ION BASED DEVELOPMENT OF CAPACITY AND STABILITY IN HVDC POWER NETWORKS

NASER MAHDAVI TABATABAEI, AHAD GHAREMOHAMMADI

Department of Electrical Engineering, Faculty of Engineering
Azarbaijan University of Tarbiat Moallem, Tabriz, Iran
n.m.tabatabaei@dr.com *n.m.tabatabaei@gmail.com*

Abstract- In most case the reason for building a high voltage direct current (HVDC) link is the need for bulk power transmission and/or interconnection of asynchronous power systems. In some cases, however, the HVDC link can also provide an enhanced over all system stability.

If the HVDC line is connected in parallel with AC lines, modulation of the active power of the HVDC link can damp oscillations on the AC connection. This is the traditional way of improving system damping by means of HVDC power modulation

The application of ION (Integrated Object Network) devices in HVDC systems is also considered for control and analyzing voltage stability and power quality.

Keywords: HVDC, Stability, ION.

I. INTRODUCTION

HVDC transmission line has become acceptable as an economical and reliable method of power transmission and interconnection. It offers advantages over alternating current (AC) for long distance power transmission and as asynchronous interconnection between two AC systems. It offers also the ability to precisely control the power flow without inadvertent loop flows in an interconnected AC system [1-3].

This paper investigates summary of DC transmission affects in stability and voltage control of an AC transmission networks.

Several control strategies have been tested for the HVDC links, for example constant power control and the use of a power flow controller with deviation in frequency or transferred active power as input signals [4-5].

The advantages of ION based intelligent monitoring and control devices are also discussed in HVDC systems [6].

II. HISTORY OF HVDC

HVDC transmission was first used commercially in 1954 when a DC submarine cable linked Gotland Island with mainland Sweden. It was an under cable, 96 Km long with ratings of 100KV and 20MW. That HVDC system and the ones that followed for almost two decades used mercury arc valves for converting from AC to DC and vice versa starting with the Eel River back to back converter application in 1972, mercury arc valves were replaced by thyristor in commercial HVDC applications. Thyristors are silicon based power semiconductors and were initially known as SCRs (silicon controlled rectifiers). Similar to diodes they allow only unidirectional current flow. However, a small current injected at the gate of a forward biased thyristor permits control of the start of current conduction. Once the thyristor is conducting, it will cease conduction only if the voltage across the thyristor reverses and the current it is conducting droops to zero. The HVDC controls send coordinated signals to the gates of groups of thyristors so that by switching the DC current through various paths at various time as described later, the AC-DC or DC-AC conversion process is realized. Approximately 50 HVDC transmission projects have been built around the world since 1954, at present, under construction or being planned. The deregulation and restructuring of the electric utility industry currently in progress may encourage more applications of HVDC transmission, perhaps for nontraditional purposes.

III. HVDC SYSTEMS OVER VIEW

A general description of HVDC systems and power conversion will be given in the following. The basic principles and configurations will be discussed and an over view of existing HVDC transmissions will be given.

III.1. Basic HVDC Configurations

There are several configurations to choose from when planning a HVDC system. Operational requirements, flexibility demands and cost determines in each case which alternative is the most suitable. HVDC transmission systems can be classified into three categories. The most common configurations are back-to-back, monopolar and bipolar links.

III.1.1 Back-to-Back System

The back-to-back interconnected, Figure 1 (a), consists of two converters at the same site and usually in the same building. They are connected directly to each other, without any transmission line in between. The option is used when the HVDC link is to connect two power systems with different frequencies or with different control philosophies.

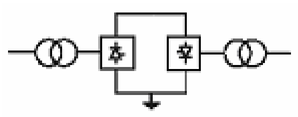
III.1.2 Two-Terminal or Point-to-Point DC Transmission

Two-terminal DC system can be either bipolar or monopolar.

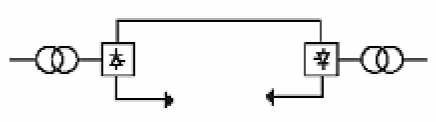
A. Monopolar Link

The monopolar scheme, Figure 1 (b) involves two converters connected with a single conductor. Earth is normally used as the return conductor, but also a metallic return conductor can be used.

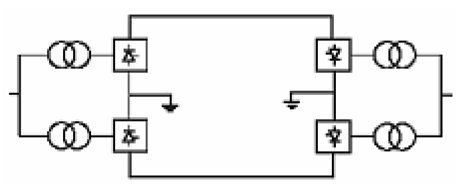
This configuration can also be used for short-term emergency operation for a two-terminal DC line system in the event of a pole outage. However, concerns for corrosion of underground metallic structures and interference with telephone and other usually the restricting criterion.



(a)



(b)



(c)

Figure 1: (a) Back-to-Back system
(b) Monopolar system
(c) Bipolar system

B. Bipolar Link

The bipolar link, Figure 1 (c) is the most widely used, for example it is the commonly used arrangement for systems with overhead lines.

In this configuration two monopolar systems are combined, one is run with a positive polarity voltage and the other with negative polarity. The alternative gives a higher reliability than the other configurations, since each pole can operate on its own using ground return, if the other pole temporarily has to be taken out of service.

III.1.3 Multi-Terminal Systems

Another alternative configuration is a multi-terminal scheme, which is a HVDC system with more than two converter stations. The additional stations can be connected either in series or in parallel, that parallel configuration can be either radial-connected Figure 2 (a) or mesh-connected Figure 2 (b) or series-connected Figure 2 (c).

In Figure 3 a schematic of a bipolar HVDC transmission is shown. The main components are basically the same for other configurations.

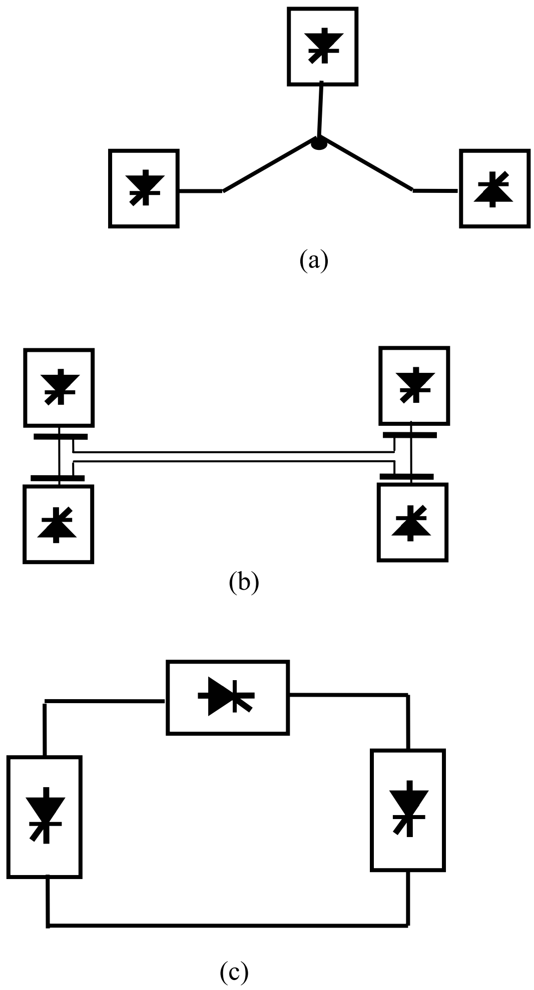


Figure 2: (a) Parallel-connected radial MTDC
(b) Parallel-connected mesh-type MTDC
(c) Series-connected MTDC system

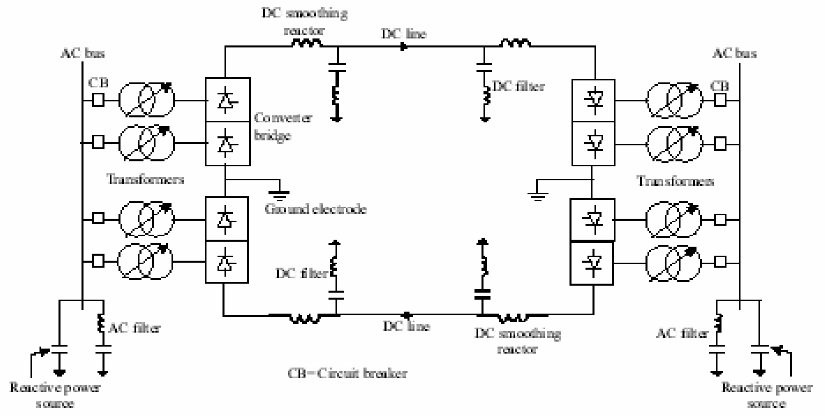


Figure 3: Schematic of a bipolar HVDC transmission

III.2 Stability Improvement with HVCD

In most cases the reason for building link is the need for bulk power transmission and/or interconnection of asynchronous power systems. In some cases, however, the HVDC link can also provide enhanced overall system stability.

If the HVDC line is connected in parallel with ac lines, modulation of the active power of the HVDC link can damp oscillations on the AC connections. This is the traditional way of improving system damping by means of HVDC power modulation.

If, on the other hand, HVDC is used to connect two asynchronous system the situation is different. Generally, inter-area oscillations do not exist between the two systems, connected through the HVDC link. Unfortunately, low frequency oscillations within one of the systems can be transferred over the HVDC link to the other system. But HVDC power modulation can be useful anyway, if any of the systems contain groups of machines oscillating towards each other. Then modulating of dc power can help in damping the oscillations on the ac tie line connecting these groups of machines How effective the power modulation can be depends on the location of the HVDC converter, relative to the inertia of the machines oscillating.

IV. HVDC POWER TRANSMISSION

HVDC power transmission is employed to move large amounts of electric power (bulk power) from one location to another in the from of direct current (DC) rather than alternating current (AC). However, the majority of bulk power in the world today is transmitted as AC. The current and voltage of AC change form positive to negative and back to positive in sinusoidal waveforms

Typically with frequencies of 50 or 60 times a second. Only a small percentage of the worlds bulk electric power transmission is done by HVDC, and current. However, HVDC transmission has become acceptable as an economical and reliable method of power transmission and interconnection. But almost all electric power is generated as ac and as virtually all interconnected transmission grids are AC, it is necessary to convert ac to dc before it can be transmitted via HVDC. After transmission, the power must be converted back to AC before it can be delivered to the AC transmission grid in the receiving system.

IV.1 Advantages of HVDC Transmission

HVDC transmission has been in successful operation in power system all over the world for about 40 years. There are some well-know and accepted facts that justify the continuation of HVDC development. In the following a comparison is made between ac and dc transmission. A common way to compare these two technologies is a two- pole dc- link versus a double three-phase ac interconnection with the same MW rating. These two alternatives are considered to have a similar reliability.

IV.2 Losses and Costs

Compared to an equivalent AC line, a DC transmission causes lower transmission losses and also lower investment. Both the losses and the required capitals for the terminals are on the other hand higher for a dc system. The "break-even" distance, that is the length of the transmission line at which the total costs are the same for both alternatives, is to economically transmit large amount of power over along distance, HVDC is the best alternative. A majority of the world's energy resources are situated for from densely populated areas; in addition the energy consumption is steadily increasing. This results in a growing need for HVDC transmissions. Variation of total costs for ac and dc as a function of line length are shown Figure 4.

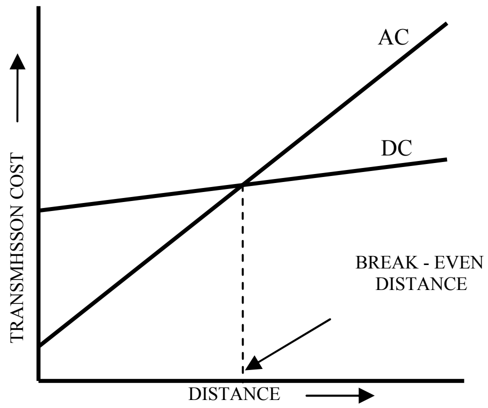


Figure 4: Transmission cost as function of line length

IV.3 Basic Power Conversion

In all HVDC converters in operation today the configuration is the three-phase bridge, shown Figure 5. It shows a three-phase bridge connected to a voltage source through an inductance that represents system and transformer impedance. The reason to use this configuration is that it results in a lower reverse voltage across the valves and a better utilization of the converter transformer than other possible alternatives [2].

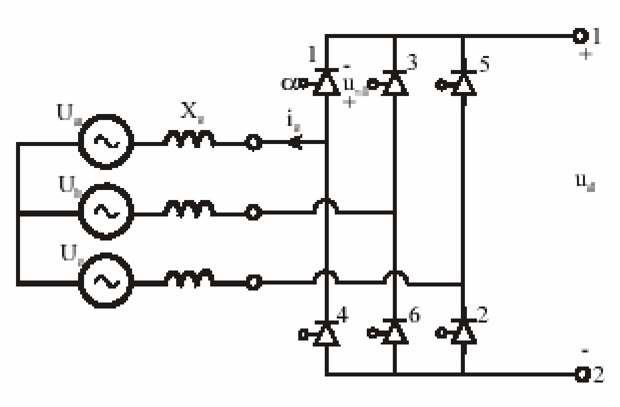


Figure 5: HVDC three-phase bridge converter

In high voltage applications several series-connected units are used to reach desired voltage level. The dominant valve-type used today is the thyristor, but the development in the power semiconductor field is going towards other semiconductor devices, such as GTOs and IGB. The voltage waveforms can be seen in Figure 6 with no firing angle delay. The voltage waveforms with a delay angle α=15º can be seen in Figure 7. In Figure 8 shows the effect of the commutation reactance on the voltage and waveforms.

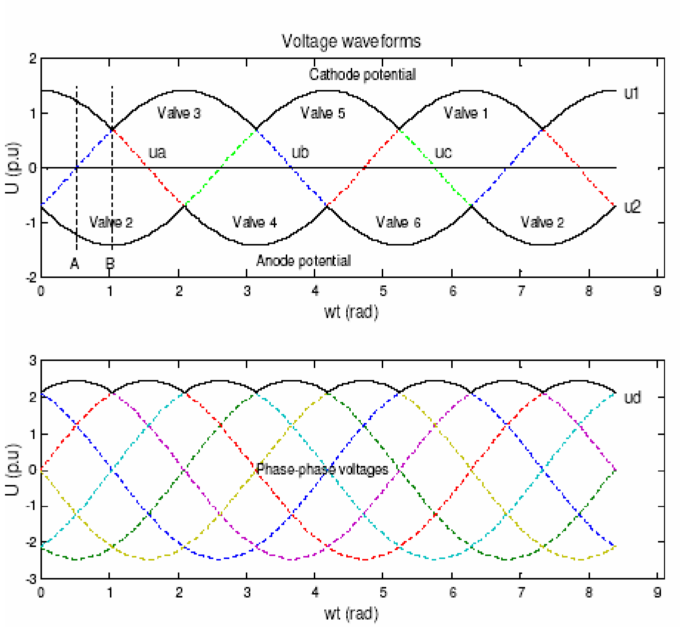


Figure 6: Voltage waveforms in six-pulse converter, with no firing angle delay

V. HVDC DEVELOPMENT

Even though voltage source converter (VSC) technology is advancing rapidly, the classical HVDC technique is still evolving and will probably keep a part of the power transmission market in the future as well. In this section some development trends will be mentioned.

V.1 Capacitor Commutated Converter

The capacitor commutated converter (CCC), brings several improvements to the converter operation. The CCC is characterized by the use of commutation capacitors in series, between the valve bridge and the converter transformer.

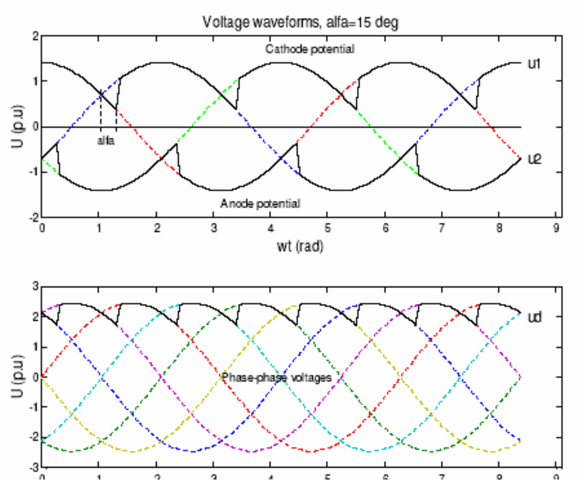


Figure 7: Voltage waveforms in a six-pulse converter, with firing angle delay α=15º and commutation reactance neglected

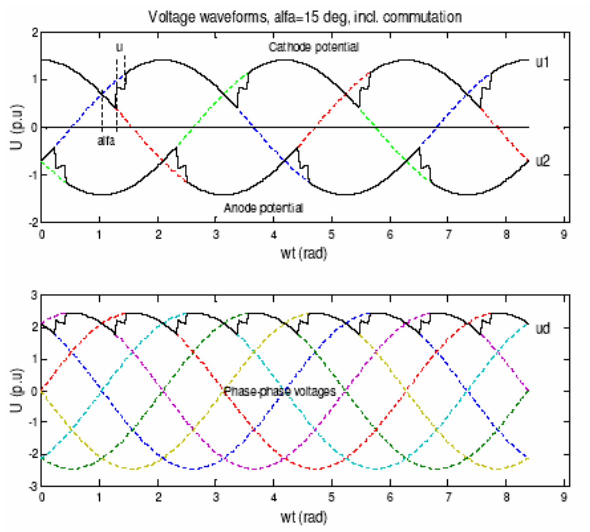


Figure 8: Voltage waveforms in a six- pulse converter, with firing angle delay α=15º and commutation reactance taken into account.

A single-line diagram is shown in Figure 9 .These capacitors provide reactive power proportional to the loading of the converter, which means that the need for reactive power compensation by shunt capacitors and large filter banks are eliminated. Filters are still needed to mitigate harmonics, but instead of filter backs with high MVAr ratings, the newly developed active dc filter and continuously tuned ac filter be used.

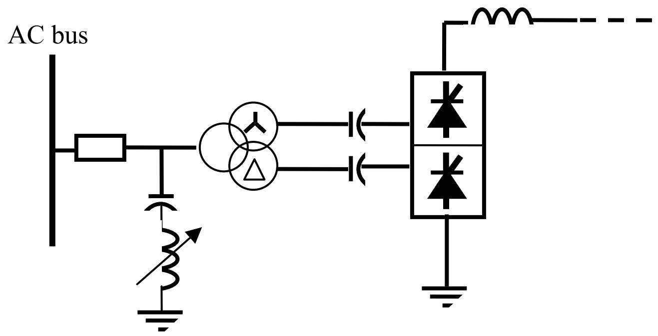


Figure 9: Single line diagram of a CCC with continuously tuned AC filter

Other effects of the commutation capacitors are:

- The commutation capacitors also reduce the risk of commutation failures in the converter.
- The capacitors provide a source of commutation voltage in addition to the voltage at the ac bus. Typically a CCC can tolerate a 15-20% voltage drop without any commutation failures. The support in commutation voltage results in reduced overlap angle as well, which in turn will give rise to a some what increased generation of harmonics.
- The converter stability is also improved with a CCC compared a conventional converter.
- Reduced valve short circuit currents, due to voltage the drop across the capacitor varistors that are used to protect the capacitors from over voltages. This also means a higher peak voltage across the valve.
- Since the reactive power flow through the converter transformer is minimized, the transformer rating can be reduced.
- The elimination of switchable filter banks considerably reduces the area required for the HVDC station.

V.2 Filters

To fully utilize the benefits of a capacitor commutated converter, the filters used should be high performance filters, such as continuously tuned ac filters and active dc filters.

The principle of a continuously tuned filter is that the reactor inductance is adjusted to meet frequency and component variations. This is done by inserting an iron core with a control winding in the filter reactor. A DC current in the control winding affects the permeability of the core, which in turn changes the inductance of the reactor.

The active DC filter is a way of meeting the increasingly stringent demands regarding interference levels from DC line. The concept is to combine an active DC filter with a small passive filter branch. A current, formed on the basis of the measured harmonics on the dc line, is then injected though the passive filter into the DC circuit to eliminate these harmonics.

VI. ION

The integrated object network (ION) is highly advanced digital power meter suited for many power monitoring and control applications shown in Figure 10.

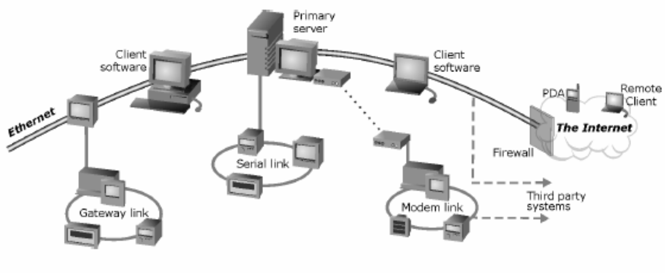


Figure 10: Applications of IONs in power monitoring and control

VI.1 ION Technology

ION has a hardware and software architectures that provide state-of-the-art solutions for power monitoring, analysis, and control needs. It can used for default configurations in meters and software, or customize them for the network particular applications. The same products can satisfy changing needs, so it doesn't have to keep re-investing in equipment to add functionality. It's like having a system built to power specifications, but not at a custom-built price.

VI.2 ION Software Modules for Defining I/O Characteristics

Every ION meter has a set of software modules that control its analog and digital I/O ports.

Inside an ION software module's setup registers, can specify characteristics for the incoming or outgoing signals, such as pulse width, signal polarity, or zero/full scale values.

The new control system for issue control signals for example to control the PWM via mechanisms set of software module's that control PWM that control firing angle to control waveforms of voltage, current, frequency inverter and converter in advanced HVDC systems as shown in Figure 11.

Some of the advantages of using ION:

1. Three blocks in control system can be replaced by one intelligent device and so resulted low complexity and low cost.
2. It has the capability of measuring monitoring voltages, currents, total harmonic distortion (THD) and other characteristics of the network in addition to controlling of the system.
3. It does a real-time on the input voltages and currents of system .And so acts as a feedback branch.

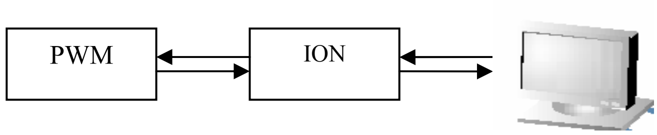


Figure 11: Using ION architecture for HVDC control

VII. CONCLUSIONS

HVDC power transmission has proven to be advantageous in applications where alternating current transmission is more expensive or technically inadequate. As the capabilities of direct current conversion technology increase and/or the costs decline, direct current will find more applications in the transmission and distribution of electric energy. New and cost-effective devices and circuits are the key to the increased application of DC in power delivery systems. Continued development of FACTs technologies and methods for interfacing AC systems with DC storage systems such as batteries and superconducting magnets will yield devices and circuit techniques that will find use in DC power delivery systems as well. Research and development efforts that are focused solely on DC-based power delivery systems. The results show intelligent architectures such as IONs are very efficient, suitable and beneficial to monitor and control HVDC systems.

---

[1] K.E. Hogberg, M. Ericsson, A. Kumar, K. Linden and W. Weibing, “Stability Improvement for Central China System”, presented at ICP, 2001.
[2] P. Kundur, ”Power System Stability and Control”, ISBN 0-07-035958-x, McGraw-Hill, 1994.
[3] N. Mohan, T.M. Undeland and W.P. Robbins, ”Power Electronics, Converters, Applications and Design”, Second Ed. ISBN 0-471-58408-8, John Wiley & Sons, Inc., 1995.
[4] Jenny Paulinder, ”Operation and Control of HVDC Links Embedded in AC Systems”, Department of Electric Power Engineering Chalmers University of Technology Goteborg, Sweden, 2003.
[5] S. Rao, ”EHV-AC, HVDC Transmission & Distribution Engineering”, Khanna Publishers.
[6] "ION Architecture", Power Measurement Ltd, http://www.pwrm.com

KOMPYUTER NƏZARƏTİ VASTƏSİLƏ YÜKSƏK GƏRGİNLİKLİ SABİT CƏRƏYAN XƏTLƏRİNDƏ STABİLLİYİN SAXLANILMASI SİSTEMİ

TABATABAEİ N.M., QƏREMÖHƏMMƏDİ Ə.

Yüksək gərginlikli sabit cərəyan verliş xətlərində dəyişən cərəyan xətlərində rəqslərin dempfer rolu oynayan kompyuter nəzarəti sisteminə baxılır.

СИСТЕМА ПОДДЕРЖАНИЯ СТАБИЛЬНОСТИ В ВЫСОКОВОЛЬТНЫХ ЛИНИЯХ ПОСТОЯННОГО ТОКА С ИСПОЛЬЗОВАНИЕМ КОМПЬЮТЕРНОГО КОНТРОЛЯ

ТАБАТАБАЕИ Н.М., ГАРЕМОХАММАДИ А.

Рассматривается применение системы компьютерного контроля стабильности работы высоковольтных линий передач постоянного тока, выполняющих роль демпфера колебаний в линиях переменного тока.