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OPTIMIZATION ALGORITHMS FOR IMPROVING THE OPERATION CONTROL IN POWER SYSTEM WITH DISTRIBUTED GENERATION

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Abstract- Existing distributed generation (DG) do not take part in the power systems operation control. At the same time numerous researches conducted show that electric networks with DG possess sufficient opportunities for power system's mode control as a whole. In particular DG can take part in active and reactive power flows control, in network voltage regulation, in system's optimal demand covering in and in other tasks connected with its functioning stability and reliability. The structure of artificial intelligence system and algorithm of its operation for voltage and reactive power control in distribution network with onsite power sources containing fuzzy logic controller is presented. The control parameters are transformers turn ratio and reactive power in distribution network. The placement of reactive power sources and their values are determined using traditional methods of optimization for selected networks. In this paper the problem of optimal correction of K_t and Q_i at the time of their deviation from the preset values to minimize losses in studied network and to maintain voltage in the nodes on the necessary level is considered. The total structure of fuzzy control for K_t and Q_i at the network, where to control Q_i in every node with reactive power source the fuzzy logic controller (FLC) is used. Algorithm of membership function formation for input variables of FLC to control / correct capacitors value is shown. Modeling results for real electrical circuit, Q correction in nodes and K_t of transformer impact on losses and voltage profile in studied network are presented.

Keywords: Voltage and Reactive Power Optimal Control, Fuzzy Logic, Power Losses, Optimal Placement of Static Capacitors, Fuzzy Logic Controller.

I. INTRODUCTION

Support of appropriate voltage level in distribution network is one of the important problems determining a power system condition. Electricity consumption changes during the day, and is determined by voltage and power flows in the network which values also change during the day in direction of increasing or reduction depending on loading.

For demanded voltage level support in a power system the voltage values control devices and also the batteries of condensers are used. In spite of the fact that these devices work properly, it is known that their operational characteristics could be improved if control was carried out according to change of trajectories of loading and voltage in real time.

In distribution electric networks for the mode profitability conditions and power quality maintenance adjustable batteries of static condensers and under loading transformers tape changers are used. In networks with the distributed generation as the voltage and reactive power regulating devices, also an automatic field controllers of local power sources (synchronous generators of diesel or gas-turbine units) are used. The choice of sizes and placement of batteries of static condensers planned for installation is the optimizing task which essence consists in active power total losses minimization.

Now methods of nonlinear optimization [1-5], and also heuristic methods are applied for this task solution [6]. By means of methods [1-6] for planning structures and predicted modes the optimum sizes of static condensers batteries capacity assumed to installation in network's nodes are defined. In real operation conditions the loadings consumption in a network continuously changes that leads to a deviation of the current production schedule from planned for specified period (days, weeks, etc.).

The actual values of reactive power in network's nodes differ from optimum chosen values which must be covered by a condensers batteries capacity installed. According to the current changes of a network's mode the nodes voltages levels and losses are also change. Such current values of voltages and losses will differ from their corresponding values in optimum modes.

A difference arisen between the current value of reactive power in node and optimum chosen condensers batteries capacity is possible to compensate quickly by change of minimum set share of capacity correction in node in direction of network's losses reduction. The module of condensers for power factor correction usually consists of several separate elements or groups of the elements, everyone with own connector or switch. The demand for a reactive power and power factor covering are continuously estimated and condenser modules are necessarily connected and disconnected for achievement of an optimum level of these indicators.

Modern achievements in the field of measurement, processing and information transfer, and also the latest control technologies made possible to monitor voltage levels in all distribution system, what allows to transfer this information to devices which can carry out the voltage U and condensers battery capacity Q regulation. By using the measurements received closer to real time, it is possible to accelerate the U and Q regulation processes.

The algorithm of fuzzy logic realized in block of a current mode condition assessment in the network with the distributed generation (DG) is developed for definition of optimum number of modules in each node. In the same block the need of planned parameters correction - the values of the condensers capacities installed in controlled nodes and transformer's coefficient of transformation is checked. The solution of a task on determination the need of capacity value correction of the switched-on condenser and choice of the coefficient of transformation is carried out by means of the made algorithm of fuzzy system in which as inputs the nodal voltages and power losses characterizing indicators are set. Thus need of the condenser correction for this or that node will be defined by a condenser's capacity variability indicator of importance. Need of correction of condenser's capacity for this or that node is defined by the big size of this indicator. For practical correction of the condensers capacity in nodes of their installation the fuzzy logic regulator is used.

II. REACTIVE POWER AND VOLTAGE CONTROL SYSTEM STRUCTURE IN DISTRIBUTED GENERATION NETWORKS

In modern practice of dispatching control expeditious modes correction in electric networks of a power system occupies importance at managing decisions making, at a deviation of network's modes on Q and U from their values received on the base of optimum modes calculation.

Thus for correcting actions choice for reactive power and voltages (RPV) control the criterion of a minimum of losses is used meeting the Standard conditions for node voltages deviations [2, 3, 7-9]. The RPV control in distribution networks in general implemented by means of the batteries of static condensers (BSC), and also the generating sources placed in a network for a local loading covering, and under loading controlled transformers. The choice of number of adjustable static condensers batteries and generating sources, their placement in an electric network are an optimizing task.

By the solution of this task for the electric network normal scheme the optimal number of control devices is determines. At operative control as far as network's mode and scheme changes the current optimum values of nodes voltages $U_{i,\max}$ and total losses $\Delta P_{i,\min}$ in a network are defined. According to the calculated new values of $U_{i,\max}$, $\Delta P_{i,\min}$ the single condensers number $K_{cond,i}$ for their installation nodes and transformers control devices status positions $K_{t,i}$ the settings are adjusted. Such optimizing calculations can be carried out within a program complex of an electrical power system condition assessment.

Algorithms used by these programs are known [10-17] and generally consist in periodical optimizing calculations carrying out for the scheme current state and a system mode data. On the base of comparison of current optimizing calculations results – values of nodes voltages and total losses in a network with their optimum values established for basic normal modes, the need of condenser batteries capacities (C_{ki}), remotely adjustable transformation coefficients and the generators placed in system with DG voltages correction is defined.

Depending on the size of a current optimum voltage values deviation in controlled nodes and losses values in a network from their corresponding values in a nominal base mode the of degree control actions are defined for condenser batteries modules installed in controlled nodes switching and status positions of the transformers control devices. Following the above-stated distributed network reactive power control mode it is possible to present the general control scheme in form of the following block structure of the static condensers batteries, position of transformers switching and synchronous generators voltages co-ordinate control, is presented on Figure 1.

The general management concept for the purpose of optimum mode support in an electric network with DG consists in a choice of static condensers capacity from among the set condensers in nodes, and also in transformer voltage ratio definition installed in connection point of DG network with a power system and its switching to position providing a minimum of power losses in a network. Necessity of correcting actions on condensers and the transformer arises at deviations of network current mode losses from their (planned) values calculated for network optimum modes. In considered statement correcting control influence on change of condensers batteries modules in network knots and transformers voltage ratio accepted in form of linear dependence on a deviation of current conditions (changes of active and reactive power of knots loadings) [18]:

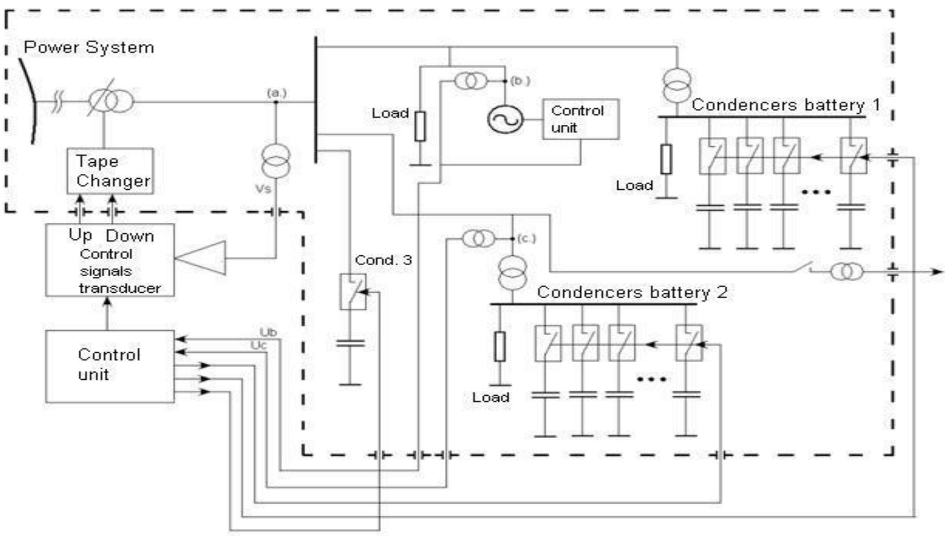

Figure 1. The Block diagram of voltage and reactive power control in electric network with DG

$$\Delta Y = f(k, \Delta d) \tag{1}$$

where,

$\Delta Y = \overline{Y} - Y$;

$\Delta d = \overline{d} - d$;

$\overline{Y}, \overline{d}$: planned values of adjustable and initial data;

$$\overline{Y} = \begin{bmatrix} C_{k1} \\ C_{k2} \\ \vdots \\ C_{kn} \\ K_{t1} \\ K_{t2} \\ \vdots \\ K_{tm} \end{bmatrix}; \; \overline{d} = \begin{bmatrix} P_1 + jQ_1 \\ P_2 + jQ_2 \\ \vdots \\ P_n + jQ_n \end{bmatrix};$$

ΔY : operating influences on change of condenser capacity rate on $\Delta C_{k,i}$ and change of adjustable transformer's voltage ratio $\Delta K_{t,i}$;

Δd : initial data changes of knot loadings $\Delta P_i + j\Delta Q_i$.

Condensers and transformers control equation adjusting parameters are defined from optimization conditions:

$$\min_{k,\ \Delta P_i,\ \Delta Q_i} M \ \Delta P(\overline{Y} + f(k, \Delta d), x, d) \tag{2}$$

where, x, d, k are dependent parameters, and $x = \begin{bmatrix} U_1 & U_2 & \cdots & U_n \end{bmatrix}^T$ is the nodes voltages vector.

III. CORRECTION OF DG NETWORK MODE PARAMETERS BY A FUZZY LOGIC METHOD

The probabilistic and indistinct-defined character of scheme and network mode parameters variability (knots power and voltage) and also the electric systems modes (ESM) models nonlinearity, its parametrical uncertainty and unpredictability complicates application of the known determined methods for active and reactive power flows control in RG network.

For the problem solution in choice of correcting control in [12, 14, 16, 17] the algorithms – as solving rules generated on the base of linear dependences in form of (1) are used. Besides, for correcting values for $C_{k,i}$ and $K_{t,j}$ an estimation of the determined active power losses equivalent is defined. But even in this case the problem becomes complicated when operating vector "$\overline{Y}$" dimension increases.

In frame of indistinct system the correcting actions choice on sizes of knots capacities and transformers voltage ratio is formalized on base of linguistic rules defined by membership functions. The purpose of reactive power flow mode correction adds up to the "max-min" problem solution [9, 10].

For a problem of correcting action definition on change of installed in knots condensers rate a resultant membership function of an admissibility of condenser rate $\mu_{S_C}(i)$ correction in i mode and at k accepted rules:

$$\mu_{S_C}(i) = \max\ k\ [\min[\mu_P(i),\ \ \mu_U(i)]] \tag{3}$$

where, $\mu_P(i)$, $\mu_U(i)$ membership functions of power losses and voltage indicators.

From the determined optimizing problem solution with taking into account the forecast of initial data:

$$\overline{d} = \left| \overline{\pi}, \overline{P}_{H,i}, \overline{Q}_{H,i} \right|$$

The planned targets for capacities rates in knots and values ratio of adjustable transformers are defined as:

$$\overline{Y} = \left| C_{k,1}, C_{k,2}, \cdots, C_{k,n}, K_{t,1}, K_{t,2}, \cdots, K_{t,m} \right|$$

where, $\overline{\pi}$ - active power losses; $\overline{P}_{H,i}$, $\overline{Q}_{H,i}$ - predictably values of active both reactive power in the ith loading node.

In frame of the fuzzy-defined statement the problem solution of an estimation of a share of correcting action on condenser batteries rate change in nodes and position of the transformers regulating devices, can be realized in the form of following stages:

1. To define total active power losses for DG system base structure (are carried out on the base of flow distribution calculation programs). The program complex ETAP which provides steady stage calculations, and also calculations of Q sources optimum placement in a network is used in this research.
2. By change of a reactive power compensation share in each knot to carry out the flow distribution calculations and define total active power losses in each case $\Delta C_{k,i.}$.
3. To calculate losses decreasing indicators as:

$$\varPi_{\Delta P}(i)=\frac{\left(\Delta P(i)-\Delta P_{\min}\right)}{\left(\Delta P_{\max}-\Delta P_{\min}\right)} \quad (4)$$

where, i=2, 3, …, n - number of knots in which batteries of condensers are placed. By indicator value (4) the capacity correction suitability for node i is defined. If this indicator is highest for any ith node the capacity correction in this node is most comprehensible.
4. The membership functions for power losses indicators $\mu(L_{\Delta P})$ and voltages in each node $\mu_U(i)$ are accepted as model (3) inputs.
5. Fuzzy model's (3) target parameter - a resultant membership function $\mu_{S_C}(i)$ defines an acceptability of capacity correction in the given node.

$$\tilde{Y}=\tilde{U}\circ\tilde{\varPi}_{\Delta P}\circ R\left(U,L_{\Delta P},Y\right) \quad (5)$$

where, «∘» - the "max-min" composition's symbol; R - the fuzzy relation.
6. De-fazzification of a fuzzy control output signal for $C_{k,i}$ condensers batteries capacity and transformers voltage ratio $K_{t,i}$ correction:

$$Y=F^{-1}\left[\tilde{Y}\right] \quad (6)$$

where, F is the fazzyfication symbol.

According to the offered algorithm for network node definition in which it would be preferable the battery of static condensers capacity correction, in the fuzzy logic regulator the nodes voltages and losses index (IL) $\varPi_{\Delta P}(i)$ calculated on (4) are accepted as input parameters. The higher limiting value for $\varPi_{\Delta P}(i)$ for i node is considered as the priority node in which it is necessary to carry out the correction established in node where the condensers battery was connected.

Fuzzy variable of nodes voltages, losses indexes $\varPi_{\Delta P}(i)$, and also an indicator of network node preference in which the condensers battery will be corrected, are described in terms of fuzzy definitions: Critical Low (CL), Low (L), Low-Medium (LM), Medium (M), High-Medium (HM) and High (H).

Power losses indicator in linguistic variables terms in form of fuzzy defined subset A_{1i} can be presented as:

$A_{11}=CL$ (Critical Low) $\underline{\underline{\Delta}}\left(p,\mu_{11}(p)\right)$

$A_{12}=L$ (Low) $\underline{\underline{\Delta}}\left(p,\mu_{12}(p)\right)$

$A_{13}=LM$ (Low-Medium) $\underline{\underline{\Delta}}\left(p,\mu_{13}(p)\right)$

$A_{14}=M$ (Medium) $\underline{\underline{\Delta}}\left(p,\mu_{14}(p)\right)$

$A_{15}=HM$ (High-Medium) $\underline{\underline{\Delta}}\left(p,\mu_{15}(p)\right)$

$A_{16}=H$ (High) $\underline{\underline{\Delta}}\left(p,\mu_{16}(p)\right)$

The fuzzy-defined subset determinate on the universe A_1 in general view can be presented as:

$$\underline{\underline{\Delta}}\left(p,\mu(p)\right)=\sum_{p\in A_1}\mu_{1i}(p_i))/p_i\ ,\ \forall p_i\in A_1 .$$

The nodes voltages in linguistic variables terms in form of fuzzy defined subset A_{2j} can be presented as:

$A_{21}=CL$ (Critical Low) $\underline{\underline{\Delta}}\left(V,\mu_{21}(V)\right)$

$A_{22}=L$ (Low) $\underline{\underline{\Delta}}\left(V,\mu_{22}(V)\right)$

$A_{23}=LM$ (Low-Medium) $\underline{\underline{\Delta}}\left(V,\mu_{23}(V)\right)$

$A_{24}=M$ (Medium) $\underline{\underline{\Delta}}\left(V,\mu_{24}(V)\right)$

$A_{25}=HM$ (High-Medium) $\underline{\underline{\Delta}}\left(V,\mu_{25}(V)\right)$

$A_{26}=H$ (High) $\underline{\underline{\Delta}}\left(V,\mu_{26}(V)\right)$

The fuzzy-defined subset determinate on the universe A_2 in general view can be presented as:

$$\underline{\underline{\Delta}}\left(V,\mu_{2j}(V)\right)=\sum_{V\in A_2}\mu_{2j}(V_j)/V_j\ ,\ \forall V_j\in A_2 .$$

In Tables 1 and 2 the membership functions for the above-stated fuzzy linguistic variables are presented.

Table 1. The membership functions for losses and voltage indicators

Descripti of variables	CL	L	LM	M	HM	H
Indicators of capacity losses	<0.15	0-0.25	0.12-0.5	0.32-0.75	0.5-1.0	>0.75
Voltages	<0.92	0.9-0.94	0.91-0.96	0.95-1.0	0.98-1.05	1.02 - 1.1

Table 2. The membership functions of an indicator of correction preference (ICP) for condensers battery capacity in network nodes

Variable	CL	L	LM	M	HM	H
$ICP(i)$	<0.15	0-0.25	0.12-0.5	0.32-0.75	0.5-1.0	≥0.75

For the network node definition with the revealed preference of connected condensers battery's capacity correction it is necessary to calculate the losses and voltage indicators for each node, and then to present each of them as they own membership functions. Using the values of node's voltages and losses indicators $L_{\Delta P}(i)$ the rules in form of the fuzzy logic conclusions set matrix are formulated and generalized in Table 3.

Table 3. Matrix of solutions for node definition in which the condensers battery capacity correction is preferable

Parameters	Voltage in nodes					
	CL	L	LM	M	HM	M	CL
$L_{\Delta P}(i)$	CL	L	L	L	L	L	L
	L	L	L	L	L	LM	LM
	LM	L	L	L	LM	LM	M
	M	L	L	L	LM	M	HM
	HM	L	L	LM	M	HM	H
	H	L	LM	LM	M	HM	H

IV. PRACTICAL RESULTS

The application of fuzzy regulator algorithm is reviewed on an example of one of regional "Azerenerji", Baku, Azerbaijan 0.4-35 kV electric network. Investigated network contains 28 nodes. With use of ETAP program complex [18] for the given network depending on nodes loading the optimum points (network nodes) for condensers batteries placing and their capacity rates are defined.

The nodes voltages, power factors, quantity and capacity of placed batteries, and also the total expenses necessary for condensers installation and operation are defined for three various loading modes. Calculations results are presented in Table 4.

Table 4. Calculation results of condensers batteries optimum distribution at 40% loading

No. Node	U_{calc} in %	PF	Information about condensers and batteries			Tot. cost, ×10³ ($)
			KVAR/SDB	No. of sections	Tot. cap. KVAR	
1	98.3	0.86	-	-	-	-
2	98.9	1.0	300	2	600	13.6
3	91.3	0.99	300	3	900	19.9
4	98.2	0.64	300	2	600	13.6
5	91.8	0.99	300	3	900	19.9
6	98.4	0.78	300	3	900	19.9
7	100	1.0	300	2	600	13.6
8	99.7	1.0	300	3	900	19.9
9	90.4	0.99	300	5	1500	32.5
10	100	0.94	300	4	1200	26.2
11	98.8	1.0	300	1	300	10.6
12	96.6	0.94	300	4	1200	26.2
13	92.8	0.97	300	6	1800	38.8
14	92.3	0.98	300	3	900	19.9
15	94.0	0.97	300	1	300	7.3
16	92.9	0.93	300	1	300	7.3
total	-	-	-	43	12900	289.2

Thus total capacities of sections of the condenser accordingly make 12.9 MVar, 6.9 MVar and 5.4 MVar, and total expenses 289.2; 221.1 and 123.4 thousand US dollars, i.e. at loading reduction the optimum capacity of sections running concerning to initial mode has decreased for 46.5%, and for the third mode on 58.1 %. According to it the total expenses for condenser batteries have decreased in the second mode for 23.5% and 57.3% in the third mode accordingly.

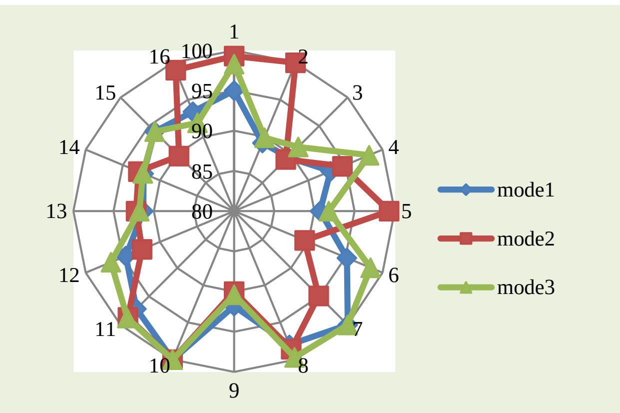

Figure 2. Voltage profiles in 10 kV nodes

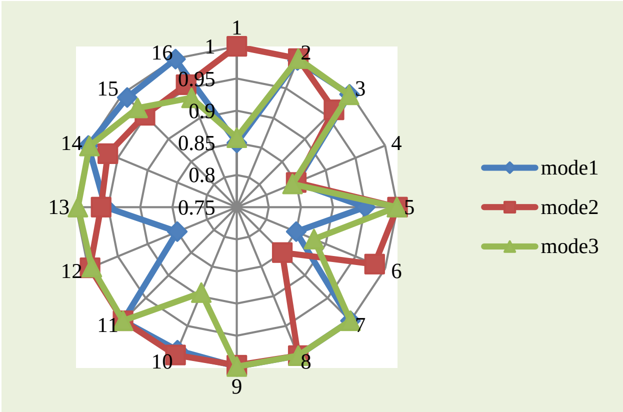

Figure 3. Power factor profiles in 10 kV nodes

In Figure 2, the profiles of voltage levels for bus 10 kV consumers of network district are shown at various modes. Apparently, in some nodes (nodes No. 4, 9, 2, 6, 3, 15) the bus 10 kV voltage has decreased on 11%. Average. It has been defined, that voltage reduction on consumer buses up to permissible level is connected not with condenser batteries placing, but with discrepancy of distributive network lines length.

In Figure 3, the power factor profiles on loading nodes are shown at various modes. Apparently management of a stream of reactive power with application of Smart Grid by technology (FLC) value of power factor in some knots (nodes No. 2, 7, 8, 11) reaches even to 1.

The above calculations results analysis shows that depending on electric network modes for increasing of electric power distribution efficiency, the periodical correction, i.e. optimum condensers batteries capacity control in nodes is necessary.

V. CONCLUSIONS

1. For optimum electric network mode correction the model of reactive power and voltages fuzzy control is developed allowing improving the nodes voltage values and reducing power losses.
2. An algorithm realizing the fuzzy logic regulator principle is developed for condensers batteries capacity operative correction in nodes by criterion of a network's mode optimality.
3. On the base of researches provided on an example of 28-nodes real network scheme, are established that the operative condensers batteries capacity correction on the by means of the fuzzy logic regulator allows to keep optimum conditions for DG mode at current loading deviations on network buses.

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Huseyngulu B. Guliyev received his M.Sc. and Ph.D. degrees and is a Lead Scientific Researcher, Manager of the Scientific Branch "Monitoring and Control of the Reactive Power" in Azerbaijan Research Institute of Energetics and Energy Design (Baku, Azerbaijan). Currently, he is an Associate Professor of Automation and Control Department in Azerbaijan Technical University (Baku, Azerbaijan). He has more than 110 published articles and 2 patents. His research interests are power systems operation and control, distributed generation systems, application of artificial intelligence to power systems control design and power quality.