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REGULATION OF REACTIVE POWER AND VOLTAGE IN ELECTRIC NETWORKS, AS ADDITIONAL SERVICE

Factors of reactive power influence on technical-economic indices of electric network, have been analyzed. It is shown, that generation, transmission and reactive power regulation expenses in market conditions must be reimbursed.

Key words: *electric network, reactive power, voltage regulation, auxiliary services.*

Introduction

Reactive power in electric networks determines the value of their technical economic parameters. Nowadays the problem of reactive power is widely discussed both by power engineers and consumers of electric energy. Many scientific papers and regulatory documents, dealing with this problem have been published. But one-sided approach, regarding the place and role of reactive power in electric networks is observed. Among problems, connected with generation, transmission and consumption of reactive power, much attention is paid to its influence on losses of active power (electric energy) in electric networks. For instance, techniques of payment calculation for reactive electric energy flow, in other words, compensations of reactive power, are developed, taking into account only this factors. At the same time, reactive power considerably influences other parameters of electric networks modes. This influence can be greater in technical and economic sences than increase of electric energy losses, caused by reactive power flow.

Reactive power in electric network, containing active resistances *R*, inductance *L* and capacitance *C*, provides (accompanies) transmission of reactive power, generated at electric power stations, to loads. Total power, being transmitted, can be presented as complex Pounting's vector $\vec{S} = \left[\dot{E}\widehat{H}\right]$ and is determined as [1]

$$-\oint\limits_{V} \vec{S}d\vec{s} = \int\limits_{V} \gamma E^2 dV + j2\omega \int\limits_{V} \left(\frac{\mu H^2}{2} - \frac{\varepsilon E^2}{2}\right) dV \quad , \qquad (1)$$

where $\vec{S}$ – is the vector of total power; $\dot{E}$ – is the vector of electric field intensity; $\widehat{H}$ – is conjugate vector of magnetic field intensity; μ – is magnetic permeability of the medium of V volume; ε – dielectric permittivity; γ – is electrical conductivity.

In (1) the first component is active power *P*, and the second component – reactive power *Q*. Thus, Umov-Poynting's theorem can be written as [1]

$$-\oint\limits_{V} \vec{S}d\vec{s} = P + jQ \quad ,$$

where reactive power *Q* equals the difference between magnetic and electric energies of the circuit, multiplied by 2ω.

In each element of electric system, where the transformation of electric energy (generation, consumption. transmission) is performed, magnetic, electric or electric-magnetic field is obligatory available. This is technologically expedient. From (1) it is seen, that if magnetic or electric energy is available in each element, under certain conditions while transmission, their difference, i.e. reactive power, can be minimized or even reduced to zero. Under such conditions, which can be called compensation of reactive power while its transmission, the influence of reactive power on technical economic indices of electric network is minimized.

While transition to electric energy market and energy supply under bilateral agreements factors of reactive power influence on engineering and economic indices of electric networks must be economically evaluated [2, 3].

The given paper analyzes the results of reactive power transmission in electric networks in modern economic conditions, when control of reactive power and, as a result, voltage regulation is considered as paid services.

Influence of reactive power on the operation of electric networks

Fig. 1 contains the list of most important factors of reactive power influence on the process of electric energy transmission.

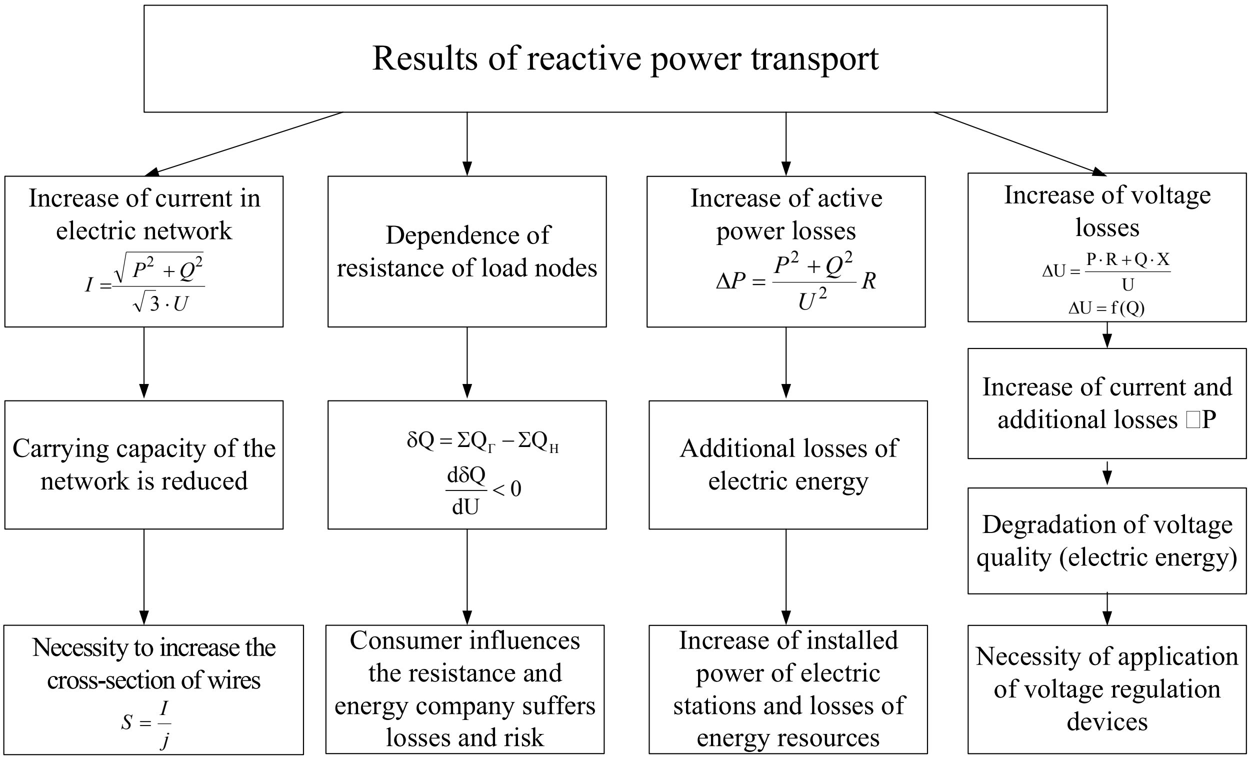

Fig. 1. Factors of reactive power influence on electric network

The necessity of reactive power transmission from electric stations to consumers, influences the constructive parameters of electric networks, since it results in increase of current and correspondingly, increase of cross-section of wires, rise in the cost of support of over-head transmission lines, etc. In case, when transmission lines are in operation, compensation of reactive power allows to increase the transmission of active power by corresponding value. Providing the installation of compensation units (CU) in electric networks at the stage of its design, losses can be reduced by decreasing the cross-section of wires and the capacity of the transformers by the share, needed for transmission of reactive power.

Transmission of reactive power by the elements of electric networks provokes additional losses of active power (electric energy) and losses of voltage. To cover additional losses of electric energy additional installed capacity must be provided at electric power stations, and to maintain voltage within admissible range in electric networks, additional voltage regulation facilities must be provided. All this requires additional capital investments.

Costs to cover the influence of reactive power on electric network modes can be allocated accurate and predicted. Exact costs are determined by the parameters of the network and can be calculated on the basis of the laws electric energy. These are expenditures for compensation of active power (electric energy) losses in electric network. Exact expenditures comprise capital investments, fixed charges, variable charges, connected with the influence of reactive power on losses of electric energy and maintenance of the facilities, intended for compensation of reactive power. Control over the process of expenses reimbursement in electric network, caused by electric energy losses, is carried out according to special techniques, for instance [4].

The problem, dealing with predicted expenses on reactive power is more complex. Predicted expenses include synchronous generators, when due to additional reactive energy, required by EES, they change planned load curve and loose profit as a result of delivery of active electric energy. These expenses are hidden expenditures. Losses of active power in synchronous generators depend on their generation of reactive power [5, 6]:

$$\Delta P = \frac{D_1}{Q_i} Q + \frac{D_2}{Q_i^2} Q^2 , \qquad (2)$$

where D_1, D_2 – are values, constant for the given generator, which depend on capacity and efficiency factor of the generator; Q_n – is nominal reactive power of the generator; Q – is current value of reactive power of the generator.

These losses are often neglected, since they are considered to be minor. For instance, for generator T-2-50-2 with Q_n =31 Mvar, D_1=36,7 кW and D_2=62,1 kW ΔP_n =98,8 kW, at Q=1,1·Q_n $\Delta P_{1,1}$ =115,5 kW, at Q=1,2·Q_n $\Delta P_{1,2}$ =133,5 kW. That is, if for the increase of voltage in electric network , it is necessary to increase the reactive power of the generator by 20%, then it will lead to the increase of active power losses in the generator by 34,7 kW or 35%. Generation of active power is reduced by 20%.

Additional losses of active power, depending on reactive power appear not only in the windings of generators but also in step-up transformers of electric stations and facilities of energy system, which are involved in balancing of reactive power (shunting reactors, synchronous compensators, STC, etc.). Their losses are also neglected, evaluating expenses of electric energy transmission organizations for regulation of reactive power and voltage. It is obvious, that in market conditions generation and transmission are not ready to agree on this.

Reactive power, produced by electric stations of the system, is connected with the voltage at loading buses U_l and excitation of generators: $E \equiv i_{iex}$. For radial network, total resistance of which is x, the dependence [7] is valid

$$U_l^2 = \left(E - \frac{Q_l + \Delta Q}{E} x \right)^2 - \left(\frac{Px}{E} \right)^2 , \qquad (3)$$

where $P = P_l + \Delta P$ – is active power of energy transmission; P_l, Q_l – are active and passive powers of load; ΔP, ΔQ are losses of active and reactive powers in the network and generator.

It follows from (3) that voltage regulation on load buses U_l and maintaining of its set value is provided by the regulation of generators excitation $E \equiv i_{iex}$, that, in its turn, means regulation of generators reactive power

$$Q_G = Q_l + \Delta Q = \frac{E^2}{x} - \frac{EU}{x} \cos\delta ,$$

where δ – is an angle between vectors E and U.

From the latter expression it follows, that the voltage level in the network (on load) is connected with the balance of reactive power or

$$\Delta U \approx f(\Delta Q) .$$

Connection of capasitor banks (CB) with load buses in order to compensate the reactive power leads not only to positive consequences, i.e., to the reduction of electric energy losses but also has negative consequences – worsens resistance [7]. Fig. 2 shows dependences of reactive power and voltage prior to CB connection (curve 1) and after connection of CB (curve 2). After CB connection negative component appears in the load, that leads to characteristic *Q=f(U)* deformation. It becomes more slope and resistance factor decreases, because

$$\frac{\delta Q_2}{\Delta U} \leq \frac{\delta Q_1}{\Delta U}.$$

Thus, compensating the reactive power in order to reduce of electric energy losses, it is necessary to provide in the system regulated sources of reactive power, which, if necessary, will correct *Q=f(U)* characteristic. It also means that in the nodes of the system it is necessary to maintain certain relationships between active and reactive powers, i.e. $tg\varphi$.

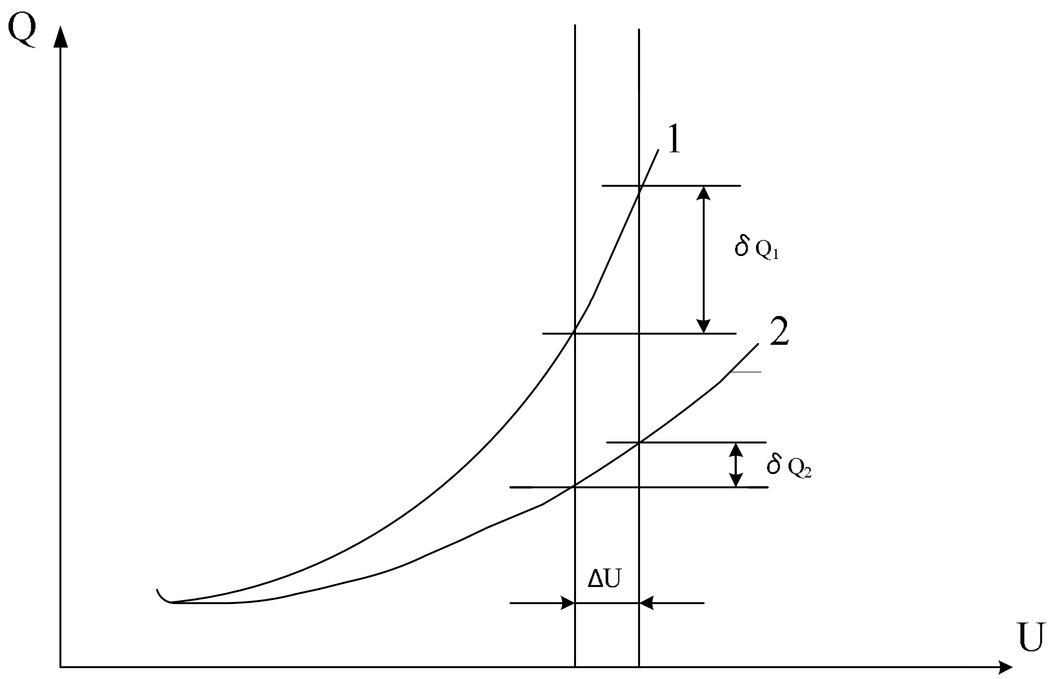

Fig. 2. To the analysis of CB influence on loading stability

Reacitve power regulation services

While creation of services market of reactive power and voltage regulation, it is not clear what is the service to be rendered and to be bought, who must be its seller or buyer. This is stipulated both by the specific feature of physical essence of reactive power and peculiarities of its generation and consumption and possibilities of local regulation of voltage levels in the network. Non sufficient provision with reactive power compensation devices leads to certain problems dealing with voltage regulation in separate nodes of EES. Unsatisfactory state of reactive power compensation facilities in separate nodes of electric network results in the fact, that generators of electric stations become the only efficient means of maintaining admissible voltage levels in these nodes and sections of the network adjacent to these nodes. Being main source of reactive power in EES, generators of electric stations are, at the same time, important means of voltage regulation. In market conditions, regulation of voltage and reactive power is the essence of services provided for the creation of normal conditions of energy supply. They are divided into systemic and auxiliary [2, 3].

Systemic services are intended to provide sustainable operation of EES, reliability of energy transmission system operation, quality and reliability of energy supply from producers to consumers in the process of on-line, dispatching control [2]. System services are provided by system operators to all users of EES, proceeding from the contract on connection and usage of electric networks. System operator is the only provider of system services, supplied to the users of EES.

Auxiliary services (AS) it is identified, personified, measured or defined with corresponding expenses, product, supplied by the subject of energy sector or by qualified consumer of electric energy and is consumed continuously, in real time mode or in definite fixed periods of time to provide optimally balanced and sustainable operation of EES on the basis of the contract, signed with system operator, regarding services provision [2].

AS concerning regulation of reactive power by producers are obligatory. There exist obligatory AS, to be provided by separate market entity and commercial services, provided by market entities optionally. Obligatory auxiliary services are used to maintain voltage and for regulation of the reactive power by the produces. It is obligatory minimum, supplied by all licensees. Other auxiliary services can be involved to maintain voltage and perform regulation of reactive power above obligatory minimum.

Commercial auxiliary services are used for reservation of voltage support facilities and regulation of reactive power by producers and consumers above the obligatory minimum [2].

Conclusions

1.Reactive power is an integral element of generation, transmission and consumption of electric energy. Transporting of energy over transmission line results in a number of negative phenomena, leading to worsening of voltage quality and increase of electric energy losses.

These phenomena also influence the stability of loading nodes, decrease carrying capacity of the network.

2. Generation and transmission of reactive power are connected with expenditures, which in market conditions, must be reimbursed. Payment of service, connected with regulation of reactive power and voltage maintaining in electric networks must be formed not only at the expence of electric energy losses, caused by the transmission of reactive power, but taking into account other factors of reactive power influence on electric network.

REFERENCES

1. Бессонов Л.А. Теоретические основы электротехники. – М.: Высшая школа, 1967. – 775 с.
2. Ілка Левінгтон. Україна – впровадження концепції оптового ринку електроенергії // Електропанорама. – 2009. – № 1–3.
3. Никитин А.А., Олефир Д.А., Франчик Е.Н. Особенности развития балансирующего рынка и рынка вспомогательных услуг в ОЭС Украины // Електропанорама. – 2010. – № 1–4.
4. Методика обчислення плати за перетікання реактивної електроенергії між енергопередавальною організацією та її споживачами (затверджена наказом Мінпаливенерго України 17.01.2002 р. за №19 і зареєстрована Міністерством юстиції України 01.02.2002 р. за №93/6381).
5. Иванов-Смоленский А.В. Электрические машины. – М.: Энергия, 1980. – 928 с.
6. Карпов Ф.Ф. Компенсация реактивной мощности в распределительных сетях. – М.: Энергия, 1975. – 184 с.
7. Веников В.А. Переходные электромеханические процессы в электрических системах. – М.: Высшая школа, 1985. – 536 с.

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