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Evaluation of Post-Dinamic Quasi-Stationary States During the Islands Operation of Power System Parts

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Abstract: This paper presents the development and practical examples of an efficient method for the simultaneous solution of post-dynamic quasi-stationary states in each of the islands, using a unique numerical procedure, retaining the same node numeration which existed in the power system before its disintegration. At the same time, the developed method enables a simple incorporation of the effects of primary frequency and voltage control, emergency control devices and a series of possible dispatch actions, both during the monitoring of the disintegration process and during power system restoration with island synchronization, if the necessary conditions are met.

Keywords: Simultaneous solution, load flow, islands operation, post-dynamic states, quasi-stationary states, power system restoration.

1 Introduction

Maintaining the necessary level of security in the operation of electric power systems (EPS's) is a task of utmost priority and significance, for without it, other high priority tasks related to the economical and satisfactory operation cannot be performed. In recent years, the increased practical interest to this problem and corresponding new challenges are essentially due to increased loading of EPS's, combined with a process of deregulation in electric power market and restructuring of the power utilities. Open access power systems need accurate transmission capacities evaluation to guarantee secure operation for all transactions. In other words, electric power markets need to know how much power can be transferred between certain points, e.g. to know the real technical limitations of these power exchanges due to the set of various network constrains.

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Several different methods (deterministic or probabilistic, based on the DC or AC network models) of transfer capability evaluation have been proposed. Refs [1]-[10] are only few from the long list of recent published work in this area.

Therefore, as evidenced by numerous papers, security analysis plays a central role in modern energy management systems, both in off-line and on-line analysis, and in the last twenty years, great progress has been made in developing analytical tools for security analysis.

If we were to look for a common denominator in approaches to security analysis in various modern power system control centers, we would immediately note that they encompass generally steady-state security analyses, with the classical load-flow model (one reference node, i.e. one slack buss), usually solved using the well known fast decoupled method [11].

Such approaches give a sufficiently accurate indication of the (non) violation of the three sets of fundamental constraints (load constraint, operational and security constraints - corresponding vector functions with a vector argument - state and control vectors), but only for a limited number of characteristic post-dynamic states of the power system.

As several papers [12]-[16] show, they enable the classification of operating states of the power system according to their capability of satisfying these constraints. These papers introduce and describe the terms ”normal secure operation” and ”normal but insecure operation” -alert (vulnerable) state, when it is necessary to apply preventive control to return the system into the normal secure state. Next, they introduce the term ”emergency” (disturbed) state, where preventive control was not applied, or was not adequate, or a (larger) unforeseen disturbance occurred, but where the power system remains undivided. However, if adequate control actions are not applied (corrective control), the power system can start to fall apart, i.e. enter into a critical state, when a number of distinct islands appear. When the disintegrative process is stopped, the power system can enter into a ”restorative” state, when it is necessary to apply all available measures and actions in order to return the system as soon as possible into the normal secure state, or at least into the vulnerable state.

The approaches based on the classical load-flow model, therefore, can give a good indication for all the cases where the system has kept its integrity, but cannot be of great practical assistance for cases when island operation occurs, and specially, during the necessary restoration process, after disintegration.

Thus, a series of new and diverse approaches appeared for the solution of these problems, founded on knowledge based methods, e.g. [17], and their interface with analytical tools, e.g. [18], or on approaches based on the application of expert systems, e.g. [19]. Lately, there are some approaches to power system steady-state security assessment based on the application of artificial neural networks, e.g. [20].

This fact motivated the authors of the paper to attempt to formulate and develop a practical method, in the category of analytical tools approach, which would, in a sufficiently adequate, simple and practical manner and without changing the initial node numeration, simultaneously treat the post-dynamic quasi-stationary states in an arbitrary number of islands which appeared during the critical stages of disintegration of the power system. Also, the method would analyze such states occurring during system restoration in post-dynamic states, when individual islands are being synchronized to the system and would study and determine all the necessary and sufficient conditions for rebuilding of the system. These objectives required the introduction of primary frequency and voltage control effects, of the effects of automatic emergency control and protection devices and of a series of possible dispatch actions, all of which is achieved in a very suitable manner due to the simplicity and flexibility of the developed method and the numerical technique for its solution.

The main intention of this paper is to present the basic characteristics of the method for evaluating the post-dynamic quasi-stationary states during the islands operation of power system parts, by presenting its mathematical model and the efficient technique developed for its solution, with an illustration on an example of electric power interconnection in the Balkans.

2 Mathematical Models of Quasi-Stationary Load-Flows in Islands Operation of Power System Parts

The system under consideration has a total of N nodes, where the first NG nodes are generator nodes. Here we would like to point out a unique characteristic of the developed method in that the initial node numeration, which holds for the fully integrated system, remains unchanged during the security analyses performed when the system is broken down into MI islands resulting from a cascade propagation of a single or multiple disturbances. The number of islands, MI, therefore, is not fixed (as opposed to the number of nodes N) and it changes with the level of disintegration of the power system and the process of system restoration during the post-dynamic period, during which there is a gradual and controlled synchronization of the previously formed islands.

For the post-dynamic quasi-stationary state of the power system, which is decomposed into MI islands, resulting from the primary voltage and frequency control, the following power balance equations hold

$$\Delta P_i = P_{G_{0i}} + k_{P_i} \Delta f_m = 0 \qquad i \in NG \tag{1}$$

$$
\begin{aligned}
\Delta Q_i = &\quad Q_{G_{0i}} + \frac{Q_{G_{0i}}(V_{0i} - V_i)}{s_{vi} V_{0i}} = 0 \quad && i \in NVRD \qquad (2)\\
\Delta O_i = &\quad P_{L_i}(V_i, f_m) - P - i = 0 && i \in NL \qquad (3)\\
\Delta Q_i = &\quad Q_{L_i}(V - i, f_m) - Q_i = 0 && i \in NL \qquad (4)\\
& && m \in MI
\end{aligned}
$$

where:

N	total number, i.e. designation of the set of indices of all nodes of the power system,
NG	number, i.e. designation of the set of indices of generator nodes,
$NVRD$	number, i.e. designation of the set of indices of generators with voltage - reactive power droops,
NL	number, i.e. designation of the set of indices of load nodes ($NL = N - NG$),
MI	number, i.e. designation of the set of indices of islands in the power system,
MR	number, i.e. designation of the set of indices of reference nodes (i.e. slack busses), one from each of the islands formed during the system disintegration or system restoration,
$\Delta f_m = f_m - f_n$	deviation of the quasi-stationary value of frequency in island m ($m \in MI$) from the nominal value f_m,
N_m	designation of the set of indices of nodes in "m-th" island,
k_{pi}	primary frequency control constant of the "i-th" generator,
P_{G0i}	active power of the "i-th" generator in the initial steady state,
s_{vi}	droop of the static voltage - reactive power characteristic of the "i-th" generator,
Q_{GOi}, V_{Oi}	reactive power and voltage at the ends of the "i-th" generator in the initial steady-state,
P_i, Q_i	injected active and reactive powers,
$P_{Li}(V_i, f_m)$, $Q_{Li}(V_i, f_m)$	load active and reactive power at node "i", as a complex function of the voltage at its ends and the quasi-stationary value of the frequency,
V_i	magnitude of the voltage at node "i".

The following constraints for the generation nodes must be satisfied

$$P_{Gmin\,i} \leq P_{Gi} \leq P_{Gmax\,i} \qquad (5)$$

$$Q_{Gmin\,i} \leq Q_{Gi} \leq Q_{Gmax\,i} \quad i \in NG \qquad (6)$$

which, contrary to the usual approaches, are not constant, but are rather corresponding functions of the states under consideration [21].

The system of equations (1) represents the active power balance for generator nodes, which include the effects of primary frequency control. The system of equations (2) represents the reactive power balance, for generator nodes with static voltage-reactive power characteristics, i.e. this system includes the effect of primary voltage control. Finally, the conditions of power (active and reactive) balance for load nodes are given in the system of equations (3) and (4).

The balance equations (1)-(4), with the constraints (5) and (6) are also valid for the states occurring after the corresponding dispatch actions (e.g. the compensation of the power debalance by engaging the available generator powers results in the corresponding correction of elements P_{G0i} in equation (1), or effects of frequency load shedding results in corresponding correction of P_{Li} and Q_{Li} in equations (3) and (4)).

Also, equations (1)-(4) are valid for states resulting from the action of automatic emergency control and protection devices which is registered through specially developed procedures (e.g. the indication of frequency load shedding and the operation of frequency generator protection is performed on the basis of a simple low - order mathematical model [22], which gives a sufficiently accurate value of the frequency in all the islands, during the initial phase of its dynamic change).

Also, we would like to point out the existence of MI unknown variables in equations (1)- (4), namely the quasi-stationary frequency values f_m in the individual islands, which are associated to all the corresponding generator and load nodes.

3 Model Solution Techniques

Before presenting the specific model solution techniques, it should be noted that there are two main approaches.

First the one in which the equations (1)-(4) are formed for each of the islands, i.e. the individual, isolated treatment of the islands during the monitoring of the disintegration process and during power system restoration.

The second approach, in which the equations (1)-(4) are applied to the power system as a whole during all these processes, with a fixed node numeration corresponding to the initial state of the system, but with a change in the values of quantities MI, MR and N_m. This second approach, naturally, also takes into consideration all the topological changes which resulted in the appearance of the islands

The authors of this paper have chosen the second approach, which simultaneously determines the state in all the islands. The main practical reason for this approach is a consequence of the requirement of continual analysis of disintegration and the ensuing reintegration of the power system under consideration. Of course, this does not mean that this approach is a priori more favorable compared to the separate treatment of the islands.

3.1 Application of the Newton-Raphson Method

The application of the Newton-Rhapson method [23] to the balance equations (1)-(4) results in the following system of 2N-NG+NVRD linearized equations

$$\begin{bmatrix} \Delta \boldsymbol{P} \\ \Delta \boldsymbol{P}_r \\ \Delta \boldsymbol{Q} \end{bmatrix}^k = \begin{bmatrix} \boldsymbol{H} & \boldsymbol{F} & \boldsymbol{N} \\ \boldsymbol{J} & \boldsymbol{G} & \boldsymbol{L} \end{bmatrix}^k \begin{bmatrix} \Delta \boldsymbol{\delta} \\ \Delta(\Delta \boldsymbol{f}) \\ \dfrac{\Delta \boldsymbol{V}}{\boldsymbol{V}} \end{bmatrix}^{k+1} \tag{7}$$

The coordinates of the vectors $\Delta\boldsymbol{P}$ and $\Delta\boldsymbol{Q}$, of orders $N - MI$ and $NVRD + NL$ respectively, are defined by expressions (1) and (4), while the MI-dimension vector $\Delta\boldsymbol{P}_r$ designates the power mismatch vector in reference nodes (i.e. in each of the created islands there is one slack node with an a priori, fixed phase angle).

Therefore, the iterative solution of the system of linearized equations (7) gives the values of the unknown variables:

- $\boldsymbol{\delta}$ vector of phase angles, dimension N-MI,
- $\Delta\boldsymbol{f}$ vector of frequency deviations in each of the islands, dimension MI,
- $\boldsymbol{V}$ vector of voltage magnitudes in all load nodes and in those generator nodes with a static voltage-reactive power characteristic, dimension $NVRD + NL$.

The elements of the sparse submatrices of the Jacobian F and G, with dimensions NxMI and $(NVRD+NL) \times MI$ respectively, relating the mismatches of active and reactive power to the newly introduced vector of unknown island frequency deviations $\Delta\boldsymbol{f}$, which does not appear in the classical load flow model, have the following form

$$F_{ij} = \begin{cases} -k_{Pi} & i \in (NG \cap N_j \quad j \in MI \\ -\dfrac{\partial P_{Li}(V_i, f_m)}{\partial \Delta f} & i \in (Nl \cap N_j) \quad j \in MI \\ 0 & i \in N \quad j \notin MI \end{cases} \tag{8}$$

$$G_{ij} = \begin{cases} 0 & i \in NVRD \quad j \in MI \\ -\dfrac{\partial Q_{Li}(V_i, f_m)}{\partial \Delta f} & i \in (Nl \cap N_j) \quad j \in MI \\ 0 & i \in NL \quad j \notin MI \end{cases} \tag{9}$$

When comparing this to the classical load-flow model, one important difference is evident. That is the existence of as many slack nodes as there are islands, i.e. different quasi-stationary frequency values. In order to eliminate the singularity, in these freely chosen nodes (between generations nodes) the value of the phase angle is a priori fixed (usually zero) and an unknown variable is associated, namely the deviation of the corresponding quasi-stationary island frequency from its nominal value. Therefore, contrary to the classical load-flow model, where there is only one balance node i.e. one slack buss (also introduced to eliminate the singularity), which is simultaneously the balance node, in the model defined by (7), all nodes practically play the role of balance nodes, as the values of powers are not given in advance. This generally improves the convergence characteristics of the applied solution procedure.

3.2 Developed fast decoupled method

The development of the fast decoupled procedure started from the system of equations (7), by introducing the corresponding simplifications and assumptions.

The first simplification, taken from the solutions of the classical load-flow model used in practice, is to neglect, during iteration, the influence of voltage change on the active power and the influence of the phase angle change on the reactive power, i.e. the submatrices $\boldsymbol{N}$ and $\boldsymbol{J}$ in equation (7) become zero matrices. Also, during iteration, the influence of frequency change on the reactive power is neglected, i.e. the submatix $\boldsymbol{G}$ in equation (7) is a zero matrix.

The next approximation results from the quantitative relationship of certain parameters in high voltage networks and the corresponding state variables, which justify the following assumption

$$Y_{ij} = \cos(\delta_{ij} - \mu_{ij}) \simeq -B_{ij} \tag{10}$$

where:

Y_{ij}	magnitude of the admittance $\underline{Y}_{ij} = G_{ij} + jB_{ij}$,
$\delta_{ij} = \delta_i - \delta_j$	phase difference between voltage phasors $\underline{V}_i$ and $\underline{V}_j$,
μ_{ij}	complementary phase of the impedance $\underline{Z}_{ij} = 1/\underline{Y}_{ij}$,
B_{ij}	susceptance of the element "$i-j$".

Next, the shunt elements in the susceptance Bii are neglected, i.e. the following relation holds

$$B_{ii} \approx -\sum_{\substack{j=1 \\ j \neq i}}^{N} B_{ij} \tag{11}$$

Finally, the influence of the load characteristics on the corresponding diagonal elements of submatrices $\boldsymbol{H}$ and $\boldsymbol{L}$ are neglected, as well as the corresponding influence on the elements of submatix $\boldsymbol{F}$.

Introducing the above assumptions and simplifications, which serve to simplify the solution procedure (only the Jacobian matrix elements are simplified and modified) and by forming vectors $\Delta\boldsymbol{P}/\boldsymbol{V}$, $\Delta\boldsymbol{P}_r/\boldsymbol{V}$ and $\Delta\boldsymbol{Q}/\boldsymbol{V}$ analogously to [21], where the voltage is taken as equal to the rated value V_n (except for the diagonal elements of the submatrix $\boldsymbol{L}$, which correspond to the generator nodes, where the initial value of the voltage is V_0), the system of equations (7) is transformed into the following two systems of decoupled equations, according to the iteration indices k and l

$$\begin{bmatrix} \dfrac{\Delta\boldsymbol{P}}{\boldsymbol{V}} \\ \dfrac{\Delta\boldsymbol{P}_r}{\boldsymbol{V}} \end{bmatrix}^{k} = \begin{bmatrix} \boldsymbol{H}' & \boldsymbol{F}' \end{bmatrix} \begin{bmatrix} \Delta\boldsymbol{\delta} \\ \Delta(\Delta\boldsymbol{f}) \end{bmatrix}^{k+1} \tag{12}$$

$$\frac{\Delta\boldsymbol{Q}^{l}}{\boldsymbol{V}} = L'\Delta\boldsymbol{V}^{l+1} \tag{13}$$

The system of equations (12) determines the $N-MI$ dimension vector of unknown angles δ, and the MI dimensioned vector of deviations of the quasi-stationary frequencies $\Delta\boldsymbol{f}$, i.e. the number of unknown frequency values corresponds to the number of islands appearing in the power system under consideration.

The unknown vector of voltage magnitudes $\boldsymbol{V}$, of dimension $NVRD+NL$ (voltage magnitudes in all load nodes and all generator nodes which have a static voltage - reactive power characteristic) is obtained by solving the system of equations (13).

The $N \times (N-MI)$ rectangular coefficient submatrix $\boldsymbol{H}'$, have the following elements

$$H'_{ii} = \quad V_n B_{ii} \quad i \in (N \backslash MR) \tag{14}$$

$$H'_{ij} = \quad V_n B_{ij} \quad i \in N, \quad j \in (N \backslash MR) \tag{15}$$

The coefficient submatrix $\boldsymbol{F}'$, also a rectangular matrix of dimension $N \times MI$, which associates the mismatches of active powers to the corresponding frequency values (i.e. each node is associated with the value of the frequency of the island in which that node is located) has the following elements

$$F'_{ij} = \begin{cases} -\dfrac{k_{Pi}}{V_n} & i \in (NG \cap N_j \quad j \in MI \\ 0 & i \in (NL \cap N_j) \quad j \in MI \\ 0 & i \in N \quad j \notin MI \end{cases} \tag{16}$$

because the influence of the load frequency characteristics in coefficient submatrix $\boldsymbol{F}'$ are justifiably neglected.

The $NVRD + NL$ square submatrix $\boldsymbol{L}'$, which relates the unknown voltage magnitudes to the reactive power mismatches, has the following elements

$$L'_{ii} = \begin{cases} Q_{G0i}(s_{Vi}V_{0i}^2) + B_{ii} & i \in NVRD \\ B_{ii} & i \in NL \end{cases} \tag{17}$$

$$L_{ij} = B_{ij} \quad i, j \in (NVRD \cup NL) \tag{18}$$

By analyzing the expressions (14), (15), (16), (17) and (18), it can be seen that the elements of the newly formed coefficient submatrices $\boldsymbol{H}'$, $\boldsymbol{F}'$ and $\boldsymbol{L}'$ have a constant value for an unchanged power system network topology. This fact significantly simplifies the procedure of the successive solution of the linearized system of equations (12) and (13), without disturbing its good convergence characteristics. The coefficient submatices are redefined and factorized only when there is a topological change of the power system under consideration.

In this way a simple iterative procedure is developed which is easily programmable, with relatively small computer memory requirements. The special characteristics of the developed method are the simultaneous determination of the state in each of the islands, retaining the initial node numeration, during the whole analysis, but with the necessary change of values of sets MI, MR and N_m, according the topological changes which give new numbers of islands.

Also it should be noted, that the problem of appearance of islands during power system disintegration, in which power balance is not possible, is very easily solved in this approach. For this kind of islands (after a simple identification test) the computation of corresponding variables is eliminating during the overall simultaneous iterative procedure. The treatment of these islands is made only after the power balance condition is satisfied (e.g. after the corresponding dispatch actions).

The developed method is characterized by very good and reliable convergence characteristics which will be described in greater detail in the next section which deals with examples of its practical implementation on an existing electric power system in synchronous parallel operation.

4 Practical Applications

The first practical experiences in the application of the method proposed were gained on an example of synchronous parallel operation of the EPSs of Serbia and Montenegro (SCG), Romania (RO), Former Yugoslav Republic of Macedonia (FYROM), Greece (GR) and Albania (AL). For 1995 expected winter peak load condition 400 kV and 220 kV networks of former Yugoslavia, Romania and FYROM were modeled, as well as, the complete 220 kV network of Albania. The Greek EPS was represented by a corresponding equivalent at the 400 kV and 150 kV levels, with the exception of the Northern part, which was modeled in detail. The data base necessary for the calculation of the characteristic post-dynamic quasi-stationary states is also taken from [24].

Fig.1 shows the load-flows (MW/Mvar) on interconnective lines for the analyzed initial steady-state, before the set of disturbances, in which the EPS of Serbia and Montenegro exports 400 MW to EPS of Romania and 200 MW to EPS of Greece.

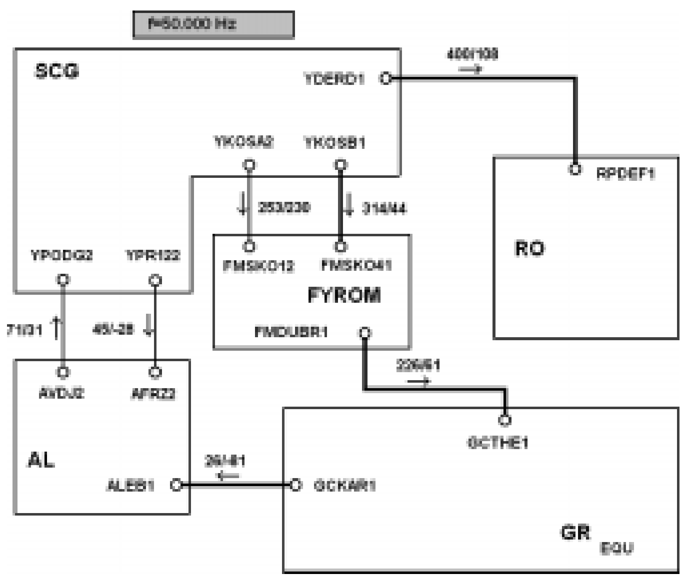

Fig. 1. Initial steady-state of interconnection considered.

It should be pointed out that the selection of the initial steady-state and set of disturbances, as well as the presentation of the obtained results serves primarily to illustrate the capabilities of the method proposed and its numerical efficiency, leaving for future papers the more detailed presentation of capabilities of the methodology, which is still under development and which deals with the relevant quasi-stationary and dynamic aspects of efficient power system restoration.

The initial disturbance is taken to be the outage of the 800 MVA unit in NPP Cernavoda (RO) (injection losses of 700 MW and 250 Mvar), which is transient stable case [24], e.g. the new post-dynamic state will be reached. The quasi-stationary value of frequency, for this outage and loads representation with constant powers, after the action of primary voltage and frequency control will be 49.856 Hz. Fig. 2 shows this post-dynamic state, e.g. the new load- flow on interconnective lines caused by primary control effects.

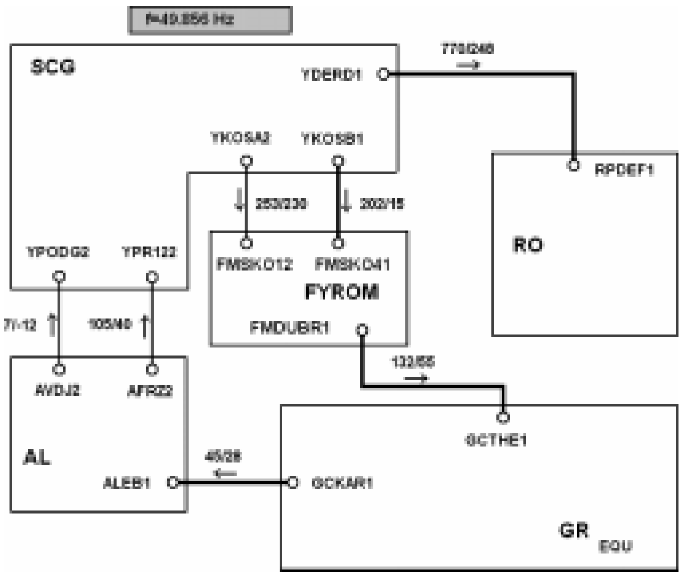

Fig. 2. Post-dynamic quasi-stationary state after the outage of the 700 MW units in NPP Cernavoda (RO).

However, the dynamic calculations, applying the methodology (and corresponding computer program) given in [25], show that the active power on the 400 kV interconnective line Djerdap (SCG) - Portile de Fier (RO), will exceed the set value of vatmeter protection installed on this line (700 MW, with time delay 2s), practically before the real start of the primary frequency control process. As a natural consequence, two islands will appear (MI=2), practically immediately after the initial disturbance.

The first island is EPS of Romania, while the EPS's of Serbia and Montenegro, FYROM, Greece and Albania form the second island. For this case, Table 1 shows the initial active power debalance (MW) in islands formed.

In this table, $\sum \Delta P$ represents the total debalance (by magnitude and sign) of the active power in the respective islands (the minus sign signifies a deficiency,

Table 1. Initial active power debalance (MW) in formed island.

No.	Island	ΔP_G	ΔP_L	ΔP_T	$\sum \Delta P$
1	RO	−700	592.6	−400	−507.4
2	SCG, MA, GR, AL	/	/	400	400

while the plus signifies a surplus of active power). The total debalance, therefore is formed as an algebraic sum of injection losses in generator (ΔP_G) and load (ΔP_L) nodes and the debalance occurring due the tripping of the interconnective lines (ΔP_T), which resulted in island operation.

The quantity presented in column ΔP_L, 592.6 MW, is the amount of load-shedding in the first island (RO). It results from the action of automatic under frequency load-shedding devices (first stage, 10% of load specified) in the Romanian EPS, when the frequency extremes during the initial period of the dynamic processes reached a value of 48.652 Hz. This value is below the first stage reaction value of 49.0 Hz (see Fig. 3). The value of 49.652 Hz is obtained according to the procedure outlined in [22], which, on the basis of a simple low-order model, gives a sufficiently accurate value of frequency, during the initial phase of its dynamic change.

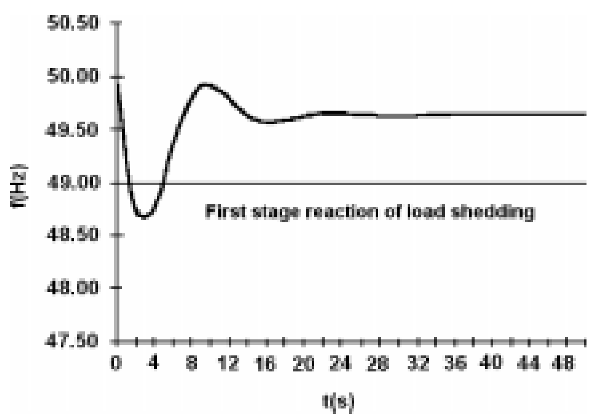

Fig. 3. Dynamic variation of frequency in island operation of Romanian EPS.

For these two islands and for the two types of load characteristics, the developed fast decoupled procedure (system of equations (12) and (13)) simultaneously determines the quasi- stationary state after the action of the islands, and, as illustrated in the following Table 2, does this very rapidly and efficiently (after only a few iterations for the desired accuracy of 0.0001 Hz and 0.1 MW i.e. Mvar). This table also gives the quasi-stationary frequency values (f_m, $m \in MI$) in the resulting island.

Table 2. The number of iterations and quasi-stationary frequency values (Hz); (a) constant active and reactive power; (b) active power is linear while reactive power is a quadratic function of the voltage; frequency dependency 0.02 p.u. /Hz; * action of underfrequency load-shedding is not taken into account

No.	Island	Load caracter.	Number of iteratins	f_m (Hz)
1	RO	(a)	6	49.819
		(b)	4	49.843
		(a)*	7	49.576
2	CS, FYROM, GR,AL	(a)	6	50.132
		(b)	4	50.138

The load-flows (MW/Mvar) on interconnective lines in the post-dynamic state, for the case when all loads are modeled as constant powers are given on Fig. 4.

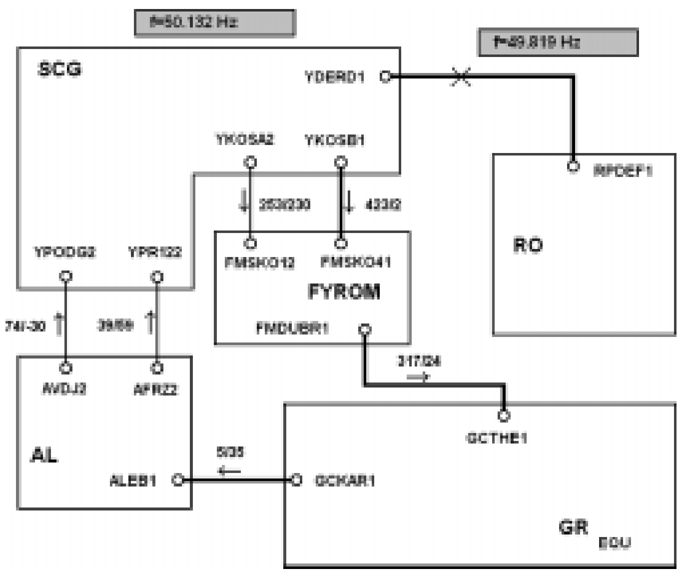

Fig. 4. Post-dynamic quasi-stationary state after the simultaneous outages of the 700 MW units in NPP Cernavoda (RO) and the 400 kV tie-lines Djerdap (SCG)-Portile de Fier (RO).

The ensuing analysis deals with the necessary dispatch actions on each of the islands. For instance, in the first island (RO), the total debalance of 507.4 MW (after load-shedding) would be compensated by a fast increase of the available power output from the HPP Portile de Fier from 750 to 1050 MW and HPP Lotru from 200 to 400 MW. After that, the new quasi-stationary state is obtained very rapidly (only in two iterations), with the frequency value of 49.992 Hz, e.g. very near the rated value, which is a logical consequence of the debalance compensation. However, in this island, for the case considered, the return of all loads to the initial level existing before the action of automatic under frequency load-shedding devices is not possible, because by an insufficient operating reserve in power plants.

This restoration of total load would be possible only after the full restoration of the interconnection considered. In the second island (SCG, FYROM, GR, AL), the amount of surplus would be compensated by rapidly reducing the power output from HPP Djerdap (SCG) and HPP B.Basta (SCG), and after the action of the existing automatic load-frequency control, the frequency and total tie-line power (SCG export 200 MW to GR) would regain the programmed values.

Therefore, after above mentioned necessary dispatch actions (naturally, many other scenarios are possible, for the same initial disturbance), which in practice reduced to only the corresponding correction of active power outputs from some generating units, the new quasi- stationary states in corresponding islands (applying the developed method) are obtained very simply and rapidly. In the case considered, the new frequency values would be 49.992 Hz and 50.002 Hz, respectively, i.e. in these conditions is possible very easily to do the full restoration of the interconnection considered.

5 Conclusions

The paper shows a method for the simultaneous analysis of post-dynamic quasi-stationary states in an arbitrary number of islands resulting from power system disintegration and the ensuing reintegration of the power system under consideration, whose practical and numerical efficiency is demonstrated on an example of an interconnection of real electric power systems.

The wide area of applicability of the developed method, which belongs to the category of analytical tools approach or sophisticated network analysis, can be seen in its capability to analyze post-dynamic quasi-stationary states of the power system divided into islands, to analyze effects of system automatic emergency and protection devices and a series of dispatch actions and, finally, to determine a satisfactory scenario for fast power system restoration in post dynamic states.

The characteristics of the presented method, incorporated into the corresponding environment, will be a significant aid to the dispatch services of electricity power boards for operational control, dispatcher training and especially for improving existing and developing new procedures for power system restoration.

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