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INVESTIGATION OF HARMONIC CURRENT SOURCE EFFECTS ON DISTRIBUTION AND TRANSMISSION LINES CAPACITY AND LOSSES: CASE STUDY

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Abstract- Recently, power quality (PQ) has because a significant issue for both power supplies and customers. Researchers in all developed countries know that power quality is one of the factors of losses in the network. Increasing power electronic equipment changes current waveform in distribution networks and this can cause many problems in networks. Distortion of voltage waveforms results in the appearance of harmonic and sometimes non-harmonic frequencies in the network voltage. Harmonic distortions on the network voltage can cause additional losses and heating of certain network equipment, faulty operation of control equipment, an increase in peak voltage and disturbance and interference in neighbouring telecommunication systems. This paper will investigate the effect of harmonic on the sample distribution network losses and then the capacity of transmission lines. The harmonic studies consist of site background harmonic measurements at the existing local distribution substations, and computer-based system modelling based on site measured results. For modeling of system in computer we used ETAP power station software.

Keywords: Harmonic, Losses, Active Power, Apparent Power, Power Factor, Distribution Network.

I. INTRODUCTION

Harmonic currents are present in modern electrical distribution systems caused from non-linear loads. These non-linear elements generate network voltages with frequencies different from the network frequency or absorb currents with non-sinusoidal waveforms. The widespread and growing of these loads has greatly increased the flow of harmonic currents on facility distribution systems and has created a number of problems. These problems include overheated transformers, motors, conductors, and neutral wires; nuisance breaker trips, voltage distortion, which can cause sensitive electronic equipment to malfunction or fail, and elevated neutral-to-ground voltage, which can cause local area networks to malfunction [1, 2].

The increased conductor temperatures of the underground power cable are estimated based on IEC 60287 at 100% loads factor in steady state condition. In fact, loading of the cable is changed with time during the operation. For instance, different rated harmonics occurred in power system for short period in overload operation conditions [2]. Increases in harmonic distortion component of a transformer will result in additional heating losses, shorter insulation lifetime, higher temperature and insulation stress, reduced power factor, lower productivity, efficiency, capacity and lack of system performance of the plant [4]. Most of the methods developed in the past for optimally locating and sizing of capacitors in distribution system, considered the system to be balanced and the supply as sinusoidal [5].

II. SOURCE OF HARMONIC DISTORTION

The characteristic behavior of non-linear loads is that they draw a distorted current waveform even though the supply voltage is sinusoidal. Most equipment only produces odd harmonics. The current distortion, for each device, changes due to the consumption of active power, background voltage distortion and changes in the source impedance. An overview will be given of the most common types of single and three phase non-linear loads for residential and industrial [1, 3]. An overview will be given of the most common types of single and three phase non-linear loads for residential and industrial use. Single Phase Loads Electronic equipment, supplied from the low voltage power system, rectifies the ac power to dc power for internal use at different dc voltage levels. Such equipment's consist of:

TV's, Video recorders, Computers, Printers, Micro wave ovens, Adjustable speed drives, H.F., Fluorescent lighting, Small UPS's, etc.

Three phase rectifiers are used for higher power applications. The rectifier can either be controlled or non-controlled and can consist of diodes, thyristor's or transistors. The DC-link consists, in most cases, of a capacitor for the lower power applications. For larger rectifiers a smoothing inductor and a capacitor are used.

For controlled transistor rectifiers the DC link consists of a capacitor and on the line side an inductor is used. The three-phase group is used mainly in industry applications and in the power system. Some examples are:
Adjustable speed drives, Large UPS's, Arc Furnaces HVDC-links, Traction, vehicles and SVC's.

III. HARMONIC EFFECT ON POWER LOSSES AND POWER FACTOR

Usually harmonic loads in power systems modeling with current sources those are parallel to the consumer. For a network with n bass bar, active losses for each harmonic order is expressed with a total loss of injected active power.

$$P_{loss} = \sum_{n=1}^{n} P_n \tag{1}$$

Active losses P_n injected to n bas bar are calculated with the following equation:

$$P_n = \mathrm{Re}\left(\sqrt{3}V_n.\mathrm{e}^{j\theta V_n}\left(I_n.\mathrm{e}^{j\theta I_n}\right)^*\right) \tag{2}$$

$$P_n = \sqrt{3}V_n.I_n.\cos\left(\theta_{V_n} - \theta_{I_n}\right) \tag{3}$$

Equation (3) shows information about the amplitude and phase of harmonic voltage and current supply to calculate active losses with any order harmonic. Finally, active power losses are calculated as Equation (4).

$$P_{loss} = R.I_{rms}{}^2 = R.\left[\sum_{n=1}^{\infty} I_n{}^2\right] = R.I^2 + R.\sum_{n=1}^{\infty} I_n{}^2 \tag{4}$$

where $R.I^2$ is related to in the main frequency and $R.\sum I_n^2$ is for the other harmonic components. One of the most important issues in network is calculated harmonic power factor for consumers. For consumers who have less power factor are detrimental factor is awarded and must pay additional fees. To calculate the power factor is many ways. In distribution networks, if we assume harmonic current model, because the voltage can be fixed, Power factor obtained from Equation (5).

$$PF = \frac{P_{ave}}{S} = \frac{I_{rms1} \times V_{rms1} \times \cos\varphi_1}{I_{rms} \times V_{rms}} = K.\cos\varphi_1 \tag{5}$$

$$K = \frac{I_{rms1}}{I_{rms}} \tag{6}$$

In the Equation (5), φ_1 is the main component of phase difference between voltage and current. So, if current includes the harmonics, we first calculate the K value and then obtain the power factor.

IV. EFFECT HARMONIC ON CAPACITY OF TRANSMISSION LINES

Today, many electrical systems have harmonic currents on their lines. Harmonics are caused by non-linear or pulsed loads and their current causes the apparent power to exceed the active and reactive powers by a substantial amount. The apparent power for a nonlinear load can be calculated using Equation (7).

$$DVA = \sqrt{S^2 - P^2 - Q^2} \tag{7}$$

where P and Q are the active and reactive powers corresponding to the fundamental component where DVA the distorted volt ampere that corresponds to the other components [2].

In harmonic conditions, network effective current will increase. According to the constant voltage by increasing the effective current network capacity will increase the transition line $S_h > S_1$ [1]. With increasing effective current power factor is reduced and thus can be reduced active power, but active power increasing a small amount. With reducing the $\cos\varphi$, $\sin\varphi$ is increasing and reactive power increase. Reactive power is increased transmission line capacity [1, 2]. The presence of harmonics increases the apparent power that must be delivered, therefore lowering the *PF*. In these situations, the form of power factor present is called distortion power factor. In a system consisting of both linear and nonlinear loads the True Power Factor (*TPF*) is a sum of Cosine of both Displacement and Distortion Angles. If harmonic currents are introduced into a system, the True PF will always be lower than the displacement PF [2].

V. CASE STUDY OF HARMONIC DISTRIBUTION NETWORK AND ANALYSES

In this section of the paper feeder 3 will be analyses by feeding the distribution of Saeed Abad (Tabriz, Iran) substation. This feeder is fed from 132 to 20 kV Saeed Abad substation. This feeder has the highest energy consumption. Feeder main consumer is the industrial factories with modern electronic systems and drives. This feeder has a resistance of 1.2 Ω and reactance is 0.9 Ω. The feeder length is 3500 meters. This feeder has a peak daily consumption with 7 MW.

In this analysis Feeder consumption average of about 6.5 MW is considered. Figure 1 shows simulated model for study distribution network with eleven feeders. Figure 2 shows the consumption profiles of the feeder for 24 hours. Amounts of feeder currents studied are given in the Table 1. According NEMA standard harmonic in network above 5% is not recommended. According to Table 1, is observed that the highest harmonic to the fifth, the seventh and thirteenth harmonic. Measure harmonic is more standard value, and then losses should be calculated and will be analyses harmonic effects of on the network. Figure 3 shows the measured values of harmonic voltage in feeder three of Saeed Abad substation, which is simulated in ETAP Power station software.

Table 1. Study feeder's harmonic order

Order	Mag%	Order	Mag%
3	0.9	17	1.8
5	15.1	19	1.37
7	6.08	23	0.75
9	0.09	25	0.56
11	4.5	29	0.49
13	4.2	31	0.54
15	0.06	THD% = 17.4	

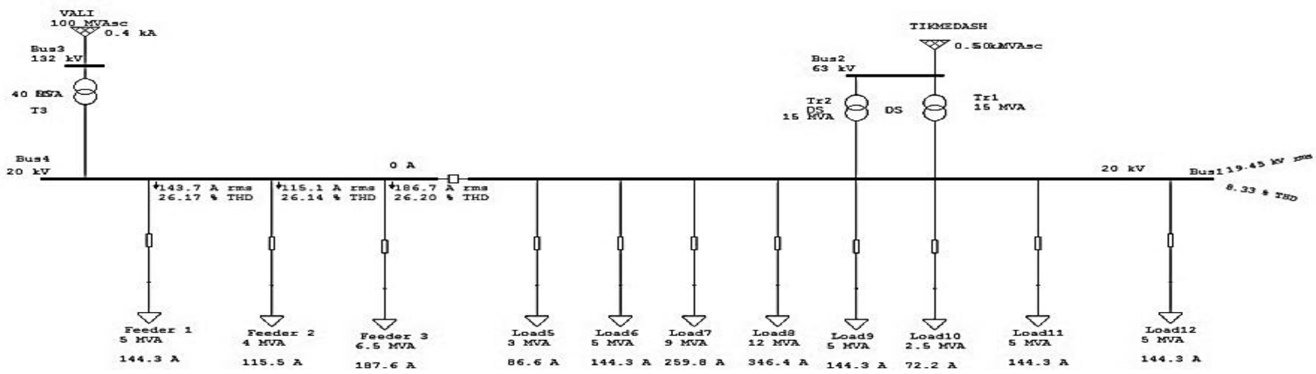

Figure 1. Simulated model for study distribution network

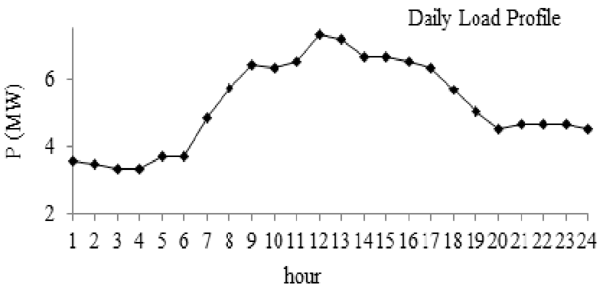

Figure 2. The consumption profiles of the feeder for 24 hour

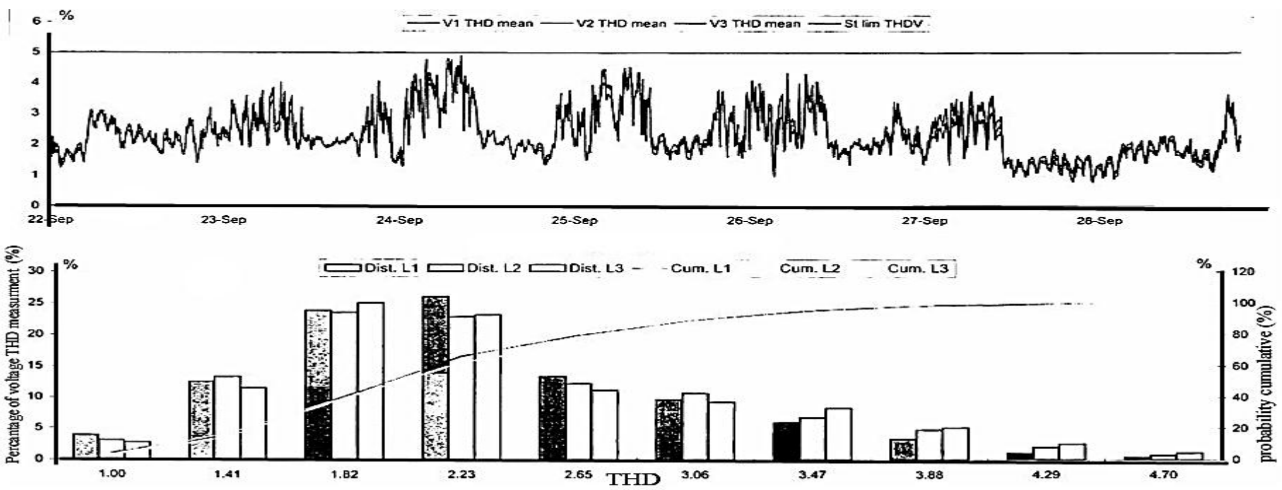

Figure 3. Feeder voltage harmonic THD and histogram (measured value)

VI. HARMONIC SIMULATION AND ANALYSIS WITH ETAP

Harmonic load flow is one of the advantages of ETAP Power Station software. In harmonic load flow, harmonic current or voltage values are produced simply in the consumer and voltage sources (feeders). Types of harmonic loads are available in the library of ETAP software. For creating harmonic voltages such as PWM model, can be used in feeder or bases. For analyses harmonic effect on distribution network losses and line transfer capacity we used to simulate the results based on real values of feeder. The harmonic studies consist of site background harmonic measurements at the existing local distribution substations, and computer-based system modelling studies. The site measured harmonic currents were used to tune the computer models to match the site harmonic measurements.

Values used to simulate the network are given in Table 2. Figure 4 shows harmonic current drawn from the Feeder number three. Figure 5 shows harmonic current spectrum drawn from the Feeder number three according to real amount.

Table 2. Harmonic orders of study feeder

Feeder	1	2	3
Loading (MVA)	5	4	6.5
Impedance (Ω)	1.12+0.9j	1.1+0.9j	1.2+0. 9j

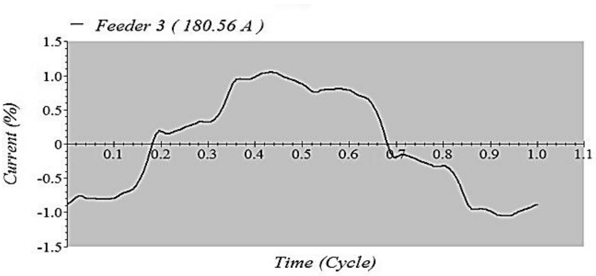

Figure 4. Current of feeder 3 with harmonic load

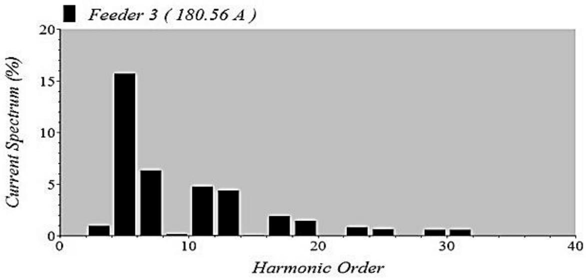

Figure 5. Harmonic Spectrum of study feeder

Table 3. The values of studied feeders before and after harmonic effect

Feeder number	1	2	3
Δp (with harmonics) kW	24.77	15.89	34.85
Δp (without harmonics) kW	23.185	14.89	32.61
Δq (with harmonics) kVAR	18.56	11.9	31.022
Δq (without harmonics) kVAR	17.38	11. 168	29.02
Active losses rise	1.585	1	2.24
Reactive losses rise	1.18	0.732	2.002

Table 3 shows study distribution feeder active and reactive losses after and before harmonic load. According to equation (4) distribution power losses is function of the square of customer current. With increasing current of consumer, network losses should be increased. According to results in Table 3 a loss without effects of harmonic is 32.61 kW and with effects of harmonic is 34.85 kW. Can be pointed to the following results according to the results of simulations and calculations performed:

For Harmonic current model, the feeder effective current increase in this study as 180.6 to 186.6 Ampere. Consumer power factor of 0.7 to 0.65 has been reduced. Due to reduction of power factor, active power of 4.368 to 4.075 MW can be reduced. Reactive power drawn from the transmission network is increased from 4.45 to 4.764 MVAR and Concluded, the apparent network power can increases with reactive power. And occupation of network capacity is resulting from increased reactive power. From voltage perspective, according to the harmonic model increased the voltage in main 20 kV feeders. Voltage increases from 19.38 to 19.45 kV. This increase could have an important role in calculating power factor of the consumer. According to Equation (5), power factor changes with the consumer's voltage and current. Today, with increasing harmonic loads, the grid voltage cannot be fixed and should be considered for calculating consumer power factor. The K factor according Equation (6) can be considering with the voltage change and improved. Capacitor banks are designed to improve the distribution network voltage and can increases power factor correction. Capacitor banks are designed based on typical power factor. According to the results, capacitor banks must designed accurately designed based on the harmonic power factor and customer harmonic. This is referred to in [5]. Table 4 shows the calculated values, to investigate the capacity of the of transmission network.

Table 4. Calculation of Transfer line parameter

Parameter	I_{rms}	$\cos\varphi$	S	P	Q
Before harmonic load	180.6	0.7	6.24	4.368	4.45
After harmonic load	186.6	0.65	6.27	4.075	4.764

VII. CONCLUSIONS

With the increase of modern electronic systems, harmonic injection to the distribution network increases. Load harmonics can cause protection faults, creating additional losses and increase stress on the cables insulation. In this paper, first as science is analyses influence of harmonics on power factor, network losses and network transfer capacity. Results show that the harmonic current, increase distribution network losses up to 6.8 percent. Transmission capacity is a function of the harmonic current, and if the harmonic is more standard level, transmission lines capacity is more occupied. The absorbed reactive power is increased in the transmission lines with harmonic and apparent power increasing. According to the results of investigation taken, the effect of harmonics on power distribution networks seems essential.

REFERENCES

[1] H.A. Attia, M. El-Metwally, "Harmonic Distortion Effects and Mitigation in Distribution Systems", Journal of American Science, 2010.
[2] Y. Gurcan, S. Faruk Aras, "Investigation of Harmonic Effects on Underground Power Cable", POWERENG, Department of Electrical Education, Kocaeli University, Kocaeli, Turkey, 2007.
[3] K. Lee, Venkataramanan, "Source Current Harmonic Analysis of Adjustable Speed Drives under Input Voltage Unbalance and Sag Conditions", IEEE Transaction on Power Delivery, Vol. 21, No. 2, April 2006.
[4] I. Daut, H.S. Syafruddin, R. Ali, "The Effects of Harmonic Components on Transformer Losses of Sinusoidal Source Supplying Non-Linear Loads", American Journal of Applied Sciences, 2006.
[5] T. Ghose, S.K. Goswami, "Effects of Unbalances and Harmonics on Optimal Capacitor Placement in Distribution System", Elsevier Electric Power Systems Research, 2004.
[6] T.S. Key, J.S. Lai, "IEEE and International Harmonic Standards Impact on Power Electronic Equipment Design", IEEE, 2009.
[7] J.F. Hibbard, M.Z. Lowenstein, "Meeting IEEE 519-1992 Harmonic Limits Using Harmonic Guard, Passive Filters", 1992.

[8] M.C. Benhabib, J.M. A.Myrzik, "Harmonic Effects Caused by Large Scale PV Installations in LV Network", 9th International Conference Electrical Power Quality, Barcelona, 2007.
[9] C. Demoulias, D.P. Labridis, "Ampacity of Low-Voltage Power Cables under No sinusoidal Currents", IEEE Transaction on Delivery, 2007.
[10] H. Shayeghi, M. Mahdavi, "Studying the Effect of Losses Coefficient on Transmission Expansion Planning using Decimal Codification based GA", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 1, Vol. 1, No. 1, pp. 58-64, December 2009.

BIOGRAPHIES

Mehrdad Tarafdar Hagh (S'98-M'06-M'2001) received his B.Sc. and M.Sc. degrees both with the first honor in 1988 and 1992, respectively and Ph.D. in 2000, all in power engineering from University of Tabriz (Tabriz, Iran). He has been with the faculty of electrical and computer engineering, University of Tabriz since 2000, where he is currently an Associate Professor. He has published more than 140 papers in power system and power electronics related topics. His interest topics include power system operation, FACTS and power quality.

Afshin Roshan Milani was born in Tabriz, Iran in 1963. He received the M.Sc. degree in power electric engineering from University of Tabriz (Tabriz, Iran) in 1991. He has published 30 papers in national and international conferences and has three papers in ICTPE conferences. His research interests are in harmonic distortion in network, protection and simulation of power grids under dynamic problems.

Mohammad Reza Azimizadeh was born in Tabriz, Iran in 1985. He received the B.Sc. degree from Azarbaijan Higher Education and Research Complex (AHERC) (Tabriz, Iran), in Power Electrical and Distribution Systems Engineering, in 2009. He is an electrical engineer in Azarbaijan Regional Electric Company (Tabriz, Iran). He has seven papers in national conferences and one paper in ICTPE conference. His research interests are in Power Quality, Energy Management in Systems, Power losses. He currently studies on harmonic and power quality event identification.