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POWER QUALITY AND REACTIVE POWER SOURCES MANAGEMENT FROM ENERGY DISTRIBUTION DISPATCH POINT OF VIEW AT DISTRIBUTION OPERATOR LEVEL

BY

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Abstract. The massive shifting of electricity consumption from high voltage (HV) to medium voltage (MV) and low voltage (LV), have required a special attention to the complex processes of reconstruction, refurbishment, design and rational operation from technical and economical point of view of electricity repartition and distribution systems (ERDS). The voltage levels in different ERDS nodes require, first, the reactive power flow control, both in transmission and distribution systems. For optimal placement of capacitor banks at the MV substation bars from ERDS, the paper proposes a multi-criteria optimization process in several distinct stages, using specialized software. The obtained results of the optimization process lead to a series of advantages, such as: the voltage quality improvement in all nodes of the ERDS; the active power losses reduction that occur in all elements (lines, transformers); avoiding the additional transit of reactive power through the elements of the systems, etc.

Key words: distribution operator; reactive sources; optimization process.

1. Introduction

The profound changes which have occurred in power sector in recent decades, both globally and in our country, accompanied by the energy markets appearance becoming more efficiently, and the massive shifting of electricity

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consumption from high voltage (HV) to medium voltage (MV) and low voltage (LV) in addition, have required a special attention to the complex processes of reconstruction, refurbishment, design and rational exploitation from technical and economical point of view of electricity repartition and distribution systems (EDRS).

In terms of policy of power quality supplied to customers and related management methods, they are priorities for any *Subsidiary Distribution and Supply of Electricity* (*SDSE*). Above-mentioned priorities should be harmonized simultaneously with the company general development strategy, with integrated quality management *system – environment – health* and *occupational safety*.

It should be noted that with the weight electricity consumption shift to MV and LV, and as a result of diversification and increasing the number of nonlinear and/or unbalanced consumers supplied with electric energy, the quality parameters maintaining of supplied electric energy to customers has become a real issue. For this reason, in accordance with our country current organization, this paper presents the contribution of *Distribution Dispatch Centre* (*DDC*) in order to maintain the power quality in its dual hypostasis of *seller* and *services*. Also are analysed the reactive power sources structure and management in ERDS, and the MV capacitor banks need in some 110 kV/MV stations, in order to maintain the voltage on all ERDS levels in admissible band.

2. Distribution Dispatch Center Competence Domains on Power Quality

The main *system* quality primary indicators, in ac, that characterize the electric energy, are: voltage frequency, voltage amplitude, temporary or transient overvoltage and voltage dips.

Regarding the Distribution Dispatch Centre (DDC), one of its main tasks, for which can be made directly responsible, is to maintain the supply voltage amplitude on all ERDS levels in admissible band. It can also contribute to limiting both voltage dips and intern overvoltages, from number and duration point of view.

In the *Performance Standard for Electricity Distribution Services* are regulated the parameters which characterize the service, taking into account the following aspects: connecting users to the *Electricity Distribution Networks* (*EDN*), ensuring the continuity of supply and quality of electric energy supplied; planning programmed interruptions, to perform maintenance works and/or network reconfiguration; solving customer complaints and intimations regarding power quality; ensuring a transparent relationship between the *Distribution Operator* (*DO*) and *EDN users*. It should be noted that to maintain power quality at all ERDS levels, *Energy Distribution Dispatcher* (*EDD*) always contribute by direct or indirect actions.

According to the *Management Regulation through Dispatcher of the National Power System*, *Dispatcher Center* (*DC*) must be organized in at least two structures, namely: *Operational Control Department* and *Planning and*

Operational Programming Department. Both departments must always contribute by direct or indirect action, to ensure the maintening of ERDS power quality parameters and the technical losses reduction that appear in operation of these installations.

The *Operational Control Department* provides the whole management for ERDS associated to SDSE to obtain operational safety and optimization, from technical and economical point of view, throughout the distribution subsidiary. In order to ensure quantitative and qualitative parameters of electric energy which flows through ERDS, EDD, by real-time operational management, carried out the following functions:

a) The supervision and the continuity in operation of distribution facilities in the responsibility area by: the monitoring of the installations scheme in operation; the verification if the state sizes are in admissible limits; the computation of power and energy absorbed by consumers, acquired from the transmission network of the *National Power System* (*NPS*) and exchanged with neighbouring distribution networks, and also produced in power plants; the computation of total power on *Automatic Load Disconnected at frequency – ALDf*.

b) Consumption curve adjustment to prevent the incidents expansion.

c) Direct command of installations and automation associated.

d) Power balance monitoring on the outline zone in the responsibility area.

e) Optimization in operation of the repartition and distribution installations by: establishing the number and loading of power transformers from 110 kV/MV stations; determining, by computation of the technical losses that appear in operating power lines, in the transformers from stations and substation and on the total area; establishing of power balance on the entire responsibility area.

f) Voltage control of 110 kV repartition and MV distribution networks and the reactive power compensation level.

g) Follow neutral treatment state in electric energy distribution networks.

h) Start and stop command micro hydro-power groups in the area of responsibility. State supervision of DMS / SCADA system installations

In order to achieve the above functions, DED must be performed in real time, a series of activities such as: supervision, optimization, monitoring, record, perform, implementation and application.

Planning and Operational Programming Department includes planning and operational programming of ERDS from SDSE management, affecting the subsidiary policy regarding electric energy acquisition and transit, ensures links with other participants to electricity market, follows and analyses their operation in terms of operational safety and efficiency from economical point of view. This department achieves its specific activities *outside real time*, ensuring relations with the *System Operator* (*SO*) in order to establish normal operating schemes and 110 kV repartition network state, and also, with *Angro Electricity Market Operator* (*OP*).

3. Reactive Power Management in Electric Energy Repartition and Distribution Networks from Responsibility Area of Subsidiary Distribution and Supply of Electric Energy

It is well known that to maintain the voltage levels within acceptable limits in all ERDS nodes and its voltage levels requires, first, the reactive power flow control, both in transmission and distribution systems. However, a structure and inadequate management of reactive power sources existing in ERDS can lead to irrational reactive power flow, to major difficulties in ensurance voltage level in all these systems nodes, to overload various elements (lines and transformers), to additional technical losses in operation.

Also, reactive power sources assuring, coupled with adjustment of reactive power supplied from the system, constitutes a basic requirement to obtain the operation safety and power system stability of each subsidiary responsibility area. In the same time, may occur particular problems in RED current operation if in empty load hours (landings) and days during a year, the existing reactive power sources remain connected, leading, in this way, a reactive power excess, which will be upstream injected and NPS, respectively (Georgescu *et al.*, 2009; Chindriş *et al.*, 2005).

Regarding the optimal compensation of reactive loads in ERDS from our country, this process began since 1975 and continued in coming years using as reactive power sources shunt capacitor banks, usually installed, in 110 kV/MV step-down stations, connected on their MV bars. At the end of 1990, capacitor banks were installed into 330 stations of *110 kV/MV*, with a total power of approximately 1,500 MVAr. However, it should be pointed that a significant share of these capacitor banks contains *polychlorinated biphenyls compounds* (*PBCs*).

Currently, according to Government Decision no. *173* of March 2000, published in Official Journal no. *131* of March 28, 2000, the capacitor banks located on MV bars of 110 kV/MV stations, which contained biphenyl compounds (PBCs), had to be disconnected from these facilities. This decision was taken to avoid negative effects on human health, of property and on environment produced by PBCs and similar compounds.The previsions of afore-mentioned resolution is applicable to all equipment containing those compounds at concentrations less than 50 parts per million (ppm) on over 5 dm^3 volume. Regarding the batteries equipped with power capacitors, as reactive power sources, the volume of designed compounds shall be calculated as a total volume of all the elements which constitute these capacitor banks.

Removing these reactive power sources of ERDS and, also, the share of electricity consumption shift to MV and LV, and as a result of diversification and increasing number of consumers supplied with electric energy from EDN, imposed a consistent analysis on the need of shunt capacitor banks installed on

MV bars from 110 kV/MV stations, and the newer generations equipment introduction which respects environmental conditions existing in our country and EU recommendations.

The detailed analysis performed in this paper has proposed the following main objectives: to establish permanent influence on the ERDS operating states, at peak and empty load, for different standard days and months over at least one year cycle, in presence of fixed or adjustable capacitor banks; optimal placement determination of shunt capacitor banks (CB) on the MV bars of 110 kV/MT stations, and their optimal power in different operating steady-state during a year.

To achieve this study, we opted for a multi-criteria optimization process, in several distinct steps, using a specialized computer program, designed for such analysis. The analysis and computing process corresponding day and time (landing) in which was achieved peak and empty load, was carried out separately, in the following steps:

a) Calculus of the 110 kV non-compensated repartition system steady state operating, under normal exploitation scheme (complex loop configuration). For the ERS non-compensated state, all CB are considered to be disconnected from the analysed network.

b) Determining the optimal sectioning points/sections of the 110 kV network and its division on sectors or areas, so that all consumers were supplied with electric energy and the resulted systems, corresponding to each sector/area, had a radial or tree configuration.

c) Establishing the CB optimal nodes (MV station bars) placement and their capacity (power) for each sector that contains a radial or tree 110 kV network.

d) Calculus of the compensated 110 kV network operating steady state, under normal operation conditions (in complex loop configuration). For compensated state, in 110 kV ERS is considered that the CB is set on the MV bars of the 110 kV/MV stations, according to the results from the previous stage.

The *goal function* of the used mathematical model consists in ensuring the power quality with special reference to the all voltage levels of the ERDS nodes, by minimizing the voltage irregularity and reducing the technical power and energy losses that occur in the analysed system elements. The mathematical model is also completed with a series of *technical restrictions* that aim the following aspects: supplying all consumers under safety conditions; maintaining the voltages level of all network nodes in the accepted operating limits; for any operating steady state, the reactive power injected by the CB must not circulate in the opposite direction, towards the supply source (National Power Systems).

4. Case Example

In order to exemplify such an analysis regarding the optimal management of the reactive power sources from a repartition network, according to methodology and algorithm above presented, was take into account a 110 kV repartition system, from the OD responsibility area in Moldova region, whose single line diagram is presented in Fig. 1.

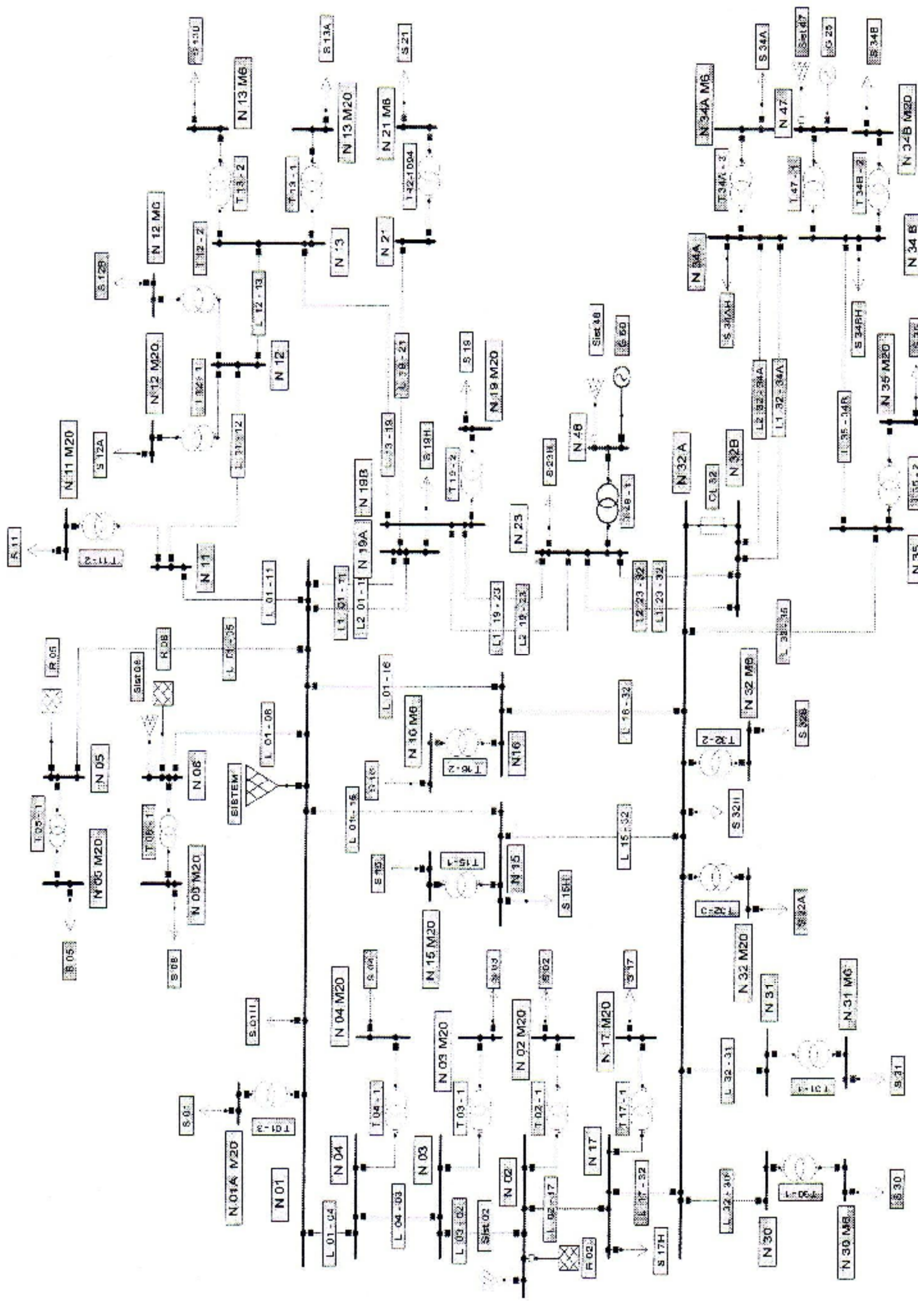

Fig. 1 – Single-phase diagram of a 110 kV repartition network.

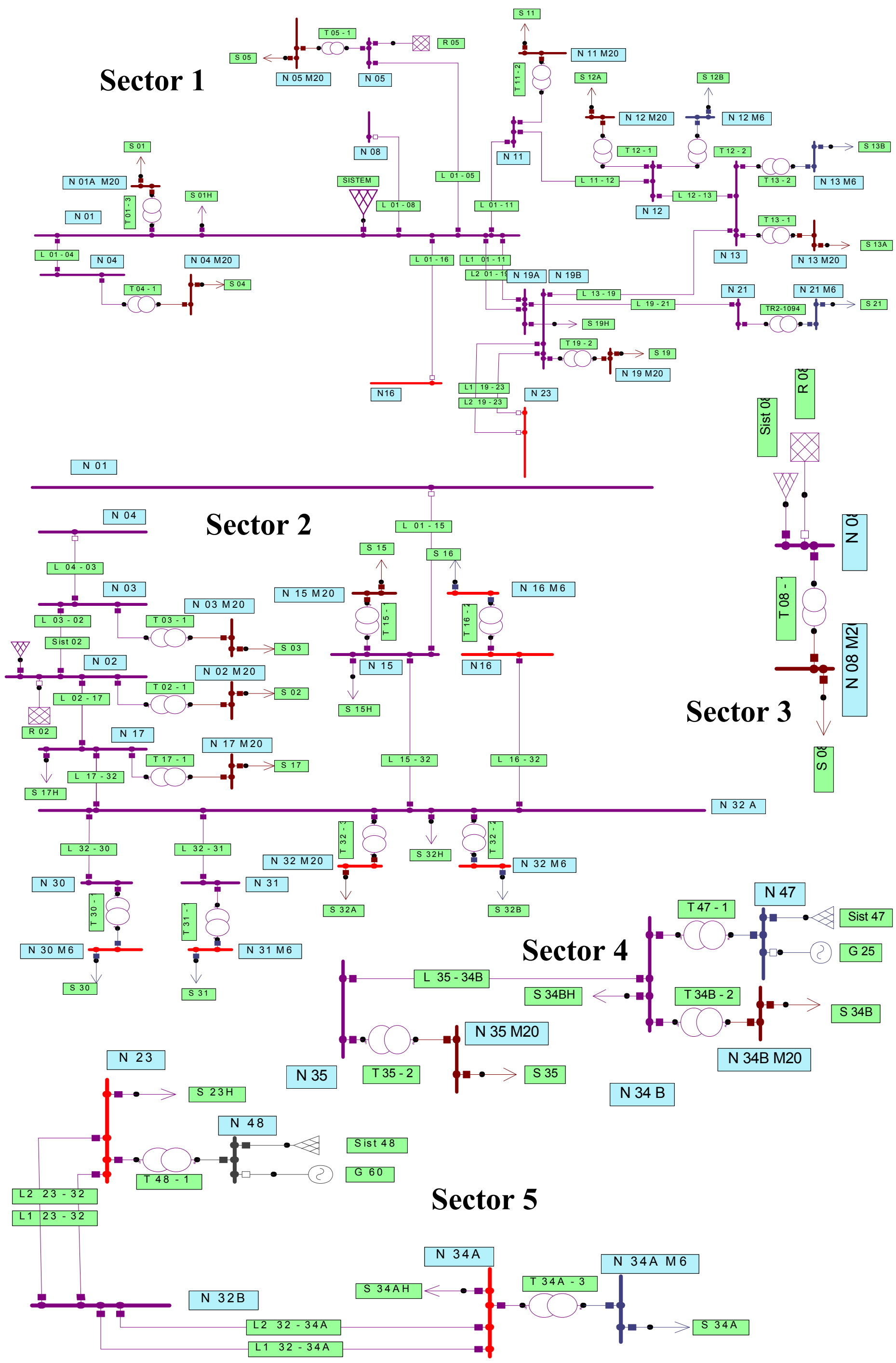

Fig. 2 – The five radial sectors (110 kV).

The normal network operation diagram was established following the analysis of a great number of permanent operating steady-states, as close to the real operating steady-state, using in the system nodes the average/maximum loads absorbed during the last three years, and also a series of forecasted loads for a period of 3…5 years. At the same time, a series of significant quotas as compared to the real operation diagram and to the possible unavailabilities, are studied in order to optimize the active and reactive power flows. The obtained results allow a rational strategy establishing, both for the current situation and for the perspective one. Under these conditions it results that the studied ERDS operate optimally, in the steady-state, following a normal operation diagram in complex loop configuration (Fig 1).

In order to optimize the reactive power sources (MV capacitor banks) placement in ERN, it is necessary to know the active and reactive daily load curves in all consuming nodes of the system so as to establish the load peak during the cold season (winter). These load curves are recorded with the help of the SCADA system, during the entire cold season of 2011. The analysis of the respective curves, processed under 24 hourly levels, emphasizes the fact that the peak load during the cold season is on the Wednesday standard day on January, at 10 o'clock (maximum load), and the minimum load, respectively the low load, is registered on the level corresponding to 2 o'clock.

For the placement optimization of the fixed or adjustable capacitor banks on the MV bars of the 110 kV/MV stations from the studied repartition system, the analysis and the computation process is performed separately for the load peak and low load, according to the methodology, in the previously presented sections. Further on, are presented synthetically some of the significant results obtained through computation for each analysed operation steady-state – peak load and low load – in each methodology stage.

a) *The peak load state analysis, $10^{\circ\circ}$ o'clock, Wednesday from January 2011*

S t a g e 1: By using NEPLAN application, the operating steady state of the repartition system (complex loop configuration – Fig. 1) in non-compensated state, for the active and reactive loads corresponding to peak load, was computed. This steady state is considered to be *non-compensated* because all compensation sources (CB) were deemed to be disconnected (removed) from all nodes of the repartition system. After this computation have resulted a series of parameters that characterize this state, out of which some of them are tabular presented, more specifically: active and reactive power injections in slack bus and the active/reactive power losses that occur in repartition system (Table 1); the voltages level from the repartition system nodes, in absolute and percentage values (Table 2).

S t a g e 2: By using *OSP (Optimal Sectioning Points)* function, was established the optimal sectioning points/sections of the analysed repartition system that, in steady-state, operate in complex loop configuration. For this purpose, the goal function was to power and energy losses minimization, that occur in analysed repartition network, and the voltages level improvement of all network nodes by minimizing the voltage irregularity. Moreover, the goal function is also completed with a *technical restriction*, which requires that each consumer node from network remain supplied from a power source. After the execution of this function and studying of some significant contingencies, the repartition system is divided into five sectors/zones in radial or tree configuration. The single line diagram of each sectors are presented in Fig. 2. At the same time, for each sector the Table 3 indicates the active/reactive power injections in the supply nodes of the networks with radial configuration, as well as the active/reactive power losses, in peak load state.

Table 1

Active and Reactive Power Injections in the Slack Bus and Power Losses in Non-Compensated State, at Peak Load

Power injections in the N1		Power losses in the network	
P, [MW]	*Q*, [MVAr]	*P*, [MW]	*Q*, [MVAr]
38,946	13,741	38,946	13,741

Table 2

Voltage Levels in Repartition System Buses in Non-Compensated State, at Peak Load

Node	*U*, [kV]	*u*, [%]	Node	*U*, [kV]	*u*, [%]
N 1	118	100.00	N 8	118	100.00
N 30 M6	5.826	92.480	N 3 M20	20.570	97.950
N 5 M20	21.115	100.55	N 2 M20	21.153	100.73
N 34B M20	21.661	103.15	N 32 M6	5.894	93.550
N 34A M6	6.283	99.720	N 32 M20	19.886	94.690
N 4	117.338	99.440	N 34A	122.044	103.43
N 5	117.945	99.950	N 34 B	121.589	103.04
N 08 M20	21.062	100.30	N 32B	122.161	103.53
N 17	117.197	99.320	N 13	121.475	102.94
N 2	118.000	100.00	N 12	121.417	102.90
N 3	117.391	99.480	N 11	117.844	99.870
N 13 M20	21.841	104.00	N 35	121.566	103.02
N 12 M6	6.478	102.83	N 47	6.300	100.00
N 12 M20	21.647	103.08	N 19A	117.906	99.920
N 11 M20	21.046	100.22	N 48	10.500	100.00
N 19B	121.866	103.28	N 15 M20	20.183	96.110
N 17 M20	20.818	99.130	N 16 M6	5.812	92.250
N 35 M20	21.701	103.34	N16	112.065	94.970
N 13 M6	6.300	99.990	N 15	112.298	95.170
N 32 A	112.383	95.240	N 21	117.884	99.900
N 1A M20	20.220	96.280	N 19 M20	21.873	104.16
N 4 M20	21.131	100.62	N 23	122.258	103.61
N 31	112.377	95.240	N 31 M6	5.898	93.630
N 30	112.328	95.190	N 21 M6	6.167	97.880

S t a g e 3: Another software function (*Capacitor Placement*) was used for each of the five sectors that contain repartition networks in radial configuration, in order to establish the CB optimal placement points and power on the MV station bars. For this purpose, in the analysed radial network nodes a multi-criteria optimization process was used, with the goal function to improve the voltage quality improvement by minimizing the voltage irregularity and active power losses under load. The goal function is supplemented by a technical restriction, that for any operating steady state, the reactive power injected must not circulate in the opposite direction, towards the supply source.

After this analysis the obtained results for each sector on peak load state and a loading factor of 0.9 and 1.1, respectively, are presented in Table 4, in the form of the nodes where CB are going to be set up, the CB power, and the active power losses reduction that occur in the network elements.

Table 3

Active and Reactive Power Injections in Slack Bus and Power Losses for the Five Network in Non-Compensated State, at Peak Load

Network sectors or zone	Power injections in slack bus		Power losses in the system sectors	
	P, [MW]	*Q*, [MVAr]	*P*, [MW]	*Q*, [MVAr]
Zone 1	71.141	20.772	0.498	0.672
Zone 2	54.229	13.555	1.067	2.063
Zone 3	3.9490	1.6580	0.024	0.287
Zone 4	13.705	4.9520	0.123	1.892
Zone 5	22.075	8.5130	0.175	1.418

Table 4

Optimal Placement and Powers of CB that are Going to be Set up in the Five Sectors and the Losses Reduction, in Non-Compensated State, at Peak Load

Network zone	Loading factor	Node/Bus	The CB power kVAr	Losses reduction %
Zone 1	0.9	N 21 M6	1,100	0.040
	1.1	N 21 M6	1,500	0.070
Zone 2	0.9	N 16 M6	1,800	1.630
		N 30 M6	2,500	1.240
	1.1	N 16 M6	2,500	2.480
		N 30 M6	3,200	1.850
Zone 4	0.9	N 35 M20	1,700	0.070
	1.1	N 35 M20	1,700	0.090
Zone 5	0.9	N 34A M6	1,800	6.740
	1.1	N 34A M6	3200	8.780

S t a g e 4: During this stage*,* was considered the studied repartition system in complex loop configuration and on MV station bars was set up the CB with the optimal results in the previous stage (Stage 3). Further on, the operating steady state of repartition system was analysed, and also a series of significant contingencies as compared to the real operation diagram and to the possible unavailabilities for the compensated state. The parameters that characterize this state are presented in Tables 5 and 6.

Table 5
Active and Reactive Power Injections in the Slack Bus and Power Losses in Compensated State, at Peak Load

Power injections in the N1		Power losses in the network	
P, [MW]	*Q*, [MVAr]	*P*, [MW]	*Q*, [MVAr]
38,270	3,906	38,270	3,906

Table 6
Voltage Levels in Repartition System Buses in Compensated State, at Peak Load

Node	*U*, [kV]	*u*, [%]	Node	*U*, [kV]	*u*, [%]
N 1	118.000	100.00	N 12 M6	6.277	99.630
N 5 M20	21.115	100.55	N 13 M20	21.192	100.91
N 30 M6	6.254	99.270	N 32 A	118.543	100.46
N 4	119.141	100.97	N 13 M6	6.106	96.930
N 34A M6	6.152	97.640	N 35 M20	21.443	102.11
N 34B M20	21.137	100.65	N 17 M20	21.377	101.80
N 3	119.514	101.28	N 2 M20	21.653	103.11
N 2	120.794	102.37	N 3 M20	20.942	99.730
N 17	120.344	101.99	N 4 M20	21.456	102.17
N 08 M20	21.011	100.05	N 1A M20	20.22	96.280
N 5	117.945	99.950	N 32 M20	20.976	99.880
N 19B	118.259	100.22	N 32 M6	6.219	98.720
N 11 M20	21.041	100.20	N 8	117.715	99.760
N 12 M20	21.004	100.02	N 34 B	118.649	100.55
N 21	117.914	99.930	N 34A	118.447	100.38
N 23	118.654	100.55	N 35	118.6	100.51
N 19 M20	21.226	101.08	N 11	117.818	99.850
N 30	118.522	100.44	N 12	117.809	99.840
N 31	118.537	100.46	N 13	117.865	99.890
N 21 M6	6.21	98.570	N 32B	118.543	100.46
N 31 M6	6.224	98.790	N 47	6.233	98.930
N 16 M6	6.206	98.500	N 19A	117.928	99.940
N 15 M20	21.228	101.08	N 15	118.109	100.09
N 48	10.227	97.400	N16	118.166	100.14

By comparing the values of the active/reactive power losses in compensated state that occur in the studied ERS, on peak load with the values of the same losses corresponding to the non-compensated state, was found a reduction of active power losses of 0.081 MW, and reactive power losses of 0.328 MVAr, respectively. Also, by comparing the voltage levels, in compensated and non-compensated state, we have noticed a significant improvement of the voltage level in compensated state for all repartition system nodes, as well as a reduction of the voltage irregularity on the entire network. Regarding the reactive powers absorbed from NPS through the slack node (N1), as expected in non-compensate state on peak load is 13,741 MVAr, while in compensated state is reduced to 3,906 MVAr.

Nevertheless, taking into account that in compensated state, at peak load, the network absorbs from NPS a 3,906 MVAr reactive power and aiming the two objectives mentioned in the paper, several possible variants have been additionally analysed, variants for increasing the compensation level or the degree of the reactive loads, maintaining the technical restriction regarding the reverse delivery of reactive power towards the electricity supply source and was found that the compensation degree of the reactive load can be slightly increased, by placing some additional CB as compared to the optimal resulted solution, in three nodes of the studied repartition system. In the case of the above-mentioned additional compensation, the voltage levels of the ERS nodes has continued to improve, remaining easily within the accepted voltage limit (95…1.05)U_n, and the irregularity of the nodal voltages on the entire system has continue to decrease. At the same time, in this additional compensation variant, we have obtained a reduction of the active and reactive power losses on the entire analysed system of 0.12 MW, respectively 0.255 MVAr, and the reactive power absorbed from NES through the slack node has decreased from 3,906 MVAr to 1,278 MVAr.

b) *The low load state analysis, 2°° o'clock, Wednesday from January 2011*

From the load curves records in repartition nodes examined, processed as 24 hourly levels, the load state (minimum load) was found to 2°° o'clock on Wednesday of January 2011. For the analysis of this operating state, with the aim of optimizing the active power sources placement on the MV station bars, the same study stages are applied as in the case of the peak load state. Thus, first, the analysed system is considered to have complex loop configuration, according to the single line diagram presented in Fig 1.

Table 7
Active and Reactive Power Injections in the Slack Bus and Power Losses in Non-Compensated State, at Low Load

Power injections in the N1		Power losses in the network	
P, [MW]	Q, [MVAr]	P, [MW]	Q, [MVAr]
16,703	–4,590	16,703	–4,590

By using the software was computed the operating state of the electric energy repartition network on low load in non-compensated state. For example, Table 7 presents the active and reactive power injections in the slack node for the studied network. Following the analysis of these active/reactive power injections in the slack node (N1), was found that the system injects reactive power in NPS mainly due to the capacitive supply of the 110 kV aerial lines. Having in view this observation, it results clearly that on low load is an excess of reactive power and, as a consequence, it is not necessary to compensate the reactive loads by setting up some new reactive power sources (CB) on MV station bars.

5. Conclusions

Due to the massive shifting of electric energy consumption from high voltage to medium voltage and low voltage, have required a special attention to the complex processes of reconstruction, refurbishment, design and rational operation from technical and economical point of view of electric energy repartition and distribution systems (ERDS). The voltage levels in different ERDS nodes require, firstly, the reactive power flow control, both in transmission and distribution systems.

For optimal placement of capacitor banks at the MV substation bars from electric energy repartition and distribution systems, the paper proposes a multi-criteria optimization process in several distinct stages, using a specialized software. The obtained results following such type of optimization processes lead to a series of advantages, such as: significant improvement of the voltage quality in all nodes of the ERDS; significant reduction of the active energy losses that occur in all elements of these systems (lines, transformers); avoiding the additional transit of reactive power through the elements of the systems; increase of the operation safety and power system stability in the responsibility area of each distribution branch.

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CALITATEA ENERGIEI ELECTRICE ŞI GESTIUNEA SURSELOR DE PUTERE REACTIVĂ DIN PUNCT DE VEDERE AL DISPECERULUI ENERGETIC DE DISTRIBUȚIE LA NIVELUL OPERATORULUI DE DISTRIBUȚIE

(Rezumat)

Datorită deplasării masive a consumului de energie electrică de la înaltă tensiune spre medie şi joasă tensiune, este necesară acordarea unei atenții deosebite reconstrucției, retehnologizării, proiectării şi exploatării raționale a sistemelor publice de repartiție şi distribuție a energiei electrice. Nivelul tensiunilor în diferitele noduri ale sistemelor publice de repartiție necesită, în primul rând, controlul circulației puterilor reactive vehiculate atât în sistemele de transport a energiei electrice, cât şi în sistemele de repartiție şi distribuție a energiei electrice. Pentru amplasarea optimă a bateriilor de condensatoare la nivelul barelor de MT ale ST din sistemele de repartiție şi distribuție, în lucrare se propune un proces de optimizare multicriterială, în mai multe etape distincte, prin utilizarea unui program de calcul specializat. Rezultatele obținute în urma unui astfel de proces de optimizare conduc la o serie de avantaje, cum ar fi: îmbunătățirea calității tensiunii în toate nodurile rețelei de repartiție; reducerea pierderilor de putere activă care apar în elementele acestor rețele; evitarea tranzitului suplimentar de putere reactivă prin elementele acestor rețele de repartiție etc.