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METHOD OF SETTINGS DETERMINATION FOR SYSTEMS OF CENTRALIZED CONTROL OF COMPENSANTING UNITS

Mathematical model intended for determination of optimal (by the criterion of minimal losses)value of input reactive power and its solution applying system approach for cases of centralized compensation or centralized control system of group or individual compensation is considered.

Key words: *reactive power compensation, system approach, input reactive power, settings determination.*

Problem set up

Determination of the settings of automatic regulators of compensating units (CU) depends on the method of compensation and control parameter, type of the unit and the value of reactive loads. The following methods of compensation are used: centralized, individual and mixed variants.

Centralized compensation might be economically expedient on condition of power supply of powerful loads (for instance, electric furnaces) by short transmission lines. In such cases CU are installed at principle step-down substation (PSS) or central switch – gear (CSG) of the enterprise. Centralized compensation has its advantages: better usage of CU, their number is reduced as compared with other types of compensation, there is no need to install communication lines. The only, but important disadvantages – except the transformers at CSG and their power supply lines, other networks operate in the mode of increased loses of electric energy. That is why, the application of compensation requires technical economical substantiation.

Balancing CU can be referred to the centralized compensation, installed at PSS or CSG of the enterprise and is intended to meet the requirements of utility company (UC) relatively consumption of reactive power from its network (for instance, to provide input reactive power (IRP)) at the inputs of the enterprise and in the nodes of UC in order to regulate the voltage, etc.). But the problem set-up and methods of setting determination for centralized control systems using system approach are missing.

Analysis of the latest research and publications

Much attention is devoted to the methods of calculation of reactive power compensation (RPC). In [1] common drawbacks of known systems and devices of CU centralized control are studied. In particular, lack of possibility to meet the requirements of UC regarding the consumption of reactive power from its network and solution of the problem of losses minimization in electric networks of consumers and UC due to under-compensated transfers of reactive energy.

Research problem set-up

In case of compensation of reactive loads, as a result of operation of transmission lines, power transformers, reactors, etc., transfer of non-compensated reactive energy to consumers is possible. In this case, there appears the necessity to define interrelated settings of CU automatic regulators. On the base of this statement the main goal of research is formulated: reduction of losses in electric networks of consumers and UC as a result of non-compensated transfers of reactive power by means of determination of optimal values of input reactive power at the input nodes of utility company and consumers - i.e., settings for centralized compensating unit or centralized control system of group or mixed compensation.

Basic result of research

Group or mixed (group or individual) compensation of reactive loads applying centralized system of control can be used at the enterprises. In all cases of application of centralized compensation or centralized control system of group or individual compensation optimal values of IRP are determined at subsystem input for j th characteristic day mode of UC. Determination is performed on the basis of system approach [1] (taking into account the networks and the effect for UC and consumers).

Mathematical model required for determination of IRP optimal value (settings at the input of subsystem networks, that comprises the networks of energy system and consumers, connected to the node substation) will be written as

$$\begin{cases} E = \sum_{i=1}^{n} E_{g_i}(1-\Psi) + \sum_{i=1}^{n}\left(E_{UC_i} + E_{cc_i}\right)\cdot\Psi + \sum_{i=1}^{n} E_{t_i}\cdot\Psi^2 \to \min; \\ 0 \le \Psi \le 1; \\ 1 \ge \alpha \ge 0; \\ \alpha + \Psi = 1, \end{cases} \quad (1)$$

where E – are expenditures for compensation in subsystem networks (efficiency function), ths. Hrs.; n – number of load nodes in subsystem networks; E_{g_i} – are expenditures for generation of reactive power in ith node of subsystem, ths. Hrs.; E_{UC_i} – cost of reactive electric energy, consumed by UC loads in ith node, ths. Hrs.;
E_{cc_i} –is cost of reactive electric energy, consumed by the enterprises in ith node; ths. Hrs.;
E_{t_i} –are expenditures for transmission of reactive power along the networks connected to ith node; ths. Hrs.; Ψ – is IRP at the input of subsystem networks in relative units (in general case $\Psi = \frac{Q_u}{Q_m}$, where Q_u – is IRP or setting at the input of subsystem networks in absolute units, Mvar; Q_m –is maximum reactive load at the input of subsystem networks, Mvar); $\sum_{i=1}^{n} E_{g_i}$ –are expenditures for generation of reactive power by all the sources of subsystem, ths. Hrs.; $\sum_{i=1}^{n} E_{UC_i}$ –is cost of reactive electric energy, consumed of UC loads in subsystem networks, ths. Hrs.; $\sum_{i=1}^{n} E_{cc_i}$ –is cost of reactive electric energy, consumed by the enterprises in ith node, ths. Hrs.;. $\sum_{i=1}^{n} E_{t_i}$ – are expenditures for transmission of reactive energy along subsystem networks, ths. Hrs.; α –is a level or degree of RPC in subsystem networks (in general case $\alpha = \frac{Q_{CU}}{Q_m}$, where Q_{CU} – is an absolute value of CU power in subsystem networks, Mvar), in a.u. [1].

The value of E_{g_i} is defined by the formula:

$$E_{g_i} = E_{sg_i} \cdot Q_i, \quad (2)$$

where E_{sg_i} – are specific mean-weighted expenditures for generation of reactive power in ith node of subsystem, ths. Hrs. /Mvar; Q_i – is reactive load of ith node of subsystem, Mvar.

Value $E_{s.g_i}$ is defined by known formula [1]:

$$З_{sg_i} = E \cdot \sum_{j=1}^{m}\left(K_{n_{ij}} \cdot \dot{U}_{ij}^{2} \cdot \gamma_{ij}\right) + 10^{-3} \cdot \sum_{j=1}^{m} \Delta P_{n_{ij}} \cdot C_{0_{ij}} \cdot \gamma_{ij}\,, \quad (3)$$

where E – is total coefficient of deduction from capital investments [1]

$$E = E_n + E_a + E_d \ , \tag{4}$$

E_n – is normalized efficiency factor of capital investments (for energy sector $E_n = 0{,}15$) [1]; E_a – is depreciation factor of capital investments[1]; E_o – is depreciation factor of capital investments for technical maintenance [1]; $K_{n_{ij}}$ – is specific cost of CU of j[th] type, installed in (or to be installed) in j[th] node of the subsystem; $\dot{U}_{ij}$ – is voltage factor (in a.u.) in connection point of j[th] type of CU to the network ($\dot{U}_{ij} = \dfrac{U_{м_{ij}}}{U_{CU_{ij}}}$, where $U_{м_{ij}}$ – is the voltage in i[th] node in connection point of j[th] CU,kV; $U_{CU_{ij}}$ – is rated voltage of j[th] CU, installed (or to be installed) in the i[th] node, кV; γ_{ij} – is specific weight of j[th] type CU in total power of CU, installed in i[th] node, a.u.; m – is the amount of CU types in i[th] node; $\Delta P_{n_{ij}}$ – are specific losses of active power while generation of reactive power in CU of j[th] type, installed in i[th] node, kWt/Mvar [1]; $C_{0_{ij}}$ – is specific cost of losses in CU of j[th] type, installed in i[th] node, hrs/kWt.

$$C_{0_{ij}} = \tau_{м_{ij}} \cdot T_r \, , \tag{5}$$

where $\tau_{м_{ij}}$ – is the number of hours of maximum losses for CU of j[th] type, installed in the i[th] node, hours.; T_r – is retail tariff for active electric energy, Hrs./kWh. .

The value of E_{t_i} is defined by the formula:

$$E_{t_i} = \frac{\tau_{м_i} T_r R_{e_i}}{U^2_{n_i}} \, , \tag{6}$$

where $\tau_{м_i}$ – is number of maximum losses hours in subsystem networks.;Hrs R_{e_i} – is equivalent active resistance of the networks, connected to the i[th] node. Ohm ; U_{n_i} –is basic nominal or average real voltage, to which the resistances of subsystem networks are reduced, kV.

The solution of equation (1) is to be performed applying the method of single-aim optimization without limitations. From the condition

$$\frac{\partial З}{\partial \Psi} = 0 \tag{7}$$

we obtain optimal (by the criterion of minimal losses) value of IRP setting at the input of subsystem networks in a.u.:

$$\Psi_{opt} = \frac{\sum_{i=1}^{n} E_{g_i} + \sum_{i=1}^{n} \left(E_{UC_i} + E_{cc_i} \right)}{2 \sum_{i=1}^{n} E_{t_i}} \, . \tag{8}$$

The value of setting (IRP) at the input of subsystem networks in absolute units is determined from the relation:

$$Q_u = \Psi_{opt} \cdot Q_m \tag{9}$$

Total power of CU, that it is expedient to install in subsystem networks is defined form the condition of reactive power balance at its input

$$Q_{CU.d} = Q_m - Q_e. \quad (10)$$

Parameter α (level of RPC) is defined from the relation $\alpha_{opt} = \frac{Q_{CU}}{Q_m}$. In this case $\alpha_{opt} + \Psi_{opt} = 1$. Carrying out of this limitation proves the correctness of the problem solution. Realization of other technical limitation is checked stepwise.

If it turns out, that Ψ_{opt} >1 and α_{opt} <0, then we take Ψ_{opt} =1, α_{opt} =0 and $Q_e = Q_m$, $Q_{CU} = 0$. In subsystem networks complete RPC is not economically expedient.

If Ψ_{opt} <0 and α_{opt} >1, then we take Ψ_{opt} =0, α_{opt} =1 and $Q_e = 0$, $Q_{CU} = Q_m$. In subsystem networks complete RPC is economically expedient.

It should be noted, that the setting of reactive power at the system input, that coincides with IRP, is not used for automatic control of CU, but it can be used for control and evaluation of real state of reactive power minimization transfer (by means of comparison of real and preset values).

Optimal economical values of $\Psi_{opt\,i}$ and Q_{e_i} are adjusted in accordance with the condition

Of possible reduction of networks and transformers capacity (at the stage of design) or delay of reconstruction terms(while operation) [1]. Corrected (i.e. decreased) values of $\Psi_{опт\,i}$ and Q_{e_i} are further used for determination of interconnected optimal (by the criterion of optimal losses) of IRP at the inputs of UC nodes and loads – settings for centralized CU or centralized control system of group or mixed compensation.

For this purpose the simplest method of serial equalization can be applied [3]. Optimality criterion is minimum losses. The method is based on hierarchical principle of energy supply systems construction and consists in gradual convolution of the circuit and recalculation of the parameters of subsystem equivalent parts. For the preset and transformed circuits of the network, special functions, equivalent, by the losses, to active power are formed. In inverse mode, function of connection perform optimal (by the criterion of minimum losses) IRP values:

$$Q_{e_{ij}} = \frac{Q_{e_j} R_e}{r_{e_i}}, \quad (11)$$

where $Q_{e_{ij}}$ – is IRP, that distributes in ith node of the subsystem in jth characteristic mode of energy consumption of UC (peak, interpeak, minimal loads), Mvar; Q_{e_j} –is IRP in jth mode at the input of the subsystem, Mvar; R_e – is equivalent resistance of the subsystem, Ohm; r_{e_i} –is equivalent resistance of connection, along which ith node of the subsystem is supplied, Oh.

While optimization of Q_{e_i} value distribution, the first node of distribution is balancing node. Further distribution is performed, applying the same formula (11). But value $Q_{e_{ij}}$ will be distributed. As R_e, the equivalent active resistance of the networks, connected to j th distribution node is taken, and as r_{e_i} the equivalent active resistance of one of these connections is taken. Distribution is completed if CU reaches these points.

Conclusions

1. Determination of optimal settings for loading nodes of UC is predetermined by the necessity to control CU, applied for compensation of reactive loads of own needs (transmission lines, power transformers, reactors) and transmission of undercompensated reactive energy by the consumers.

2. Usage of electric energy system and consumers networks parameters allows to define by the formula (11) interconnected values of settings and optimize the transfer of reactive power (by the criterion of minimum losses) in UC and consumers networks.

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