MEĐUNARODNO REGIONALNO SAVETOVANJE O ELEKTRODISTRIBUTIVNIM MREŽAMA

REGIONAL CONFERENCE AND EXHIBITION ON ELECTRICITY DISTRIBUTION

Crna Gora, Herceg Novi, 5 - 8. oktobar 2004. / ***Montenegro, Herceg Novi, October 5 - 8, 2004***

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THE REDUCTION OF THE ENERGY LOSSES BY USING UP-TO-DATE MATHEMATICS METHODS TO ESTIMATE THE POWER FLOW'S STEADY STATE OF THE DISTRIBUTION SYSTEMS

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INTRODUCTION

In Romania, the electric power distribution is the object of activity for eight Companies and forty-two Branches. This new structure of the Distribution Power System wants to satisfy better the power demand on the (future competition-based) power market. The electric distribution networks, with the nominal voltage to 110 kV inclusive, means approximately 90 % from the total of the high and medium voltage networks of the National Power System. The energy losses in these networks have important increasing as the consumption of the electric power moved to medium and low voltage. At the same time, regarding the EU integration, the Distribution Power System must adapt the national regulations to the EU rules, in the power sector. The Green Book of the Safety Power Supply, adopted by the European Committee on November 2000, has the first point of the Long-time Strategy Project named "Stop the waste of energy". Considering the facts mentioned above, also the perspectives of the Power Market (the eligibility of the big customers), to reanalyze the possibilities of reducing the price of the power distribution become a priority direction for the management of the Companies mentioned above.

1. UP-TO-DATE MATHEMATICS METHODS TO ESTIMATE THE POWER FLOW'S STEADY STATE OF THE DISTRIBUTION SYSTEMS

In the first chapter of this paper, there is few mathematics methods used to estimate the power flow's steady state of the Distribution Power Systems.

1.1. The representation of the Distribution Network elements

1.1.1. The representation of the Over-Head Lines and Under-Ground Cables. The Over-Head Lines (OHL) and Under-Ground Cables (UGC) are represented by the symmetrical Π equivalent scheme, with the concise parameters (figure 1.1).

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The impedance and the longitudinal admittance of the lines are:

$$\underline{Z}_{ik} = R_{ik} + jX_{ik}. \quad [\Omega] \qquad (1.1) \qquad\qquad \underline{y}_{ik} = \frac{1}{\underline{Z}_{ik}} = \frac{R_{ik}}{R^2_{ik} + X^2_{ik}} - j\frac{X_{ik}}{R^2_{ik} + X^2_{ik}} \quad [\Omega] \qquad (1.2)$$

where: $\mathbf{R_{ik}}$ is the line's resistance;
$\mathbf{X_{ik}}$ is the line's inductive reactance.
Line's quadrature-axis admittance, if the conductance $\mathbf{G_{ik} = 0}$, is:

$$\underline{y}_{ik0} = \underline{y}_{ik0} = -j\frac{B_{ik0}}{2} \quad [S] \qquad (1.3)$$

where: $\mathbf{B_{ik0}}$ is the capacitive susceptance.

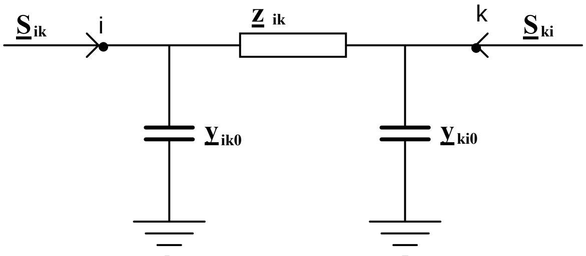

Figure 1.1. The symmetrical ∏ equivalent scheme of the OHL or UGC

1.1.2. The representation of the transformers and autotransformers. The transformers and the autotransformers with two windings and with actual transformation ratio of a voltage, in-phase control, can be represented by impedance or an admittance series connection with an ideal transformer (figure 1.2.a).

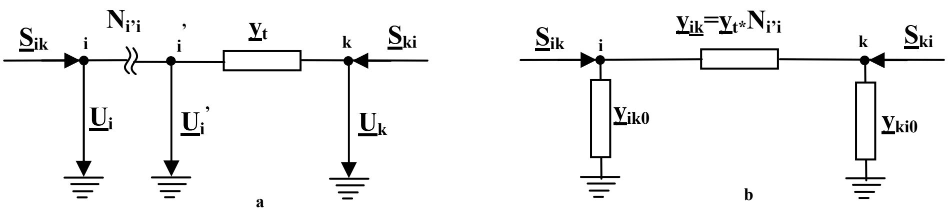

Figure 1.2. The representation of the actual transformation ratio of a voltage transformer.

This representation is according to the ∏ shape four-terminal network with the galvanic links (figure 1.2.b), with the follow elements:

$$\underline{y}_{ik} = N_{i'i} \cdot \underline{y}_t; \qquad \underline{y}_{ik0} = N_{i'i} \cdot (N_{i'i} - 1) \cdot \underline{y}_t; \qquad \underline{y}_{ki0} = (1 - N_{i'i}) \cdot \underline{y}_t; \qquad (1.4)$$

where: $\mathbf{N_{i'i} = U_{i'} / U_i}$ is the actual transformation ratio of a voltage;
$\mathbf{\underline{y}_t = 1 / \underline{z}_t = 1 / (R_t + jX_t)}$ -is the transformer's admittance, [S];

$$R_t = \Delta P_{Cu} \cdot \frac{U^2_{nt}}{S^2_{nt}} \cdot 10^{-3}$$ -is the resistance of transformer's windings, [Ω];

$$z_t = \frac{u_{sc}\%}{100} \cdot \frac{U^2_{nt}}{S_{nt}}$$ -is the modulus of impedance of transformer's windings, [Ω];

$$X_t = \sqrt{z_t^2 - R_t^2}$$ -is the inductive reactance of transformer's windings, [Ω].

1.1.3. The representation of the consumers. There was many studies for the determination of the most suitable models to simulated of the consumers by demand set up, concerning the variation of the voltage and frequency from the Power System. From these imposed the follow relations:

$$\frac{Q}{Q_{nom}} = \left[A + B \cdot \left(\frac{U_{nom}}{U}\right)^2\right] \cdot \left(\frac{f}{f_{nom}}\right)^{qf}$$

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$$\frac{P}{P_{nom}} = \left(\frac{U}{U_{nom}}\right)^{pu} \cdot \left(\frac{f}{f_{nom}}\right)^{pf} \qquad (1.5)$$

where: p_u **= 0.2 ÷ 2.0;** p_f **= 1.0 ÷ 1.1;** q_f **= -1.1 ÷ -1;**
A = -0.41 ; B = 0.44; C = 1.03 for U_{nom} **> 20 kV;**
A = -0.61 ; B = 0.32; C = 1.29 for $U_{nom} \leq$ **20kV.**

1.1.4. The representation of the shunt reactors and the capacitors. The shunt reactors and the capacitors used in the Power Systems are models by electric dipoles with reactance, linked between a node and earth. In the relations (1.6) and (1.7) are used the following elements: -**ΔP** -is the active power losses in the shunt reactor, [MW];

-Q_{bn} –is the rated reactive power of the shunt reactor, [MVAr};
-Q_{cn} –is the rated reactive power of the capacitor, [MVAr].

-for shunt reactors:

$$X_b = Q_{bn} \cdot \frac{U_n^2}{\Delta P^2 + Q_{bn}^2} \quad [\Omega] \qquad (1.6)$$

-for capacitors:

$$X_c = -\frac{U_n^2}{Q_{cn}} \quad [\Omega] \qquad (1.7)$$

1.2. The mathematics model to estimate the power flow's steady state. The estimation of the power flow's steady state for the big network which has ***l*** branches and ***N*** nodes can be made by node's voltage method. Is adopted the generalized branch with ideal sources of current and voltage (figure 1.3).

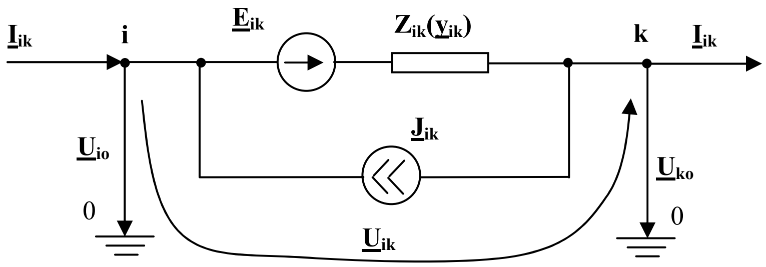

Figure 1.3 The representation of the generalized branch with ideal sources of current and voltage

Chosen a certain reference node and voltage's value of it, remains **n = N – 1** free nodes. To find the voltage's value of these is enough for determination the power flow in the branches of the network. For all ***l*** branches of the electric network, we can write by matrix form, the relations that express by generalized mode the link between known and unknown elements:

$$[\underline{U}] + [\underline{E}] = [\underline{Z}] \cdot ([\underline{I}] + [\underline{J}]) \qquad \text{or} \qquad [\underline{I}] + [\underline{J}] = [\underline{Y}] \cdot ([\underline{U}] + [\underline{E}]) \qquad (1.8)$$

where: $[\underline{U}]$ -is the column type vector of the voltage to terminals of ***l*** branches;
$[\underline{I}]$ -is the column type vector of the current in ***l*** branches;
$[\underline{E}]$, $[\underline{J}]$ -are the column type vectors of the ideal e.m.f. and current sources in ***l*** branches;
$[\underline{Z}]$ -is the mutual and proper impedance matrix of the branches;
$[\underline{Y}] = [\underline{Z}]^{-1}$ - is the mutual and proper admittance matrix of the branches.

For the determination of unknown elements $[\underline{U}]$ and $[\underline{I}]$, which means ***2l*** unknown elements, are needed ***2l*** equations which for vast networks are from the matrix of the graph's theory. The equation of the voltage's nodes method is:

$$[\underline{I}_n] = [A] \cdot [\underline{Y}] \cdot [A]^t \cdot [\underline{U}_n] \qquad \text{or} \qquad [\underline{I}_n] = [\underline{Y}_{nn}] \cdot [\underline{U}_n] \qquad (1.9)$$

where:

$$[\underline{Y}_{nn}] = [A] \cdot [\underline{Y}] \cdot [A]^t$$

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1.3. Methods using the nodal admittance's matrix The nodal matrix's admittances **[$\underline{Y}_{nn}$]** is a square symmetrically matrix, it has the number of rows and column equal as number of free nodes **(n = N – 1*)***. This can be determinate by the matrix of the graph's theory or by direct rules of writing.
Using the relation between current, voltage and nodal power, the equation of power system's operation of the voltage's nodes method (1.9) will be:

$$\left[\frac{\underline{S}_n^*}{\underline{U}_n^*}\right] = [\underline{Y}_{nn}][\underline{U}_n] \qquad (1.10)$$

or:

$$\underline{I}_i = \frac{\underline{S}_1^*}{\underline{U}_1^*} = \underline{Y}_{i1}\underline{U}_1 + \underline{Y}_{i2}\underline{U}_2 + \ldots + \underline{Y}_{ii}\underline{U}_i + \ldots + \underline{Y}_{in}\underline{U}_n = \sum_{k=1}^{n} \underline{Y}_{ik}\underline{U}_k \qquad i = 1,2,\ldots,n \qquad (1.11)$$

1.3.1. The Seidel-Gauss method. The Seidel-Gauss method has an important field from the estimation of the power flow's steady state of the Distribution Systems. The solution of the nodal equations system (1.11) means to put of **i** the node's voltage as explicatory form:

$$\underline{U}_i = \frac{1}{\underline{Y}_{ii}}\left(\frac{P_i - jQ_i}{\underline{U}_i^*} - \sum_{\substack{k=1\\k\neq i}}^{n} \underline{Y}_{ik}\underline{U}_k\right), \quad i \neq e \qquad (1.12)$$

This is The basic relation of the repetitive Gauss method. For a step **(p + 1)** which follows the **p** step in the repetitive process, the relations (1.12) will be:

$$\underline{U}_i^{(p+1)} = \frac{1}{\underline{Y}_{ii}}\left(\frac{(P_i - jQ_i)^p}{\underline{U}_i^{(p)*}} - \sum_{\substack{k=1\\k\neq i}}^{n} \underline{Y}_{ik}\underline{U}_k^{(p)}\right), \quad i \neq e \qquad (1.13)$$

In the case of the modified Seidel-Gauss method the characteristic feature consisted of determination of the node **i**'s voltage, taking supplementary correction into account applied the node **k**'s voltage**,** contiguous the **i** nodes**.** For the reduction of the calculation's time are used acceleration relations of the convergent process.

1.3.2. The quadratic equation method. Using the quadratic equation method presents the advantage, in comparison with Seidel-Gauss method, the successive approximations of the node's voltage aren't affected of the linearity errors of the node equations. The main relations of calculus are:

$$Y_{ii}^2 \bullet U_i^4 - [A_i^2 + 2(G_{ii} P_i - B_{ii} Q_{ii})] \bullet U_i^2 + S_i^2 = 0 \qquad (1.14)$$

$$U_i' = [(A_i' P_i - A_i'' Q_i) - (A_i' G_{ii} + A_i'' B_{ii})\cdot U_i^2]/A_i^2 \qquad (1.15)$$

$$U_i'' = [(A_i' Q_i + A_i'' P_i) + (A_i' B_{ii} - A_i'' G_{ii})\cdot U_i^2]/A_i^2 \qquad (1.16)$$

$$\arg(\underline{U}_i) = \mathrm{arctg}\left[\frac{\left(Q_i + \frac{A_i''}{A_i'}\cdot P_i\right) + \left(B_{ii} - \frac{A_i''}{A_i'}\cdot G_{ii}\right)\cdot U_i^2}{\left(P_i - \frac{A_i''}{A_i'}\cdot Q_i\right) - \left(G_{ii} + \frac{A_i''}{A_i'}\cdot B_{ii}\right)\cdot U_i^2}\right] \qquad (1.17)$$

where:

$$A_i = \sum_{\substack{k=1\\k\neq i}}^{n} \underline{Y}_{ik}\cdot\underline{U}_k, \qquad i = 1,2,\ldots,n \qquad (1.18)$$

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The terms affected with **(‘)** represents the real parts and those affected with **(“)** represents imaginary part of the respective quantities.

1.3.3. Newton-Raphson methods. The Newton-Raphson methods assure a better convergent of the process and there are more economics about the calculus time, these been use for big electric networks. The Newton-Raphson methods involve solving the follow linear system of equations:

$$\mathbf{F_i(X) = 0, \qquad i = 1, 2, \ldots, n} \tag{1.19}$$

where: $\mathbf{X=[x_1,x_2,\ldots x_n]}$ is the variable’s vector.
The initial values $\mathbf{X^{(p)}}$ know been, we must found $\mathbf{\Delta X^{(p)}}$ differences with must be add for to obtain the correct solutions. Supposed that $\mathbf{X^{(p+1)} = X^{(p)} + \Delta X^{(p)}}$ represent the solutions, then these will satisfy the equation: $\mathbf{F_i(X^{(p)} + \Delta X^{(p)}) = 0;\ i = 1,2,\ldots,n.}$ If will be develop like Taylor series these equations around initial values and will be neglect the superior rank terms, will result from this a system which in the matrix form will be as follow:

$$\mathbf{[-F_i^{(p)}] = [J^{(p)}]\bullet[\Delta X^{(p)}]} \tag{1.20}$$

where:

$$[\mathbf{J}^{(p)}] = \begin{bmatrix} \dfrac{\partial \mathbf{F}_1}{\partial \mathbf{x}_1} & \dfrac{\partial \mathbf{F}_1}{\partial \mathbf{x}_2} \cdots & \dfrac{\partial \mathbf{F}_1}{\partial \mathbf{x}_n} \\ \vdots & & \\ \dfrac{\partial \mathbf{F}_n}{\partial \mathbf{x}_1} & \dfrac{\partial \mathbf{F}_n}{\partial \mathbf{x}_2} \cdots & \dfrac{\partial \mathbf{F}_n}{\partial \mathbf{x}_n} \end{bmatrix} \tag{1.21}$$

represent the **Jacobian** of the non linear equation system.
Determining the initial values $\mathbf{\Delta X^{(p)} = [\Delta X_1^{(p)}, \Delta X_2^{(p)}, \ldots, \Delta X_n^{(p)}]}$ will be calculated a new point near the $\mathbf{X^{(p+1)} = X^{(p)} + \Delta X^{(p)}}$ solution. The cycle of operations will be repeat to the $\mathbf{\Delta X}$ values will become enough lessees. In the practice calculus, after explicatory the relation (1.11), respective after active and reactive node powers explicatory, the system of equations (1.19), which means the balance sheet of the node’s powers, will be write as follow:

$$\mathbf{P_i - P_i^{imp} = \Delta P_i' = 0; \qquad Q_i - Q_i^{imp} = \Delta Q_i' = 0; \qquad i=1, 2, \ldots, n;\ \ i \neq e} \tag{1.22}$$

Applied the linearization like (1.20) form, (1.22) equation systems will be:

$$-\Delta \mathbf{P}_i' = \sum_{k=1}^{n} \frac{\partial \mathbf{P}_i}{\partial \mathbf{x}_k} \cdot \Delta \mathbf{x}_k \qquad -\Delta \mathbf{Q}_i' = \sum_{k=1}^{n} \frac{\partial \mathbf{Q}_i}{\partial \mathbf{x}_k} \cdot \Delta \mathbf{x}_k \qquad \mathbf{i = 1,2,\ldots,n;\ \ i \neq e} \tag{1.23}$$

With the uncoupled Newton Method will be solve separately $\mathbf{P}$- $\mathbf{\Theta}$ and $\mathbf{Q - U}$ equations, will be negligee the conductance, $\mathbf{G_{ik} = 0}$ and will be considerate $\mathbf{\sin(\Theta_I - \Theta_k) \cong 0}$.
The uncoupled fast Newton Method adoptee new approximates:

$$\mathbf{\cos(\Theta_i - \Theta_k) \cong 1; \qquad G_{ik}\sin(\Theta_i - \Theta_k) \ll B_{ik}; \qquad Q_i \ll B_{ii}U_i^2.}$$

1.4. The Methods used the node’s impedance matrix. To solve like linear form of the obtained equations by node’s voltage Methods suppose to introduce the node’s impedance matrix into (1.9) relation:

$$\mathbf{[\underline{U}_n]=[\underline{Y}_{nn}]^{-1}[\underline{I}_n]=[\underline{Z}_{nn}]\,[\underline{I}_n]} \tag{1.24}$$

For to obtain the node’s impedance matrix we can use one of follow methods:

- **The unitary current Method**;
- **The transfiguration Method**;
- **The direct inversion of $[\underline{Y}_{nn}]$ matrix;**
- **The synthesis Method.**

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1.4.1. The Seidel-Gauss-Brown Method. Use of the Seidel-Gauss-Brown Method means to put (1.24) node's equations of the system like follow form:

$$\underline{U}_i = \sum_{k=1}^{n} \underline{Z}_{ik} \cdot \underline{I}_k^* = \sum_{k=1}^{n} \underline{Z}_{ik} \frac{\underline{S}_k^*}{\underline{U}_k^*}; \qquad i = 1,2,\ldots,n \tag{1.25}$$

To increase the converging of the process, in comparison with Seidel-Gauss Method, will be replaced the loads with impedances connected between the respective nodes and earth.

2. DETERMINATE THE DISTRIBUTION NETWORK'S OPTIMAL POWER FLOW

The importance of the security and safety analyses of the power systems is actually more obvious, than the far-reaching and complexity of this is bigger. The social-economic implications to the appearance of the faults into big Power Systems was imposed the selection of the properly adapted models to the real phenomena. With theirs aid will be preliminary the operative performances of the Power Systems. In particular, case of the Distribution Systems, decision-man (Control Room Engineer) is building his line of action-optimal strategy or the multitude of optimal decision alternatives, in few of the cases following the achievement of only one objective. In most of the cases is desirable that a certain solution, optimal it considered, to be better answer to the multitude of the restrictive requests which from the decision-men point of view has divergent tendentious. Like was demonstrated [2], to adoptee the decisions on the basis of the personal experience and the intuition, can lead to erroneous decisions. The subject matter which broach in the scientific mode the phenomena for the systems organize and it allow the scientific preparations of the decisions is named **Operational Research**. The specific method of the operational research is the method of mathematic model. The mathematic model of a organization phenomenon is made by the objective function and mathematical restrictions. Meanwhile the system restrictions can be many, the objective function can be only one. The optimization of a process involves minimizing or maximizing the objective function regarding the mathematical restrictions. The decision based upon is obtained the optimal action is called de **optimal decision**. Establishing the mathematical model of a process represent an abstract way of looking at it.

2.1. Tackling the matter. Power supply of some consumption areas from few sources can do by more variants. The known dates are the sources and consumers locations, the electric feature and rated voltage of the network, the available capacity in correlation with the price of the energy from each source and the subscribed demand of each consumer. Taking into consideration the vast number of possible variants, regarding the operating diagram, on the basis of the Dispatcher's experience, will be selected a few number from this, to be calculate. The graph of the Supplying Network for three geographical areas (under Leading Operative Authority of the one Distribution Control Center) from three source, respective one Thermal Power Station, a group of Hydroelectric Power Stations and from Transmission Network is showed into figure 2.1., it has drawn as broken line. The method allows that from this complete graph keep only certain branches, so that selected element for to characterize a supply network should be extreme value.

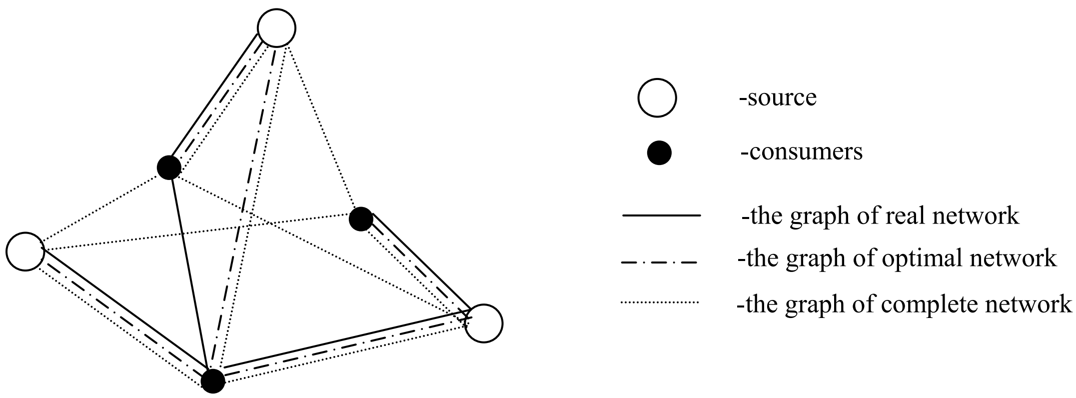

Figure. 2.1. The graph of the Supplying Network for three geographical areas

The proper graph has drawn as dashed line. The graph obtained, as result of the optimization process, has corrected without substantial modifications, for carry out the safety level. Another corrections means to be considered only one branch as substitute the nearly branches. The final

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graph has drawn as standard line. As estimation criteria of the network configuration is use the active power losses value. For a single branch the expression of the active power losses is:

$$p = 3RI^2 = 3\rho\frac{l}{S}I^2 = 3\rho\frac{I}{S}lI = 3\rho\frac{I}{S}l\frac{P}{\sqrt{3}U\cos\varphi} = \sqrt{3}\frac{\rho j}{U\cos\varphi}Pl = KPl \tag{2.1}$$

Supposed yearly duration of utilization of the maxim power and the power factor hading nearly values for all consumers, result from it that the loosed power on each branch are proportional to **Pl** product. Consequently, the optimal configuration of the Supplying Network will be that which has the minimum value of the product's sum **Pl –** the moment's loads sum.

2.2. The mathematic model of the transport problem. The transport problem, on the generally mode, solve the repartition of a homogeneous produce from **m** production centers to **n** consuming centers, so that the transport expenses will be minimum value. Are known the quantity owns into each production centers **i**, $\mathbf{a_i}$; the necessary quantity each consuming centers **j**, $\mathbf{b_j}$; the expenses for the unit's product transported from **i** to **j**, $\mathbf{c_{ij}}$. Are not known the quantities transported on different routes $\mathbf{x_{ij}}$, so that the transport expenses has minimum values. From the character of the problem result: $\mathbf{a_i}$, $\mathbf{b_j}$, $\mathbf{c_{ij}}$, $\mathbf{x_{ij}} \geq \mathbf{0}$. If we note: **I = 1, 2,…,m** the multitude of the production centers and **i** $\in$ **I**; **J = 1, 2, …,n** the multitude of the consuming centers and **j** $\in$ **J**; assuming that all the produced quantity is distributed, will result:

$$\sum_{i\in I} a_i = \sum_{j\in J} b_j = A \tag{2.2}$$

In this situation, the mathematic model of the transport problem will be:

$$[MIN]f = \sum_{i\in I}\sum_{j\in J} c_{ij}x_{ij} \tag{2.3}$$

$$\sum_{j\in J} x_{ij} = a_i; \quad i \in I = 1,2,...,m; \tag{2.4}$$

$$\sum_{i\in I} x_{ij} = b_j; \quad j \in J = 1,2,...,n \tag{2.5}$$

$$x_{ij} \geq 0 \tag{2.6}$$

Considering the cost acquisition of electric energy as consuming features of power station's respective of the transmission network, we can solve the following problems:

- The optimization of the productivity's repartition between generating stations of the power system;
- The optimization of the electric power's repartition in certain moment between the interconnected power stations;
- The optimization of the electric power's repartition for a short term between the interconnected power stations;

3.THE POWERWORLD SIMULATOR PACKAGE

3.1. Introduction to PowerWorld Simulator. PowerWorld Simulator is a power system simulation package designed from the ground up to be user-friendly and highly interactive. Simulator has the power for serious engineering analysis, but it is also so interactive and graphical that it can be used to explain power system operations to non-technical audiences. With Version 10.0 we've made Simulator easier to use, yet even more powerful and more visual. Simulator is actually a number of integrated products. At its core is a comprehensive, robust Power Flow Solution engine capable of efficiently solving systems of up to 100,000 buses

3.2. Analyzing the Distribution Network under the authority of an area Control Center. The distribution network owned by Muntenia Nord Branch has been completely modeled and divided in interest areas regarding the power flow between them. The need to divide the network comes form the fact that the PowerWorld package program, in the demo version, doesn't accept more than 13 nodes. The number of branches and equipments added to the network's nodes is not limited. The studied area, shown in figure 4.1, reach on his peek load approximate 80-100 MW, supplied in the normal operating diagram from following source:

- Auto-Transformer 220/110 kV, 200 MVA from Stalpu Substation;
- Maneciu-Patarlagele 110 kV Overhead Line;

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- Mizil-Sahateni 110 kV Overhead Line;
- Nehoiasu, Vernesti, Candesti, Simileasca Hydroelectric Power Stations.

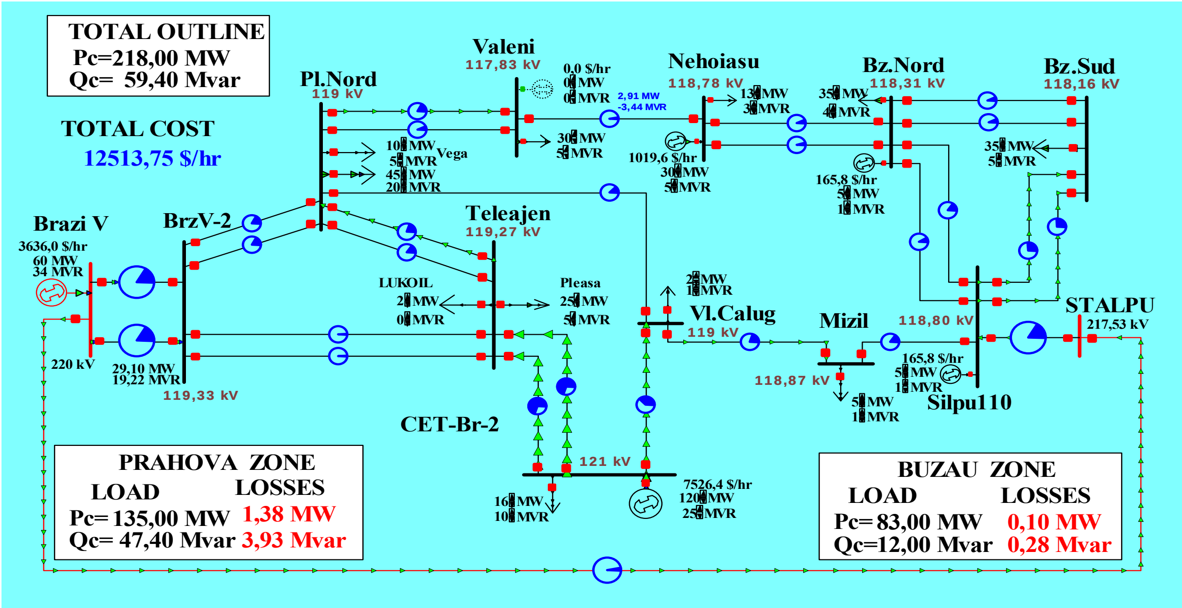

Figure 4.1 Supplying Buzau zone on the normal operating diagram

The contingent with major effect on the level of losses is the unavailability of the 200 MVA Auto-Transformer from Stalpu Substation. It is the main source of the area's power injection. Regarding the fact that local Hydroelectric Power Station's running is restricted by the water's level, the supply of the local consumers in the situation mentioned above, is done by the 110 kV interconnected overhead line between the areas. In the interest area the nodes less important were eliminated, throwing their loads to the important nodes. Analyzing with the PowerWorld Simulator package program the power losses for the availability/unavailability 200 MVA Stalpu Auto Transformer is noticed that active losses are increasing with 3,86 MW (~ 200%) and reactive losses are increasing with 9,03 MVAr (~160%). The value estimated for this losses is about $150 / hour.

CONCLUSIONS

- The need to use performance soft package that can provide fully information about Distribution Network features in any operation conditions.
- New tasks for the Control Room Engineers (Distribution Operators) to reduce the energy losses, respecting the safety criteria, by:
  - To analyze the shut-down maintenance schedules by computer simulator to find the optimal solutions.
  - To analyze the significant contingents against Normal Operation Network and/or simultaneous possible forced outages, also regarding optimal power flow.
  - To know at any time the price of power energy on the Power Market.
  - To accomplish the adequate power distribution diagrams for the acquisition of the power energy to a optimal price.
  - To change network configuration taking the load curve into account.

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