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IMPROVEMENT OF CALCULATION METHOD OF REACTIVE POWER COMPENSATION

In the article the advanced method of calculation of reactive power compensation is analyzed. Improvements allowing to substantiate higher levels of reactive power compensation and accordingly to increase its efficiency are suggested.

Keywords: *reactive power compensation.*

Statement of the problem and analysis of recent research and issues

In [1] functions of expenses at RPC are resulted:
in enterprise networks

$$З = З_{S.G} \cdot Q_M (1-\psi) + З_{S.C1} \cdot Q_M \cdot \psi + \frac{З_{S.C2} \cdot Q_M^2 \cdot \psi^2}{K_0}, \qquad (1)$$

in subsystem networks

$$З = \dot{Q}_н \dot{Д} \cdot (1-\Psi) + \dot{Q}_н \cdot \dot{П} \cdot \dot{R} \cdot \dot{C} \cdot \left(\dot{Q}_н \cdot \dot{П} \right)^t \cdot \Psi, \qquad (2)$$

where $З_{S.G}$ - weighted average specific expenses for reactive power generation by all CI (compensating installations), thousand grn / MVAr; $З_{S.C1}$ - specific expenses of consumer for reactive power and input energy from PP network, thousand hrn. / MVAr; $З_{S.C2}$ - specific expenses for transfer of reactive power through network, thousand hrn. / MVAr^2; Q_M - maximum of reactive power at the input of consumer networks, MVAr; ψ - input reactive power in relative units (ψ = Q_e/Q_m, Q_e – input reactive power in absolute units, MVAr; value ψ - is variable of function optimization (1)); K_0 - deviation factor of actual flux-distribution of reactive power from optimum value, at which losses in network are minimum (at K_0=1), relative units; $З_{S.C2} \cdot Q_M^2 \cdot \psi^2$ - expenses for transfer of reactive power through a network at actual flux-distribution (before compensation) at this or that value Ψ, thousand hrn; $\frac{З_{S.C2} \cdot Q_M^2 \cdot \psi^2}{K_0}$ - is minimum possible expenses for reactive power transfer through a network (after compensation) provided that CI in network knots installed optimally (by criterion of minimum losses) at solution of balance problem of RPC, thousand hrn.; $З_{S.C1} \cdot Q_M \cdot \Psi$ - expenses of consumer for reactive power and energy which are consumed from power supply system of network, thousand hrn. $\dot{Q}_н = (Q_{н1} ... Q_{нн})$ - vector-row of reactive loads of subsystem knots, MVAr; $\dot{D} = (З_{пг1} ... З_{пгn})^t$ - vector of specific expenses for generation of reactive power by its sources in networks knots of subsystem, thousand hrn. / MVAr; $\dot{П}$ - matrix of routs; $\dot{R}$ - diagonal matrix of active resistance of branches of equivalent circuit of subsystem networks, Ohm; $\dot{C}$ - diagonal matrix of factors C_i $(i = 1...n)$.

From the equations (1) and (2) we can see, that criterion function (1) has a component which reflects expenses of consumer for consumption of reactive power and energy from energy system network, and in function (2) such component is absent. It is explained by introduction for consumers since 1998 of payment for reactive energy, and for utility companies such payment is absent [2]. There is a question, whether it is expedient noted above component to take into account at system calculation of RPC in subsystem networks, that is in criterion function (2). If we assume the positive answer to this question then, how can we determine cost of losses for networks of subsystem which includes networks of utility companies and associated consumers?

At the stage of solution of RPC economic problem the optimum distribution of CI and, accordingly, remaining (undercompensated) distribution of reactive power is not known, but there is a possibility prior to solution of economic problem to determine K_0 by the formula [1]:

$$K_0 = \frac{R_{e.l}}{R_e} \geq 1, \tag{3}$$

where $R_{e.l}$ - equivalent active resistance of network determined at actual losses (before compensation), Ohm; R_e - equivalent active ohmic resistance of network determined by means of its consecutive equivalentiation, Ohm.

Value $R_{e.l.}$ is determined by the formula [1]:

$$R_{e.l} = \frac{\sum_{i=1}^{n} Q_i^2 r_i}{Q_M^2}, \tag{4}$$

where Q_i ,r_i - accordingly reactive load and resistance of i^{th} element of network, MVAr·Ohm.

By condition $\partial З/\partial\psi$ optimum (by criterion of minimum expenses) values of input reactive power and total power of CI are obtained in relative and absolute units:

$$\psi_0 = \frac{(З_{S.G.} - З_{S.C1}) \cdot K_0}{2З_{S.C2} \cdot Q_M}, \tag{5}$$

$$Q_{e.0.} = \frac{(З_{S.G.} - З_{S.C1}) \cdot K_0}{2З_{S.C2}}, \tag{6}$$

$$a_0 = 1 - \psi_0, \tag{7}$$

$$Q_{CI.0} = Q_M - Q_{e.0}, \tag{8}$$

where a_0 - degree or level of reactive power compensation in electric network, in relative units.

The equation (8) follows from condition of balance of reactive power at the input of electric network of enterprise, and (7) - by division of the equation (8) on value Q_m.

The analysis of formulas (4) and (5) shows, that more intensive increase in cost of compensation means, as compared with electric power cost, leads to reduction of economically proved level RPC (a_0). And on the contrary, presence of payment for reactive energy and increase in cost of losses allows to substantiate higher level of RPC.

Purpose of the paper - Offer improvement of known method for increase of accuracy of RPC calculation and, accordingly, its efficiency.

The basic materials of researches

In the last 10 - 15 years disparity of prices for compensation facilities (complete condenser units, devices of account of electric power, switching equipment) and electric power has emerged. The prices for electric power are supervised by the state (NCPIR - national commission for power industry regulation) and grow slower than prices for compensation facilities. As a result paradoxical situation appeared: the most effective energy saving technology in electric networks which is RPC, often appears economically inexpedient. The problem of economic substantiation of levels RPC in electric networks was created. Introduction in criterion function (1) costs of reactive electric power increases economically proved of RPC level or reduces IRP (input reactive power), (see formulas (5 - 8).

Determination of IRP and RPC level by formulas (5) and (7) allows to substantiate its efficiency from the point of separate consumer and to make specification in certain cases of system calculation [1]. At the same time, use of system approach to RPC calculation essentially increases economically proved level of RPC (networks of utility company and consumers associated to it are considered simultaneously [3]). It is logical to make conclusion that inclusion in function of expenses on RPC for its system calculation of cost of reactive energy for consumer will lead to still greater increase of economically proved RPC level. For system calculation of RPC the function (1) as more simple at performance of calculations by personnel of power supply systems and consumers is offered to use.

It is necessary to note, that due to non-efficiency of operating procedure of payment for reactive energy [2], Ministry of Fuel and Energy of Ukraine took decision about elaboration of new edition of this technique in which the offer about mutual settlements between subjects of wholesale market of electric power of Ukraine can be realized. In that case cost of losses in subsystem networks is offered to be determined at weighted tariff by the formula:

$$T_w = \frac{\Delta W_e \cdot T_{whol} + \Delta W_{con} \cdot T_{ret}}{\Delta W_e + \Delta W_{con}}, \tag{9}$$

where $\Delta W_e, \Delta W_{con}$ - accordingly electric power losses in networks of power supply system and associated consumers, kW $\cdot$ hour; T_{whol}, T_{ret} - accordingly wholesale and retail tariff for active electric power.

Introduction in criterion function (1) of factor K_0 allows to consider on the stage of solution of economic problem, optimization of reactive power flows after compensation (by means of optimum placing of CI and their control). In other words, to consider optimization of remaining (undercompensated) overflows of reactive power (K_0 was introduced according to requirements [4]).

On the other hand, introduction in criterion function of factor K_0 leads to increase of input reactive power (ψ_0 and $Q_{e.o}$) and, accordingly, to reduction of RPC level (a_0) and total capacity of CI which should be installed in electric network (Q_{CI}). If we take into consideration, that value K_0 can change basically in networks from 1,05 to 2,0 and more reduction of economically proved level of RPC can be essential. At the same time reduction of cost of losses (at presence of K_0) from remaining (after compensation) overflows of reactive power by absolute value is insignificant.

For elimination of noted contradiction the factor K_0 in criterion function (1) is offered not to be introduced, and to use it at determination of economic and power efficiency of compensation. Taking into account noted changes the mathematical model for decision of economic problem of RPC will look as:

$$\begin{cases} З = З_{S.G} \cdot Q_M (1-\psi) + З_{S.C1} \cdot Q_M \cdot \psi + З_{S.C2} \cdot Q_M^2 \rightarrow min \\ Q_M = Q_{CI} + Q_e \\ \psi_0 \le 1, a_0 \ge 0. \end{cases} \tag{10}$$

At condition $\partial З / \partial \psi = 0$ we will obtain optimum (by criterion of minimum expenses) parameters of RPC for networks of subsystem (enterprise):

$$\psi_0 = \frac{\left(З_{S.G.} - З_{S.C1}\right)}{2З_{S.C2} \cdot Q_M},$$

$$Q_{e.o.} = \frac{\left(З_{S.G.} - З_{S.C1}\right)}{2З_{S.C2}}. \tag{11}$$

$$a_0 = 1 - \psi_0,$$

$$Q_{CI.0} = Q_M - Q_{e.0}. \tag{12}$$

Values of parameter $З_{S.G}$ are determined by the formula resulted in [1]. Parameters $З_{SC}1$ and $З_{SC}2$ are offered for determining by formulas, accordingly, (thousand hrn. / MVAr;

thousand hrn. / MVAr^2):

$$З_{S.C1} = 10^{-3} \cdot \frac{П1 + П2 - П3}{Q_M}, \tag{13}$$

$$З_{S.C2} = \frac{T_W \cdot \tau \cdot R_{e.l}}{U_M^2}, \tag{14}$$

where $П_1$, $П_2$ - basic and additional payments for reactive energy, hrn.; $П_3$ - discount from payment for reactive energy, hrn. [2]; τ - number of hours of maximum losses of electric power, hours.

Specification of formulas (11) and (12) are predetermined by establishment of payment for reactive energy and determination of specific cost of losses of active electric power from imparting reactive energy according to operating technique [2].

If as a result of calculation it will appear $\psi \geq 1$, and $a_0 \leq 0$ it means, that RPC in networks of this subsystem is economically inexpedient.

Final and important stage of RPC calculation is determination of its economic and power efficiency. Actually by results of this calculation the decision about its introduction is made.

Necessity in specification of estimation method of RPC efficiency is caused by changes in requirements of standard documents and in approaches to its calculation.

Generally all possible sources of financing of RPC projects can be divided into two groups:

a)own means (profits, accumulation, depreciation charges and other kinds of actives of enterprises, involved means from internal and external sources: sale of shares; means which are allocated with holding and joint-stock companies, industrially-financial groups; from state and local budgets centralized and off-budget means);

b)borrowed means, including credits given by the state, credits of foreign investors, loans, credits of banks and other investors - investment funds and companies, insurance organizations and companies, insurance organisations and others; foreign investments in the form of financial and other participation in elaboration and realization of innovations - direct investments, and also participation in authorised capital of joint ventures.

It should be noted , that capital investments in RPC are realized within one year, that is are simultaneous unless cases when restrictions of financial resources take place.

In case of financing sources which are referred to group "a", annual economic benefit is offered to be determined by the formula:

$$E_y = З_{SC2} \cdot Q_м^2 \left(\psi_ф^2 - \frac{\psi_0^2}{K_0} \right) + З_{SC1} \cdot Q_м \left(\psi_ф - \psi_0 \right) + \Delta З - З_{SG} \cdot (1+p) \cdot Q_м (1 - \psi_0), \tag{15}$$

where $\psi_ф$ - input reactive power before compensation (at absence of RPC $\psi_ф = 1$), relative units;

$З_{S.C2} \cdot Q_м^2 \cdot \psi_ф^2$ - cost of losses to RPC or to additional RPC, thousand grn; $З_{S.C2} \cdot Q_м^2 \cdot \psi_ф^2 / K_0$ - cost of losses after RPC or after additional RPC taking into account optimization of remaining flows of reactive power, thousand hrn.; $З_{S.C1} \cdot Q_м \cdot \psi_ф$ - cost of consumption of reactive energy from network of power supply system to compensation or to additional compensation, thousands hrn.; $З_{SC1} \cdot Q_м \cdot \psi_0$ - cost of consumption of reactive energy from network of PP after compensation, thousands hrn.

Time of recoupment of capital investments:

$$T_{rec} = \frac{З_{SG} \cdot Q_м (1-\psi_0)}{E_y}. \tag{16}$$

Decrease of losses:

- active power (kW)

$$\Delta P = \frac{10^{-3} \cdot R_{e.l} \cdot Q_м^2}{U_n^2}\left(\psi_ф^2 - \frac{\psi_0^2}{K_0}\right); \tag{17}$$

- active electric power

$$\Delta W_0 = \frac{10^{-3} \cdot R_{e.l.} \cdot Q_м^2 \cdot \tau_{м.p}}{U_н^2}\left(\psi_ф^2 - \frac{\psi_0^2}{K_0}\right). \tag{18}$$

In case of financing sources which are referred to group "b", at determination of annual economic benefit, credit cost (or other loans) is considered:

$$E_p = З_{SC2} \cdot Q_м^2\left(\psi_ф^2 - \frac{\psi_0^2}{K_0}\right) + З_{SC1} \cdot Q_м(\psi_ф - \psi_0) + \Delta З - З_{SG} \cdot (1+p) \cdot Q_м (1-\psi_0), \tag{19}$$

where p - bank credit rate, in relative units.

Conclusions

1. Criterion function specification on compensation, determination of specific cost of electric power losses, method of estimation of economic and power efficiency of RPC - allows to substantiate higher level of RPC in electric networks of consumers and PP, and more precisely to estimate its efficiency.
2. Identical method of RPC calculation in networks of subsystem and separate consumer is offered, necessity for elaboration of different programs thereby disappears.

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