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A WINDOWS-BASED DIGITAL FILTER DESIGN

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Abstract- This study aims to describe a general digital filter, practically for Windows' users. For this purpose, an I/O interfacing circuits base on PIC16F877 was designed to receive analog signal into the PC and return filtered signals. This I/O module was then communicated with PC using parallel port protocol with EPP mode, and a digital filter program was introduced using C++. Various filters; such as LPF, HPF, BPF, and BSF were designed using the method of frequency transformation on normalized Butterworth and Chebyshev analog filters. The grades of the designed filters range from n=1 to n=8. Using this application the proposed windows-based digital filter design worked better and faster.

Keywords- Analog filter, digital filter, filter design, PIC, C++

1. INTRODUCTION

Digital signal processing is concerned with the representation of signals by sequences of numbers or symbols, and the processing of these sequences. One of the purposes of digital signal processing is designed an algorithm or devices, which is called as a digital filter. Digital filters are classified such as linear or non-linear, continuous-time or discrete-time, and recursive or non-recursive. In a non-recursive filter the output depends only on present and previous inputs. So a non-recursive digital filter possesses only z-plane zero (apart from any poles at the origin). The output from recursive digital filter depends on one or more previous output values, as well as on inputs. In other words, it involves feedback. Thus, a recursive filter has one or more strategically placed z-plane poles. In general we may write its transfer function and difference equation as:

$$H\left[e^{j\Omega}\right]=\frac{\sum_{k=0}^{M} a_k e^{-j\Omega k}}{1+\sum_{k=1}^{N} b_k e^{-j\Omega k}} \qquad (1)$$

and

$$y[n]=\sum_{k=0}^{M} a_k x[n-k]-\sum_{k=1}^{N} b_k y[n-k] \qquad (2)$$

where N>0 and M≥0.

At the time-domain analysis, this is total of the convolution.

$$y[n] = \sum_{l=0}^{\infty} h[n]\ x[n-l] \tag{3}$$

where h[n] is the impulse response of digital filter.

In addition, properties of digital filter are generally given as frequency-domain. The frequency response of filter can be found by using transformation z= $e^{j\Omega}$ instead of z.

$$H\left[e^{j\Omega}\right] = \frac{\sum_{k=0}^{M} a_k e^{-j\Omega k}}{1 + \sum_{k=1}^{N} b_k e^{-j\Omega k}} \tag{4}$$

The frequency response of the digital filter obtained Eq. (4) is related to the frequency response of the continuous-time filter. In the impulse invariance design procedure, the digital filter specifications are transformed to continuous-time filter specifications by inverse Fourier transform of H[$e^{j\Omega}$].

The design of digital filter involves three basic steps: 1) the specification of desired properties of the system; 2) the approximation of these specifications using a causal discrete-time system; and 3) the realizations of the system using finite-precision arithmetic [1]. In this study, it is confirmed the digital filters, which has infinite impulse response (IIR). Design of IIR filters implies approximation by a rational function of z. The transfer function of IIR filter can be written as;

$$H[z] = \frac{a_0 + a_1 z^{-1} + a_2 z^{-2} + \ldots + a_M z^{-M}}{1 + b_1 z^{-1} + b_2 z^{-2} + \ldots + b_N z^{-N}} \tag{5}$$

where M≤N, the parameters of b_k ($k = 1,2,\ldots,N$) is not zero.

The aim of design is to find the parameters of a_k and b_k. The traditional approach to design of IIR digital filters involves the transformation of an analog filter into a digital filter, meeting prescribed specifications. This is reasonable approach because:

1) The art of analog filter design is highly advanced and, since useful results can be achieved, it is advantageous to utilize the design procedures already developed for analog filters.

2) Many useful analog design methods have relatively simple closed-form design formulas. Therefore, digital filter design methods based on such analog design formulas are rather simple to implement.

Harmonics arise in thyristor controlled reactor because of phase control. TCR includes various harmonic components beside fundamental components of voltage at the edge of reactor and reactor current depends on firing angle α and conduction σ angle.

In balanced loading TCR produces odd harmonics, but there will be no triple harmonics injected into the power system since triple harmonics flow within the Δ. The percentage of current harmonic components $I_r^{(h)}$ to that of fundamental components $I_r^{(1)}$ is shown in Figure 3.

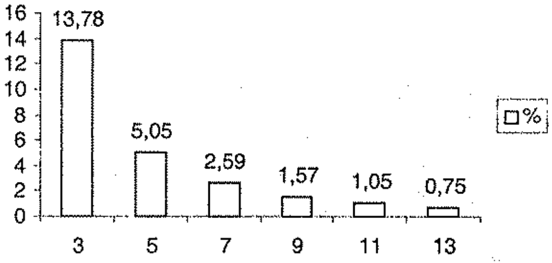

Figure 3. Maximum amplitude of harmonic currents in TCR

3. STABILITY AND HARMONICS

If there is increased load demand or variation in the system state, the system may become unstable with an uncontrollable decrease and increase in the voltage. The main reason for instability is insufficient condition of the power system corresponding to the demand of reactive power. This drawback may be remedied by use the static VAR compensator including TCR [6]. However, static VAR compensators cause instability in the power system on some operating conditions because of using power electronics to perform static VAR compensation.

One of the harmonic components of nonsinusoidal quantities may cause resonance in the system and uncharacterized harmonic components may occur. For this reason, it is required to pay attention to the operation of circuits including TCR, in order not to produce undesirable harmonics, which may cause discontinuity in the system. Stability analysis performed on the power systems show that instability conditions arise when resonance cases are involved.

4. TCR AND RESONANCE CONDITIONS

The installation of large capacitors to improve voltage and shift power factor causes very significant resonance problems in the power system. The resonance frequency of the system's inductive and capacitive reactance generally occurs near fifth and seventh harmonic. In addition to this, there may sometimes be seen resonance at eleventh and thirteenth harmonics [7].

It is very difficult for a power system to withstand the large amount of harmonic currents without any problem. Inductive reactance is proportional with frequency, but capacitive reactance is inversely proportional with frequency. At the resonance frequency, capacitive reactance is equal to inductive reactance. If there is a resonance near the harmonic frequencies in the system, there exists high amount of harmonic currents and voltage. These high amounts of currents and voltage occur when the capacitors used for compensation cause resonance with the inductance of the other circuit elements.

5. METHOD OF ANALYSIS

In this study, Fourier matrix method [3] and MATLAB software are both used to perform the resonance analysis. The reactor impedance versus conduction angle of the thyristors is given below [3]

$$X_{rh}(\sigma) = j\frac{hX_r\pi}{\sigma - \dfrac{\sin(h\sigma)}{h}} \tag{2}$$

For the circuit given in Figure 4, the data of a system including TCR is entered and lower value of natural frequency ω_{ol} and upper value of natural frequency ω_{ou} are determined for the values of conduction angle (σ) between 0° and 180°. The natural frequency is determined by the following equation.

$$\omega_0 = \sqrt{X_{ch} / \frac{X_{sh} + X_{rh}(\sigma)}{X_{sh}.X_{rh}(\sigma)}} \tag{3}$$

where X_{cn}, X_{sn}, and X_{rn} are the nth harmonic component of capacitor reactance, nth harmonic of system reactance and nth harmonic of TCR reactance, respectively.

Existence of odd harmonics is examined. If odd harmonics are detected, then it is determined what values of the conduction angle σ put the system into resonance between 0° and 180°. Resonance condition for nth harmonic component is given by:

$$\frac{X_{sh}.X_{rh}(\sigma)}{X_{sh} + X_{rh}(\sigma)} = X_{ch} \tag{4}$$

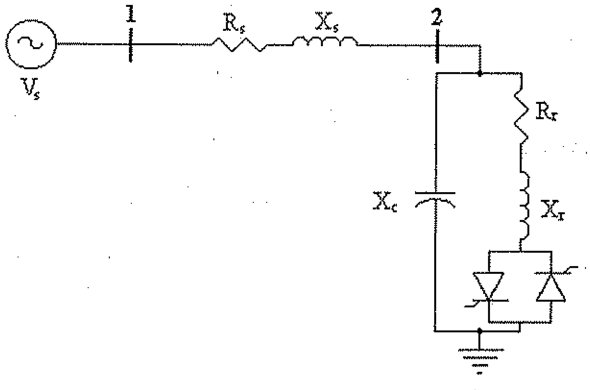

Figure 4. The sampled power system including FC-TCR

6. NUMERICAL APPLICATION

In this study, the circuit is modeled with Fourier matrix method and MATLAB software and the numerical application is performed and the results have been discussed when the TCR is used. The p.u. values of the system parameters are used and their values are: $V_s=1\angle 90°$ p.u, $Z_r=0.0735\angle °$p.u., $X_s=0.6268\angle 87.14°$ p.u., $X_c=1.77\angle -90°$ p.u.

First, Fourier matrix analysis is used. A computer program is written for implementation of the Fourier matrix analysis [8]. Using the same program a resonance analysis is conducted and the results are given in Table 1.

Table 1. Results obtained by Fourier matrix analysis

h	$\omega_{0a} \leq \omega_0 \leq \omega_{0u}$	σ, conduction angle (degree)
5	$4.9077 \leq \omega_0 \leq 5.1877$	$41^0 \leq \sigma \leq 70^0$

Where;

ω_0 is natural frequency
ω_{0a} is the lower value of natural frequency
ω_{0u} is the upper value of natural frequency
h is harmonic frequency
σ is conduction angle.

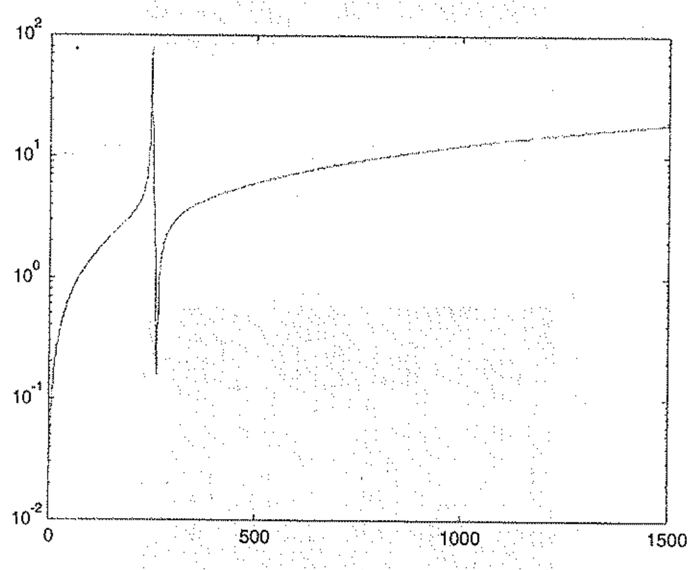

Figure 5. The impedance magnitude versus frequency at the bus including TCR

As it is seen from Figure 5, there exists a resonance near fifth harmonic and it occurs between the critical frequencies values of 240 Hz and 264 Hz. These frequency values correspond to the conduction angle between 41° and 70° of TCR. The results obtained in Table 1 and the results obtained with the analysis done using MATLAB software are similar to each other. Thus, system is not stable for the conduction angels of between 41° and 70°.

To verify the above analysis, the time domain analysis is done for the conduction angles inside and outside the range of 41° and 70°. As a result of this last analysis the variation of the bus voltages including TCR are obtained as given in Figures 6 to 8.

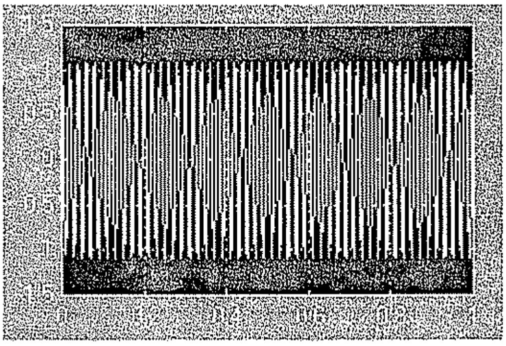

Figure 6. The bus voltage including TCR when the conduction angle is 20°(stable case)

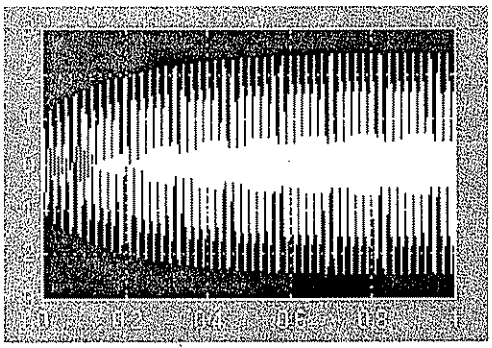

Figure 7. The bus voltage including TCR when the conduction angle is 55°(unstable case)

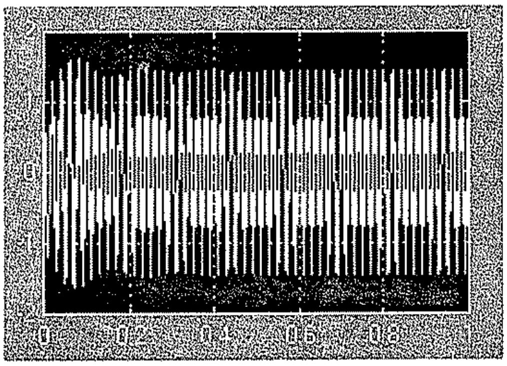

Figure 8. The bus voltage including TCR when the conduction angle is 160°(stable case)

7. CONCLUSIONS

- Although use of thyristor controlled reactor with fixed capacitor or a group of capacitors for voltage stability and dynamic load factor improvement has many advantages, it causes harmonics and some undesired situations as a result of harmonics.
- Harmonics flowing in the power system can cause resonance and high distortion. These cases have undesired effects on system stability; therefore the effects of

harmonics should be analyzed.

- The operation point and parameter values of TCR should be determined with an analysis. TCR should be operated according to this analysis; otherwise these values may affect resonance frequency of system causing resonance.
- Possibility of system unstability arising from non-linear loads should be determined. If non-linear loads affect the system stability, then the harmonic components affecting the system stability have to be determined.

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