POWER QUALITY IMPROVEMENT WITH A DYNAMIC VOLTAGE RESTORE (DVR) USING A SERIES ACTIVE FILTER

AHAD KAZEMI
kazemi@iust.ac.ir

HAMIDREZA HAFEZI
hamidreza_hafezi@ee.iust.ac.ir

Electrical Engineering Department
Iran University of Science & Technology
Iran

Abstract: In three-phase ac distribution power systems, a dynamic voltage restorer (DVR) can be used to protect sensitive power customers from voltage disturbance. This paper presents a PI controlled dynamic voltage restore (DVR) for power conditioning. this device designed to cancel harmonics generated by nonlinear load and voltage sag and swell using a series active filter and a LC bank. The LC bank cancels higher order harmonics. The inverter acts with a pulse width modulation (PWM) for independent control lower order harmonics and voltage disturbance . The active filter control algorithm is simulated in MATLAB and the harmonics cancellation and voltage mitigation process is verified.

Keywords: Dynamic Voltage Restorer (DVR), active filter ,voltage sag.

I. introduction

The recent growth in the use of nonlinear loads has caused many power quality problems such as voltage flickers, harmonics and unbalances, which may cause the modem automatic devices to fail, misoperate, or shut-down. The ac power system has substantial number of large harmonics generating devices,i.e. adjustable speed drives for motor control and switch-mode power supply used in a variety of office equipment such as PCs, fax machines, etc. These devices draw nonsinusoidal load currents consisting primarily of lower order 5^{th} ,7^{th},11^{th} and 13^{th} harmonics that distort the system power quality. These effects can be very expensive for customer. According to EPRI report(1995), the revenue losses due to poor power quality to U.S business alone were $400 billion per year[1].It is well known that two types of countermeasures to minimize the adverse effects of impactive or nonlinear loads on system have been used so far. One is load-oriented, which generally adopts passive or active compensators such as LC compensator, static var compensator (SVC)[2], active power filter(APF) and static var generator(SVG)[3] to achieve this goal. In theory, load-oriented method is an effective remedy. However, it is impossible and unnecessary to install compensators for all the impactive or nonlinear. Furthermore, the tree-phase supply voltage disturbance cannot be completely avoided considering system faults. Thus system-oriented method is introduced traditionally, uninterrupted power supply (UPS)[4], power line conditioner (PLC)[5], and backup lines with switches and backup generators are commonly used to achieve it. A common remedial measure for reducing the effect of harmonics is passive filtering[6]. The addition of passive “LC” filters alters, or interfaces, with system impedance, and is known to cause resonance with other network impedances and can result in an excessive amplification of harmonics rather than harmonics reduction. In addition passive filters cannot adapt to voltage sag or voltage swell, thus a separate filter may be required for these faults.

Voltage sag and outage refer to short-period reduction of the amplitude of the power supply voltage. They are predominantly caused by faults which are unavoidable on the distribution systems [7]. Typically, the duration of such voltage disturbances is between 0.5 to 30 cycles, which the amplitude reduction could vary within a relatively large range. Voltage sag and outage can cause significant disruptions to modern industrial processes and hence has generated a greater awareness to mitigate the effect of such voltage disturbances.

A device consists of a voltage source inverter and a dc-link storage called dynamic voltage restorer (DVR) has been developed to solve this problem[8,9].

The dynamic voltage restorer (DVR) is a series custom power device which is designed specifically to improve Power quality at the distribution system level [10].the development and application of the DVR have attracted considerable interest over the past few years. Since the installation of the first DVR in 1996, several other restorers have been put into commercial operation. The restorers have been put considered as effective custom power devices in mitigating voltage sag problems. This paper presents a PI controlled dynamic voltage restore (DVR) for power conditioning. This device designed to cancel harmonics generated by nonlinear load and voltage sag and swell using a series active filter and a LC bank.

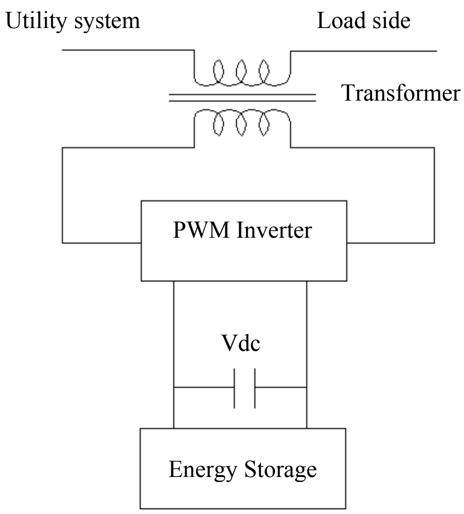


Fig.1 Diagram of a series DVR

II. Principle of the proposed DVR

The traditional series-connected DVR is typically designed to inject the missing voltage onto the power line through an isolating transformer ,as shown in Fig.1.

The primary purpose of a DVR is an alleviate the effect of voltage sag/swell With a suitable set of control algorithms. It can also be used to correct harmonics up to bandwidth capability. The DC to AC inverter is controlled to inject a voltage compensation component to restore the load voltage to an acceptable level during periods of voltage sag and swell. From practical point of view ,the special considerations taken for the DVR design are as follows:

1- The DVR must lock into the supply phase and must detect supply voltage distortions accurately.

2- During the restoration, dc-link voltage should be maintained at a certain level to ensure proper voltage injection. A large capacitor bank or a rectifier circuit with a relatively small capacitor bank can be used for this purpose.

3- As the PWM modulation scheme is used to synthesize the injected voltage, the switching frequency harmonics must be prevented from entering into the utility and customer system. A low pass filter must be introduced to accomplish this function.

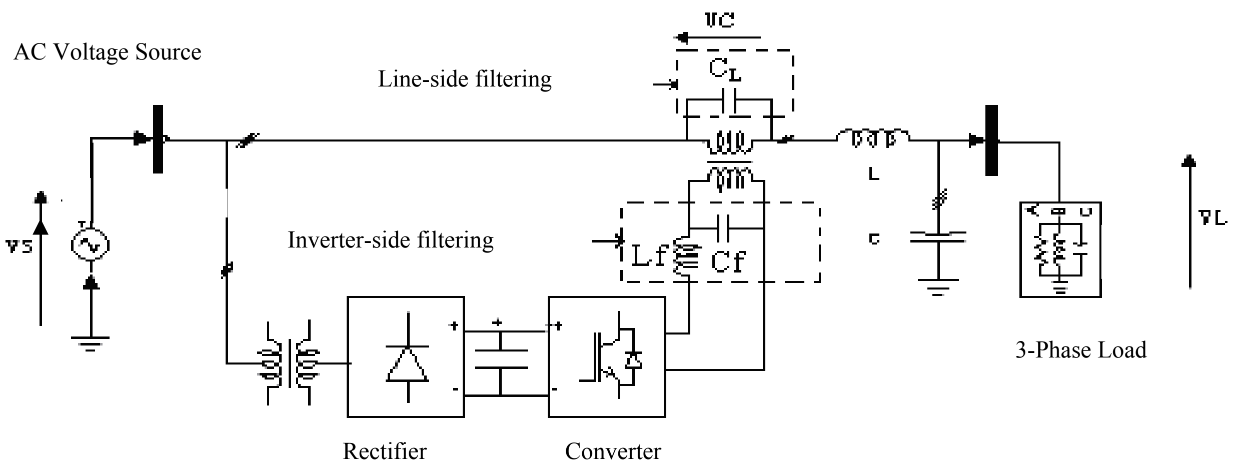


Fig.2. The DVR configuration

The DVR proposed in this paper for keeping the load voltage sinusoidal and steady, by placement in series between the utility bus and the load, is shown in Fig.2. The DVR contains three main parts: voltage-source inverter, DC energy storage device and a control system. The inverter configuration adopted for this DVR is a pulse width modulated full bridge inverter design. The L_f and C_f in Fig.2 represent the filter which is necessary to suppress the sidebands for PWM based inverter operation. Also The L and C represent The filter which suppress the high order harmonics.

In the proposed DVR , the dc link is fed by three-phase full rectifier. The switching inverter is controlled by a PI controller. Fig.3 shows the basic topology of an inverter where the switching devices are shown as ideal switches.

III. Sag magnitude specification

The DVR is normally designed to compensate for the voltage sag with depths of up to a certain percentage of the nominal network voltage. Thus one parameter influencing the specifications of a DVR is the maximum single-phase and three-phase voltage sag to be compensated for by the restorer. Given the finite energy storage capacity of the DVR system, it is clear

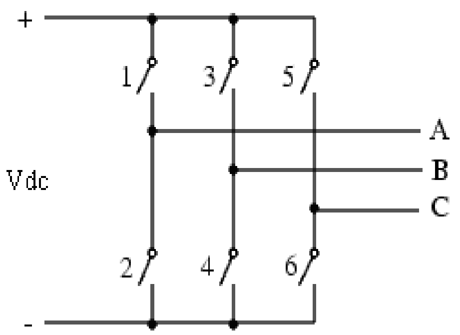


Fig.3. Basic inverter topology

that maximum single-phase voltage sag depth that is to be compensated for should be used to determine the primary-side voltage rating of the transformer. Suppose the rated voltage (rms) of the primary feeder is V_p (per phase) and the maximum single-phase voltage sag to be compensated for is $D.V_p$ (D<1.0).
The rated voltage on the primary side of the injection transformer can be tentatively selected as:

$$V_r = D.V_p \tag{1}$$

Clearly $V_s = (1-D)V_p$ is the lowest source voltage to be compensated for. Fi.4 shows equivalent circuit of the DVR given in Fig.1. Thus the compensated voltage (V_c) on The secondary side of the injection transformer should be:

$$\overline{V_c} = \overline{V_L} - \overline{V_S} \tag{2}$$

$$|V_c| = \sqrt{V_L^2 + (1-D)^2 V_p^2 - 2V_L(1-D)V_p cos\alpha} \tag{3}$$

where V_c is the compensated voltage , V_S is the source voltage as shown in fig.2, and α is the largest possible phase angle difference between V_L and V_s.

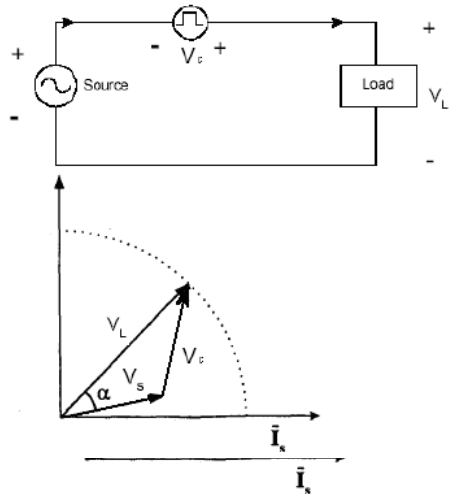


Fig. 4. Equivalent circuit of the DVR and phasor diagram of the currents and voltages

IV.Control Strategy

The function of the DVR is to mitigate voltage sag and swell .The functions of this technique are as follows:

1-Detecting the reduction positive sequence components.

2- compensating the zero sequence components.

3- compensating the negative sequence components.

The block diagram of the control algorithm is demonstrated in Fig.5. this block diagram shows how the control algorithm performs the previous functions to mitigate the voltage sag and swell. *D-q* orthogonal coordinates technique is used to perform the previous functions . This transformation is called "Park transformation".

The transformation from *abc* to *dq0* axes is based on the following equation:

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} sin(\omega in & sin(\omega i - \frac{2\pi}{3}) & sin(\omega i + \frac{2\pi}{3}) \\ cos(\omega os & cos(\omega o - \frac{2\pi}{3}) & cos(\omega o + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{4}$$

where ω is rotational speed (rad/s) of the rotating frame.

This transformation is commonly used in three-phase electric machine models. It allows us to eliminate time-varying inductances by referring the stator and rotor quantities to a fixed or rotating reference frame. In the case of a synchronous machine, the stator quantities are referred to rotor. *Id* and *Iq* represent the two dc currents following in the two equivalent rotor winding (*d* winding directly on the same axis as the field winding,

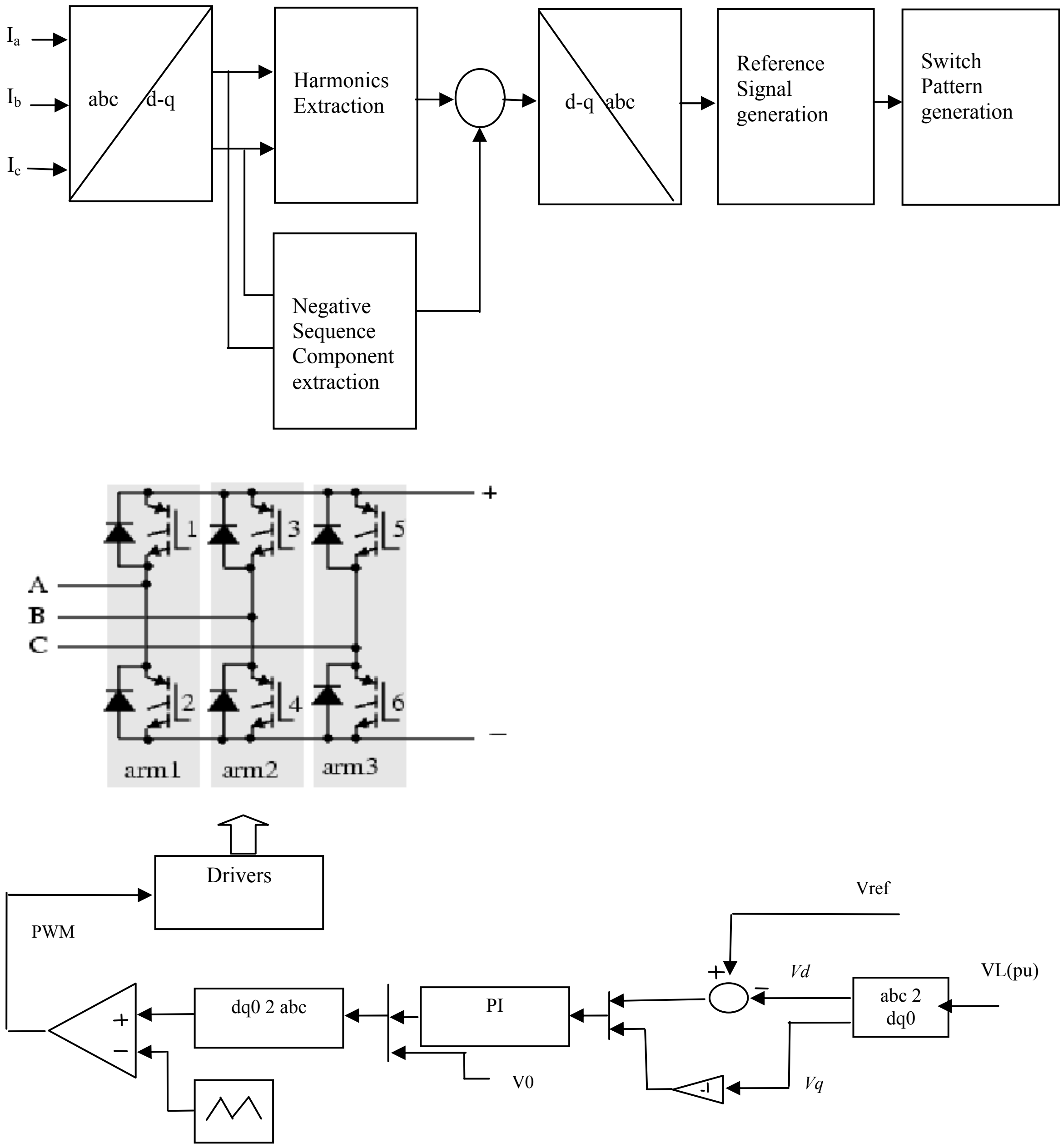
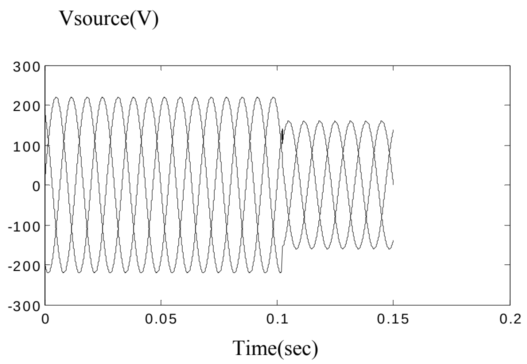


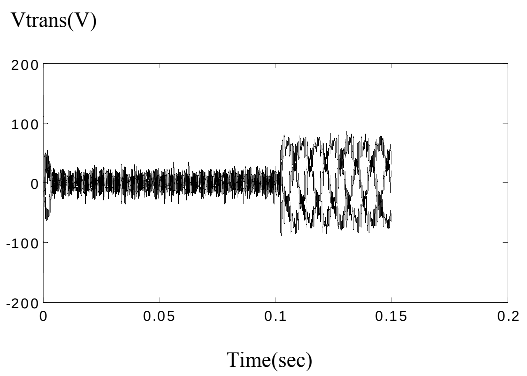
Fig 5. Block diagram of the DVR control Circuits

V. Simulation results

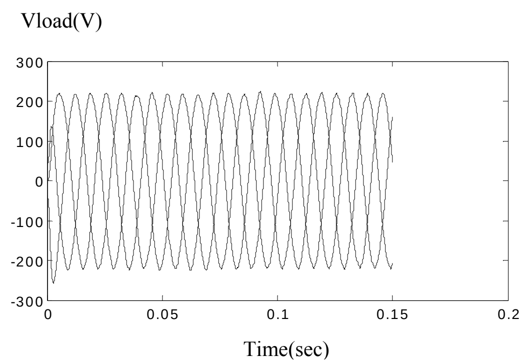
MATLAB software package is used for the simulation of the performance of DVR proposed in this paper. Fig .6a, b and c show sagged voltage, injected voltage for compensation and mitigated voltage respectively. In the waveform (a) , the voltage sag of 30% at t=0.1s is occurred. The waveform (b) shows voltage disturbance of line which comes from equation (2). The waveform (c) illustrates how the DVR injects a synchronized voltage to mitigate voltage sag Fig.7 shows the performance of the DVR when at t=0.1s voltage swell of 30% is occurred. Fig .7 a, b and c show swell voltage, injected voltage for compensation and mitigated voltage respectively. Fig 7 (b) shows when source voltage increases to 66 volt ,the voltage of the injection transformer decreases to 66 volt, until load voltage is fixed. Fig .8 shows how that DVR compensates the 5^{th} harmonics .



(a)

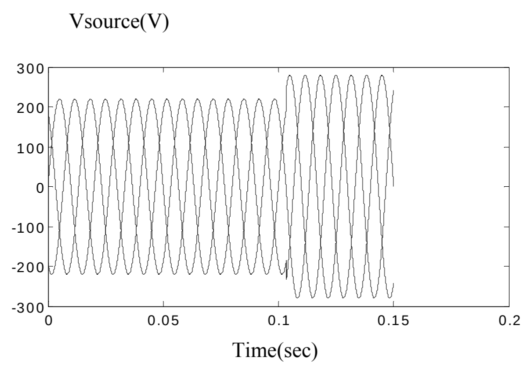


(b)

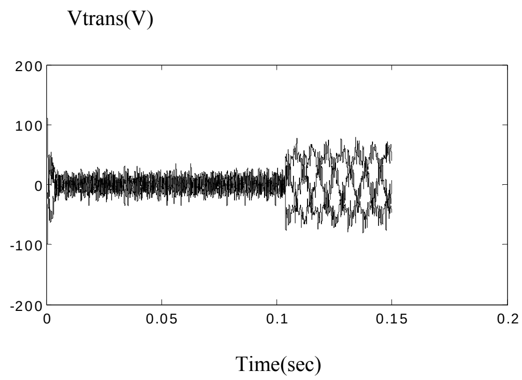


(c)

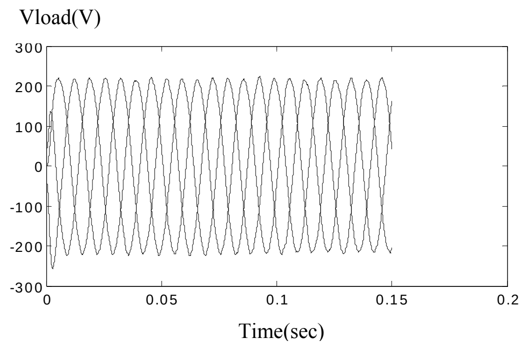
Fig.6. voltage sag:
(a) Saged voltage waveform at source
(b) Injected voltage by DVR
(c) Mitigated voltage after compensation



(a)

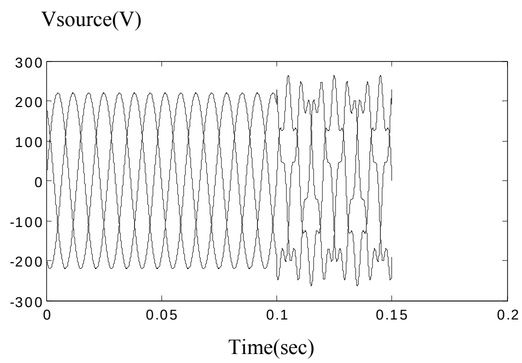


(b)

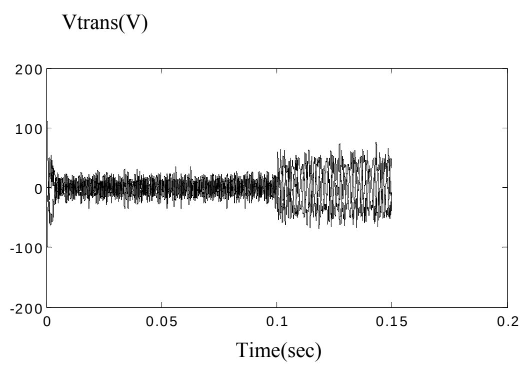


(c)

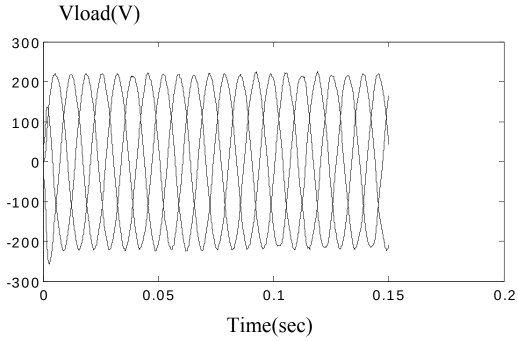
Fig .7. voltage swell:
(a) Swelled voltage waveform at source
(b) Injected voltage by DVR
(c) Mitigated voltage after compensation



(a)



(b)



(c)

Fig .8. Harmonics distortion:
(a) Harmonics voltage waveform at source
(b) Injected voltage by DVR
(c) Mitigated voltage after compensation

VI. Conclusions

This paper has presented a PI controlled dynamic voltage restore (DVR) for power conditioning. This device designed to cancel harmonics generated by nonlinear load and voltage sag and swell using a series active filter and a LC bank. The LC bank cancels higher order harmonics. the inverter acts with a pulse width modulation (PWM) for independent control lower order harmonics and voltage disturbance. The active filter control algorithm is simulated in MATLAB and the harmonics cancellation and voltage mitigation process is verified.

References:

[1] John S.Hsu, "Instantaneous phasor Method For Obtaining Instantaneous Balanced Fundamental Components for Power Quality Control and Continuous Diagnostics" IEEE Transactions on Power Delivery, vol.13, No.4,October 1998,pp.1494-1500.

[2] San-Yi Lee,Chi-Jui Wu,"On-Line Reactive Power Compensation Schemes for Unbalanced Three-Phase Four Wire Distribution Feeders, " IEEE Transactions on Power Delivery, vol.8,No.4,October 1993,pp.1958-1965

[3]. G.Hochgraf,R.H.Lasseter, "Static Compensation for Unbalanced Systems Using a Voltage Source Inverter" The Future of Power Delivery Conference (FPDC), Washington , April 1996.

[4] C.C.DeWinkel and P.F.Koeppe," Superconducting Magnetic Energy Storage System Provides Continuous Power to Megawatt Loads,"Power Quality ssurance,September/October 1993,pp.59-63.

[5] G.Venkataeramanan,B.K. Johnson and Sundaram, "An AC-AC Power Converter for Custom Power Applications," IEEE Power Engineering Society 1996 Winter Meeting ,Baltimore MD,Paper 96 WM 088-5-PWRD.

[6] IEEE recommended practices for power systems Analysis, IEEE inc, New York, NY,1992.

[7] Stephen W Middlekauff and E Randolph Collins,"System and customer impact: Considerations for series custom power devices," IEEE Transactions on Power Delivery,vol.13, No.1,January 1998.

[8] Arun Arora et.al," Innovative system solutions for power quality enhancement,"ABB Review ,March 1998,pp.4-12

[9] N H Wooley ,L Morgan,Ashok Sundaram,Wade Malcolm,"Experience With An inverter-based dynamic voltage restorer, " IEEE Transactions on Power Delivery,vol.14, No.3,July 1999.

[10] HINGORANI,N.G:"Intruducing custom power ",IEEE Spectrom 1995

[11] S.W. Middlekauff and E.R. Collins," System ans customer impact: considerations for series custom power devices,"IEEE *trans,power delivery*, vol.13, no.1 January 1998,pp.278-282.

ARDICIL QOŞULMUŞ AKTİV SÜZGƏC TƏTBİQ ETMƏKLƏ GƏRGİNLİYİ BƏRPA ETMƏK ÜSULU İLƏ ELEKTRİK ENERJİSİNİN KEYFİYYƏTİNİN YÜKSƏLDİLMƏSİ

KAZEMİ A., HAFEZİ H.

Ardıcıl qoşulmuş aktiv süzgəc tətbiq etməklə qeyri xətli yüklə əlaqədar olan yüksək tezlikli harmonikləri ləğv etmək üçün qurğu təqdim olunur. Aktiv süzgəci MATLAB sistemində modelləşdirərək harmoniklərin ləğv olunması və gərginlik dəyişmələrinin azalması təsdiq olunmuşdur.

ПОВЫШЕНИЕ КАЧЕСТВА ЭЛЕКТРОЭНЕРГИИ ПУТЕМ ВОССТАНОВЛЕНИЯ НАПРЯЖЕНИЯ С ИСПОЛЬЗОВАНИЕМ ПОСЛЕДОВАТЕЛЬНОГО АКТИВНОГО ФИЛЬТРА

КАЗЕМИ А., ХАФЕЗИ Х.

Предлагается устройство для подавления высокочастотных гармоник, обусловленных нелинейностью нагрузки, с помощью последовательного активного фильтра. Путем моделирования активного фильтра в системе MATLAB подтвержден факт подавления гармоник и ослабления колебаний напряжения.