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Research Article

Reducing the effects of harmonics on the electrical power systems with passive filters

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Abstract

Users or customers of the electrical power systems must pay attention to some factors during operation and design of these systems in order to operate safe and in desired format. One of these factors is harmonic caused by non-linear elements determining the quality of the power as a parameter. Some harmful effects of harmonics can be listed as; disruption of control devices, explode of capacitors, overload of transformations and additional losses in rotating machines, motors, and the occurrence of extra noise to motors and other elements, to cause telephone interference, parallel and serial resonance frequency. The most important and useful method of eliminating or reducing of harmonics is using harmonic filters.
In this study, two different factory in the city of Van located at the east of the Turkey are examined in detail with a variety of different dates by Zera MT310's power analyzer measurements (instantaneous electrical values, harmonics, current and voltage waveforms, etc.). With these measurements, some power lacks of quality are determined and examined. After this process, single-tuned passive filter is designed by using Matlab/Simulink software for these factories.

Keywords: : Power quality, harmonics; passive filters, electrical power systems.

1.Introduction

Users or customers of the electrical power systems must pay attention to some factors during operation and design of these systems in order to operate on safe and desired format. One of these factors is harmonics caused by non-linear elements determining the quality of the power as a parameter (Yacamini R., 1994). In an ideal power system, electrical energy is supplied at a constant frequency and at a specified voltage level of constant magnitude with sinusoidal wave shape. However, in practice, none of these conditions is fulfilled to the fullest extent, due to the presence of voltage and current harmonics of multiple orders. (Diwan S.P., et.al., 2011). Both of electric utilities and their customers are responsible to hold harmonic levels at steady-state limits. The underlying philosophy is that customers should limit harmonic currents since they have to control their loads, and electric utilities should limit harmonic voltages since they have control on system impedances (Aziz M. et al, 2007). One of the technical challenges is how to fast and accurately estimate the grid impedance, even under the distorted and unbalanced conditions. However, these injected disturbances will deteriorate the power quality due to harmonics caused by the injected disturbances (Guo X., et.al., 2014). Nonlinear loads affect the system by generating harmonic currents and voltages. Harmonics in the current and voltage waveform cause extra power lose, heating in the system elements and damage in the insulation of system equipment. For these reasons, elimination of harmonics in electrical system has gained more importance. One of the suitable methods for removing harmonics is to use passive filters (Efe, S.B., 2006).
In this study, two different factory in the city of Van located at the east of the Turkey are examined as detailed with a variety of different dates by Zera MT310's power analyzer measurements (instantaneous electrical values, harmonics, current and voltage waveforms, etc.). With these measurements, some power lacks of quality are determined and examined. Single-tuned passive filter is designed using by Matlab/Simulink for these factories.

2.Harmonics

Harmonic distortion can be caused by both active and passive non-linear devices in a power system. The power transformer, for example, generates a magnetization current with third-order and higher-order odd harmonics. In the past, these passive devices were the primary source of harmonics. (Vlahinic et al, 2009). Generation, transmission, distribution and consumption of the electrical systems' main voltage in a correct 50 Hz sine curve is very important for operating accurate, regular, efficient and trouble-free of electric power system and electrically operated devices. However, because of some components or side effects caused by consumers connected to system and disruptive events, sinusoidal waveform of the basic electrical quantities such as flux, current and voltage is distributed and the integer multiples of 50 Hz as unwanted harmonics are added (Kocatepe C. et al, 2003; Kücük S., 2005). Voltage and current waveforms of a distribution or transmission system are usually not pure sinusoids; they may consist of a combination of the fundamental, harmonics and other frequencies caused by transients. The presence of harmonics in the network causes many problems to the customers, starting with home appliances to interfacing with communication equipment and temperature rise in all connected electrical elements. To make the network more reliable and secure, standards of power quality are

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applied in many distribution networks, and limits are designed for total harmonic distortion (THD) (El-Ela A., 2008). Therefore, some precautions and limitations are identified by standard enterprises in order to keep the level of harmonics at certain limits. Total Harmonic Distortion (THD) is used commonly for limiting the harmonic quantities with standards and THD of voltage and current can be found by using these equations (Kocatepe C. et al, 2003; Kücük S., 2005).

$$THD_V = \frac{\sqrt{\sum_{n=2}^{\infty}(V_n)^2}}{V_1} \quad \text{and} \quad THD_I = \frac{\sqrt{\sum_{n=2}^{\infty}(I_n)^2}}{I_1} \qquad (1)$$

THD equations showed in Equation 1 are the ratio of harmonic components effective value to the basic component effective value. THD is usually expressed as a percentage value. As IEC standards, THD value has to be maximum 3% for voltages and 6% for currents (Kücük S., 2005). THD is used to determine the deviation of periodic waveform containing harmonics. THD value of a correct sine waveform consisting only fundamental frequency is zero.
The IEEE standard 519 clearly states that harmonic currents should be reduced to minimize voltage distortion since the power supply system can only control the quality of the voltage and has no control over the currents that particular loads might draw. Therefore, the norms in the power quality area are voted to maintaining the voltage at the point of common coupling (PCC) with the utility, within certain limits; these limits generally refer to aggregate harmonics, helping to assure efficiency and reliability for industrial applications (Aleem, S.H.E.A, et.al, 2012). Power system harmonics are not only discussed in low voltage systems but also in high voltage systems. The design of passive harmonic filters for high-voltage level is more complicated than the design in the low-voltage level. In low-voltage level, one can use one or more single tuned filters. But in high-voltage level, one needs more types of filters such as second-order high-pass filter and designs capacitor banks used for high-voltage harmonic filter (Tupsa-ard, J., et.al, 2011).

3.Harmonic and Spectrum Analyzer

The capacities of these type devices are quite large. These devices should include some properties;

- Measure capacity for current and voltage at the same time (to obtain information about harmonic power flow)
- Measure capacity for phase angle and magnitude of examined harmonic component (for power flow calculations)
- Measure capacity for harmonic components up to at least 37th harmonic.
- Characterize capacity for statistical nature of harmonic distortion levels (harmonic levels can change with nature of the load and varieties at system requirements).

In this study, the MT310 Zera's portable etalon reference test analyzer was used for measurements as a harmonic analyzer. Front view of Zera MT310 analyzer is shown in Figure 1.

Figure 1. Front view of Zera MT310 analyzer

With this analyzer, test of all types' electrical meters, voltage, current, power and energy measurements, representation of harmonic phase angle up to 40th harmonic and magnitude, linear and logarithmic display of harmonics, current and voltage vectors, instantaneous active, reactive, capacitive, apparent powers, power factor, distortion factor, frequency measurements, representation of current and voltage waveforms can be performed.
Current measurement up to 120A can be performed by using Zera MT310 analyzer and clamp current transformers. Besides of this, current measurement up to 10000A with extra current sensors and voltage measurement up to 40000V with high voltage sticks can be performed too. Accuracy class of this model is 0.1%. Internal memories are available for storing of the results. Additionally, data management software called as MTV is based Windows OS are used to create test reports and evaluate test results. The device performs necessary measurements for the connected points. In this study, measurements were performed at connection point of meters fed through three-phase four-wire direct connected meters and three-phase four-wire current.

4.Passive Filters

Harmonic filtration is carried out in two methods. These mechanisms are passive filters and active filters. Passive filters consisted of variable connection types of passive circuit elements, have been used for long years and they are still used as they are economical. Passive LC filters used to filter harmonics and to increase power factor of load, have some disadvantages in that they have resonance risk, harmonics increase so much depending on resonance and that they occupy a large place (Rüstemli, S. et al, 2014).
A traditional single-tuned passive harmonic filter design adapts a single unit trap tuned at a specific harmonic frequency. These types of filters offer mature technology, reliable operation and lower installation and maintenance cost. A traditional passive filter design scheme needs the interlocking control when the 5th, 7th, 11th, and 13th harmonic filters are installed in the system. (Liang, X., 2011). In many cases, harmonic currents produced by nonlinear loads may have probabilistic characteristics due to the variation of load levels which are changing over time. For the passive harmonic filter planning, if harmonic currents and the system impedance are regarded as deterministic, the capacities of installed passive harmonic filters may not be properly sized, which also may lead to excessive cost. To have an efficient control of harmonic currents injected by the nonlinear loads, a new approach for planning the single-tuned passive filters of an industrial power system, where the probabilistic

characteristics of the system parameters (i.e., harmonic currents and harmonic impedances of the source and linear loads) for the passive filter planning can be taken into account (Chang, G.W., et.al, 2007). Passive filter placed between the source and receiver is designed to eliminate the components other than fundamental frequency. It is consisted with capacitance, inductance and resistance in some cases. There are two types of passive filters are used and these are serial passive filter and parallel passive filter. In addition, serial inductance usage is commonly encountered in applications as a passive filter.

The aim of passive filters' optimal design is to meet requirements and to maximize overall efficiency. Optimal parameters shall meet the following requirements (Juan Z., et al, 2009):

- Low total harmonics distortion of voltage or current,
- Low initial investment costs,
- Higher power factor, whereas reactive power can't be overcompensation,
- No series or parallel resonance with impedance of the system results in the amplification of harmonic,
- The design should ensure that in the normal fluctuation of frequency, the filter can also meet the technology requirements.

4.1.Series passive filters

Series passive filters are used in front of the AC motors drive circuits and high-power AC/DC in applications. A simple structure of a series passive filter is given in Figure 2.

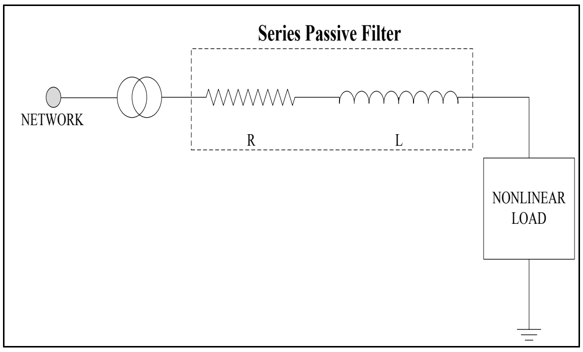


Figure 2. A simple structure of series passive filter

There are some difficulties in the implementation of series passive filters. The entire load current passes through the filter and voltage drop occurs. Therefore, isolation is required for full-line voltages.

4.2.Parallel passive filters

Parallel passive filters are consisted with capacitors, inductors, and in some cases resistance and used between harmonic source and network. A simple structure of a parallel passive filter is shown in Figure 3.

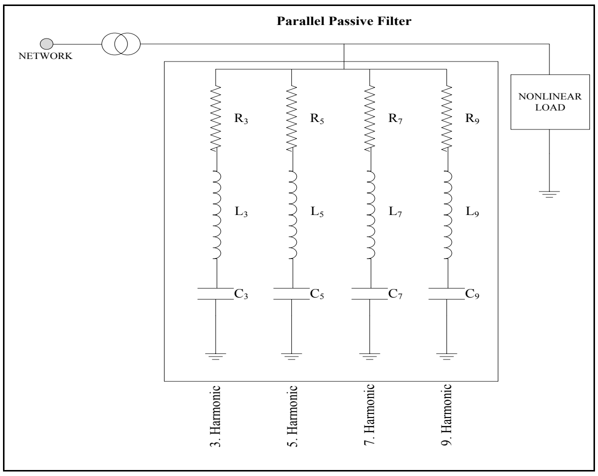


Figure 3. A simple structure of parallel passive filter

The basic principle of passive filters is to connect inductance and capacitance to power system, and calculate the values of them in order to resonance and eliminate of unwanted harmonics. It is necessary to constitute resonance arms separately for each harmonic frequency, and connect them to the power systems. For optimal solution, the most effective method for harmonics is to constitute arms for harmonic frequencies that have high amplitude value. There is only one arm can be connected to the system for eliminating the frequencies have small amplitudes. The biggest risk of using the parallel passive filters is the formation of parallel resonance with power system. Therefore, a detailed analysis of the system is required before the parallel passive filter is applied to the power system. There are four types of parallel passive filters are used in applications. These are;

- Single-tuned (band pass) filters
- Double-tuned filters
- Auto-tuned filters
- High-pass filters

In this study, single-tuned (band pass) filters are examined and designed using by Matlab. Single-tuned (band pass) filters provides diversion of only one harmonic current has unwanted frequency from the line by creating a short circuit path. Single-tuned (band pass) filters are contained with series R, L and C circuits. A simple single-tuned (band pass) filter is given in Figure 4.

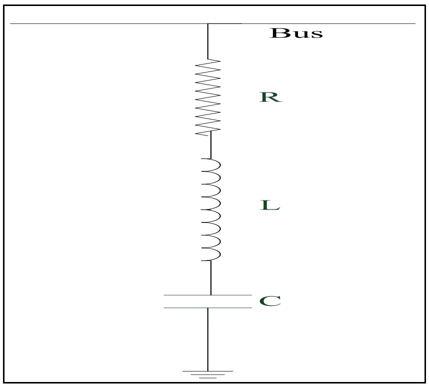


Figure 4. Single tuned passive filter

Filter impedance of single tuned passive filter (band pass) at fundamental frequency and harmonic frequencies other than the tuned harmonic frequency are expressed by;

$$Z_T = R + j(X_L - X_C) = R + j(2\pi f_n L - \frac{1}{2\pi f_n C}) \quad (2)$$

Table 1. The definitions of variables in the impedance equation (Eq.2.)

Variable	Definition
Z_T	Impedance of filter at fundamental frequency and harmonic frequencies other than the tuned harmonic frequency.
R	Internal resistance of filter' inductance and capacitance
X_L	Inductive reactance of filter
X_C	Capacitive reactance of filter
f_n	Frequency of n. harmonic
L	Inductance of filter
C	Capacitance of filter
Z_{T0}	The impedance consisted as a result of resonance at desired frequency
f_0	Harmonic frequency of filter (resonance frequency)

The principle of this filter is to provide X_L=X_C with resonance at desired harmonic frequency. In this case, the filter impedance at tuned harmonic frequency is;

$$Z_{T0} = R \quad (3)$$

When the filter parameters is being calculated, capacitance value should be determined to meet the compensation requirements since filter capacitance show compensation effect in system for fundamental frequency and other frequencies than tuned harmonic frequency. Then, inductance value must be calculated depend on this capacitance for resonance. These calculations are performed in the following order starting with eq.4.

First of all, requirements of the system are identified for reactive power. For this purpose;

$$Q = P(\tan\varphi_1 - \tan\varphi_2) \quad (4)$$

is used. Where, Q is the capacitor power which must be connected to the system for achieving the desired power factor of the system, P is total active power of the system, $\tan\varphi_1$ is tangent of the power angle before the application of compensation, $\tan\varphi_2$ is tangent of the power angle after the application of compensation. After calculating of the compensation power, capacitive reactance of the capacitance required for system must be determined by using Eq.5.

$$X_{CT} = \frac{U^2}{Q} \quad (5)$$

Where, X_{CT} is capacitive reactance of the capacitance required for system and U is operating voltage of the system.

After the calculation of capacitive reactance value, this value proportionally distributed to the single-tuned filters which separately tuned according to the effective harmonic orders in system and depends on the flowing currents. Then, the X_L values for each filter stages corresponding to each X_C must be calculated and connected depend on the tuned harmonic frequency of filter. The positive effects of the single-tuned filter can be listed as follows;

- Losses are less if there is no intentionally resistance added.
- It shows impedance near zero against harmonic current for tuned harmonic frequency.
- More than one parallel can be used for filtering more than one harmonic current.

The change in the values of the elements over time is a disadvantage of this filter. This situation can be resolved with an additional capacitor and resistor. At this time, single-tuned filters can be installed only in constant power and nonlinear loaded systems. Because, the capacitors can't respond to the changes of power and when the inductive loads leave, the capacitors continue to remain so that over-compensation may occur. If the constant load cut out of the system, the filter must be cut out of the system too.

Passive filters are constituted with passive components (inductance, capacitance and resistance) which are compatible with attenuated harmonic frequencies. Value of the inductor and capacitor is used to obtain low impedance at selected frequency. Passive filters are generally designed for eliminating one or two harmonics (generally 5th harmonic and 7th harmonic). However there are some naturally limitations. These can be listed as follows.

- Internal interaction with the power system,
- Constitution of parallel resonance circuits with the system impedance,

This situation leads to a worse situation than the corrected situation. At the same time it also causes malfunction of the system.

- Filter characteristics change due to changes of filter parameters,
- The emergence of unsatisfactory performance due to change of non-linear load parameters,
- Compensation of limited number harmonic,
- Not to be for entire system power quality,
- The possibility of parallel resonance occurrence.

This resonance frequency should not coincide with any major harmonic of the system. Passive filters are usually tuned to a lower value of attenuated harmonic as a security when system parameters change (change of temperature and/or fault status). Therefore, these types of filters are added to the system starting from the lowest unwanted harmonics. For example, filter of 5th harmonic should be placed before filter of 7th harmonic. The following steps should be followed for the design of passive filter design.

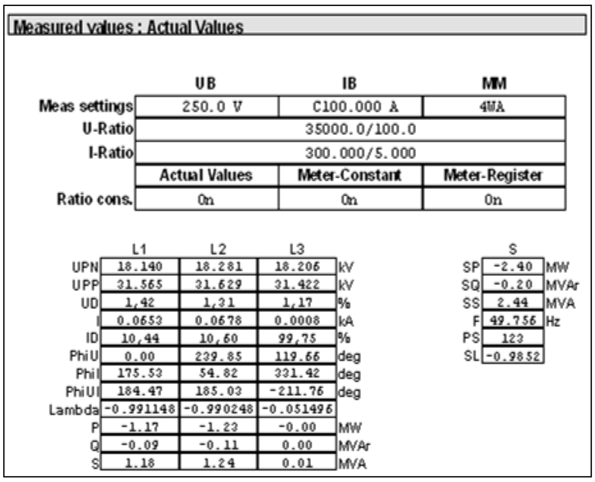
- Modeling of power system that contain of nonlinear loads and linear loads to determine harmonic source. A harmonic power (load) flow algorithm must be used.
- An equivalent circuit and calculations are enough for some applications of a simple dominant harmonic source.
- System must be checked with placing of the harmonic filters on model. Filters should be fully compatible with the dominant harmonic frequencies.
- If unexpected results (such as parallel resonance) are provided, place of the filter is changed and the parameter values are changed until the desired result is obtained.

In addition to the development of power quality, harmonic filters can be configured to provide power factor correction. Filter must be designed to carry both resonance harmonic currents and fundamental currents as well.

5. Results And Discussion

5.1.Measurements on Askale Van Cement Factory with Zera MT310

Different measurements were made in two factories belong to different groups with the model of Zera MT310 power analyzer in the city of Van.
Figure 5 shows the measurements of instant values obtained from Van Cement Factory in date of 10.02.2011. Figure 6 shows absolute value of voltage harmonics with angles which belongs to phase A. Figure 7 shows voltage wave form of this phase. Figure 8 shows that linear presentation of voltage harmonics belongs to phase A and Figure 9 shows that linear presentation of current harmonics belongs to this phase.



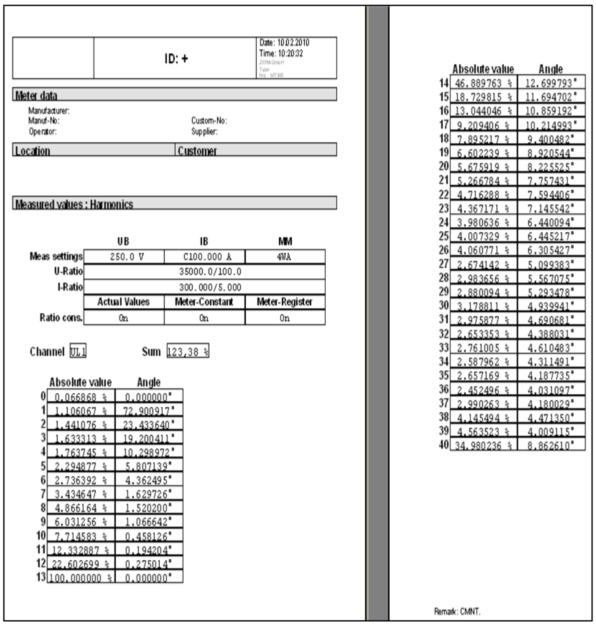
Measured values : Actual Values

	UB	IB	MM
Meas settings	250.0 V	C100.000 A	4WA
U-Ratio	35000.0/100.0		
I-Ratio	300.000/5.000		
	Actual Values	Meter-Constant	Meter-Register
Ratio cons.	On	On	On

	L1	L2	L3	
UPN	18.140	18.281	18.206	kV
UPP	31.565	31.629	31.422	kV
UD	1,42	1,31	1,17	%
I	0.0653	0.0678	0.0008	kA
ID	10,44	10,60	99,75	%
PhiU	0.00	239.85	119.66	deg
PhiI	175.53	54.82	331.42	deg
PhiUI	184.47	185.03	-211.76	deg
Lambda	-0.991148	-0.990248	-0.051496	
P	-1.17	-1.23	-0.00	MW
Q	-0.09	-0.11	0.00	MVAr
S	1.18	1.24	0.01	MVA

	S	
SP	-2.40	MW
SQ	-0.20	MVAr
SS	2.44	MVA
F	49.756	Hz
PS	123	
SL	-0.9852	

Figure 5. Instant values for Van Askale Cement Factory



ID: +

Date: 10.02.2010
Time: 10:20:32

Meter data
Manufacturer:
Manuf-No:
Operator:
Custom-No:
Supplier:

Location
Customer

Measured values : Harmonics

	UB	IB	MM
Meas settings	250.0 V	C100.000 A	4WA
U-Ratio	35000.0/100.0		
I-Ratio	300.000/5.000		
	Actual Values	Meter-Constant	Meter-Register
Ratio cons.	On	On	On

Channel UL1 Sum 123,38 %

	Absolute value	Angle
0	0.066868 %	0.000000°
1	1.106067 %	72.900917°
2	1.441076 %	23.433640°
3	1.633313 %	19.200411°
4	1.763745 %	10.298972°
5	2.294877 %	5.807139°
6	2.736392 %	4.362495°
7	3.434647 %	1.629726°
8	4.866164 %	1.520200°
9	6.031256 %	1.066642°
10	7.714583 %	0.458126°
11	12.332887 %	0.194204°
12	22.602699 %	0.275014°
13	100.000000 %	0.000000°
14	46.889763 %	12.699793°
15	18.729815 %	11.694702°
16	13.044046 %	10.859192°
17	9.209406 %	10.214993°
18	7.895217 %	9.400482°
19	6.602239 %	8.920544°
20	5.675919 %	8.225525°
21	5.266784 %	7.757431°
22	4.716288 %	7.594406°
23	4.367171 %	7.145542°
24	3.980636 %	6.440094°
25	4.007329 %	6.445217°
26	4.060771 %	6.305427°
27	2.674142 %	5.099383°
28	2.983656 %	5.567075°
29	2.880094 %	5.293478°
30	3.178811 %	4.939941°
31	2.975877 %	4.690681°
32	2.653353 %	4.388031°
33	2.761005 %	4.610483°
34	2.587962 %	4.311491°
35	2.657169 %	4.187735°
36	2.452496 %	4.031097°
37	2.990263 %	4.180029°
38	4.145494 %	4.471350°
39	4.563523 %	4.009115°
40	34.980236 %	8.862610°

Remark: CMNT.

Figure 6. Absolute values of voltage harmonics with their angles belongs to phase A

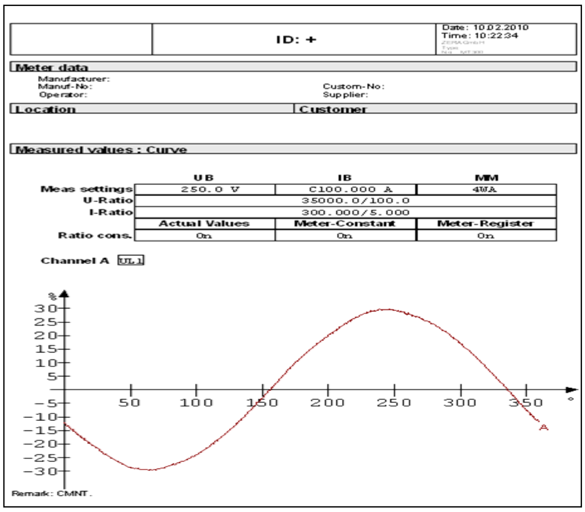


Figure 7. The voltage waveform of phase A

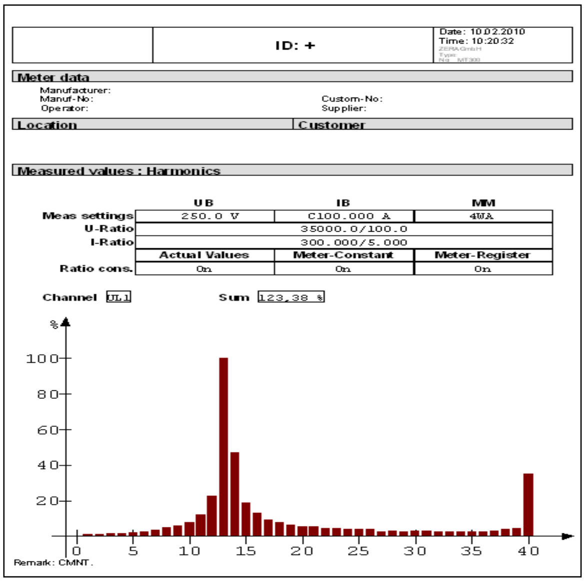


Figure 8. The linear presentation of voltage harmonics belongs to phase A

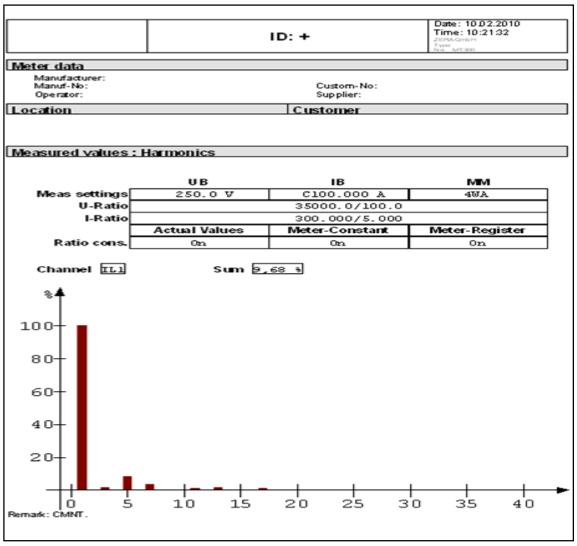


Figure 9. The linear presentation of current harmonics belongs to phase A

5.2.Measurements on Van Ercis Sugar Factory

Figure 10 shows the absolute values of current harmonics and their angles belongs to phase B of Van Ercis Sugar Factory and Figure 11 shows the FFT results of current harmonics belongs to this phase. The current waveforms of this phase are shown in Figure 12 and instant values are shown in Figure 13.

	UB	IB	MM
Meas settings	250.0 V	C1.000 A	4WA
U-Ratio	31500.0:sqrt(3)/100.0:sqrt(3)		
I-Ratio	25.000/5.000		
	Actual Values	Meter-Constant	Meter-Register
Ratio cons.	On	On	On

Channel IL2 Sum 23,57 %

	Absolute value	Angle
0	0.134052 %	0.000000°
1	100.000000 %	0.000000°
2	0.472294 %	27.065643°
3	5.569700 %	83.705444°
4	0.420751 %	81.081390°
5	22.647034 %	5.604858°
6	0.460043 %	37.030136°
7	2.857733 %	40.209080°
8	0.442694 %	44.577438°
9	0.592696 %	31.259064°
10	0.054677 %	32.536758°
11	1.230665 %	32.530190°
12	0.065657 %	19.767258°
13	0.846653 %	18.444044°
14	0.027083 %	11.231684°
15	0.064325 %	5.886581°
16	0.029539 %	0.881760°
17	0.262242 %	11.497969°
18	0.087707 %	18.297195°
19	0.196363 %	3.923050°
20	0.044190 %	16.141434°

Figure 10. Absolute values of current harmonics with their angles belongs to phase B

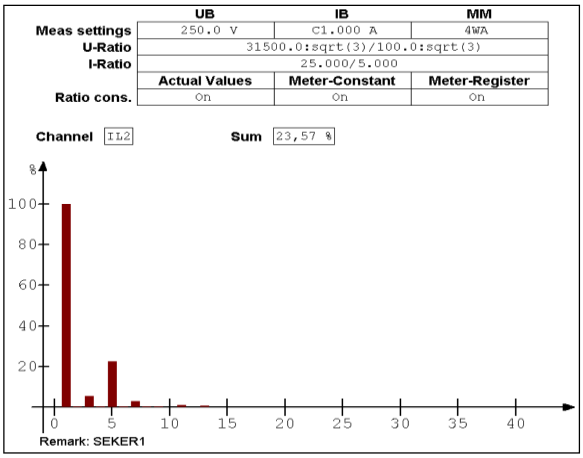


Figure 11. The FFT results of current waveform belongs to phase B of Ercis Sugar Factory

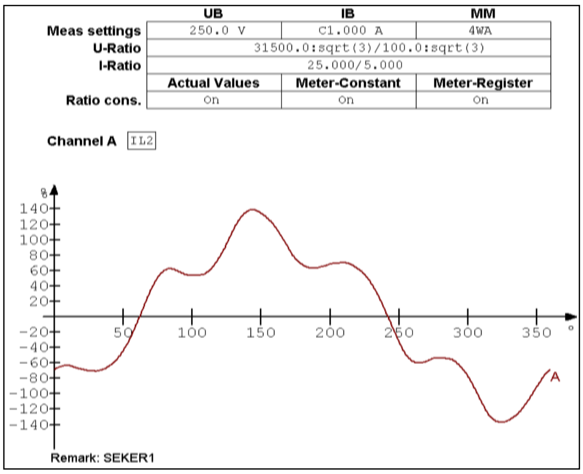


Figure 12. The harmonics belongs to phase B

	UB	IB	MM
Meas settings	250.0 V	C5.000 A	4WA
U-Ratio	31500.0:sqrt(3)/100.0:sqrt(3)		
I-Ratio	25.000/5.000		
	Actual Values	Meter-Constant	Meter-Register
Ratio cons.	On	On	On

	L1	L2	L3	
UPN	17.737	17.708	17.501	kV
UPP	30.746	30.419	30.541	kV
UD	1,46	1,42	1,46	%
I	2.215	1.903	2.306	A
ID	17,84	22,68	16,57	%
PhiU	16.17	255.85	136.33	deg
PhiI	0.00	248.03	130.95	deg
PhiUI	16.17	7.81	5.37	deg
Lambda	0.943598	0.963875	0.979453	
P	0.0371	0.0325	0.0395	MW
Q	0.0107	0.0044	0.0037	MVAr
S	0.0393	0.0337	0.0404	MVA

	S	
SP	0.1091	MW
SQ	0.0189	MVAr
SS	0.1134	MVA
F	49.974	Hz
PS	123	
SL	0.9624	

Figure 13. Instant values of Sugar Factory

Major deficiencies about electrical power quality in the region of Van are determined with the measurements and obtained graphics. When the system is installed and operated, they should be kept under control on electrical power systems by consumers for healthy functioning, long life of materials and energy quality.

It can be seen in the above results of measures for Askale Cement Plant, the installation of electrical current values were found unstable. The star point is shifting on transformers due to unbalanced loads. Therefore, electrical current pass through from neuter and causes the shortening the life of transformer due to overheating. Result of measurements show that total harmonic distortion of phase A is 123,38%. This overload cause some problems and these are overload of transformers, isolation distortion of the cable due to overheating and slide of basic components on factories that have big power.
When instant values are examined of Van Ercis Sugar Factory, some results are obtained that input voltage value is approximately 28000V but this value should be approximately 31500V. In addition, it was determined that powers relatively distributed balanced to the phase, voltage harmonics remained below to the tolerance limits, however, current harmonics remained above the tolerance limits and 5. harmonic was effective. The system can be worked properly by using a basic passive filter system.

5.3.Simulation of Passive Filter for Harmonics Elimination of Ercis Sugar Factory

In this section, this filter of the system to response separately is examined as applied single tuned filter is connected to series inductance on electrical energy system of Ercis Sugar Factory. This examine is designed using of Matlab/Simulink for current and voltage of system that have THD and FFT values.

Table 2. Current harmonics and its amplitudes of Ercis Sugar Factory

Harmonics order	Amplitudes of harmonics (Ercis Sugar Factory)
1	165,76 A
3	9,28 A
5	37,52 A
7	2,57 A

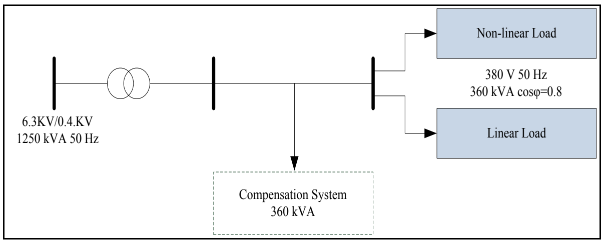


Figure 14. Diagram of Single Line for Ercis Sugar Factory

Passive filter is applied single line of Ercis Sugar Factory in Figure 14. Nonlinear loads of the system are modeled by current source. Current harmonics and its amplitudes of Ercis Sugar Factory are given in table.2. It is assumed that the loads of the system are distributed balanced.

Prepared simulation of the electrical system given in Figure 15. is performed by using Matlab/Simulink. This simulation contains measurement block, nonlinear load for phase of A, phase of B and phase of C called blocks.

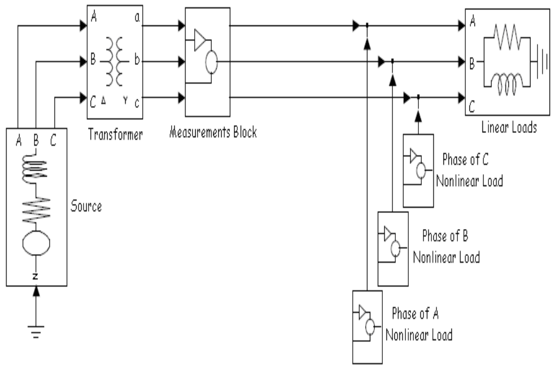


Figure 15. Prepared simulation of the electrical system

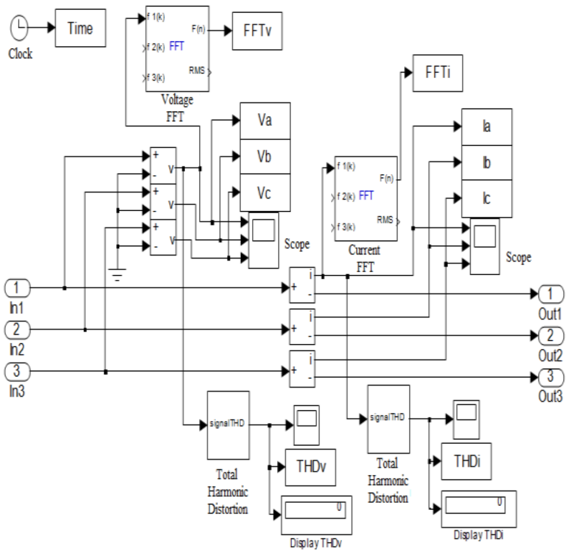


Figure 16. Measurement blocks of the simulation

Figure 16 shows the inside of closed block called of "measurement block" given in Figure15. All the necessary measurements can be performed by using this block (separately current and voltage of each phases, THD values of currents and voltages, FFT values of currents and voltages etc.).

Figure 17 shows the inside of nonlinear loads given in Figure 15. The amplitudes of each harmonic degree are modeled in this block by a current source connected 3-phase system.

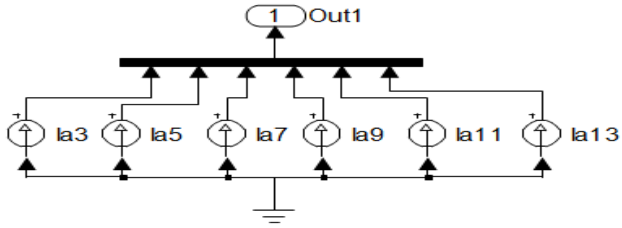


Figure 17. Measurement block of prepared simulation circuit for the system

Current graphic of the system is shown in Figure 19, FFT spectrums of current and voltage are shown in Figure 19 and Figure2 1 respectively. At this time, THD graph of the current is given in Figure 20.

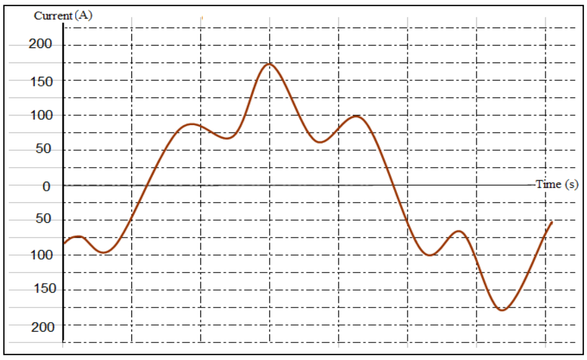


Figure18. The current of phase B

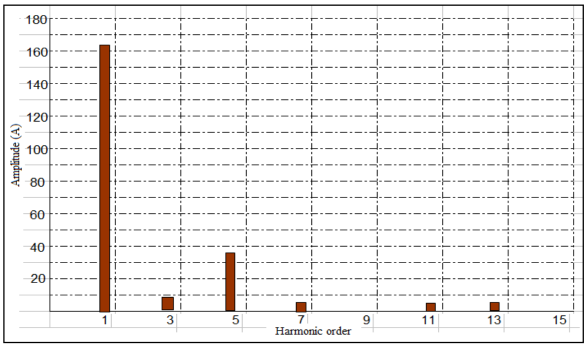


Figure 19. The FFT of current belongs to phase B

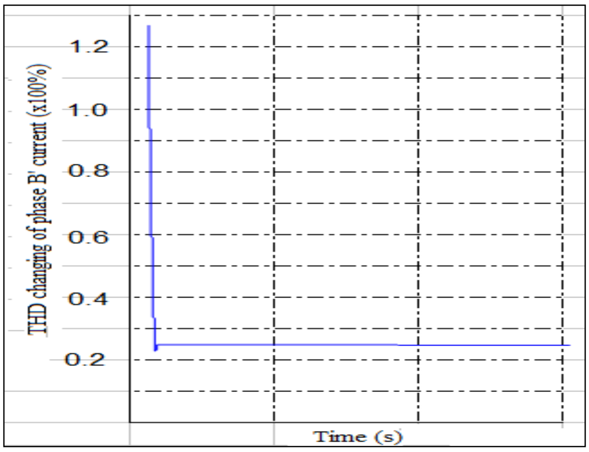


Figure 20. The changing of THD belongs to phase B' current in time

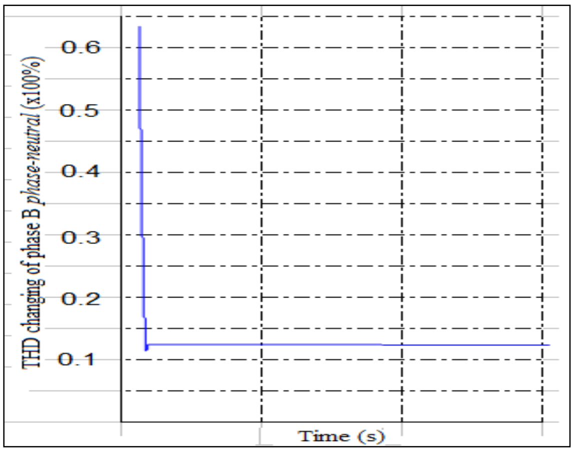


Figure 21. The changing of THD belongs to phase B voltage (phase-neutral) in time

Electrical data of the system is obtained from Matlab/Simulink simulation through the measurement block. All of electrical data is taken from a phase of the model system since it is a balanced system and these data are accepted for other phases.

In this section, single-tuned filter simulated as in Figure15 is implemented and the response of the system is examined. When this filter is applied to the system, capacity elements used in the filter must be met required compensation power. Power coefficient of the system is 0,8 and this value should be increased to 0,95, so required capacitor power is calculated as Q_c;

$$Q_C = P(\tan\varphi_1 - \tan\varphi_2) \tag{6}$$

$$Q_C = 288(\tan 36{,}86 - \tan 18{,}19) \tag{7}$$

$$Q_C = 121{,}28 \text{ kVAr.} \tag{8}$$

Capacitor power must be taken bigger than the Q_c value found in eq.8. as 125 kVAr.

$$X_C = \frac{U^2}{Q_C} = \frac{380^2}{125000} = 1{,}1552\Omega \tag{9}$$

$$C = \frac{1}{2\pi f X_C} = \frac{1}{2\pi 50.1.1552} = 0{,}00276F \tag{10}$$

$$I_h = I_3 + I_5 + I_7 = 9{,}28 + 37{,}52 + 2{,}57 = 49{,}37 \tag{11}$$

$$C_3 = I_3 \frac{C}{I_h} \tag{12}$$

$$C_3 = 0{,}000519F \tag{13}$$

$$C_5 = 0{,}002098F \tag{14}$$

$$C_7 = 0{,}000144F \tag{15}$$

If the inductor value is calculated with the same way, eq.16 can be written as;

$$L_3 = \frac{1}{(2\pi f_3)^2 C_3} \tag{16}$$

For each three harmonic (3., 5., 7. harmonics), inductor values is found as;

$$L_3 = \frac{1}{(2\pi 150)^2 0{,}000519} = 2{,}169.10^{-3} \text{ H} \tag{17}$$

$$L_5 = \frac{1}{(2\pi 250)^2 0{,}002098} = 1{,}932.10^{-4} \text{ H} \tag{18}$$

$$L_7 = \frac{1}{(2\pi 350)^2 0{,}000144} = 1{,}4359.10^{-3} \text{ H} \tag{19}$$

Figure 22 shows the simulation of the electrical system and the filter prepared by Matlab/Simulink according to the calculated L and C values for each parallel arm.

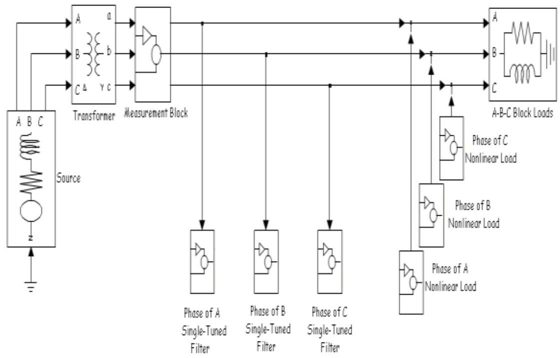


Figure 22. Simulation of the electrical system and filter for Ercis Sugar Factory

Single-tuned filter is shown in Figure23 belongs to block A, B and C (Phase of A,B,C Single-Tuned Filter) are shown in Figure 22.

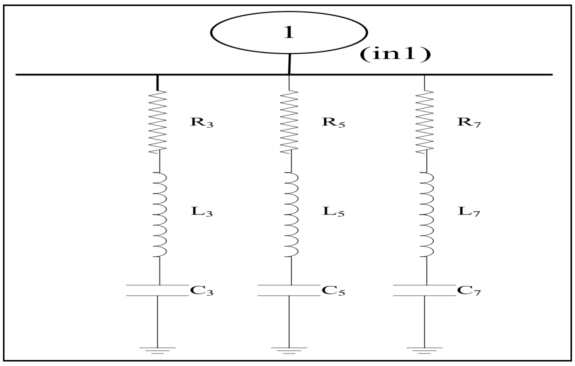


Figure 23. Single-tuned filter for Ercis Sugar Factory

Figure 24 shows the obtained current of system after applying the filter as shown in Figure 22. FFT and THD graphics of this current is shown in Figure 25 and Figure 26 respectively. At the same time, Figure 27 shows the THD graph of voltage.

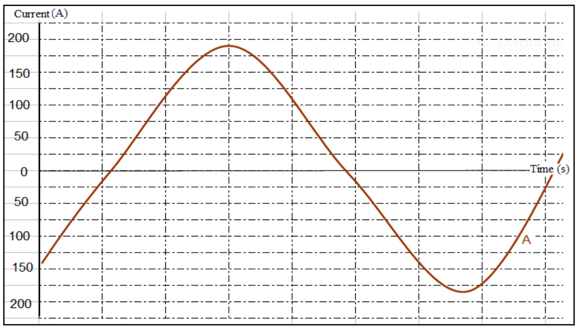


Figure 24. The current waveform after applying the filter to the system

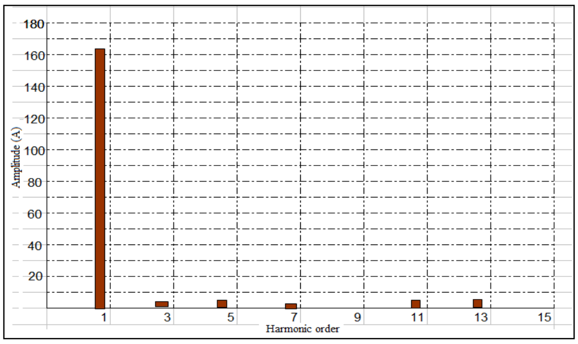


Figure 25. The FFT graph of current after applying the filter to the system

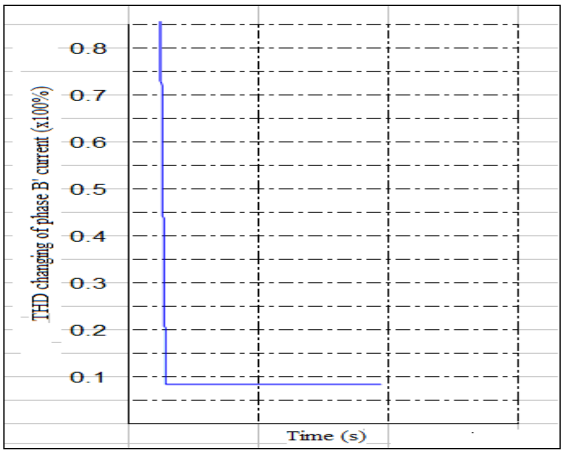


Figure 26. The THD graph of current after applying the filter to the system

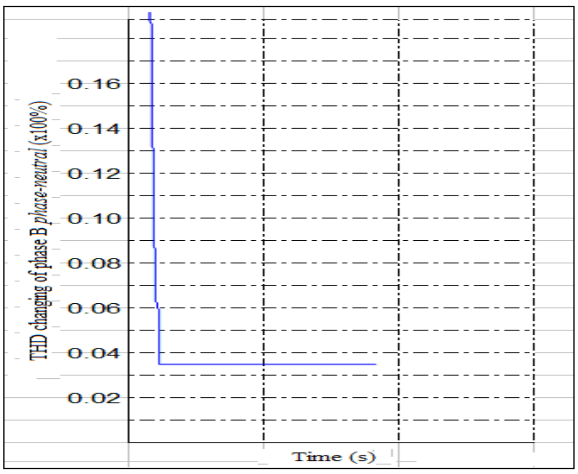


Figure 27. The FFT graph of voltage after applying the filter to the system.

Before the filter application, the THD values of current is approximately 23,57%, voltage is 11,70%. After the application, these values is decreased to 7,6%, voltage is 3,5% respectively. The obtained THD values of current and voltage are at acceptable levels. However, should not be seen as sufficient. Other high order harmonics in the system must be suppressed as well for better results. It is understood that each parallel arms are showed near-zero impedance if the internal resistances of elements is neglected on set frequency.

The performance of single-tuned filter is observed as good, however, this filter has some disadvantages. First, it is the most important problem that the system sensitively depends on changing of filter elements values in time due to sensitive calculations and setting. In addition, the nonlinear single-tuned filters are installed and used only for fixed power systems because the over compensation may be happen due to fixed capacity and variable inductive loads. Ercis Sugar Factory has not stable or fixed loads. Load status and load characteristics vary according to demand at the factory. This situation is caused problems of single tuned filter. When nonlinear loads are out of the circuit; for example, if the cause of 5th harmonic is out of circuit, the arm of this harmonic in filter stay in circuit and this situation is caused extra energy consumption. Therefore, these filters should be used on systems have fixed nonlinear loads. When constant load is out of circuit, single-tuned circuit filters should be removed.

Every factory should take precautions according to their load characteristics and load movements for proposed corrections and protection. This condition is seen as extra cost in the short-term but in the long term; beneficial consequences happen for the economy of the country and development the total quality of products. Especially universities, chamber of trades, customers and foundations should be come together to improve the quality of education and awareness-raising activities.

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