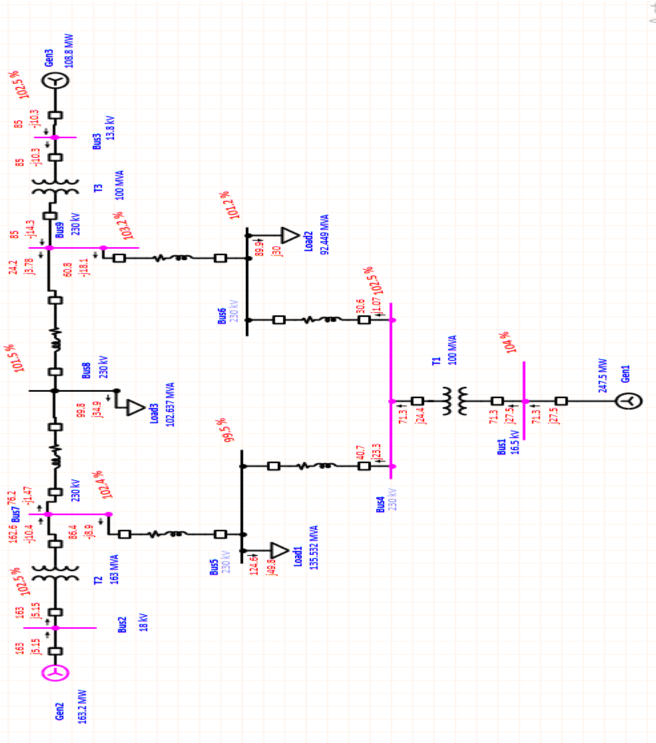

Fig. 3 Shows load flow analysis results for the designed 60Hz nine bus system.

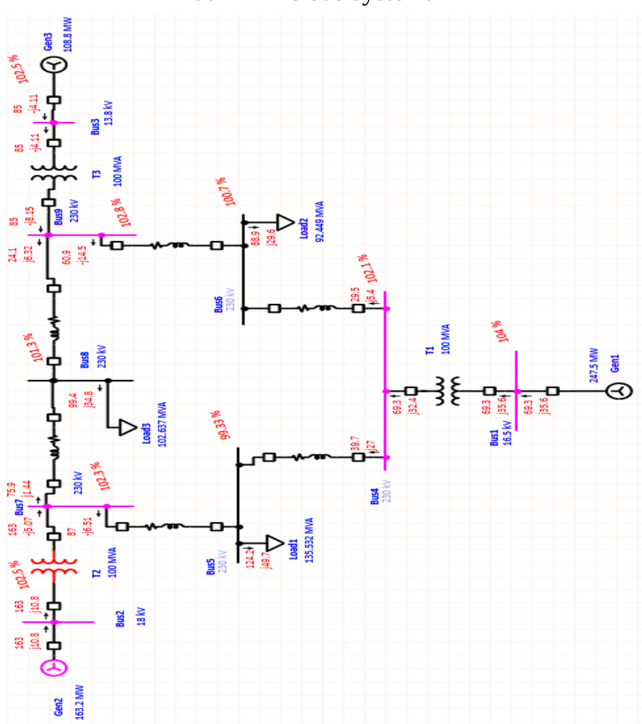

Fig. 4 Load flow analysis results for the converted system (from 60Hz to 50Hz).

4. HARMONIC ANALYSIS USING ETAP

Engineers utilize ETAP in the design, analysis, maintenance, and operation of electrical power systems in hundreds of organizations and electric utilities throughout the world. This program has a unique feature in that it includes a centralized database system in which all of the analysis that has been performed is saved, and this data can then be easily downloaded using Microsoft Access [2].

ETAP is one of the most effective tools for analyzing harmonics in a power system. It's a program that assists electrical engineers in the process of planning, modeling, operating and optimizing power systems. ETAP provides a complete set of tools for power system design. Load flow analysis, short-circuit analysis, harmonic analysis, transient stability analysis, and other analyses can be performed on the designed project, also advanced analysis like state estimation, optimal power flow are available in ETAP. These things are hard to do in MATLAB [15].

With the help of ETAP we can study the harmonics analysis of any type of circuit and we can also study the harmonics spectrum. By load flow analysis we can study the harmonics analysis. First of all, we study the load flow analysis at the fundamental frequency. In order to properly analyze the harmonics, the components of the power system must be identified and modeled correctly.

A general load was modeled as a harmonic source. then, harmonic load flow analysis was performed to analyze the effect of harmonic current on the system. Harmonics library contains Several types of harmonic manufacturer and models. Depending on the THDv% indices, the appropriate type of harmonic model was selected. The THDv% of all types of harmonic models on all the buses was checked (as shown in table 1) and the type with the highest THDv% values (one of the worst models of typical IEEE manufacturer) which is typical IEEE 6pulse1 model was chosen and compared with typical IEEE 12pulse2 model that contain low THDv% values (one of the best models of typical IEEE manufacturer).

Table (1): THDv% for different types of harmonic models and manufacture.

Model Type	THDv %								
	Bus1	Bus2	Bus3	Bus4	Bus5	Bus6	Bus7	Bus8	Bus9
Normal condition	0	0	0	0	0	0	0	0	0
ABB ACS600 6P	23	1.13	4.8	42	49.5	47	23	27	25
ABB ACS600 12P	2.3	0.1	0.8	4.19	4.26	3.2	2	2.2	4.1
ABB ACS 1000 12P	2.43	0.1	0.8	4.44	4.93	2.9	2.1	2.2	4.1
ABB DCS 500 6P	16.1	0.79	3.4	29.4	33.5	31	16	19	17
Rockwell 6P VFD	12.7	0.63	2.7	23.2	27.4	26	13	15	14
Rockwell 12P VFD	3.65	0.16	1.2	6.67	7.48	5.2	3.3	3.6	5.9
Rockwell 18p VFD	1.37	0.04	0.3	2.51	2.85	2.5	1.3	1.5	1.7
Rockwell PWM Rect	2.71	0.14	0.5	4.94	4.42	4.2	2.9	3.2	2.8
Toshiba PWM ASD	60.2	2.74	14	110	124	111	57	60	71
Typical LCI	13.9	0.67	2.9	25.4	27.8	26	14	16	15
Typical locomotive	11.3	0.54	2.4	20.7	23.9	22	11	12	12
Typical IEEE 6P1	14	23	2.9	25.5	27.4	25	14	15	15
Typical IEEE 6P2	12.2	0.58	2.6	22.4	25.4	23	12	13	13
Typical IEEE 12P1	3.94	0.15	1.6	7.19	7.95	2.5	3.1	4.4	8.1
Typical IEEE 12P2	3.51	0.13	1.4	6.41	6.97	2	2.8	3.3	7.1
Typical IEEE 18P CT	3.55	0.19	0.5	6.49	4.29	4.4	4	4.2	2.4
Typical IEEE 18P VT	3.3	0.18	0.4	6.03	3.16	3.4	3.8	3.9	1.9
Typical IEEE Fluorecent	5.65	0.27	1.2	10.3	12.2	12	5.7	6.4	5.9
Typical IEEE Large ASD	2.49	0.1	0.8	4.55	5.01	2.7	2.1	2.1	4.3
Typical IEEE SPC	3.28	0.13	1.2	5.98	6.53	2.9	2.7	3	6.2
Typical IEEE XFMR Magnet	10.6	0.52	2.2	19.3	23	22	11	13	11
Typical Furnace	5.72	0.28	1.2	10.5	11.7	12	5.7	6.7	6.3
Typical G2/3P-FL_LL	1.19	0.06	0.3	2.17	2.47	2.5	1.2	1.4	1.3
Typical G2/3P-FL_LN	1.09	0.04	0.2	2	2.27	2.3	1.1	1.3	1.2
Typical G2/3P-NL_LL	0.93	0.04	0.2	1.69	1.91	2	0.9	1.1	1
Typical G2/3P-NL_LN	0.83	0.03	0.2	1.52	1.71	1.8	0.8	1	0.9
Typical G5/6P-FL_LL	0.29	0	0.1	0.52	0.52	0.4	0.3	0.3	0.3
Typical G5/6P-FL_LN	281	0	0.1	0.51	0.5	0.4	0.3	0.2	0.3
Typical G5/6P-NL_LL	0.27	0	0.1	0.5	0.55	0.5	0.3	0.3	0.3
Typical G5/6P-NL_LN	0.3	0	0.1	0.55	0.61	0.6	0.3	0.4	0.4

Table (1) shows the values of THDv% at the buses. Comparing different types of harmonic model after running harmonic load flow we notice that the typical IEEE 6 pulse 1 model has the highest THDv% comparing other harmonic models of Typical IEEE manufacturer. From table (1) it is obvious that the value of THDv% for Typical IEEE 12 pulse 2 model is much less than 6 Pulse 1 model, also 12 pulse 2 model has almost the lowest THDv% value. Table 2 illustrate the difference between the values of THDi% for 6 Pulse 1 and 12 Pulse 2 models at harmonic order = (total, 5, 7, 11).

Table (2): the difference between the values of THDi% for 6 Pulse 1 and 12 Pulse 2 models.

Model type	line No.	H	THDi %
Typical IEEE 6puls1	1	Total	21.76
		5	2.63
		7	9.44
		11	7.87
	2	Total	36.52
		5	3.58
		7	17.15
		11	19.41
	3	Total	37.54
		5	29.94
		7	15.89
		11	7.4
	4	Total	48.86
		5	39.61
		7	21.37
		11	2.27
	5	Total	39.94
		5	34.77
		7	9.41
		11	7,088
	6	Total	15.46
		5	7.4
		7	7.68
		11	5.93
	Tr No.	H	THDi %
	1	Total	44
		5	39.31
		7	17.75
		11	5.42
	2	Total	22.99
		5	21.25
		7	7.54
		11	2.54
	3	Total	42.13
		5	37.85
		7	14.71
		11	5.68

Model type	line No.	H	THDi %
Typical IEEE 12pulse2	1	Total	9.79
		11	7.18
	2	Total	21.6
		11	17.7
	3	Total	7.19
		11	6.74
	4	Total	14.63
		11	5.72
	5	Total	9.14
		11	6.46
	6	Total	5.61
		11	5.41
	Tr No.	H	THDi %
	1	Total	5.76
		11	9.94
	2	Total	2.45
		11	2.31
	3	Total	9.71
		11	5.18

Typical IEEE 6pulse1 model has the highest THDv% values comparing to other typical IEEE models. From fig. 5 we notice that THDv,i% exceeding the voltage and current harmonic limits, after injecting the system with harmonic source (typical IEEE 6 pulse 1) from load harmonic library. Comparing to other typical IEEE models, 6 pulse1 model has the highest THDv,i% values, thus, it causes a big distortion to the system. Fig. 6 shows harmonic analysis plots for buses, transformers and transmission lines at a typical IEEE 6 pulse 1 model, from this figure, we notice the distortion that this model caused for the system is high.

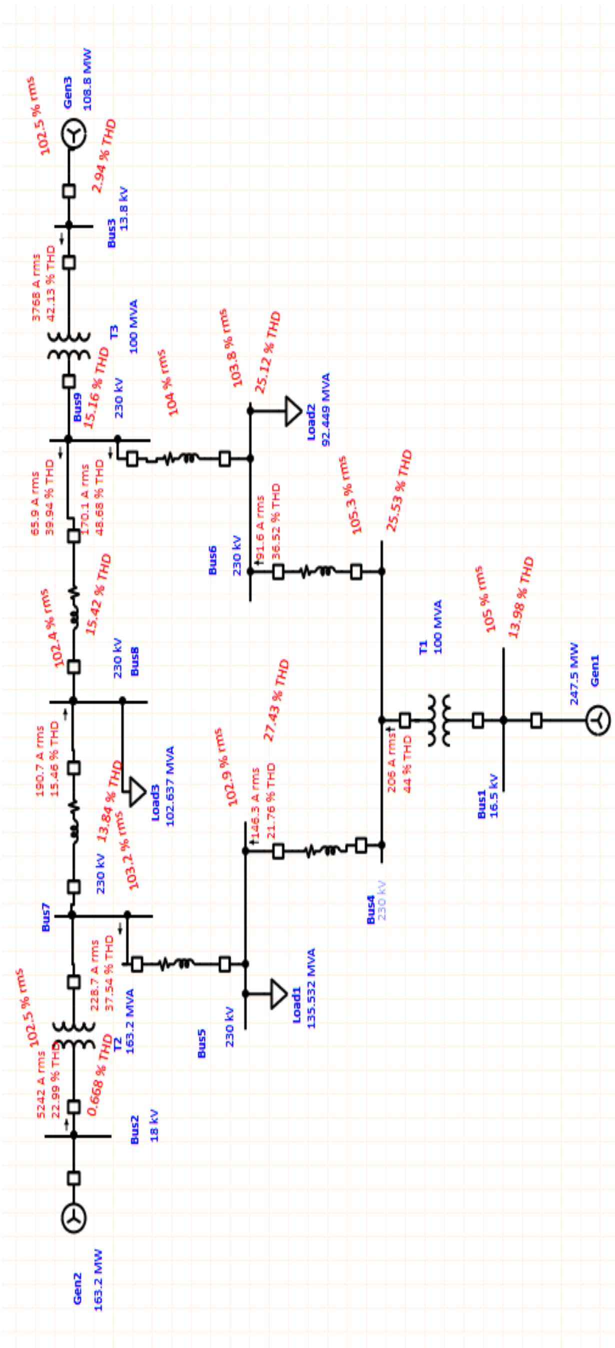

Fig. 5 THDv,i% values for typical IEEE 6 pulse 1 model.

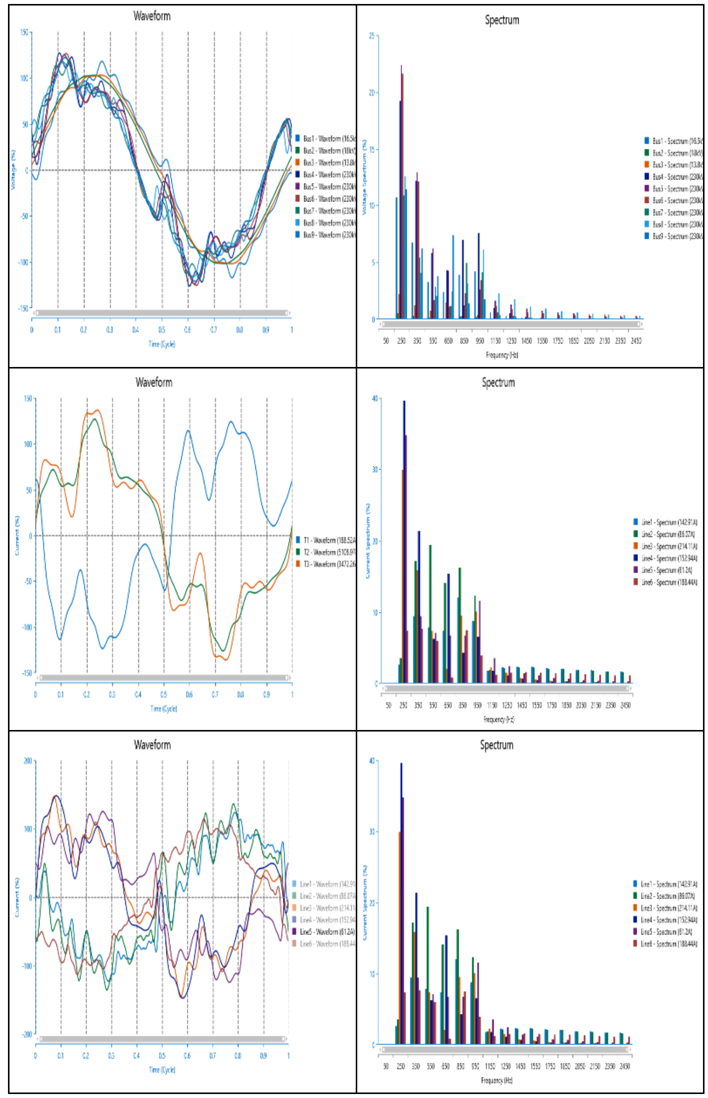

Fig. 6 Harmonic analysis plots for buses, transformers and transmission lines for typical IEEE 6 pulse 1 model.

Fig. 7 shows the values of THDv,i% at the buses, after inserting a source of harmonics (typical IEEE 12 pulse 2) from the load harmonic library and after running harmonic load flow. From this figure we notice that the value has almost the lowest THDv% compared to other typical IEEE models, thus, this model is considered one of the best typical IEEE models. Fig. 8 shows the harmonic analysis plots for buses, transformers and transmission lines for typical IEEE 12 pulse 2 model. Like the typical IEEE 12 pulse 2 model this model also has a low THDv,i% value, and from fig. 8 we notice that the distortion on the bus waveform is low.

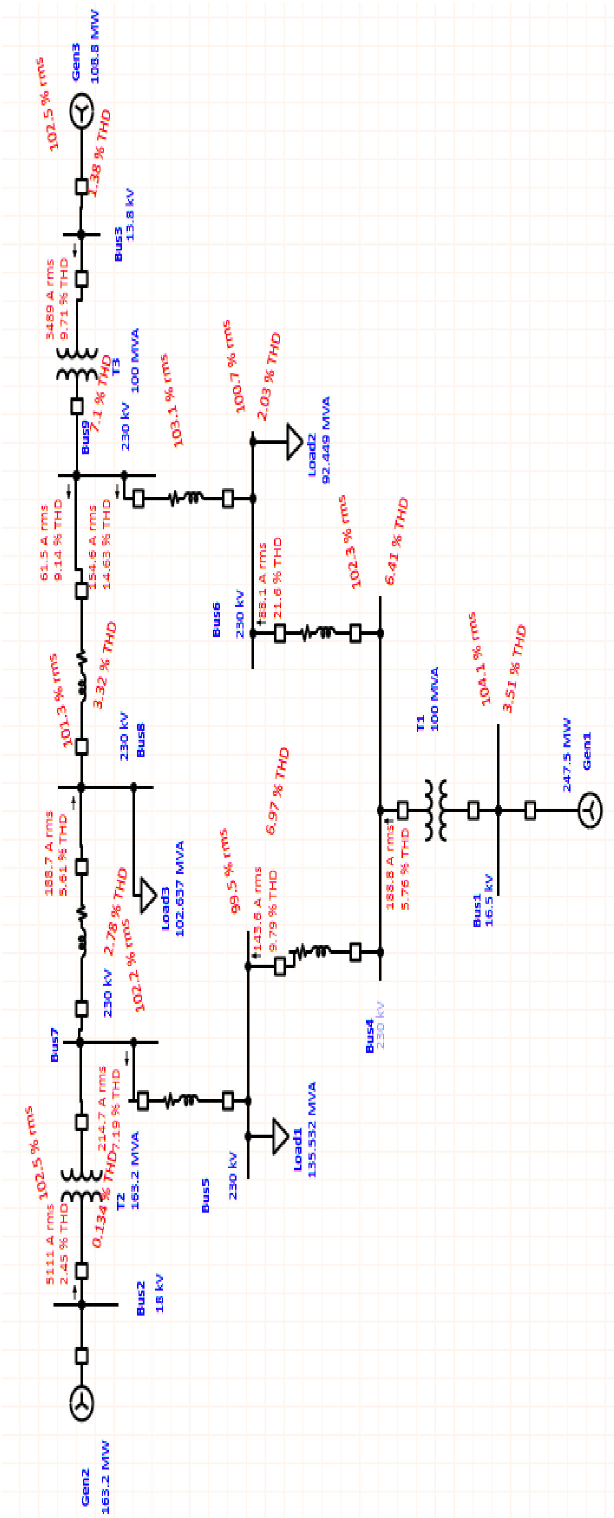

Fig. 7 Shows the values of THDv,i% at the buses for typical IEEE 12pulse2 model.

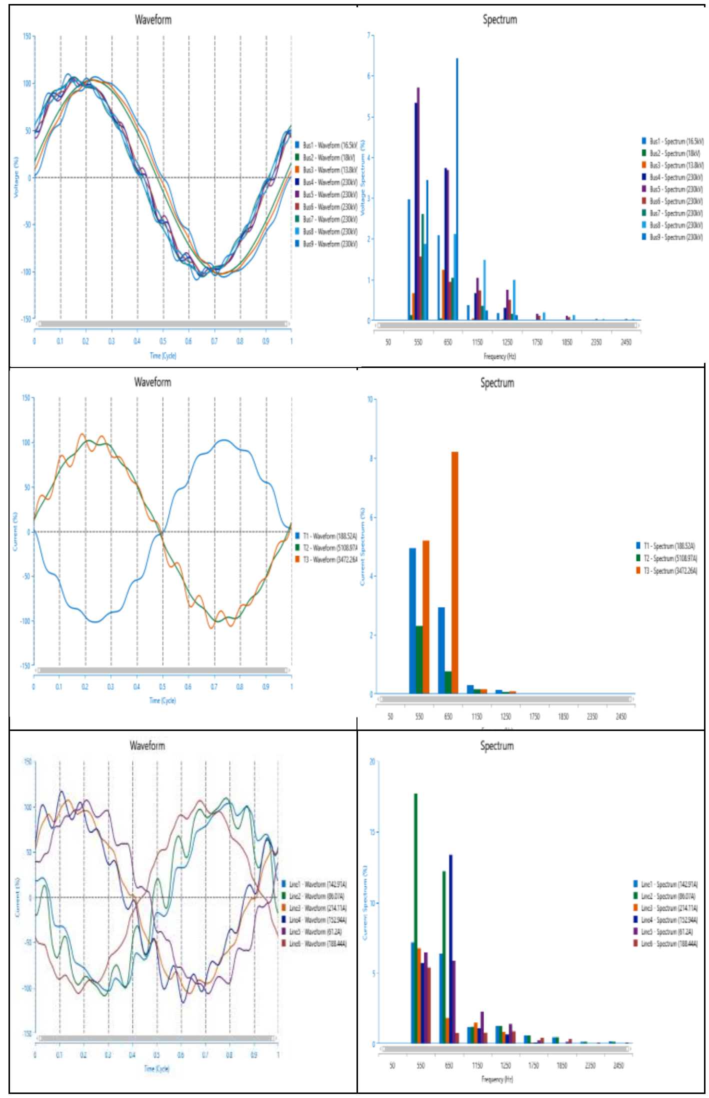

Fig. 8 Harmonic analysis plots for buses, transformers, and transmission lines at a typical IEEE 12 pulse 2 model.

5. CONCLUSION

To perform Harmonic Analysis on the power network, many types of power system software can be employed. In this work, ETAP is used to simulate a nine-bus ring system and perform harmonic analysis. The harmonic analysis of the ring system is more complex than the harmonic analysis of the radial system. ETAP is a user-friendly program with crucial features for effective harmonic analysis that are simple to use and produce superior results. It is also capable of displaying the real-world repercussions of establishing the needed power network. In this paper ETAP software is being used to model a 50 Hz nine bus system and to analyze the power system harmonics. A general load was modelled as a source of harmonics to generate harmonic distortion in power network by injecting the load buses (5, 6, 8) with harmonic filters, then, a comparison was made between the different harmonic models. On running harmonic load flow study, harmonic distortion was seen on the one-line diagram and plotted curve for the different harmonic models. In this study we focused typical IEEE manufacturer. By comparing between the harmonic models after doing the harmonic analysis study we conclude that:

1- Typical IEEE 6 pulse1 was identified as the worst typical IEEE model because it has almost the highest THDv% value, this means that there is a big distortion in the system.
2- Typical IEEE 12 pulse2 was identified as one of the best typical IEEE models because it has low THDv% values, this means that the distortion is not big as in 6 pulse1 model.

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تحليل توافقيات نظام طاقة كهربائية بأستخدام ETAP

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الملخص

يتم أنتاج الطاقة عادةً بترددات ثابتة تبلغ 50 هرتز أو 60 هرتز ويمكن اعتبار E.M.F المولدات عمليًا جيبية. ومع ذلك ، عند تطبيق مصدر جهد جيبي على جهاز أو حمل غير خطي ، فإن التيار الناتج يكون ليس جيبيًا تمامًا. بسبب الأحمال غير الخطية ، يتم انتاج تشوهات في شكل الموجة الجيبية لذلك يتم استخدام المرشحات لتقليل هذه التشوهات. يهدف هذا البحث إلى بناء نموذج محاكاة لنظام حلقي مكون من تسعة قضبان عمومية لتقييم خصائص التوافقيات في حالات الدراسة المختلفة باستخدام برنامج التحليل الكهربائي العابر (ETAP) ، والذي يعتبر من أفضل الأدوات لدراسة التوافقيات في نظام الطاقة ، وبالتالي ، يتم تحليل التشويه التوافقي في ETAP. لتوليد تشويه توافقي في شبكة الطاقة ، يتم نمذجة الحمل العام كمصدر للتوافقيات. تم إجراء تحليل تدفق الحمل التوافقي(harmonic load flow analysis) من أجل تحديد تأثير التيار التوافقي على شبكة الطاقة ، وتم فحص % THD لجميع أنواع النماذج التوافقية على جميع القضبان العمومية وتم اختيار نموذج typical-IEEE الذي يحتوي على أعلى % THD و مقارنة بالنموذج الذي يحتوي على مؤشرات% THD منخفضة (أحد أفضل طرازات الشركة المصنعة).

الكلمات الدالة:
أحمال غير خطية، ETAP، توافقيات، THD%، typical-IEEE .