POWER SYSTEM NODAL RISK ASSESSMENT: CONCEPTS AND APPLICATIONS

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Summary

This paper discusses the concept of nodal risk, by characterizing a number of factors that may be utilized as useful indicators to the degree of importance of each power system node. The concepts of local and system-wide risk are proposed. A simplified and practical method is also developed for fast assessment of system nodal risk from the static point of view. A set of results is presented illustrating the method efficiency when applied to the Brazilian Southeast system.

KEY WORDS: nodal risk, system performance, multiple contingencies, static analysis

1. INTRODUCTION

Risk management is an important activity in the new institutional scenery on the Brazilian electric sector. It is known that despite being rare, multiple contingencies constitute a risk factor that requires special treatment. The March 11, 1999 disturbance in the South/Southeast/Center-West (S/SE/CW) Brazilian system provides a good picture of this type of event and its consequences. In general, multiple contingencies can involve a group of transmission lines, transformers, generators and other equipment that may be spread over a wide geographical region. From this perspective, a comprehensive analysis of the effect of any multiple contingencies in the system is essentially a problem with a huge combinatorial nature, not complying with an exhaustive analytical treatment (it is, par excellence, called a *transcomputational problem*). Moreover, simultaneity is a concept that also lacks precise specification, since, in practice, it is almost always possible to identify a certain sequence of events, with infinitesimal time lags. In fact, simultaneity is an abstraction.

Given the complexity of the problem, a feasible alternative is to evaluate just a subset of the probable contingencies. The object of this analysis should be the simultaneous outages associated with the transmission lines connected to each substation of the system.

This approach makes possible to identify the more critical substations from a static analysis point of view. Those buses will then be submitted to a dynamic behavior analysis, with detailed representation of the equipment and associated controllers [1]. In this context, this paper will be restricted to the treatment of simultaneous *multiple nodal contingencies* (i.e. total or partial removal of the elements connected to a certain node) in substations of an electric system. It is presented an application of the proposed methodology, taking the S/SE/CW subsystem as a basis. Emphasis is given to the analysis of substations at voltage levels equal or superior to 138 kV.

2. NODAL RISK ESTIMATES

The concept of nodal risk, from a system security perspective, is associated with the operational and topological conditions to which a certain substation is submitted. A key factor to establish this concept refers to the poor performance that both equipment and protection may present in response to a local disturbance. This may cause undesirable interactions among special protection schemes associated with a particular bus or neighboring substations. In consequence, there is a need for guidelines to determine the "*level of impact*" of the analyzed substations so they can be classified. This classification would create means to identify those substations that require special attention and a more detailed analysis, given their ability to impact system security. Several factors can contribute to define the risk level associated with the system nodes. To each of these factors could be assigned a *significant weight*, based on practical operative assumptions. Initially it is convenient to characterize the risk as ***intrinsic*** and ***system-wide***. The *intrinsic* risk is of fundamentally *local* nature. The *system-wide* risk translates the impact level of certain substations on the operation (continuity, adequacy and security) of the system as a whole. Some of the factors that contribute to the *intrinsic risk* of the substations are shown as follows.

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- *(i)* **Bus arrangement**: this factor can be quantified through a heuristic function dependent on the number of switches, circuit breakers, physical arrangement of buses and other typical substation equipment (*feasible weighting estimate*);
- *(ii)* **Protection scheme:** this factor is directly associated with the type of protection scheme adopted in the substation (*feasible weighting estimate*);
- *(iii)* **Voltage level:** the importance of the node should have direct relationship with the higher voltage level (*obvious weighting*);
- *(iv)* **Connectivity level:** this factor would be indicative of the number of branches linked to the node. The larger the number of connected transmission lines to a given node, the greater the connectivity level and consequently, greater its relative importance (*obvious weighting*);
- *(v)* **Environmental:** this factor indicates the exposure level of the substation to some environmental factors such as: thunderstorms, wind, pollution, wild animals, vegetation, floods, erosion, natural catastrophes, etc. (*feasible weighting estimate*);
- *(vi)* **Other local factors:** other factors of local nature, with distinct degrees of difficulty of quantitative evaluation, can still be considered, including: *probabilistic risk of multiple contingency events in the node, political-social impact due to failures in the substation, systematic maintenance, degree of technological obsolescence, automation level, volume and complexity of the routine switchings, aging and degeneration degree, design limitations, exposure to air traffic routes, theft, pillaging and sabotage, etc.*

Some of the factors of interest for *system-wide risk* are as follows:

- *(vii)* **Degree of static violation of system continuity and adequacy considering multiple contingencies in the substation:** this factor indicates the quality of the system static operation point under multiple contingencies of the elements connected to the substation under interest. The *continuity* is associated with the amount of necessary load shedding to restore feasibility to the new operation point, while the *adequacy* is concerned with the operational constraints of reactive power, line and transformer loading (overloads) and voltage (under and overvoltage). Such weighting is feasible to estimate;
- *(viii)* **Dynamic stability:** this factor is related to the system strength, facing dynamic contingencies associated with the elements connected to the substation (*feasible weighting estimate*);
- *(ix)* **Type of the substation:** the nodes may be of the following type: generation, load, and transformation or sectioning. The attribution of weights for each type depends on the specific system topology (*proposition of non-trivial weighting, being dependent of the system complexity*);
- *(x)* **Average power flow:** is a factor of great relevance whose determination would depend on the incoming power flows (active, reactive, apparent) to the node during a certain observation period. The importance of the node would have direct relationship to the values of those power flows (*feasible weighting estimate*);
- *(xi)* **Flowing currents during short-circuits:** this factor can be a useful indicative of the importance that a node renders to the system when disturbances occur (*feasible weighting estimate*).

3. CONVENTIONAL IDENTIFICATION OF CRITICAL NODES

Several important substations of the S/SE/CW system have already been classified [1] according to a straightforward method of increasing importance according to the level of *intrinsic risk*. This method is based on the evaluation of the *physical arrangement of buses* (*see item **i**, Section 2*) and *the local protection scheme* (*see item **ii***). Table 1 depicts the classification criteria regarding the *intrinsic risk*, which were adopted in [1].

Table 1 – Classification of Intrinsic Risk of Substations [1]

Type	Characteristics
A	*Local Robustness*
B	*Intermediate Situation (Higher)*
C	*Intermediate Situation (Lower)*
D	*Local Fragility*

The classification **D** was applied to substations whose bus arrangement and/or protection schemes are less capable of constraining the impact of locally originated faults. This would render to the system a greater risk of possible cascaded tripping and collapse. Conversely, the substations with classification **A** would have appropriate configurations that present a minimum risk of causing extreme contingencies.

From the point of view of *system-wide risk*, it was performed an analysis of global dynamic behavior (*see item **viii** Section 2*). The complete outage of the substation under analysis was simulated [1], neglecting the action of emergency schemes or any other protection device. The heavy load configuration of the S/SE/CW system for June 1999 was studied. The *system-wide risk* evaluation had its focus on the buses with voltage levels equal or higher than 345 kV, to which line-to-ground faults were applied, followed by the opening of all the incoming elements. Some special scenarios of light or medium loading, were also considered. Regarding the system-wide analysis, it was adopted the criteria for qualitative classification shown in Table 2. The combined use of the *intrinsic* and *system-wide* results led to the development of the so-called ***Network Security Matrix*** (***NSM***), originally presented in [1] and reproduced in Figure 1. The NSM classifies several substations of the S/SE/CW system according to their associated risks.

Table 2 – Classification of System-Wide Risk of Substations [1]

Type	Characteristics
P1	*Multiple Contingency causes **electromechanical instability or accentuated voltage depression***
P2	*Multiple Contingency causes **stable or marginally stable** behavior. Possibility of starting a cascaded tripping process followed by voltage collapse.*
P3	*Multiple Contingency causes **stable behavior**. Damaging effects are not detected on the system. It is recommended the **investigation of other load scenarios** (amount, composition and modeling), **types of faults and detailed modeling**.*
P4	*Multiple Contingency causes **stable behavior**, without any serious consequence to the system*

	S1 (D)	S2 (B/C)	S3 (A)
P1	Bauru 440 Ilha Solteira 440	Grajaú 500 Adrianópolis 345 Samambaia 345 Bandeirantes 345 Brasília Sul 345 Itumbiara 345 Baixada 345 Interlagos 345	Foz do Iguaçu 750 Ivaiporã 750 Itaberá 750 Tijuco Preto 750 Tijuco Preto 500 Adrianópolis 500 Angra 500 C. Paulista 500 Itumbiara 500 Serra da Mesa 500 São José 500 Samambaia 500 Tijuco Preto 345 Ibiúna 345 Jaguara 500 Neves 500 São Simão 500 Emborcação 500 Areia 500 Curitiba 500 Blumenau 500 Gravataí 500 Ivaiporã 500 Itaipu 500 Água Vermelha 440 Araraquara 440
P2 / P3	Cabreúva 440 Jupiá 440	G.B. Munhoz 500 Guarulhos 345 Furnas 345 P. Caldas 345 L.C. Barreto 345 Campinas 345 Jacarepaguá 345 Nordeste 345 Jaguara 345 Pimenta 345	Araraquara 500 Campinas 500 Marimbondo 500 P. Caldas 500 Itá 500 Campos Novos 500 Salto Santiago 500 Salto Segredo 500 Mesquita 500 Taubaté 500 Água Vermelha 500 Assis 440 Embuguaçu 440 Santa Bárbara 440 Santo Ângelo 440
P4		Capivara 440 Itapeti 345 V. Grande 345 Barreiro 345 Taquaril 345 Corumbá 345 P. Colômbia 345	Nova Ponte 500 São Gotardo 500 Salto Caxias 500 Taubaté 440 Três Irmãos 440 Bom Jardim 440 Sumaré 440 Neves 345 Embuguaçu 345

Figure 1: Network Security Matrix (NSM) Determined for the South/Southeast/Central-West System

4. EXPEDITIOUS CHECKING OF NODAL RISK

The computation of the NSM involves a rigorous analysis, which demands a remarkable effort from the specialists. Aiming at reducing this effort, an approximate but expeditious procedure was proposed to allow a preliminary evaluation of the levels of nodal risk in a generic system. In addition to the items ***(i)*** and ***(ii)***, described in *Section 2*, this procedure enhances the analysis of nodal risk dealing with the system-related item ***(vii)***. The methodology involves the processing of the NH2 program [2], which was specially prepared to simulate multiple nodal contingencies, i.e., those involved with the removal of all the elements connected to a given node of the system. From the simulation of contingencies in a number of buses, it is possible to quantify the effects of each bus on the system, based on the information associated with the new operating point. These informations are: *amount of load shedding needed to return to solvability, violation of the permitted voltage limits in buses, violation of loading limits in lines and transformers, and operation of generators on their reactive power limits.*

5. HIPOTHESES FOR PROCESSING

5.1 Analyzed Configurations: the systematic analysis is restricted to multiple events occurring in the S/SE/CW system configuration for June 1999, heavy load (complete Brazilian network with 2317 buses and 3362 lines, including the North-South interconnection and the N/NE system), from now on designated as **base-case**. This configuration considers a total dispatched generation in the Brazilian network of 54 650 MW and a load of 40 482 MW in the S/SE/CW system. It is interesting to observe that, in the **base-case,** the Angra I nuclear plant delivers 620 MW, the N-S interconnection supplies 655 MW to the Southeast and the Itaipu plant is generating 11 160 MW.

5.2 Simulated events: the static behavior of the system was studied in response to multiple nodal contingencies, which are supposed to result in major collapses. The analysis of additional single contingencies is beyond the scope of this investigation. Although the total or partial removal of incoming elements to the node in question may be considered as a multiple contingency, the analysis has focused only on total outages.

6. IMPACT OF MULTIPLE NODAL CONTINGENCIES

A modified version of the NH2 program was used for the static simulation of nodal contingencies, consisting of the removal of all lines connected to the node under analysis. A total of 1135 nodes was analyzed in the S/SE/CW system. A sample of the obtained results is presented in Table 3, depicting the worst operational violations caused by the applied nodal contingencies. Column (2) displays the load shedding which were needed to establish the system solvability. Columns (3) to (5) quantify the violations caused by each multiple outage. Taking as an example the complete removal of the node AREIA----525, it may be observed that the static solution of the system was obtained after a load shedding of 2001 MW. Moreover, 83 line flow violations and 92 voltage violations were observed. This contingency forced 19 generators to operate at their reactive power limits. It should be remarked that, after the nodal contingency associated with some substations (see Table 4), a static solution could not be found. These cases need to be treated by more detailed analysis. Most buses in this situation are placed in the light gray blocks of the NSM. It is important to emphasize that the static operational feasibility of pre and post-disturbance operating points does not imply that the dynamic trajectory between these states is possible.

Table 3 – Consequences of Multiple Nodal Contingencies

(1) Bus	(2) Load Shedding (MW)	(3) Bus Voltage Violations	(4) Gen. on Reactive Limits	(5) Circuit Flow Violations
AREIA----525	2001	92	19	83
GRAVATAI-230	1179.5	63	15	86
CURITIBA-525	1054.6	45	20	86
CINDUS---230	564.4	54	13	90
INTERL---345	472	11	20	81
B.SUL----138	466.9	22	13	78
CURITIBA-230	440.3	66	10	83
JAGUARA--500	423.3	18	32	84
CNOVOS---525	385.2	71	20	73
NEVES----500	373.9	29	18	86
ITA------525	328	35	25	72
B.SUL----345	302.2	34	14	74
ADRIANO--345	236.9	85	10	88
SSANTIAG-525	223.2	30	34	78
CINDUS---138	220.5	10	14	78
CAMPOS---345	177.3	60	15	87
TMARIAS--345	154.9	3	20	80
XAVANTES-230	144.5	19	18	73
BLUMENAU-230	135.6	60	19	88
SOSORIO--230	130.3	90	13	83
BNORTE 138	129.9	15	12	84
ADRIANO--500	128.1	46	38	80

Table 4 – Cases without Static Solution

Bus	Classification According to NSM	
F.IGUACU-765	P1, A	LtGr
IVAIPORA-765	P1, A	LtGr
ITABERA--765	P1, A	LtGr
T.PRETO--765	P1, A	LtGr
IBIUNA---345	P1, A	LtGr
C.PAULIS-500	P1, A	LtGr
SAMAMBAI-500	P1, A	LtGr
SAMAMBAI-345	P1, B/C	DkGr
EMBORCAC-500	P1, A	LtGr
MESQUITA-230		
MASCAR.--138		
ITAIPU60-500	P1, A	LtGr
GRAVATAI-525	P1, A	LtGr
IVAIPOR-E525	P1, A	LtGr
PFUNDO---230		
JARAGUA--138		
ENTR.WEG-138		

7. INDEX OF SYSTEM-WIDE SEVERITY

The quantitative evaluation of nodal contingencies is a subject of great interest. For this purpose, Table 5 gives normalized information of *severity*, which were developed according to the system effects depicted in Table 3: voltage violations, generators operating at their reactive power limits and line flow violations. Such information was composed taking into consideration, for each one of the nodal contingencies, the sum of the percent violation for each observed effect. A weighting factor based on the voltage level where the effect is measured was adopted. Therefore, columns "*Rank_V*", "*Rank_Q*" and "*Rank_F*" contain the normalized vectors with the obtained severity indices for the three effects, in regard to the operational adequacy issues. It may be observed that the nodal contingency in Gravataí 230 kV is the most severe from the point of view of voltage constraints. In the same way, the contingencies in Bauru 440 kV and Ilha Solteira 440 kV are shown to be most critical considering the reactive power limits and line power flow, respectively. The column "*Sum*" displays the global severity measure for each nodal contingency: the algebraic summation of the ranks associated with the three effects. Table 5 is then suitably sorted starting in a decreasing sequence of the 30 largest values of the column "*Sum*". Different weighting factors can be assigned to these three effects, to compose the global classification.

Table 5 - Adequacy-based Severity Evaluation

Bus	Rank_V	Rank_Q	Rank_F	Sum
GRAVATAI-230	**1.0000**	0.2204	0.9664	2.1867
BAURU----440	0.1213	**1.0000**	0.6309	1.7522
IVAIPORA-525	0.4028	0.5618	0.6346	1.5992
T.PRETO--500	0.0542	0.6332	0.6162	1.3036
AREIA----525	0.6593	0.2119	0.4315	1.3028
ITAUBA---230	0.5966	0.3569	0.3181	1.2716
ITA------525	0.5226	0.4023	0.3399	1.2648
ITA-TP-1-765	0.0666	0.5353	0.6607	1.2627
ITA-TP-2-765	0.0660	0.5353	0.6601	1.2614
CNOVOS---525	0.6948	0.2371	0.3127	1.2446
CINDUS---230	0.6337	0.1435	0.4277	1.2049
FURNAS---345	0.0607	0.6445	0.4778	1.1831
SOSORIO--230	0.5032	0.2646	0.4129	1.1808
ANGRA----500	0.1154	0.5923	0.4588	1.1665
CURITIBA-525	0.3273	0.3273	0.5110	1.1656
IV-FOZ-3-765	0.0505	0.7167	0.3861	1.1533
IV-FOZ-1-765	0.0471	0.7134	0.3877	1.1481
IV-FOZ-2-765	0.0482	0.7134	0.3865	1.1481
ADRIANO--345	0.5761	0.1037	0.4540	1.1338
ARARAQUA-440	0.0389	0.5929	0.4950	1.1268
IV-ITA-1-765	0.0493	0.4375	0.6347	1.1215
IV-ITA-2-765	0.0493	0.4375	0.6340	1.1208
SSANTIAG-525	0.2678	0.5088	0.3425	1.1190
T.PRETO--345	0.0556	0.4666	0.5947	1.1169
ITUTINGA-345	0.0660	0.4812	0.5655	1.1127
ISOLTEIRA440	0.0350	0.0774	**1.0000**	1.1124
AREIA----230	0.2493	0.3572	0.4857	1.0922
GBMUNHOZ-525	0.1841	0.4790	0.4251	1.0881
MARIMBON-500	0.0371	0.5261	0.5111	1.0743
ADRIANO--500	0.0634	0.4999	0.4783	1.0416

Another information to be considered in the classification of system-wide risk refers to the load shedding amounts determined by the interior-point algorithm [2] to converge to the solution of some nodal contingencies. A sample of this information, which is related to the supply continuity, is given in Table 6. The amounts of load shedding (L.S.) are expressed both in MW and in per unit (p.u.), considering the total load of the S/SE/CW system (40 482 MW) as base.

Table 6 – Load Shedding Amounts

Bus	L.S. (MW)	L.S. (p.u.)
AREIA----525	2001.0	0.0489
GRAVATAI-230	1179.5	0.0288
CURITIBA-525	1054.6	0.0258
CINDUS---230	564.4	0.0138
INTERL---345	472.0	0.0115
B.SUL----138	466.9	0.0114
CURITIBA-230	440.3	0.0108
JAGUARA--500	423.3	0.0103
CNOVOS---525	385.2	0.0094
NEVES----500	373.9	0.0091
ITA------525	328.0	0.0080
B.SUL----345	302.2	0.0074
ADRIANO--345	236.9	0.0058
SSANTIAG-525	223.2	0.0055
CINDUS---138	220.5	0.0054
CAMPOS---345	177.3	0.0043
TMARIAS--345	154.9	0.0038
XAVANTES-230	144.5	0.0035
BLUMENAU-230	135.6	0.0033
SOSORIO--230	130.3	0.0032
BNORTE 138	129.9	0.0032
ADRIANO--500	128.1	0.0031

It shall be noticed that it is not an easy task to identify the correct relative importance of the load shedding over the other effects (generators on their reactive power limits and violations of voltages and line flows). This should be done in order to render sense to the composition of information needed to organize the new global classification. In an ideal environment, in which all data are made available, the relative weight of load shedding should be estimated from the cost of supply interruption. Moreover, the other three effects should be weighted by the cost for losses (constraint of voltage and line flows), shortening of equipment life span (line flows and reactive generation), maintenance (reactive generation), etc. For the purpose of this paper, in order to lessen the difficulty to work out these data, an exercise will be undertaken in which there will be a specific weighting (or penalty) for load shedding. Since this operational measure is highly undesirable, its cost was considered to be *ten times* greater than the one assigned to the constraints of the three adequacy-based effects. The product of this cost and the amount of load shedding in p.u. (Table 6), describes the load shedding rank which is summed up to the global index of severity shown in Table 5. The result of the new classification is defined as the *Index of System-Wide Severity* (ISS), which is presented in Table 7 for the 70 most critical substations.

Table 7 – Nodal Risk Estimates via ISS
(70 most critical substations)

Bus	ISS	Classification According to NSM	
GRAVATAI-230	2.4748		
AREIA----525	1.7914	P1, A	LtGr
BAURU----440	1.7522	P1, D	DkGr
IVAIPORA-525	1.6137	P1, A	LtGr
CURITIBA-525	1.4232	P1, A	LtGr
ITA------525	1.3449	P2/P3, A	LtGr
CINDUS---230	1.3427		
CNOVOS---525	1.3387	P2/P3, A	LtGr
T.PRETO--500	1.3036	P1, A	LtGr
ITAUBA---230	1.2847		
ITA-TP-1-765	1.2627		
ITA-TP-2-765	1.2614		
SOSORIO--230	1.2126		
ADRIANO--345	1.1917	P1, B/C	DkGr
FURNAS---345	1.1848	P2/P3, B/C	DkGr
SSANTIAG-525	1.1736	P2/P3, A	LtGr
ANGRA----500	1.1665	P1, A	LtGr
IV-FOZ-3-765	1.1533		
IV-FOZ-1-765	1.1481		
IV-FOZ-2-765	1.1481		
ARARAQUA-440	1.1268	P1, A	LtGr
IV-ITA-1-765	1.1215		
IV-ITA-2-765	1.1208		
ISOLTEIRA440	1.1185	P1, D	DkGr
T.PRETO--345	1.1169	P1, A	LtGr
ITUTINGA-345	1.1127		
AREIA----230	1.0922		
GBMUNHOZ-525	1.0881	P2/P3, B/C	DkGr
MARIMBON-500	1.0743	P2/P3, A	LtGr
ADRIANO--500	1.0729	P1, A	LtGr
BLUMENAU-525	1.0402	P1, A	LtGr
ARARAQUA-500	1.0393	P2/P3, A	LtGr
CABREUVA-440	1.0085	P2/P3, D	DkGr
AVM440	0.9848	P1, A	LtGr
CURITIBA-230	0.9808		
INTERL---345	0.9584	P1, B/C	DkGr
JAGUARA--500	0.9509	P1, A	LtGr
CAMPOS---345	0.9465		
GRAJAU---500	0.9403	P1, B/C	DkGr
S.JOSE---500	0.9337	P1, A	LtGr
ITUMBIARA500	0.9273	P1, A	LtGr
PITANGA--138	0.9211		
BLUMENAU-230	0.9210		
VITORIA--138	0.9142		
VITORIA--345	0.8980		
B.SUL----345	0.8762	P1, B/C	DkGr
CASCAVEL-230	0.8730		
P.CALDAS-345	0.8728	P2/P3, B/C	DkGr
SBARBARA-440	0.8686	P2/P3, A	LtGr
SBARBARA-138	0.8624		
SSEGREDO-525	0.8623	P2/P3, A	LtGr
PROMISSAO138	0.8523		
NEVES----500	0.8463	P1, A	LtGr
SGONCALO-500	0.8301		
LONDRINA-525	0.8210		
STOANGELO440	0.8135	P2/P3, A	LtGr
RIBPRETO-440	0.8082		
ASSIS----440	0.8068	P2/P3, A	LtGr
JUPIA----440	0.8061	P2/P3, D	DkGr
GRAJAU---138	0.8036		
B.SUL----138	0.7986		
GPARIGOT-230	0.7928		
SSIMAO---500	0.7900	P1, A	LtGr
BANDEIR--230	0.7881		
LBARRETO-345	0.7841	P2/P3, B/C	DkGr
BAIXADA--345	0.7784	P1, B/C	DkGr
CAMPINAS-500	0.7782	P2/P3, A	LtGr
AVM500	0.7767	P2/P3, A	LtGr
BAURU----138	0.7741		
MMIRIM-3-440	0.7740		

8. VALIDATION

It should be noticed that most of the substations in the network security matrix of Figure 1 also show high levels of system-wide severity (ISS), as depicted by the two last columns on the right of Table 7. However, some substations detected as critical in the NSM have shown reduced ISS values. Such substations are depicted in Table 8. On the other hand, some substations with high ISS were not identified as critical in the NSM evaluation [1]. Further investigation should be carried out on these cases.

Table 8 – Nodes of NSM with Low ISS Values

Bus	ISS	Classification According to NSM	
TAQUARIL 345	0.67	P4, B/C	Wt
JACAREPAGUÁ 345	0.66	P2/P3, B/C	DkGr
EMBUGUAÇU 440	0.66	P2/P3, A	LtGr
SUMARÉ 440	0.65	P4, A	Wt
EMBUGUAÇU 345	0.64	P4, A	Wt
BOM JARDIM 440	0.64	P4, A	Wt
TAUBATÉ 440	0.63	P4, A	Wt
CORUMBÁ 345	0.62	P4, B/C	Wt
NORDESTE 345	0.60	P2/P3, B/C	DkGr
ITUMBIARA 345	0.57	P1, B/C	DkGr
S. DA MESA 500	0.37	P1, A	LtGr

Figure 2 illustrates the suitability of the proposed ISS method to the identification of the critical buses which were previously pointed out by the NSM. It is interesting to observe that, in the 50 buses with highest ISS, almost 45.5 % of the buses of the blocks that mean greater risk (in dark gray) of NSM and 46.3 % of the buses within the blocks of moderate risk (in light gray) were identified. Not a single bus of the blocks of minimum risk (in white) has been identified for the first 50 entries in the ISS. Extending the *x-axis* range to the 100 greatest ISS entries, it is possible to identify 72.7 % of the buses of the blocks in dark gray of NSM, 68.3 % of the buses of the blocks in light gray and 25 % of the buses of the blocks in white. In 200 buses classified according to ISS, it may be noticed a saturation characteristic, resulting in the maintenance of the index for the blocks in light gray and in a total of 81.8 % and 62.5 % for the blocks in dark gray and white, respectively. The final composition, which will result in the totality of buses analyzed by NSM, considers the information of the cases which were not convergent by the ISS method (Table 4) and the cases that were classified with values less than 0.67 for this index (Table 8).

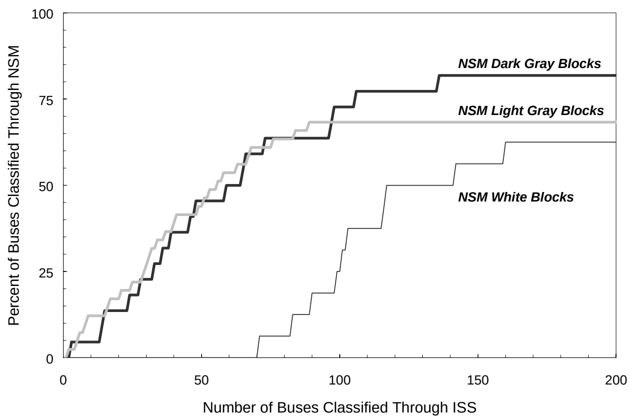

Figure 2 – Relation between ISS and NSM

Therefore, the proposed method, based on static analysis of contingencies, is capable of giving a good indication of the severity associated with nodal contingencies. Naturally, the procedure involved in the determination of the NSM, since it considers both the dynamic performance of the system and the analysis of the substation arrangement, renders greater precision to the final information. Conversely, the calculation of the ISS offers advantages for the systematization of studies, since its processing is very fast.

Besides the presented results, the procedure to determine the index of system-wide severity was also applied to different operative scenarios. Four distinct cases were considered, playing with the combinations involving the system loading and hydrological regime of the Paranaíba river. The results were also adequate demonstrating the suitability of proposed methodology for expeditious investigations.

9. CONCLUSION

This paper discussed a computationally efficient method for identifying the level of system-wide nodal risk. This methodology is useful for generating candidate scenarios for further analysis of electromechanical stability in the presence of multiple contingencies. The models of special protection schemes must be represented in these dynamic studies.

It is recommended that the suggested scenarios (contingencies in substations listed in Tables 7 and 8) are evaluated from the point of view of dynamic robustness.

The investigation of the substations with a high level of ISS which were not identified as being critical in the Network Security Matrix is particularly recommended. It is also recommended that the proposed methodology be routinely tested observing its evolution, improvement and performance evaluation under other operative conditions not studied in this work.

10. REFERENCES

[1] Joint Committee GCOI/ELETROBRÁS/CEPEL/ONS, Identification of Critical Substations of the Interconnected Brazilian System, Regarding to Multiple Outages, Report 1, Executive Summary, Rio de Janeiro, April 30, 1999 (in Portuguese).

[2] A.C.G. Melo, J.C.O. Mello, A.M. Oliveira, C.R.R. Dornellas, S. Granville, J.O. Soto, R.M. Azevedo, G.C. Oliveira, S.P. Romero, R.N.Fontoura Filho, "Probabilistic Analysis in Power System Performance Evaluation: New Developments in the NH2 Model", *Proceedings of the VI SEPOPE*, Salvador, Brazil, May 1998.