DOI: 10.14621/ce.20160206

Enhancement of the Operational Security of the Kosovo Power System by applying N-1 Criterion of the Deterministic Methodology

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Abstract

This paper presents the application of the N-1 criterion in critical sections of the system as the deterministic approach in the planning methodology for the enhancement of its operational security. The deterministic approach is applied in order to establish the planning base that will provide for a secure, continuous and quality supply of power system consumers. The security of supply is determined by the Network Code also for havaric conditions respectively in cases of outages or loss of any of the essential elements of the full system configuration, transmission lines or substations/transformers. Irrespectively of whether occurring conditioned by faults, overloads, operator interventions or due to imposed changes of the system configurations.

This analysis and planning methodology for the enhancement of the operational security of the system by applying the deterministic approach respectively the N-1 respectively N-k approach is used in the Kosovo Power System (KPS) and its transmission system operator (TSO). It is widely applied also in the regional ones depending on the level of accuracy and reliability demanded by the respective analysis. It can and usually is augmented and complemented with state-of-the-art probabilistic-stochastic approaches few basic premises and practices of which are presented also in this paper.

Keywords: Power system planning methodology; Power system operational security; Deterministic approach; N-1 criterion

Article history: Received: 28 January 2016
Revised: 04 November 2016
Accepted: 08 November 2016

1. Introduction

The intense development of the contemporary electric energy market in the region and in Kosovo, imposes permanent new challenges to power system operators. Hence they are consequentially obliged to provide a much higher degree of security, quality, reliability and availability of supply and operation compatible with the conditions and provisions defined in respective Network Codes. The increasingly competitive environment of power system operators demands an increasingly efficient and flexible system operation, primarily from the point of view of security and availability of supply, both in quantitative or quality terms. Operational security and availability of supply capacities with the demanded quality of supply are determined meritorily by the operational system stability within the required framework of Network Codes. One of the principal methods for achieving these objectives in the KPS consists in the application of the deterministic planning methodology respectively in the application of the N-1 respectively N-k criterion.

The principal objective for the planning methodologies is the determination of the maximal levels of power flows through the elements of the power system. In view of this, the N-1 criterion is an essential technical criterion on basis of which the power system is to operate in such a flexible mode as to be able to withstand outages or unanticipated system interventions in any elements of the system such as transmission line, generator or power transformer. However, this should hold true with none of the power system elements being affected unacceptably negatively by overstepping as a consequence the Network Codes requirements. The application of this criterion has proved to provide fully solid indicators for the reliable assessment of the power system security of operation. It should be mentioned also that it does not, nor does it need to include in this the context of the technical i.e. emergency operation of the system the economic aspects of its operation.

In the recent period there has been a permanently increasing interest for the application of deterministic methodology by applying the n-1 criterion due to the credible and reliable results that the methodology provides in enhancing the security of operation of the system. As in the case of most regional system operators, the Kosovo TSO (KOSST- Kosovo Electricity Transmission, System and Market Operator) applies consistently the (N-1) criterion for the assessment and long-term enhancement of its system operation.

In this paper the deterministic methodology is elaborated by applying appropriate simulations of the system operation in relevant operational configurations. The program software applied for this purpose was the industrial/commercial scale power system software PSS/E. The objective of the analysis was to provide relevant, reliable and credible data for determining the optimal transmission system configuration that would provide for a high degree of system operational security, reliability and availability. In other words, to be able to provide continuous supply also in the cases of outages of its critical sections and/or elements that has a high probability of occurrence.

The relevant data obtained from the software simulation of the system consists of power system flows, levels of relative percentage load or overload levels of each element of the system, as well as voltage profile of the system. These data provide a solid base for the assessment and consequential planning methodology for the long-term enhancement of security, reliability and availability of the system operation as well as its further expansion.

2. The deterministic methodology and the application of the N-1 criterion

The security and reliability of power system operation is of essential importance for upholding the objective of continuous and quality supply of power system consumers. The operational security and reliability of the system is assessed on basis of the capability of the system to enable the continuous supply of all its consumers in within the quantitative and quality requirements as determined by the Network Code, in conditions of outages of any elements of the system, even in most critical ones. Enhancement of the operational security and reliability of the power systems can be determined in a very efficient manner by applying the deterministic methodology respectively by applying the N-1 criterion [1].

This criterion determines that the operational power transmission system security and reliability is provided for if the system is capable of withstanding in a safe, stable and flexible manner unexpected faults and outages or consequential major changes in the system configurations resulting from such disruptions. These faults and outages could affect any of its respective elements such as transmission lines or power transformers. But the system nevertheless must continue with the required quantitative and quality indicators of supply of its consumers compatible with the Network Code.

It should be mentioned in this context that the deterministic methodology does not account for the quantitative aspect of probability of incidence of such faults and/or outages that can endanger the normal and reliable system operation. This means that the deterministic methodology is applied and considered practically in critical high loaded conditions of the system operation, which in the elaborated case of the KPS means operational conditions with maximal i.e. peak anticipated load. In principle, the planning methodology of the Kosovo TSO /KOSST/ is such that the system should be upheld within the Network Code requirements during its entire operation for any given anticipated N-1 configuration .i.e. for any outage of any system element.

Within this framework the outage of any of the comprising elements of the power transmission system that might occur for whatever reason, may not cause:

- Overload of transmission lines/cables beyond their thermal limits;
- Overload of power transformers;
- Reduction of power supply capacity;
- Overstepping of the voltage profile requirements including their respective rate of change;
- Endangering transient and/or dynamic stability;

The deterministic planning methodology is applied by the Kosovo TSO as in many other countries worldwide.

The deterministic planning criteria uses N, (N-k) terminologies to describe the system configuration for which a system is planned , where ‘k’ is the number of elements out of the N-normal system configuration at any given time for the analyzed contingency due to the respective outage of its elements. These terms are defined as follows:

- (N) criterion denotes the Normal system configuration planned with all transmission power system elements in a satisfactory mode of operation.
- (N-k) criterion denotes the system configuration planned with all but k transmission system elements in a satisfactory mode of operation for any ‘k’ credible contingency resulting with outage of k number of system elements [2].

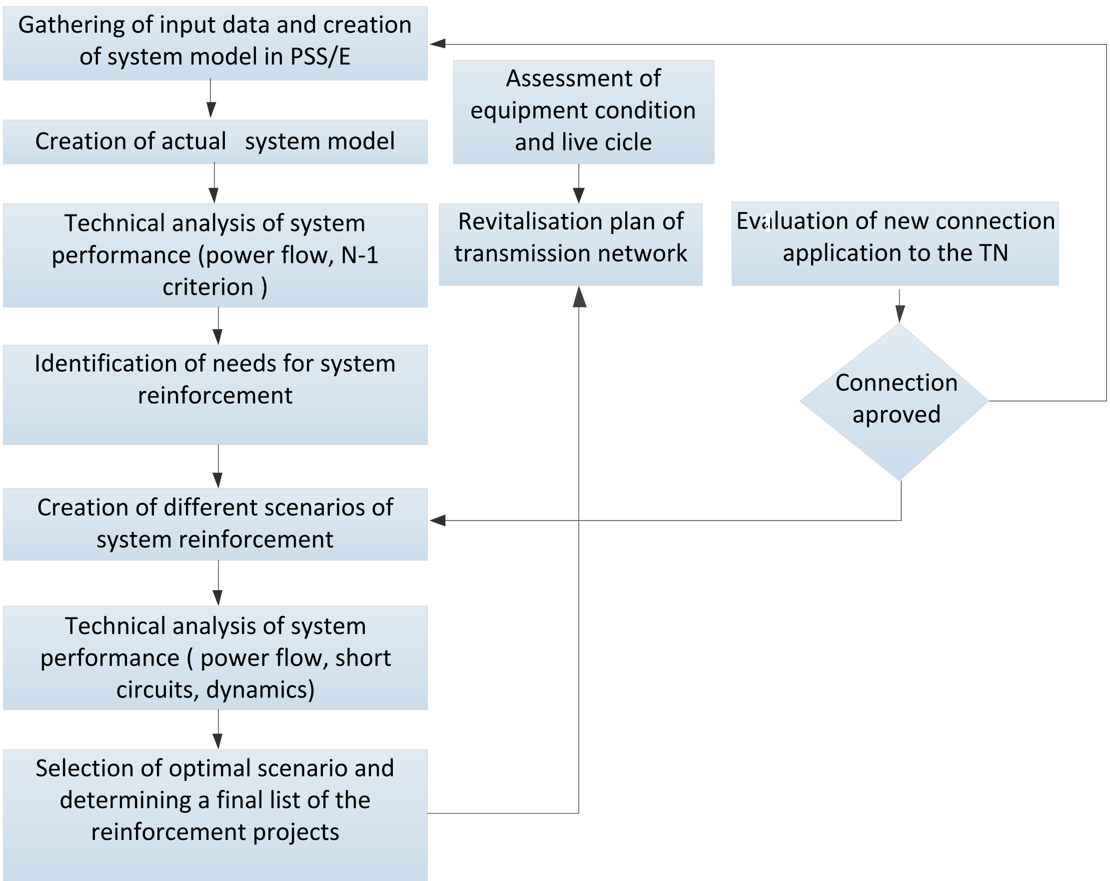

Figure 1. Algorithm of transmission planning methodology

The algorithm on Figure 1 shows a summarized schematic presentation of the transmission network planning methodology.

3. The planning methodology for the deterministic approach

The approach of the transmission network planning methodology consists of the following steps:

- Collection of input data (creation of the data base for network modeling network);
- Definition of different scenarios taking into account factors strengthening the development of generation, load, balanced power system exchanges, etc.;
- Creation of computer models of the network transmission compatible with PSS/E;
- Determination of plans for revitalizing existing system facilities and equipment as based on their anticipated life cycles;
- Identification of network constraints (N-1 simulations);
- Definition of the possibilities of network strengthening the network based on N-1 contingencies;
- Analysis of voltage profiles and system losses;
- Defining system reinforcement and expansion plans.

The basic principle upholding the security and reliability of the transmission power systems respectively their planning and development methodology consists of the necessity of fulfilling the system technical criteria as required by the Network Code for the Normal system configuration, but also for the N-1 system configuration. Furthermore these conditions have to be fulfilled even foremost demanding respectively most critical conditions of system operation.

For the N-1 criterion i.e. the single contingency criterion, the transmission system shall be designed to maintain operational reliability within the Network Code requirements for the N-1 configuration meaning the Normal configuration minus the loss/outage of any of its elements such as power line or transformer. N-1 is a common security standard in ENTSO/E. The single contingencies to be considered under an N-1 criterion are:

- Loss of a single transmission circuit
- Loss of a single generator
- Loss of a single bus section
- Loss of an interconnecting transformer

The loss of a system element could be either planned (as part of scheduled maintenance) or unplanned (as an unanticipated disruption fault event or intervention), either by inadvertent disconnection or as a consequence of the incidence of fault occurrence.

In other words, for an N-1 contingency that the system must maintain:

- TSO elements must operate within acceptable short term ratings during contingencies;
- - No load curtailment required to maintain N-1 security level for any operating condition;
- - Voltage quality provided within the Network Code requirements;
- - Cascading outages do not occur.

4. Application of the deterministic methodology for the elaborated case study

In this paper the case study subjected to the application of the deterministic methodology refers to the KPS operational security and reliability in its full transmission configuration as presented in Figure 2 more specifically in one of its critical sections as shown in Figure 3 below.

Simulation and the technical analysis of the performance of the system for a sequence of different cases in different time periods have been carried out with the respective software package programs of the PSS/E. The programming iterative package FNR (Fast Newton Raphson) Load Flow is applied for calculating the power flows and voltage profiles in the system, whereas for the calculation of the network reliability criterion the ACA-AC Contingency Solution integrated in the PSS/E is applied.

The deterministic methodology for the analysis of the operational security and reliability of the system respectively the application of the N-1 criterion consists in the necessity of the systems upholding its normal operating mode as required by the Network Code. This pertains to all times, in any given case of contingencies resulting in an outage of any of the elements of the system, power line or transformer, irrespective of the cause of the outage [3].

4.1. Case study N normal configuration operation

The results obtained from the system operation simulation for the case N i.e. for the Normal full

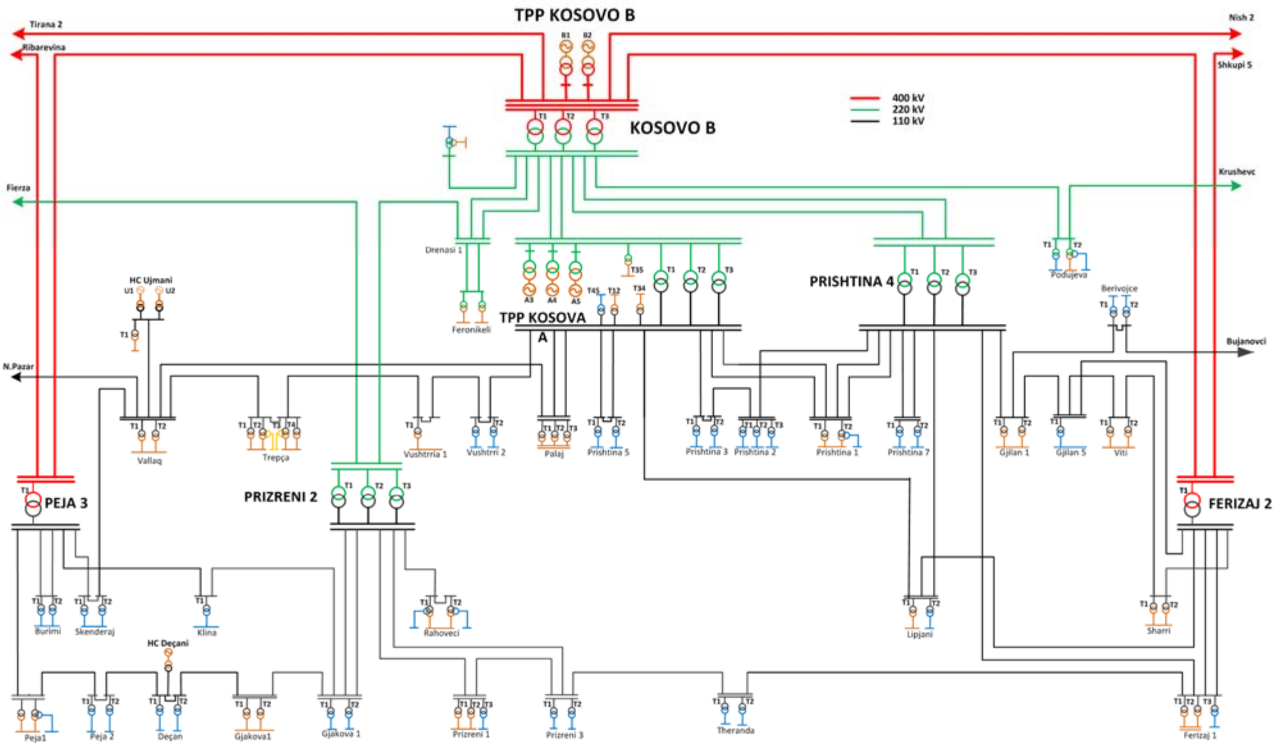

Figure 2. Actual single line representation of the Kosovo Power System

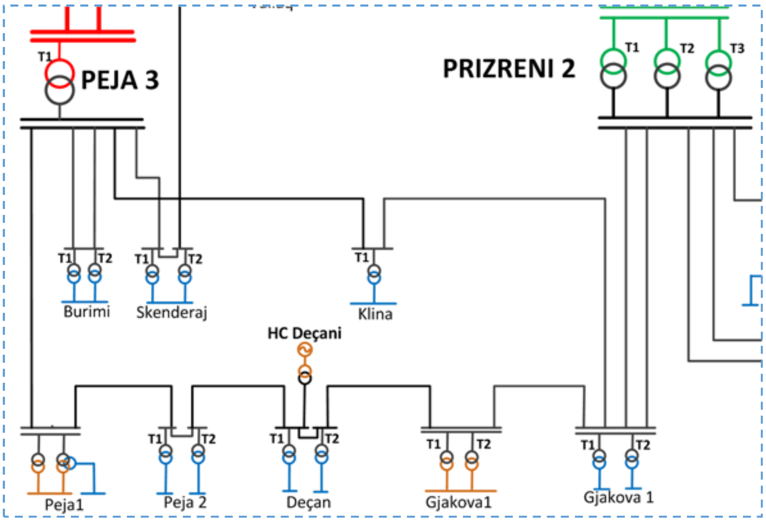

Figure 3. Case study section of the Kosovo Power System

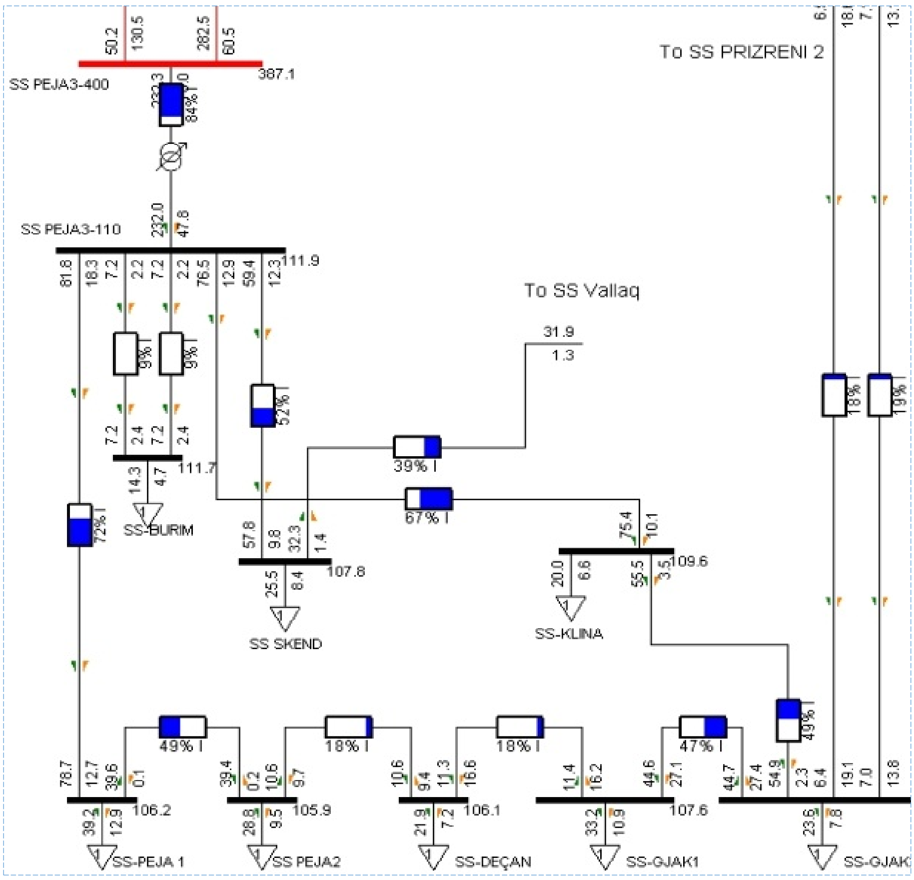

Figure 4. Case study N – Power flows, voltage profiles, relative system element loads

configuration of the system, provide the data for power flows and voltage profiles for each of the system buses as well as the relative percentage loads of each of the system elements for the entire system and for its peak load of 1.126 /MW/. The results have been graphically and numerically presented in Figure 4 for the analyzed critical section of the analyzed system focusing on its eastern section between the busbars of Peja-Gjakova-Prizren as shown in Figure 3. The relative percentage loads of each element of the system i.e. in every line and transformer are presented in graphical and numerical form in Figure 4.

Table 1: Case Study N – Percentage load of system elements/lines

110 kV lines	I_{therm} (%)
Peja3-Peja1	72
Peja3-Klina	67
Peja3-Skenderaj	52
Peja1-Peja2	49

It can be seen from Figure 4 that the relative percentage loads for the N-normal configuration case considered are well within the r Network Code requirements and not even remotely close to their respective thermal limits. Furthermore, the majority of the system elements stand amply in the safe domain of relatively lightly loaded levels.

However, in this context, it can be seen from the results shown in Table 1 that relatively high percentage load flow for the analyzed N case configuration have the line element Peja 1–Peja 3, as well as the transformer connected to buses Peja 3 – Peja 1 with 72% and 84% respectively. Consequentially the two referred elements are thus indicated to be potentially of critical importance for the system operational security. Hence between the two the critical element is to be found that has to be switched off for the purpose of simulating the element outage for the application of the deterministic methodology i.e. the N-1 criterion.

4.2. Case study N–1 configuration operation

From the results obtained from the analysis of the case study N, it can be concluded that the element that is clearly indicated to be considered and verified by applying the deterministic method respectively the N-1 criterion, is the outage of the power line Peja 1 – Peja 3. Therefore the system is re-configured with the outage of this line, respectively without this critical line and the simulation of the system operation is carried out. The results for the power flows, voltage profiles and the relative percentage loads of each elements of the system are then presented graphically and numerically as shown in Figure 5. It is obvious from the results presented in the figure that four lines of the N-1 system configuration exceed their respective relative load limits ie are overloaded beyond their thermal power limits. Clearly this comes about due to the outage of the referred line and consequential collapse of the two-way power supply caused by the outage.

It can be easily concluded from what is presented in this figure that line Gjakova 1 – Deçan exceeds its thermal limit with its 109% of the relative percentage load, while lines overloaded beyond or close to their respective thermal limits result to be also the lines Peja 3 – Klina with 101%, the line Klina – Gjakova 1 with 100% and the line Deçan – Peja 2 with 98%, which also stands above the thermal limit of 95% of the continuous power rating. In Table 2 are shown the relative overloads of these critical lines resulting from the power flows of the N-1 system configuration. From what has been presented above, it can be concluded that the application of the N-1 criterion with the outage of the referred line does not fulfill and uphold the security criteria as required by the Network Code.

Hence the evident conclusion is that the line would need to be electrically reinforced Furthermore not by enhancing its transmission capacity with increased conductor cross sections respectively their thermal power limits, but instead, with the construction of a parallel line Peja 1 – Peja 3. Preferably, providing for maximal power transmission capacity for the given voltage level. It can also be concluded from the above analysis that the outage of this line results with a seriously worsened voltage profile in this section of the system that is not compatible with the Network Code requirements. Furthermore, the voltage in the Peja 1 bus collapses to a value of 84.1 /kV/, followed closely with the voltage drop of the Peja 2 substation at only 89.8 /kV/. From what has been said above in the beginning of this analysis, it can be concluded that a relative (over)load of 109.2% occurs in the given N-1 system configuration in the line Gjakova 1 – Deqan. This situation can cause a trip cascading effect, respectively local black out when the relay protection trips the overloaded line Gjakova 1- Deqan.

Hence, of it can also be concluded that the application of the N-1 criterion in this configuration, that the outage of this line is also highly relevant for the upholding of the N-1 criterion i.e. for the operational security of the system. This is clearly the one case, alongside the case of potential contingency caused by the outage of the power transformer on the busbar Peja 3. Namely, from the analysis of the considered case N /normal configuration/ that has been already been indicated to be a potentially even more critical contingency.

It has been concluded also that network transformer voltage regulation would be insufficient to positively enough address and affect the network contingency resulting from an N–1 element outage. Otherwise should such alternative options of power generation adjustment and/or voltage control in the form of transformer tap changes, referred to frequently as optimizing measures, be sufficiently effective to correct the effects of the N–1 contingency, it would have presented a much more cost-effective solution to this type of contingencies. But such major N-1 configuration changes are normally addressed with power system

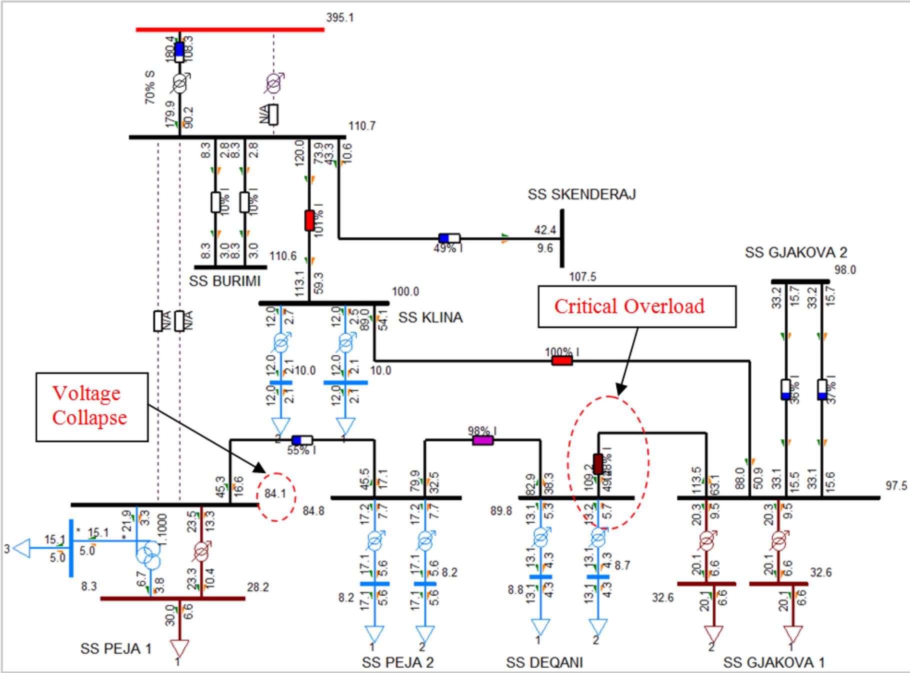

Figure 5. Case N-1 – Power flows, voltage profiles, relative system element loads

Table 2: Case N-1 – Percentage load of system elements/lines

Critical outage	Overloaded 110 kV lines	Ithrm (%)	Voltage (kV)	
110 kV line Peja3-Peja1	Deçani-Gjakova1	109	Peja1	84.1
	Peja3-Klina	101	Peja2	84.8
	Klina –Gjakova 1	100	Deqan	89.8
	Peja2- Deçan	98	Gjakova 1	97.5

construction measures, such as adding or enhancing system elements i.e. lines and/or substations as is presented in the next section.

In this context it should be said that the analysis carried out with the application of this method results in the conclusion that the N-1 criterion would not be fulfilled in either of these two cases considered. Therefore, both of these two elements i.e. the respective section of the transmission system should be electrically reinforced appropriately with additional power transmission capacity. It would be redundant and indeed superfluous to conclude additionally that N-k criterion with k>1 would be indicated for the further assessment of the system operation security and reliability [4-5].

4.3. Case study N+1 configuration operation

In the above presented analysis of the application of the deterministic approach it has been concluded that for the outage of the line Peja 1 – Peja3 the N-1 criterion cannot uphold the operational security of the system. Hence the referred line should be reinforced with a parallel line between the respective buses. Therefore in order to substantiate the conclusion of the necessity of line reinforcement in order to increase the transmission capacity with concrete operational simulation results, the case study has been analyzed in which the construction of a second i.e. of a parallel line between Peja1 and Peja 3 substations has been simulated. For the purposes of this analysis, the case has been labeled as Case N+1 Configuration and the results of the respective power flows, relative percentage loads of the system elements and the overall voltage profile of the system obtained by the simulation has been presented graphically and numerically as given below in Figure 6.

It can be concluded from the figure above that the transmission capacity reinforcement of this segment of the considered system with an additional parallel line to the existing one, which as a single line has proved to be critical and not being able to uphold the N-1 criterion, has proved to be efficient from the point of view of the system operational performance and security as it has enhanced its indicators well within the Network Code required ranges. More specifically, the resulting optimized power flows in the elements of the system have therefore resulted in a maximal percentage relative load which is low and does not exceed 59% of nominal load of the line Peja 2 – Peja 1. Whilst the other line relative percentage loads are still lower and stand in the range of relatively lightly loaded lines. Thus they provide for a high margin of security and an increased availability of the transmission capacities of this part of the system.

From the figure it can be seen that the voltage profile in the referred section of the system in this case is practically an optimal one with voltage deviation of 3-4% of Un and with a voltage that drops only 106 kV. Voltage increases in this case do not rise above 112.8 kV.

A chronological enhancement of the transmission capacities of the KPS for the N case and for the N-1 case as determined by the application of the deterministic methodology referring to the N-1 criterion for the forthcoming period, are within the framework of the respective long-term planning period KOSTT [3]. The respective anticipated transmission capacity development is presented in Figure 7.

Hence, based on the application of the N-1 criterion it can be concluded that the operational system security can be near-optimally enhanced with such an intervention of power network reinforcement by addition of a parallel line. This is consistent with long-term KPS development system planning [3]. This can be contested in somewhat relative terms, but not in essential ones, nor with any high probability of occurrence only from probabilistic and stochastic aspects of various comprising elements of the system and their component parts. Such effects that could potentially occur depending on respective component/equipment quality and duration of operation, conditions of system operation, meteorological conditions and other for which it should be mentioned that they have a limited incidence, frequency and gravity of occurrence. However, in certain sets of circumstances they might additionally negatively affect the system operational security.

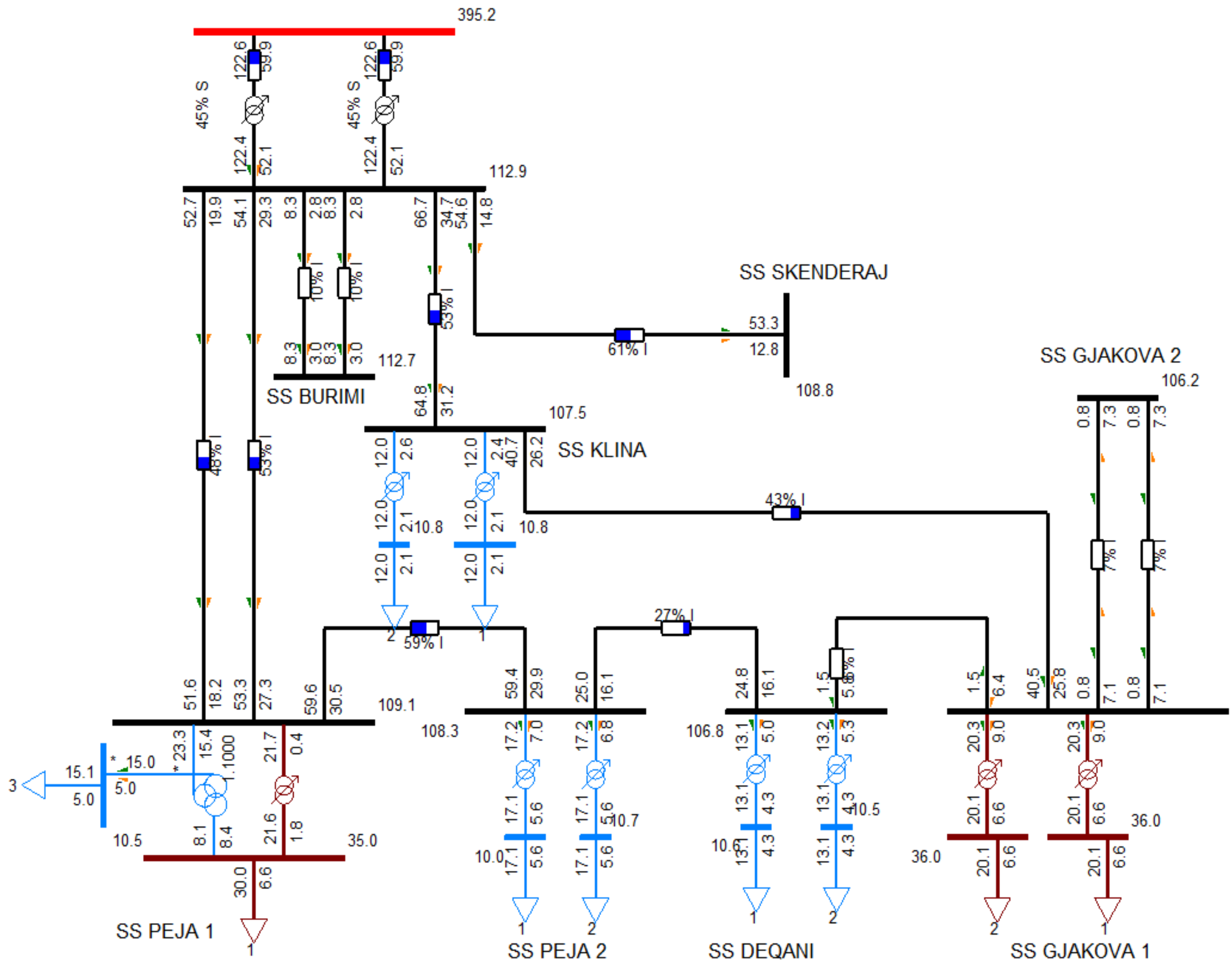

Figure 6. Case N+1 – Power flows, voltage profiles, relative system element loads

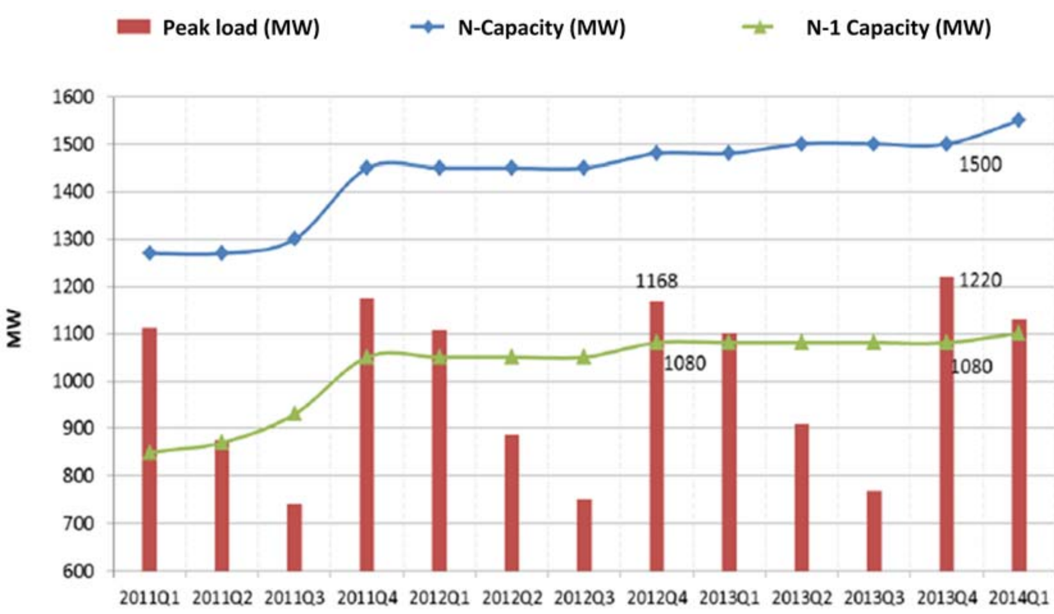

Figure 7. Chronological development of the KPS transmission capacities for N and N-1 configurations

5. Conclusions

Transmission power system operational security is an important study topic that has been researched widely and intensely in the recent years. Within this framework the deterministic methodology, the application and the observation of the N-1 criterion has proven to have decisive and meritory significance. The upholding of this criterion demands that the system be capable to flexibly withstand the outage or loss of any of its elements due to whatever cause of occurrence and to maintain its normal operational performance indicators within the Network Code requirements. In other words, the system should be able to accommodate its consequential mode of operation in a flexible manner, meaning by fulfilling all Network Code requirements. This should hold true for any arbitrary system configuration changes caused by the loss or outage of any of its elements, at any given time or in any operational conditions, including critically high load conditions. It should be mentioned in this context that the application of the deterministic methodology in the form of the N-1 criterion does not take into account the probabilistic and stochastic aspects of the incidence of occurrence.

With the application of the deterministic methodology respectively of the N-1 criterion for the considered case of the KPS, it has been provided for a near-optimal ie a very reliable system configuration within the framework of the long-term planning methodology of KOSST. Thus a solid operational performance is provided well within Network Code requirements. From what has been elaborated above, it can be concluded that the application of the deterministic methodology i.e. the N-1 criterion provides for a highly reliable long-term enhancement of the operational security of the system. Namely it provides for normal operational performance indicators also in the case of outage or loss of any element of the system, even of the critical ones. This includes power system operation even under critical load conditions accommodating in a flexible manner an outage or loss of any of its elements with an alternative power flow and operational reliability. Hence it can preclude bottle-neck critical phenomena in issues of transmission capacities/capabilities. Furthermore, without overloading system elements and risking operational security even in conditions of grave faults.

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