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EFFECTS OF POWER QUALITY TERMS ON PASSIVE POWER FILTERS

Oktay Arikan
Electrical Engineering
Yildiz Technical University
ISTANBUL/TURKEY

Bedri Kekezoğlu
Electrical Engineering
Yildiz Technical University
ISTANBUL/TURKEY

Celal Fadıl Kumru
Electrical Engineering
Yildiz Technical University
ISTANBUL/TURKEY

ABSTRACT

Power quality is becoming a major problem of modern power systems. Harmonics, which are the most significant power quality term, can have substantial effects on electrical devices. Nonlinear loads as electric arc furnaces, power electronic devices cause harmonic problems on power systems, due to their voltage-current characteristics. Passive Power Filters (PPF) are used effectively for harmonic mitigation in power systems. In this study, harmonic measurement data of a steel-iron plant which are obtained from National Power Quality Project supported by The Scientific And Technological Research Council Of Turkey (TUBITAK) are used. A passive harmonic filter is designed for a nonlinear load which is measured within the context of the project. In the case of distorted power quality conditions such as voltage variations, frequency fluctations, unsteady loads and changes in phase angles, behaviour of the designed passive filter is analyzed with simulation studies and obtained results are presented.

Keywords: Power Quality, Harmonics, Passive Power Filter, Iron-Steel Industry.

INTRODUCTION

The power grid is distorted severely with the increase of nonlinear loads in power systems. Major distortions that are also known as power quality problems are classified as harmonics, flicker, voltage sag and voltage swell [1]. Harmonics which can be defined as components with periodic waveforms having multiples of fundamental frequency are the most common power quality problems.

Iron-steel plants which are lined up at the beginning of organizations that affect power quality have harmonic components with wide frequency spectrum. Electric arc furnaces (EAF) are primary harmonic sources in iron-steel facilities. Due to the unsteady discharge that occurs during the operation of melting, EAFs have nonlinear voltage-current characteristic. Most considerable problem of iron steel industry is the harmonics produced by EAF [2].

In power systems, various types of harmonic elimination methods are used for improving power quality. Passive Power Filters (PPF) and Active Power Filters (APF) are widely used to decrease harmonic component level. Due to performance-price ratio, PPFs provide suitable solutions for harmonic mitigation on power systems [3].

In the literature, several works have been realized for determining and solving harmonic problems on power transmission lines. M. B. Jannat and J. S. Abdulmalek improved a passive harmonic filter for electrical arc furnaces in Misurata Steel Plant by using field measurements [2]. Babak Badrzadeh et al designed a new passive harmonic filter for a grid connected aluminum smelting plant accordance with field measurements [4]. D. C. Bhonsle and R. B. Kelkar designed and simulated passive filter for Electrical Engineering Department of C. K. Pithawalla Collage of Engineering and Technology by using MATLAB [5]. Julio C. Churio-Barboza et al presented a new method for passive filter design on behalf of systems with time-varying nonlinear loads [6]. J. C.

Das investigated operation of two types of passive filters with respect to the design and system limitations [7]. S. J. Bester and G. Atkinson-Hope analyzed passive harmonic filter performances on distribution system with two resonant points for six different scenarios [8]. Thomas J. Dionise et al investigated harmonic efficiency of a high-voltage anode foil manufacturing factory for three passive filter cases [9]. Alexandre B. Nassif et al examined selection of filter topology for passive filter applications [10].

In this study, field measurements of an iron-steel plant that measured by members of National Power Quality Project in Turkey, are analyzed. Considering the harmonic measurements, an optimum passive filter design is realized for given plant. The performance of the designed filter is individually analyzed in the cases of frequency fluctuation, voltage rise/decrease or unsteady state. As a result of the analysis carried out, measured THDV values at several measuring points and the active power losses on the passive filter for all cases are presented and commented.

This paper is structured as follows. Section II introduces considered iron – steel plant and shows the field measurement results. Section III describes mathematical background and standards. Section IV indicates results and Section V concludes this paper.

HARMONIC FIELD MEASUREMENTS

Field measurements are taken from an iron – steel facility that connected to transmission system with a radial line in Turkey. Single line diagram of considered plant is given in Figure 1. Both the primary and secondary of 180 MVA power transformer is measured as shown in Figure 1.

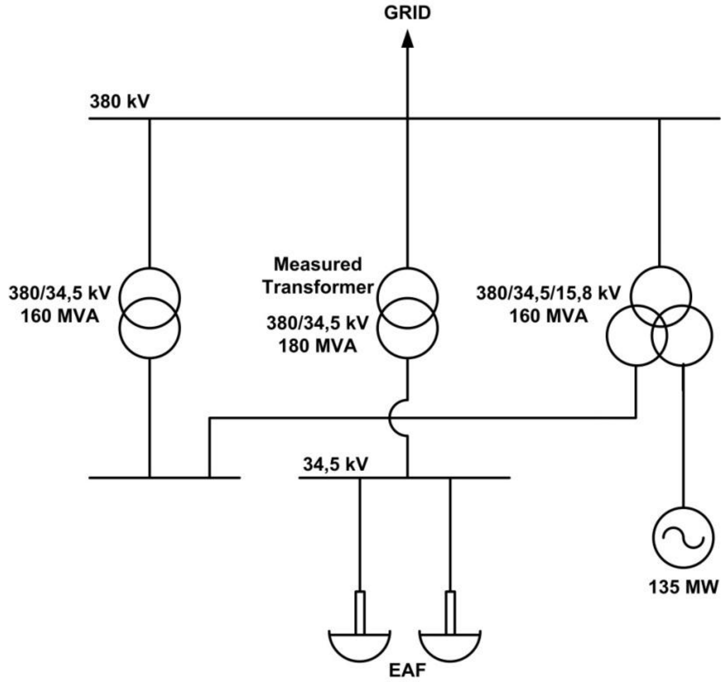

Figure 1. Single line diagram of considered iron – steel plant

Outdoor switchyard of measured iron – steel facility is shown in Figure 2. Analyzed system has three power transformers with 160 MVA, 180 MVA and 160 MVA rated power, respectively. EAFs are feed from 34,5 kV voltage bus. System has a generation unit with 135 MW rated power.

Figure 2. Switchyard of measured iron – steel facility

Voltage harmonic measurement results are given for secondary of measured transformer in Figure 3, by harmonic order.

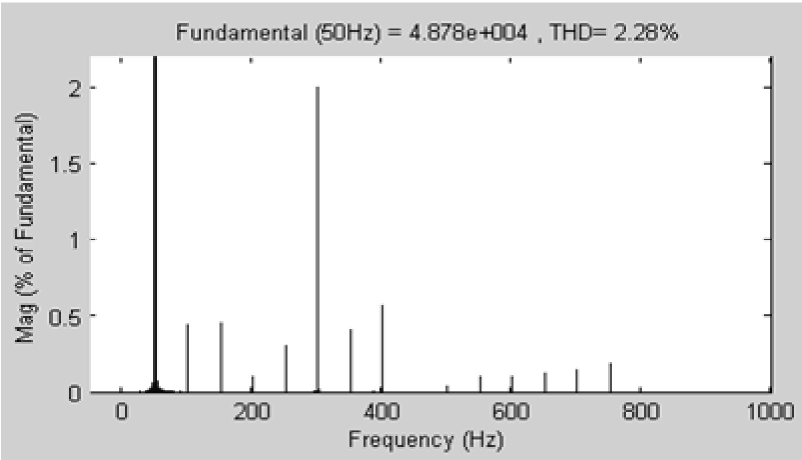

Figure 3. Harmonic measurement results of considered plant

In consequence of the measurements conducted, it is clearly seen that especially the sixth harmonic component is dominant on the system. As a result of the measurements made, it is specified that all harmonic components up to 15^{th} harmonic are exist on the system.

MATHEMATICAL BACKGROUND AND STANDARDS

The definitions and expressions about electrical quantities which are valued for sinusoidal state are not enough for nonsinusoidal conditions. Since, these electrical quantities must be redefined for nonsinusoidal conditions [11].

Instantaneous values of voltage and current with harmonic components,

$$v(t) = \sum_{n=1}^{\infty} v_n(t) = \sum_{n=1}^{\infty} \sqrt{2}\, V_n \sin(n\omega_1 t + \theta_n) \tag{1}$$

$$i(t) = \sum_{n=1}^{\infty} i_n(t) = \sum_{n=1}^{\infty} \sqrt{2}\, I_n \sin(n\omega_1 t + \delta_n) \tag{2}$$

can be expressed as above [12]. Where, n presents the harmonic degree, θ and δ are phase degree of voltage and current respectively. In figure 4, a distorted harmonic wave is shown.

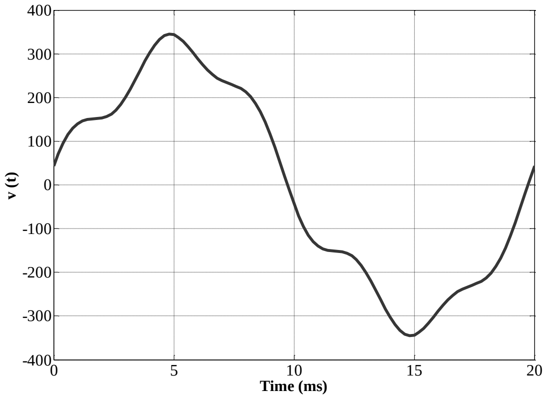

Figure 4. Harmonikli gerilim dalga şekli [13]

In the case of harmonic distortion, active and reactive powers are given,

$$P = \sum_{n=1}^{\infty} V_n I_n \cos(\theta_n - \delta_n) = \sum_{n=1}^{\infty} P_n \tag{3}$$

$$Q = \sum_{n=1}^{\infty} V_n I_n \sin(\theta_n - \delta_n) = \sum_{n=1}^{\infty} Q_n \tag{4}$$

with these equation.

Total Harmonic Distortion (THD) is a major parameter to show the effects of harmonics on electrical power systems. THD is used in standards to limit harmonics and defined as given in Equation 5 for voltage and current respectively [14]

$$THD_V = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V_1} \qquad THD_i = \frac{\sqrt{\sum_{n=2}^{\infty} i_n^2}}{i_1}$$

(5)

where, n is harmonic order, v_n and in are voltage and current values for harmonic order n, v_1 and i1 are fundamental values of voltage and current, respectively.

Passive filters are effective solutions for improving the power quality on energy systems. Various types of passive filters are used in practice. Nowadays, industrial applications are to combine passive filters with different topologies to provide standard limits [10].

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Considered Passive Power Filter Types

Nowadays, there are effective harmonic components in power systems by the reason of nonlinear loads. These harmonic components should be kept at a certain level given in related standards to prevent the distorting effects on system operation. A quite few standards and regulations are prepared by the national and international corporations.

One of the most effective methods to eliminate harmonic components is passive harmonic filters. The fundamental working principle of a passive harmonic filter is to eliminate the harmonic components by use of the resonance phenomena between inductance and capacitance of the filter. Several filter types that are used to eliminate harmonic components on electrical power systems are shown in Figure 5.

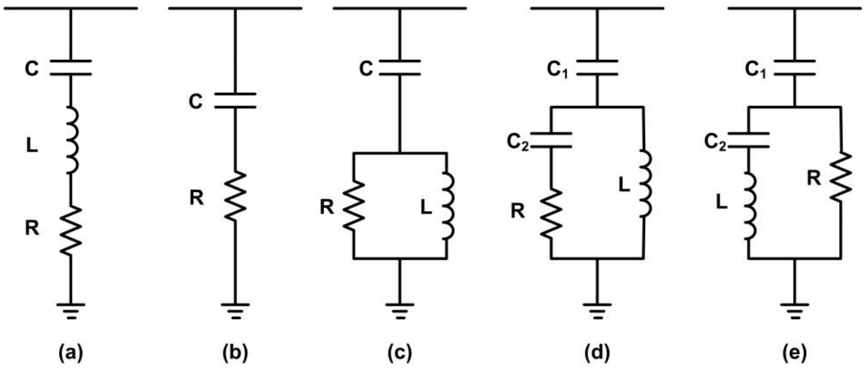

Figure 5. Various types of passive filters: (a) single tuned, (b) first order damped, (c) second order damped, (d) third order damped, (e) C-type.

The most suitable passive filter design is introduced for mentioned power plant by using tuned filters, detuned filters which is tuned between two following resonance frequencies and high-pass filters together. The details for both types of filters are given below.

Single-Tuned Filter

Single-Tuned filters have simple structures and consist of serial RLC elements. The filter impedance (Z_f) at the ω angular frequency is acquired as in Eq. 6.

$$Z_f = R + j\left(\omega L - \frac{1}{\omega C}\right) \quad (6)$$

In Eq. 6, R, L and C are respectively state the resistance, inductance and capacitance of the passive filter. While a passive filter is designed for a power system, it is important to pay attention to the reactive power compensation function of the filter. Therefore, the capacitance value of the filter is calculated initially according to the reactive power need. In the case of one filter branch is connected to the system, the capacitance value for reactive power compensation at fundamental frequency is acquired with the equation 7.

$$Q_C = \omega \cdot C \cdot U^2 \quad (7)$$

In here, Q_c is the capacitive reactive power for system need and U is the phase-phase voltage. In the event of more than one filter branch connected to the system, the obtained capacitance value is allocated equally.

In accordance with the filter principle, the absolute values of capacitive and inductive reactance at resonance frequency should be equal. Accordingly, the inductance value of the filter is derived in Eq.8.

$$L = \frac{1}{(2 \cdot \pi \cdot f_r)^2 \cdot C} \tag{8}$$

For passive harmonic filters, precision of the resonance frequency is specified with the quality factor (Q). The quality factor which is belongs to low and high Q type filters are respectively calculated with the formula given in equation 9 where X_r is resonance impedance.

$$Q_L = \frac{X_r}{R}, \qquad Q_H = \frac{R}{X_r} \tag{9}$$

High Q type passive filters' quality factor value vary between 30-60 while this range is 0,5-5 for low Q type passive filters.

Damped Filter

Damped passive filters are generally preferred for eliminating the high degree harmonic components. The characteristic feature of this kind of filters is that they have low impedance at high frequencies while this impedance is higher at lower frequencies. There are different types of damped passive filters as shown in figure 5. The difference between the filter types is result from the impedance characteristics and the active power losses at mains frequency.

Damped passive filter display low impedances below a specific corner frequency and the filter is designed considering this frequency value. In this study, quadratic damped filter (figure 5-c), which is the easiest one to implement among the high pass passive filters, is used and relevant equations are given below.

As in the single tuned passive filter, capacitance value of the damped passive filters is calculated based upon reactive power demand. According to the capacity obtained and corner frequency which the passive filter will be designed for, the resistance value of passive filter is acquired by equation 10.

$$R = \frac{1}{2 \cdot \pi \cdot f_0 \cdot n \cdot C} \tag{10}$$

where, f_0 for corner frequency and n for harmonic degree related to corner frequency. The inductance of the filter is calculated by the equation 11.

$$L = m \cdot C \cdot R^2 \tag{11}$$

The m coefficient stated in the equation varies between 0,5-2.

Power Quality Standards

According to the voltage level, harmonic component values in a power system are asked for being below the values given in the standards. In this work, the behavior of the passive filter, which is designed for the measured nonlinear load, is analyzed in the cases of working under normal system operation and distorted power quality conditions. The study results obtained are compared with the values in standards and introduced.

In power systems, it is aimed to satisfy the electrical system parameters at a desired level by the electric suppliers. However, there might be oscillations in all magnitude with the alterations occurred in the interconnected system. Especially, even small frequency variations might have significant effects on the network. In TURKEY, the mains frequency is considered as 50 Hz. For the loads below 200 MW in power system, frequency oscillation lower and upper limits are specified as 49,8 Hz and 50,2 Hz respectively [15].

Frequentative changings in load demand in a power system cause the voltage oscillation to increase at serious levels. The permitted limit values for voltage oscillation in an interconnected system of TURKEY are shown in Table 1 [15].

Table 1. Permitted voltage changing limits

Nominal Voltage Level (kV)	Limits	
	Maximum (kV)	Minimum (kV)
380	340	420
154	140	170
66 <	±10	

Harmonics are the most serious distortionary component in power system. For the whole harmonic components, limit THDV values, which are defined for the 380 kV nominal rated networks, are given in Table 2 [15].

Accordingly, total harmonic distortion value for 380 kV networks is 2%. Similarly, maximum total harmonic distortion value is limited to 3% for 20-154 kV networks.

Table 2. Permitted harmonic voltage levels in 380 kV transmission system

Odd Harmonics (Non-triplen Harmonics)		Odd Harmonics (Triplen Harmonics)		Even Harmonics	
Harmonic No.	Harmonic Voltage (%)	Harmonic No.	Harmonic Voltage (%)	Harmonic No.	Harmonic Voltage (%)
5	1.25	3	1.0	2	0.75
7	1.0	9	0.4	4	0.6
11	0.7	15	0.2	6	0.4
13	0.7	21	0.2	8	0.4
17	0.4	>21	0.2	10	0.4
19	0.4			12	0.2
23	0.4			>12	0.2
25	0.4				
>25	0.2+0.2 (25/h)				
Total harmonic distortion level 2%					

SIMULATION RESULTS

In this study, harmonic measurements of a iron-steel plant in TURKEY-Marmara Region is presented. By considering the measurement results, a passive harmonic power filter is designed for the investigated system. The behavior of the filter, which works properly at normal operation conditions, under distorted power quality conditions and active power losses of the designed filter is analyzed. According to the results obtained by measurements, three branched passive filter is approved for the investigated system. Thus, a detuned filter for 2^{nd} and 3^{rd} harmonic components, a single tuned filter for 6^{th} harmonic component and a high pass filter for 8^{th} and over harmonic components are designed. Within the scope of the studies performed, passive filter parameters calculated for the investigated system are given in Table 3. In the filter design, reactive power need of the system is also taken into consideration. When the designed passive filter is applied to the system, the power factor value is increased to 0,99 while this value is 0,914 without the filter.

Table 3. Calculated Filter Values

Harmonic Order	Filter Type	R (ohm)	L (mH)	C (μF)
2-3	Detuned	3,263	166,177	9,755
6	Tuned	1,360	28,850	9,755
8	High Pass	40,786	16,228	9,755

As it is known that the passive harmonic filters are generally designed according to the nominal operation conditions and then taken into operation. However, oscillations within and over the limits of the values in standard might be occurred according to the frequency, voltage and phase angle alterations. In this case, there might seem some differences in the designed filter's behavior.
In the present study, by taking into account the situations that remaining and exceeding the defined limit values of the standards, the behavior of the designed passive filter is analyzed with the simulation circuit in MATLAB/Simulink software. In the investigation, harmonic distortions occurred at the network, transmission line and load buses are considered. Single-line diagram of the system simulated and the measurement points are shown in figure 6.

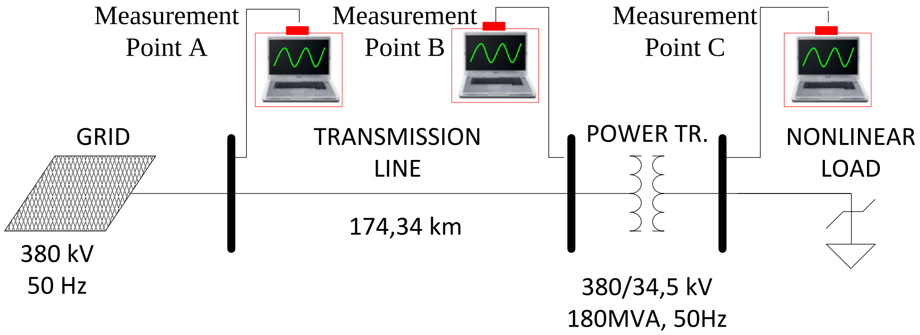

Figure 6. Single line diagram of simulated system and measurement points

In the simulation study, the system is tested in normal operating conditions in the first place. At this stage, two cases are considered that the designed passive filter is on-line and out of circuit. The results obtained are presented in Table 4.

Table 4. THDV values for nominal conditions

Measurement Point	% THDV	
	Without Filter	With Filter
A	0,01	0,01
B	2,39	0,84
C	2,29	1,09

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In the investigated system, the network and transmission line measurements are carried out on 380 kV buses. The total harmonic voltage distortion limit value in 380 kV networks is specified as 2% within the standards. Therefore, it is clearly seen from the Table 4 that when the filter is out of circuit, harmonic voltage distortion value measured at the line is exceeding the limit values permitted in the related standard.

The harmonic measurements data obtained for the load bus are collected from the 34.5 kV medium voltage bus. The measurement results show that total harmonic voltage distortion value is below 3% specified in standard.

When the measurements results are considered it is obviously seen that total harmonic distortion values at all measurement points are considerably decrease with the use of designed passive harmonic filter. Besides with the passive filter application on system, measured total harmonic distortion at the transmission line bus is also below the limit value specified in the standard.

As part of the study conducted, the probable circumstances such as frequency and voltage level variations and unbalance of loads are considered and performance of designed passive filter is analyzed for every cases. For all cases, active power losses of the designed filter are analyzed.

Frequency Variations

In this study, the effect of the probable frequency variations on designed passive filter is analyzed. According to the regulations in our country, variation of frequency in a power system is limited to ±4%. In the simulation study made, for two cases where the frequency is below and over the limit values are separately investigated. The results obtained are given in Table 5.

As it is clearly seen in Table 5., that when the frequency increases over the nominal values, crucial increase in the harmonic distortion is occurred. The maximum harmonic distortion among the investigated circumstances is seen for 49.5 Hz frequency. When the frequency value is become distant from the nominal value, it is confirmed that harmonic distortion at the load bus is increasing over the standard value. When the filter is not in the operation, it is seen that THDV values measured at load and transmission line buses exceed the limit values for both 49.5 Hz and 50.5 Hz frequencies.

Table 5. Performance of the designed passive filter for frequency variations

Frequency (Hz)	Measurement Point	% THD_v	
		Without Filter	With Filter
49,5	A	0,73	0,73
	B	3,92	1,53
	C	3,75	1,8
49,8	A	0,62	0,62
	B	2,64	1,26
	C	2,62	1,59
50,2	A	0,64	0,63
	B	2,69	0,92
	C	2,48	0,95
50,5	A	0,74	0,74
	B	3,85	1,53
	C	3,68	1,8

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For these circumstances, when the designed passive filter is used for the elimination of harmonic components, it is confirmed that there is a decrease in the performance of the filter although the results obtained are in the range of limit values. In the simulation where the designed passive filter is used, the best harmonic elimination is obtained at 50.2 Hz frequency and 66 in percentages of total harmonic distortion.

Voltage Changes

Frequently occurred load variations in interconnected systems have an important effect on network voltage and cause to change voltage value. Therefore, effects of the changings occurred in the system on the filter's performance should be analyzed. In our country, voltage variations that might be occurred in a network are limited with the band of ±10%. In this study, the designed filter's performance is analyzed for both 340 kV and 420 kV which are limit values and 320 kV and 440 kV which are the values over limits. The results obtained are presented in Table 6.

Table 6. Performance of the designed passive filter for voltage changes

Voltage (kV)	Measurement Point	% THDv	
		Without Filter	With Filter
320	A	0,01	0,01
	B	2,84	1
	C	2,72	1,29
340	A	0,01	0,01
	B	2,68	0,94
	C	2,56	1,22
420	A	0,01	0,01
	B	2,25	0,76
	C	2,16	0,97
440	A	0,01	0,01
	B	2,09	0,74
	C	1,99	0,95

As a result of the studies performed, it is seen that total harmonic distortion changes inversely proportional to the fundamental component magnitude of the system voltage. Consequently, while the maximum harmonic distortion occurs at 320 kV system voltages, the minimum harmonic distortion value is seen at 440 kV. Among the investigated circumstances, the maximum harmonic distortion value is achieved as 2.84% at the transmission line bus. After the designed passive filter is connected to the system, considerable decreases are observed in harmonic components. In the 420 kV transmission line bus, 66% of harmonic components are eliminated with the usage of designed passive filter. For all voltage levels considered, the designed passive filter performed better behavior compared to the performance at the frequency variation cases.

Voltage Instability

In power systems, instabilities might occur at network voltage by the reasons of unbalanced distribution of loads. Such instabilities which occur in both magnitude of voltage and phase angel could cause negative effect on the system. In this part of the study, the instabilities which could occur in both magnitude of voltage and the phase angel are analyzed respectively. The analysis results are shown in table 7 and table 8.

The results showed that voltage instability causes the THD_V values in measurement points to be changed. With and without the passive filter, it is understood that the effects of the both instability cases are independent from each other. It is confirmed that distorted power quality conditions caused by the voltage instability show difference for the cases of lower and upper the nominal voltage instability values.

Table 7. Performance of the designed passive filter for voltage instability

Phase	Voltage (kV)	Measurement Point	% THD_v					
			Without Filter			With Filter		
			Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
A B C	400 380 380	A	0,01	0,01	0,01	0,01	0,01	0,01
		B	2,24	2,36	2,36	0,78	0,82	0,82
		C	2,15	2,25	2,25	1,02	1,08	1,08
A B C	380 400 380	A	0,01	0,01	0,01	0,01	0,01	0,01
		B	2,36	2,24	2,36	0,82	0,78	0,82
		C	2,27	2,14	2,25	1,08	1,02	1,07
A B C	380 380 400	A	0,01	0,01	0,01	0,01	0,01	0,01
		B	2,39	2,4	2,28	0,83	0,83	0,79
		C	2,32	2,28	2,17	1,08	1,08	1,03
A B C	360 380 380	A	0,01	0,01	0,01	0,01	0,01	0,01
		B	2,25	2,39	2,39	0,87	0,82	0,82
		C	2,43	2,27	2,27	1,14	1,08	1,08
A B C	380 360 380	A	0,01	0,01	0,01	0,01	0,01	0,01
		B	2,37	2,51	2,38	0,82	0,86	0,82
		C	2,28	2,39	2,26	1,07	1,14	1,08
A B C	380 380 360	A	0,01	0,01	0,01	0,01	0,01	0,01
		B	2,35	2,35	2,48	0,83	0,83	0,87
		C	2,27	2,24	2,36	1,08	1,08	1,14

In the case where the voltage instability is occurred in, the maximum harmonic distortion is obtained as 2.51% in phase B of transmission line whose voltage is 360 kV. For the +30° of phase angel instability in phase A, the maximum harmonic distortion is acquired as 2.31% in the phases B and C of transmission line.

In consequence of the studies analyzed, it is seen that the harmonic distortion value differ for each phases in the case of instability between the phases. This effect is changeable due to the cases with or without the passive filter. The analyses of the results obtained indicate that the most distortive effect is seen on the phase C.

Table 8. Performance of the designed passive filter for phase angle instability

Phase	Phase Angle (°)	Measurement Point	% THD$_v$					
			Without Filter			With Filter		
			Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
A B C	30 -120 120	A	0,01	0,01	0,01	0,01	0,01	0,01
		B	2,29	2,31	2,31	0,79	0,8	0,8
		C	2,21	2,21	2,21	1,06	1,07	1,07
A B C	0 -90 120	A	0,01	0,01	0,01	0,01	0,01	0,01
		B	2,25	2,23	2,25	0,8	0,79	0,8
		C	2,16	2,12	2,15	1,07	1,06	1,07
A B C	0 -120 150	A	0,01	0,01	0,01	0,01	0,01	0,01
		B	2,23	2,24	2,22	0,79	0,79	0,79
		C	2,15	2,14	2,13	1,07	1,07	1,06
A B C	-30 -120 120	A	0,01	0,01	0,01	0,01	0,01	0,01
		B	2,27	2,26	2,25	0,8	0,8	0,79
		C	2,17	2,16	2,14	1,07	1,07	1,06
A B C	0 -150 120	A	0,01	0,01	0,01	0,01	0,01	0,01
		B	2,24	2,27	2,25	0,8	0,8	0,79
		C	2,18	2,19	2,16	1,07	1,08	1,06
A B C	0 -120 90	A	0,01	0,01	0,01	0,01	0,01	0,01
		B	2,27	2,25	2,28	0,8	0,79	0,8
		C	2,18	2,15	2,17	1,07	1,06	1,07

Filter Losses

In the cases of passive filter usage in power systems, the analyses of the active power losses on the filters are discussed as an important subject. In this part of the study, the active power losses of the designed filter are individually analyzed for all cases and the maximum values of the results obtained are introduced.

Table 9. Filter Losses

	Loss of Phase A (kW)	Loss of Phase B (kW)	Loss of Phase C (kW)	TOTAL (kW)
Nominal Operation	78,81	78,80	78,80	236,42
Frequency Variations	76,01	76,90	76,92	229,84
Voltage Changes	56,49	56,45	56,46	169,41
Voltage Instability	78,87	70,96	78,69	228,51
Phase Angle Instability	80,41	78,75	79,05	238,21

As it is seen from the table 9 that maximum active power loss is resulted in the case of phase angle instability. The active power loss of the designed filter connected to the phase A, where phase angle instability is occurred, is obtained as the maximum value 80.41 kW among the investigated cases. Also, the minimum active power loss value is occurred in the case of voltage decrease. In comparison to the normal operating condition of the system, it is observed that total active power losses are only increasing in the case of phase angle instability while it decreases in other cases.

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CONCLUSION

In this study, power quality measurements of an iron-steel plant in TURKEY are introduced. Considering the measurements carried out, a passive power filter design is performed. Analysis studies in the cases of operation with and without the filter are conducted by modeling the handled system simulated with the MATLAB/Simulink software. The performance and the active power losses of the designed filter are analyzed for the fluctuations of network voltage and frequency.
In this paper, the cases of nominal operating conditions, frequency and voltage variations, voltage and phase angle instabilities are analyzed separately. The circumstances where the designed filter is on line and out of circuit are analyzed for each network condition. The maximum harmonic distortion value for the frequency variation is obtained as 49.5 Hz frequency. Also, in the case of voltage variation, maximum harmonic distortion value is acquired in 320 kV network voltages. The highest harmonic distortion value in the case of voltage magnitude variation is obtained as 2.51% from phase B of the transmission line. For the +30° of phase angel instability in phase A, the maximum harmonic distortion is 2.31% seen on the phases B and C of transmission line. For all circumstances discussed, it is introduced that the designed passive filter shows different performances.

Additionally, analyzed active power losses of the designed filter proved that different power quality conditions in a power system significantly affect the losses. The maximum active power losses occur in the case of phase angle instability. The active power loss of the designed filter connected to the phase A, where phase shift is occurred, is obtained as the maximum value 80.41 kW among the investigated circumstances.

Consequently, it is seen that the designed passive filter satisfied the allowable harmonic distortion limit values specified in standards. As a result of the analysis carried out, it is suggested that system components of power system should be monitored regularly for a proper operation. Furthermore, not only the harmonics but also other factors such as frequency, voltage and phase angel variations should be taken into account for the system stability.

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