# Chapter 6
# Reactive Power Control and Voltage Stability in Power Systems

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**Abstract** Reactive power control is sometimes the best way to enhance power quality and voltage stability. In the first part of chapter we describe the reactive power flow impact in the system starting from the definitions of power components and presentation of the electrical equipment that produces or absorbs the reactive power. Then we present the reactive power control and the relations between voltage stability and reactive power. The third part of chapter contains reactive power control methods for voltage stability. In the end of chapter we present the management of voltage control based on case studies.

## 6.1 Introduction

It is known that the energy system is a great system, complex and continuous change. The electro-energetically system is a system made up of an ensemble of interconnected sub-systems. These sub-systems consist of generators, transformers, electric lines and many types of consumers, those that actually constitute the load of this system [1, 2]. Every moment of time the system operates in and out of its elements causes changes in system parameters. The quality of electricity delivered to consumers is a very important requirement in the power system operation. For every moment in time, for a system with a stable functioning, there must be a very good balance between the quantity of energy produced by hydro-generators, turbo-generators, nuclear reactors and the energy consumed by the loads at a certain moment. For an optimal functioning of the system and for reducing the energy losses in the system, it is necessary to lower the reactive power circulation [2].

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Due to a permanent need for consuming electric energy, on the one hand, and the rise in the prices of the classic fuels, on the other, new sources of renewable energy have been developed [3, 4]. Their placement has led to the appearance of the problems related to the instability of the system and of the voltage in its nodes. The voltage stability is intimately related to the reactive power control, achieved by means of series capacitors, synchronous condensers, and the modern static compensator.

Another extremely important problem in the energetic system is the quality of the delivered electric energy as it conditions the proper functioning of the electro-energetic system and of its consumers.

Power quality parameters are:

- Voltage supply;
- Frequency;
- Total harmonic distortion of the voltage wave;
- Symmetry phase voltage system;
- Continuity of supply.

Voltage stability and frequency stability have lately become became the two important electric power quality parameters in the functioning of the power system. Equally important is the knowledge of how the power system elements that can cause system instability function. The voltage is a parameter of the electric energy which is different in the energy system nodes. This parameter depends on the values of the impedance of the elements which are in the network or exit the system and, implicitly, on the voltage drops on these impedances. Maintaining the imposed voltage level in a network node constitutes a problem of the area corresponding to that node and can be achieved by different means of adjusting the voltage. The ways the voltage can be adjusted in the power system is the focus of the specialists in the field of electric energy. The voltage stability within the nodes of the system is very important in coordinating and operating the system. Problems related to the voltage instability led to the fall of energy systems in countries like Japan in July 1987, on August 14th 2003 in US and Canada, on September 23rd 2003 in eastern Denmark and southern Sweden and days later in Italy and Central Europe following the cascade outage [5].

Considering the possibility of such blackouts appearing in energy systems, artificial intelligence based systems have been developed and tested, aimed at helping the adjustment of voltage and, implicitly, the system's stable functioning [6]. Such an example of information system was called STABTEN and it was developed and tested by using the CIGRES 32 scheme [7].

The method of using such a device for controlling voltage in an energy system pilot, electronic device which is called ASVR—Automatic Secondary Voltage Regulation—as it is presented in the final of the chapter, is a successfully used method for adjusting voltage by means of optimal reactive power control.

## 6.2 Impact of Reactive Power Flow in Power System

In order to study the reactive power impact in the system, it is important to start with the term—power—in the electrical system it refers to the energy-related quantities flowing in the transport and distribution network.

The instantaneous power is the product of voltage and current with the following equation:

$$p(t) = u(t)i(t) \tag{6.1}$$

Voltage and current can be in phase or not. When these are not in phase there are two components of power:

- active power $P$, that is measured in Watts

$$P = UI \cos\varphi \,[\mathrm{W}] \tag{6.2}$$

- reactive power $Q$ (it is known as imaginary of apparent power), that is measured in VAr

$$Q = UI \sin\varphi \,[\mathrm{VAr}] \tag{6.3}$$

In the above equations, $I$ and $U$ are rms values of current and voltage, and $\varphi$ is the phase angle by which the current out phasing the voltage.

The combination of active power with reactive is apparent power $S$, measured in VA.

$$S = P + jQ[\mathrm{VA}] \tag{6.4}$$

Reactive power—$Q$ represents a part of apparent power—$S$. Reactive power is in opposition with active power—$P$. Reactive power is necessary to maintain voltage and to distribute active power through transmission lines. In this way different loads that use reactive power to convert the received power in mechanical, illumination and others will be in use. In case the presence of reactive power is under the acceptable level the voltage cracks down. The system can become unstable because the loads do not receive necessary power through the transmission line.

It is important to study reactive power flow in system because some equipment depends on these few factors can absorb or produce this type of power. Depending on the phase angle between current and voltage, the electrical equipment will consume an amount of reactive power.

In power system there are types of electrical equipment of the system that producing or absorbing reactive power, such as [10]:

- **Synchronous machines** are electrical machines with three operating conditions: motor, generator and condenser. In generator mode the electrical machines depending on the excitation level can generate or absorb reactive power together with active power. When the machine is overexcited it supplies reactive power, and when is under excited it absorbs reactive power.
- **Loads** are in a great number in the power system. The number of loads, their characteristics or power are dependent on the time of day, season or weather. In rated state every load absorbs active power and reactive power both leading to voltage variations. Some loads operate with low power factor (can be indeed 0.6), with important losses of active power in transmission network. In this case is mandatory for industrial consumers to improve the load power factor by natural means first and specialized devices second.
- **Transmission lines** are parts of the transport and distribution system. Across the lines the voltage and current parameters change in every moment, proving the series and shunt parameters. Based on equivalent circuit it is settled that a transmission line is characterized by the following circuit parameters:

  – longitudinal or series parameters: resistance $R$ and reactance $X$;
  – and transversal or shunt parameters: conductance $G$ and susceptance $B$.

Symbols of the parameters indicate their per-kilometer values.

Depending on the load current lines absorb or supply reactive power. In case of loads below the natural load, the lines produce net reactive power, if the opposite situation applies, at loads above natural load, the lines absorb reactive power.

The reactive power is given by [1]:

$$Q[\text{VAr}] = U^2[\text{V}]B[\text{Siemens/km}] \tag{6.5}$$

All parameters of the line are significantly different functions of the conductor size, material, spacing, height above ground, and temperature.

- The distribution network is built sometimes in *underground cables*. These cables are always loaded below their natural loads. The series parameters—especially reactance is lower but shunt parameter—capacitance is higher, affects by charging reactive power under all operating conditions. Based on these, it is very important to design the line with the proper length in order to respect the cable thermal capability.

  Reactive power flow in electrical network has a negative impact on the power system. In practice almost always the specialists work to reduce the level of reactive power in order to improve the system efficiency.

  Effects of the reactive power flow in network are:
- active power losses increase. In reactive power presence this losses will be:

$$\Delta P = \Delta P_a + \Delta P_r \tag{6.6}$$

- equipment oversize that increase the installation's cost. It is known that the equipment's proportion is according to:

$$S_n = P_n / \cos \varphi_n \tag{6.7}$$

Operating mode with:

$$\cos \varphi < \cos \varphi_n \tag{6.8}$$

leads to

$$S_{proportion} > S_n \tag{6.9}$$

- decrease of supporting capacity of electrical networks:

$$P = S \cos \varphi < P_n = S_n \cos \varphi_n \tag{6.10}$$

- increase of lost voltage:

$$\Delta U = U_1 - U_2 = RI \cos + XI \sin = \Delta U_a + \Delta U_r \tag{6.11}$$

## 6.3 Reactive Power Control in Electrical Networks

### *6.3.1 Reasons and Nature of Voltage Variations in Electrical Networks*

Reactive power control is fulfilled according to reactive power variations. In steady state of electrical network the voltage is a parameter variable in time and space. Voltage variation in space is given by the different voltage nodes induced by the drops in voltage. These drops in voltage are brought by active and reactive power flow in electrical networks and power transformers.

Considering a power transformer or an electrical network with the following single phase equivalent diagram, Fig. 6.1—longitudinal impedance with equation [8, 9]:

$$Z = R + jX \tag{6.12}$$

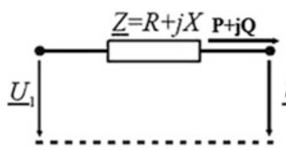



**Fig. 6.1** Single phase equivalent circuit

It establishes the complex drop in voltage with two components:

- a longitudinal component $\Delta U$, regularly named drop in voltage, with the equation:

$$\Delta U = U_1 - U_2 \cong \frac{PR + QX}{U_2} \cong \frac{PR + QX}{U_n} \tag{6.13}$$

- a transversal component $\delta U$, determination of angle $\theta$ value between voltage in the extreme of network, with the equation:

$$\delta U = \frac{PX - QR}{U_2} \cong \frac{PX - QR}{U_n} \tag{6.14}$$

Practical longitudinal impedances of transmission lines are characterized by the small value of resistance comparative with inductive reactance $R \ll X$.

Based on the phase diagram of drop in voltage, Fig. 6.2, and equations of drop in voltage, approximate equations of $\Delta U$ are

$$\Delta U \cong \frac{QX}{U_n} \tag{6.15}$$

$$\theta = \arcsin \frac{\delta U}{U_1} \cong \arcsin \frac{PX}{U_n^2} \tag{6.16}$$

These equations point out an important characteristic of the system, the level of voltage is determined by the reactive power flow and the $\theta$ value by the active power flow.

Time variations of voltage in network nodes are tie-in with the voltage drops variations in time. These variations have the following causes:

- active and reactive power flow variability in time as a consequence of variation of absorbed power by the consumers and produced power by the power plant, also.

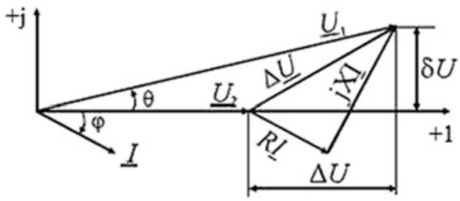



**Fig. 6.2** Phasor diagram of drop in voltage on longitudinal impedance

– modification of the network topology, longitudinal impedance and transversal admittance. This change is imposed by the necessity for optimizing the technical indicators of loaded transmission lines.

As a result, in one node of the network the voltage is variable in time $U(t)$. Voltage variation in time in the node is named voltage deviation, measured as per cent at one moment in time, with the equation:

$$\Delta U(t) = \frac{U(t) - U_n}{U_n} 100[\%] \tag{6.17}$$

These voltage variations can be hard growing or fast.

Hard growing variations appear as a consequence of a flawed control or overloaded electric network. This variation can be automatically controlled through regulators. The regulators send an impulse to beakers in order to introduce the compensation equipment into the circuit, such as synchronous compensators, bank of capacitors or transversal coil.

Fast growing of reactive power can be controlled automatically trough regulators with static commutation (GTO) in order to introduce quickly compensation equipment in the circuit.

Synchronous machines, bank of capacitors, GTO and various types of other equipment are used to maintain voltages throughout the transmission system. Injecting reactive power in the system increases voltages, and absorbing reactive power decreases voltages.

### 6.3.2 Reactive Power Control Methods for Voltage Stability

The voltage is one parameter that fluctuates in time due to the modification of the total power absorbed by the receptor, together with operating specification of the power system (revisions, failures, etc.). Also, the voltage fluctuates in dimension because of lost voltage in network leads to different values of voltage in different nodes.

Level of voltage is indissolubly linked to a stable operating of the power system. Also the voltage adjustment is interrelated with the reactive power control possibilities. Reactive power control methods for voltage stability are presented in the next section.

## 6.4 Voltage Stability in Power System

### *6.4.1 Voltage Control by Reactive Power Flow Adjustment*

The voltage adjustment by reactive power flow control can be continuous, used like a primary means of voltage regulation, or discrete used like a secondary means of adjustment.

The principle of voltage regulation by reactive power flow adjustment can be illustrated in Fig. 6.3.

In Fig. 6.3, $k$ is the installation of reactive power compensation linked to consumer bus, producing $Q_k$ reactive power. In this case reactive power transmitted on the line decreases to ($Q_2$–$Q_k$) value. As a consequence, dropping voltage decreases and the voltage value increases.

In another case, with the $k$ installation absorbing reactive power, having inductive consumer operating, dropping voltage increases and $U_2$ decreases. The conclusion of this paragraph is that by modifying the reactive power, we can control voltage on consumer bus.

This type of control is based on the reactive power sources of the power system (generators, synchronous compensators, capacitors). The same role is played by the coil mounted in the high voltage electrical network. These are consumers of reactive power.

In the next section there are presented characteristics of important voltage control means: *generators, condensers and inductors*.

**Generators:** The main function of electric-power generators is to convert different type of energy into electric power. The generators have significant control on their terminal voltage and reactive power output. This can produce or absorb reactive power depending on the magnetizing current value.

The increasing of the magnetic field in the synchronous machine implies the raising of generator's terminal voltage in order to produced reactive power. The magnetic field increasing requires current increasing in the rotating field winding.

Absorption of reactive power is limited by the magnetic-flux design in the stator, which leads to over-heating of the stator-end iron. It is known that in every electrical machine there are the core-end heating limits [10].

**Synchronous Compensators** are synchronous motors used sometimes to provide dynamic voltage support to the power system as they provide mechanical

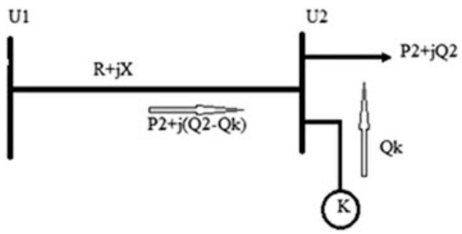



**Fig. 6.3** Reactive power compensation on consumer bus

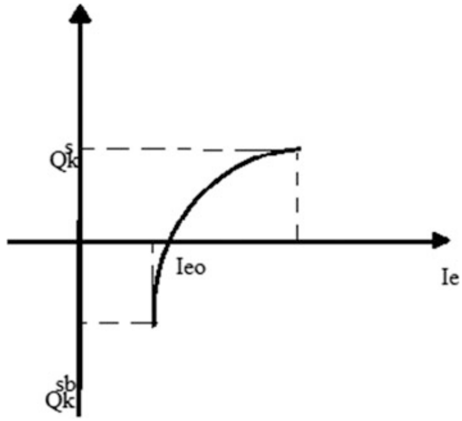



**Fig. 6.4** Reactive power variation versus magnetizing current

power to their load. In some power plants the hydro units are designed to permit the generator to function without its mechanical power source simply to provide the reactive power capability to the power system [10]. These hydro units work as a compensators when the active power generation is not necessary, Fig. 6.4.

For a magnetizing current value $I_{e0,produced}$ reactive power is zero. In case $I_e > I_{e0}$ the synchronous condenser operates overexcited, with power factor capacitive conveying in electric network reactive power. When $I_e < I_{e0}$ the synchronous condenser operates under excited, with power factor inductive absorbing from electric network reactive power. Proportion of maximum reactive power absorbed $Q_k^{sb}$ and produced power $Q_k^s$ it is a very important characteristic of the condenser operation.

Advantages of using synchronous condenser are:

– operating possibilities as reactive power generator or consumer;
– continuous regulation of produced or absorbed reactive power by magnetization current;
– contribution to the system stability, with auto-regulation effect, once the decrease of voltage leads to an increase in reactive power supplied.

A disadvantage can be the limited applicability of synchronous condensers on a large scale. The disadvantage is due to the consumption of active power around 3% of machine's reactive power rating, or operating expenses.

**Capacitors** are passive devices that generate reactive power, with some advantages:

– significant real-power losses around 2–3% from the rated power;
– low operating expense;
– possibility to space out payment of investment by gradually developing the capacitor bank with new elements.

Capacitor banks are composed of individual capacitor connected in series and/or parallel in order to obtain the desired capacitor-bank voltage and capacity rating

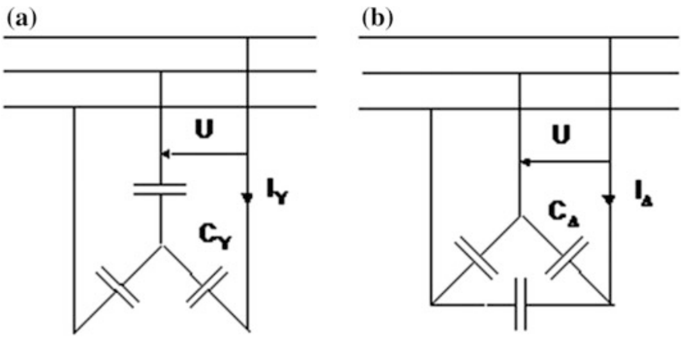



**Fig. 6.5** **a** Star connection of bank-capacitor, **b** triangle connection

[10], Fig. 6.5 [13]. Banks capacitor are discrete devices but they are often configured with several steps to provide a limited amount of variable control, and are spread in small power [10].

Produced reactive power is given by

$$Q_k = m\omega CU^2 \text{ [MVar]} \tag{6.18}$$

where

- $U$—network voltage, in kV;
- $C$—bank capacity, in F;
- $m$—coefficient with value 1 in star connection and *3* in triangle connection.

The output of capacitors is proportional to $U^2$. In fact this effect is bad in voltage control and in operating conditions of the system, also. To avoid this, the bank capacitors should be input by autotransformer.

**Inductors** are passive devices that absorb reactive power. The inductors are shunt connected to high voltage transmission lines or to the tertiary autotransformer's winding with purpose to absorb capacitive power generate by these lines in low load operation. In this case there were reduced possibilities to have in the system overvoltage produced by capacitive currents flow.

Inductors are built in three phases or formed with three single phases. Frequently the principle of reactive power control consists in modifying the number of inductors in shunt connection.

**Static VAR Compensators (SVCs)**

By combining the banks capacitor with inductors we will obtain static VAR compensators. These compensators can be designed to absorb or produce reactive power. These devices have an operating principle like a synchronous condenser, the reactive power can be controlled continuously or step by step. In order to adjust in the continuous mode the power of installation is used for inductor's control a bias

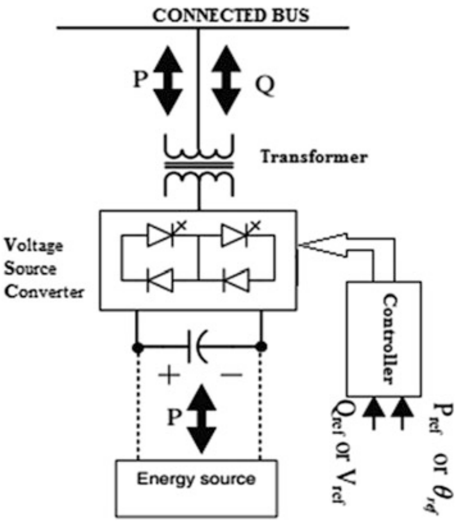



**Fig. 6.6** STATCOM schematic diagram [16]

winding or thyristors control scheme. This control is very useful for the receivers, whose operations produce power surges in the electrical network.

**Static Synchronous Compensators (STATCOMs)**

The STATCOM (STATic synchronous COMpensator) is a shunt-connected reactive compensation equipment which generates and absorbs reactive power. Its output can be varied so as to maintain control of the power system specific parameters [14–16, 19].

The STATCOM belongs to the family of devices known as flexible AC transmission system (FACTS). The schematic diagram is presented in Fig. 6.6.

STATCOMs give the power system the following advantages:

– using capacitors and inductors combined with fast switches, finally, STATCOM uses power electronics to synthesize the reactive power output [10].
– output capability is commonly symmetrical, providing as much capability for production as absorption [10].
– controls are designed to provide a fast and effective voltage control
– STATCOMs capacity is not affected by degraded voltage.
– STATCOMs are current limited so their MVAr capability responds linearly to voltage, increasing STATCOMs' usefulness in preventing voltage collapse [10].

The voltage control in the medium voltage network can be made using a system called by its developers UPQC (Unified Power Quality Conditioner), Fig. 6.7 [17]. It has the role of compensating the voltage variations and of ensuring the user's clamps receive a set voltage, practically constant. This installation was tested within the medium voltage network which a photo-voltaic plant was connected to.

The installation has the role of correcting the $i_r$ electric current loop absorbed by the user as the parallel converter introduces a $i_f$ current with such a synthesized form

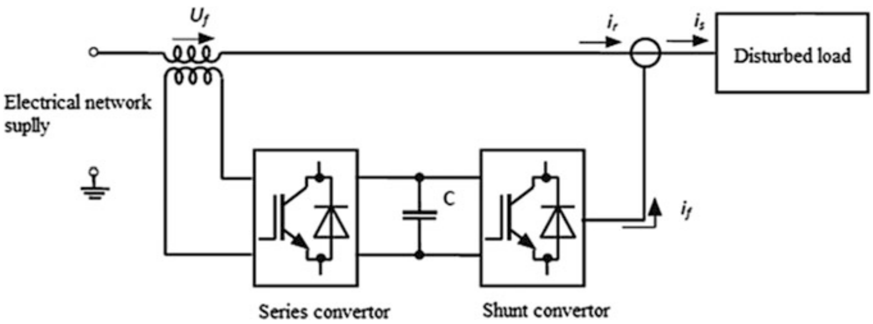



**Fig. 6.7** Electrical network conditioner UPQC [17]

that the $i_r$ electric current to be sinusoidal. The $U_f$ voltage introduced in series with the network voltage by the serial converter maintains a constant value of the user supply voltage.

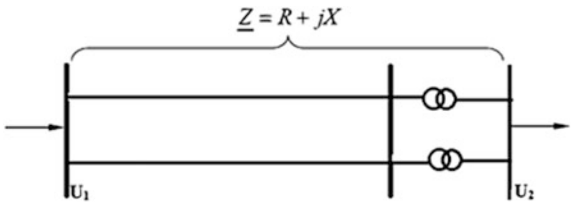
### *6.4.2 Voltage Control by Power Network Parameters Adjustment*

This process of voltage adjustment involves changes in electrical network parameters, either by connecting or disconnecting circuits operating in parallel, or by compensating the inductive reactance power lines.

Some parts of the electrical network are built in parallel connection—two or three circuits, transmission lines or power transformers connected in parallel [8]. One of these can be activated or also stopped from operating, can modify longitudinal parameters (impedance) of network, leading to change voltage in consumption nodes.

In the analyzed Fig. 6.8 under the minimum load operating conditions or empty load voltage $U_2$ consumer bars may increase above the rated value. Disconnecting a circuit power line or a transformer in the network increase the longitudinal impedance of the circuit and voltage drop, respectively, so that the voltage level can lower the $U_2$ consumer bars.

**Fig. 6.8** Electrical network to a consumer through two parallel circuits



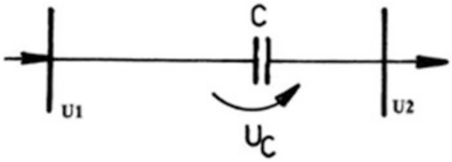



**Fig. 6.9** Capacitor mounted in cascade on transmissions line

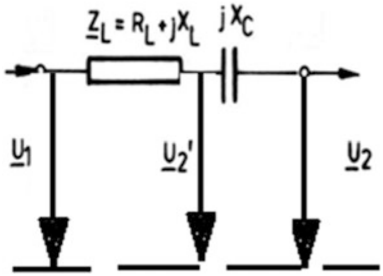



**Fig. 6.10** Single phase equivalent circuit of compensated electrical network

In practice, disconnecting transformers operating in parallel, with voltage control purpose in low load operating case is a measure recommended in terms of reducing power losses and active energy in electricity network. Because the power transformer is a component of the electrical networks that presents a high level of safety in operation, it is generally accepted to operate transformer stations with a single transformer.

Regarding take off transmission lines, it is important to know that these are less reliable in operation and in practice, it is not recommended to disconnect transmission line circuits to control voltage in electrical networks.

Another procedure used for voltage control is used cascade circuit compensation of an electrical network by inductive reactance. This is accomplished by the capacitors mounted in cascade with reactance, Fig. 6.9, obtaining a reduction longitudinal reactance of the line and thus a decrease of voltage drops.

In Fig. 6.10 there is represented a single phase equivalent circuit of a compensated electrical network

$$X_L = \omega L \tag{6.19}$$

is transmissions line reactance, and

$$X_C = \frac{1}{\omega C} \tag{6.20}$$

is capacitive reactance series on line. Resulted reactance will be

$$X = X_L - X_C = \omega L - \frac{1}{\omega C} \tag{6.21}$$

Based on the capacitive reactance's value there are the following situations:

- under-compensated line, when $X_C < X_L$;
- total compensated line, when $X_C = X_L$;
- over compensated line, when $X_C > X_L$.

Longitudinal compensation with banks capacitor series connected with long lines of electricity transmission is done in order to increase the transport capacity of these lines and limits of stable operation of the power system.

To control voltage from a practical standpoint, series compensation with banks capacitor is important for the medium voltage lines in the following cases:

- overhead lines relatively long, slow voltage variations reduction to consumers;
- electrical lines feed to consumers that produce shock load in the network, in order to reduce shock occurring in the voltage corresponding to power supply.

On the other hand, it must be known that the compensation process causes some negative phenomenon: ferro-resonance, under-synchronous resonance or oscillation of the synchronous machines. For limiting them a research to develop possibilities and removing their appearance is required.

Measures that can be taken to avoid these are:

- restrict the compensation to between 1.5 and 2;
- using series or parallel resistors with banks capacitors.

Another drawback of the procedure- series bank capacitors for compensation of the inductive reactance of the power lines is the increase of the short-circuit current, symmetrical and non-symmetrical. The capacitors are protected by special circuits in the short circuit case within power system. This method is used in heavy growing and fast variation of reactive power in the system.

### *6.4.3 Node Voltage Set Up*

The importance of voltage control in electrical network nodes is to change the level of voltage in admissible in them. This process seems to be the most natural, but it will not remove the cause of voltage fluctuations causing variations reactive loads transiting through electric transmission elements and distribution network. This voltage control method consists in injection of supplementary voltage in order to compensate longitudinal component of lost voltage. The injection voltage is realized by autotransformers or power transformer equipped with adjuster under longitudinal load or transversal. Often are used in power system voltage control by the automat voltage regulator.

Base on introducing additional voltage in an electrical network, there are the following types of control methods [18]:

- longitudinal adjustment, which is intended to compensate the longitudinal component of drop in voltage. Additional being introduced in phase with the line voltage at that point;
- transverse adjustment when additional voltage is in with quadrature voltage network at that point, and serves mainly to modify the power flow in the mesh network topology;
- adjustable long-transverse, when the longitudinal adjustment is used to adjust the transverse correlated.

In terms of structural and functional features of the used means to introduce additional voltage, there are to be distinguished two types of control:

– direct control, which is performed using power transformers and autotransformers fitted with sockets for adjusting the working windings, as well as with devices for switching them in the presence or absence of load;
– indirect control, which is performed by means of special transformers and special autotransformer-overvoltage transformer. These constitute complexes devices that can be associated to regulating power transformers non-adjustable or can be used separately. These also include the regulators induction.

### *6.4.4 Management of Voltage Control*

Base of voltage adjustment consists of generating units by using their capability to absorb and debit reactive power (to modify the magnetization current and implicit electromotive force linked by synchronous reactance), within diagram *P-Q* available.

For basic voltage control use the following devices:

– Synchronous condenser;
– Synchronous generators operating in thermo and hydro plants;
– Wind power plants;
– Photovoltaic power plants.

All other means of voltage control, maintained by the consumers/network operators have a secondary role regardless of their number and capability and they come in support of the generating sets without replacing the first.

These are:

– Banks capacitors;
– Inductors;
– Control by power transformer sockets;
– Connect/disconnect of electrical lines transmission.

## 6.5 Case Studies

1. ***Q–V*** **voltage regulation approach in the pilot node using an automatic voltage control (ASVR—Automatic Secondary Voltage Regulation) developed in Romania**

The goal is to maintain the required voltage in the pilot node within the desired voltage domain. ASVR equipment consists of an independent regulator working on the principle of regulatory with negative feedback response.

ASVR are placed in the power plant or electrical station, and the desired voltage it is received by the voltage domain that must keep it in pilot node.

**ASVR = Automatic Secondary Voltage Regulation in pilot node of 400 kV—automation which controls the voltage in the 400 kV pilot node from a transformation station**.

Further on we will refer to such a system associated to a wind plant, but this system can be used for any kind of plant, photo-voltaic, for example.

The wind plants management system—which is capable of controlling in real time depending on the imposed voltage level, meaning the decrease of increase of produced reactive power, by controlling the voltage in the medium voltage network (MT) and in the 110 kV, through the modification of the plots at the transformers (power transformer 110/MT from the power transformer transformation stations and power transformer 400/110 kV from the system station), according to the set voltage value from the 400 kV pilot node, but also to the park's reactive power availability at that moment, increasing or decreasing the transit of active energy from the wind park, if the adjustment analysis takes into consideration the electric scheme from Fig. 6.11.

The automatic installation for the secondary adjustment of the ASVR voltage is destined to the voltage adjustment at the 400 kV level in the 400/110/MT station, as the reference is given the voltage value on the station's 400 kV bars.

Thus, in order to achieve this objective, there are used both the wind generator capacity to produce/consume reactive power, but also switching the plots of the MT/110 kV transformers and the 400/110/MT transformers.

The primary adjustment loop *U–Q* of the wind generator group has as reference the value of the voltage on the 110 kV bars so that the reactive power variation of the generators would follow the variation of this voltage, which, in turn—according to the ASVR logic—is proportional to the voltage variation on the 400 kV bars. Additionally, in order to extend the adjustment band, under the conditions of maintaining the inferior voltage of 110 kV, MT and 0.5 kV within the admitted limits, there are used the voltage regulators of the MT/110 kV transformers, respectively the 400/110/MT which act on the plot switches at the ASVR command.

From a practical standpoint, compared to the initial (primary) function of adjusting the voltage to the 110 kV through the variation of the wind generators

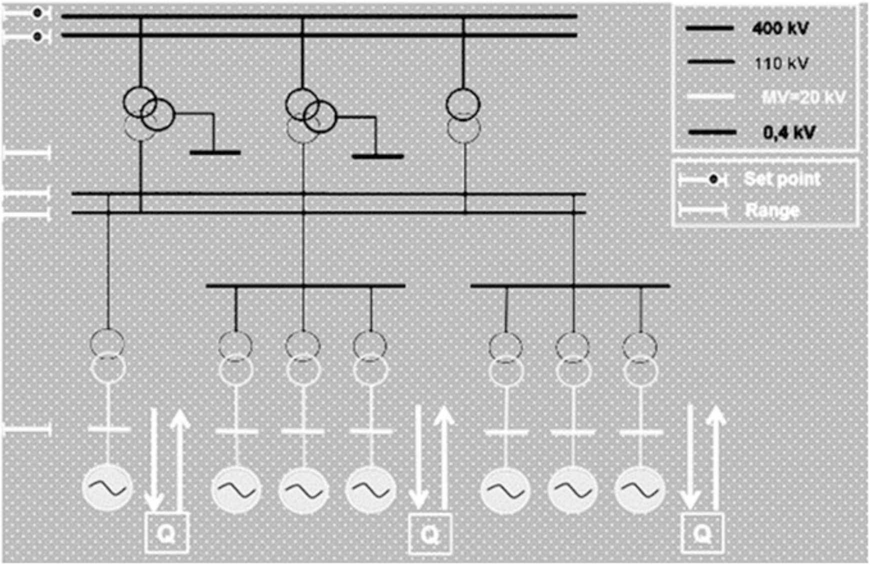



**Fig. 6.11** The transformer station through which a central debits

reactive power, the ASVR installation is designed to perform the following supplementary functions:

- The voltage adjustment by modifying the reactive energy produced by the wind generators from the wind power plants by means of the command-control system WFMS, having as reference the voltage at the level of 400 kV bars;
- automatic switching of 400/110/MT transformer plots from the 400 kV station;
- automatic switching of MT/110 kV transformer plots from all stations corresponding to the plant;
- coordinating the three preious functions.
- observing the condition to maintain the voltage levels inferior to 400 kV (meaning 110 kV, MT and 0.4 kV) within the admitted limits.
- ASVR is composed of three adjustment loops, as follows:
- adjustment loop voltage 400 kV;
- adjustment loop voltage 110 kV;
- adjustment loop voltage MT.

The three adjustment loops function simultaneously, as they coordinated by the ASVR logic. Not including one of the loops in the ASVR scheme implies the ASVR functioning without the adjustment system corresponding to that loop (for example, not including the Mt adjustment loop determines the ASVR functioning without the MT/110 kV plot switching).

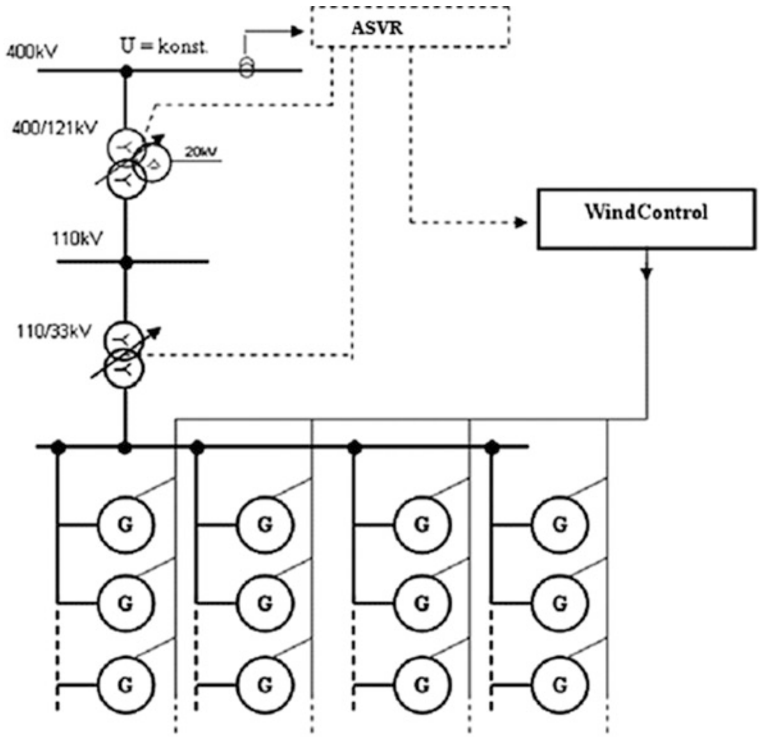



**Fig. 6.12** ASVR integration in electrical network

The coordinating function of the three adjustment loops leads to a hierarchy of their actions, so that the adjustment process records the following hierarchy (priority):

1. loading/unloading with reactive energy the wind generator ensemble from the electric plant;
2. plot switching at the MT/110 kV transformers of the producer (from the plant stations);
3. plot switching at the 400/110/MT transformers from the 400/110 kV where the pilot node is considered.

The adjustment loop ensemble which ASVR consists of is schematically presented in Fig. 6.12.

**Release period/start:** The interval between two control interventions are usually set on 18 ÷ 20 s. Also every deviation must be eliminated by occurred adjusting 120 s of its release.

- The ASVR will command the power transformers 400/110 kV on the basis of criterion of minimal voltage difference between the sockets;
- In case of increase voltage 110 kV will be used by the transformer with the socket on lower voltage;
- When voltage decreases 110 kV the transformer is used with socket to the higher voltage;
- The criterion of reactive power transfer will be applied in voltage equality between the sockets.

2. ***Q*–*V* voltage control in wind power plant, with imposed *Q***

We have a wind power plant to which a ASVR is used in order to maintain voltage in the 110 kV, the consign the plant receives being of reactive power $Q_{abs}$ or debited $Q$, according to the 'scale' chart from Fig. 6.13 and the adjustment itself consists in loading/unloading the wind generator group from the wind plant with reactive energy.

In the diagram presented in Fig. 6.13, imposed $Q$, as follows ASVR, $Q$ absorbed or $Q$ produced to be as close to the preset value. These values are indicated by $Q$ measured which falls or how much it increases depending on the preset value $Q$. Also voltage of 110 kV aims at absorbing or dispensing $Q$, dropping respectively $U$ with an increase for which we have in view the achievement of a certain preset $Q$.

Acquisition and execution of preset reactive power provided by ASVR controllers will be using the entire reactive power reserves that actions wind power plant, including the existing compensation means to them. In case $P = 0$ for a wind plant will provide for the adjustment $Q = 0$ or $Q \neq 0$, and the controller must know the limits of maximum and minimum reactive power that wind plant led so it can provide active power when it's generated or not.

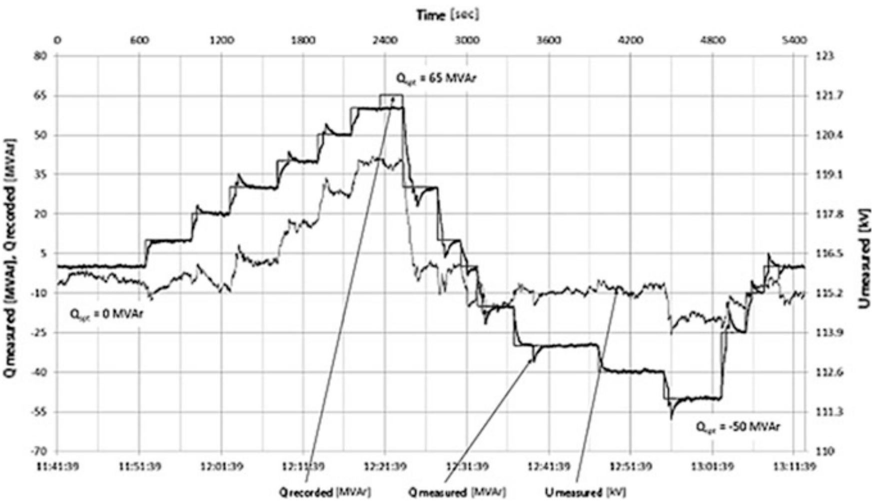



**Fig. 6.13** *Q*–*V* diagram with imposed *Q*

3. ***Q–V* voltage control in photovoltaic power plant, with imposed *U***

We have a wind power plant to which a ASVR is used in order to maintain voltage in the 110 kV, the consign the plant receives being of voltage adjustment *U*, according to the 'scale' chart from Fig. 6.13 and the adjustment itself consists in the three loops' coordinated functioning, thus leading to a hierarchy of their actions so that the adjustment process can be performed.

In the diagram, in Fig. 6.14 can be seen as an imposed voltage, ASVR follows that voltage 110 kV to be as close to the preset value. These values are indicated by measured voltage that goes up and down depending on the value of voltage. Also instruction for reactive power *Q* is produced or absorbed in order to increase, decrease voltage respectively, as we have in mind to reaching any preset voltage.

According to the short-circuit on bar power at the voltage level for which the voltage is aimed to be adjusted, there are the results $\Delta Q/\Delta U$ [MVAr/kV] for the voltage level we want to maintain, meaning, for example, that, at a variation of 2 kV we approximate ±16 MVAr (Fig. 6.14), respectively at a de ±8 MVAr variation, as the voltage varies with ±1 kV/8MVAr (the mentioned values are just for exemplification, as they depend on the voltage level where the adjustment is made). The $dU/dT$ value shows the response speed, the decrease/increase of voltage in a minute, indicating the system's capability to reach the values for *U* consign, according to the voltage rise.

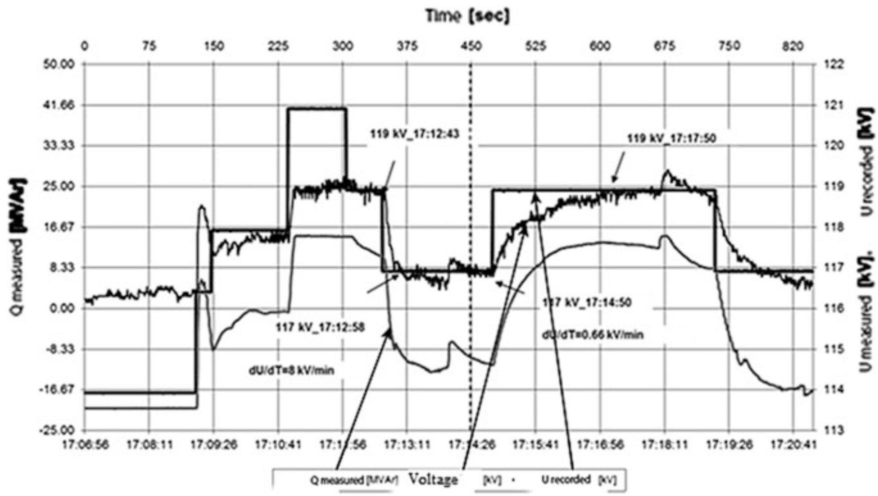



**Fig. 6.14** *Q–V* diagram photovoltaic power plant—*U* preset

## 6.6 Conclusion

The wide development of renewable energy sources connected to the high medium voltage lines imposed the development of specific solutions for the voltage control in the point where these sources connect or in their vicinity.

Today’s energy systems are facing the problem that, in some areas of the system there are is an exceeding production, while in other areas the production is lower, while energy is transited from the sources in order to balance the consumption. All these occur as result of the way the plants are located, as they, for different reasons, chosen for other criteria than the optimal location and, considering the degree to which the network in loaded, the power is transited to a consumption node which can be, in some situations, very far from the source, this leading to a decrease in the area’s level of voltage. The phenomenon can also appear in reverse, meaning an increase in voltage, in the situations when the plant connection is made in nodes with reduced short-circuit power, thus appearing the limitation of the power debited by the plant in accordance with the voltage maximally admitted at the final consumers, especially in the cases of plants recorded at the MT lines.

For these reasons, it is important to control the voltage level, and this is why one must always analyze solutions to maintain the voltage within the limits which are adequate for the user’s system.

For the transport network, one of the solutions is the ASVR system which maintains the voltage in pilot node chosen in the system, compensating the voltage variations in the system, with the three presented adjustment loops, thus using two of the adjustment methods, the reactive energy absorption and debit and the longitudinal and long-transversal voltage adjustment in the transformers by using the plots. The ASVR can be also used in the distribution network, with less control loops, two or even one.

Considering the voltage variation at the final user clamps, from each voltage level from the system, depends in each moment on production, consumption, network loading, using an automated voltage regulator for that voltage level allow for the necessary conditions of ensuring the quality of the energy from the network and, consequently, for all users.

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