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EVALUATION OF THE STABILITY RESERVE OF TRANSELECTRICA'S TRANSMISSION SYSTEM BY USING QUICKSTAB PROFESSIONAL

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Abstract This paper describes the utilization of QuickStab® Professional to compute the steady-state stability reserve of the National Electric System (SEN) as required in system dispatching and operations planning. Used since early 2003, this application demonstrated its usefulness both in terms of quality of the results and computational speed, required for fast and reliable on-line decision making, and ease of interpretation of the results, i.e., the ability to see how far is the transmission network from system conditions where a blackout might occur without having to interpret large amounts of information and to perform complex data analysis chores. Theoretical and practical aspects, as well as actual case studies, are also reviewed and analyzed. The approach and results presented herein are particularly relevant in the aftermath of the wave of blackouts that affected utilities in US, UK and mainland Europe in 2003, and point to an application that can help system dispatchers and reliability engineers foresee whether the transmission loading progresses, or is projected to progress, beyond the operating reliability limit.

Index Terms**:** open access transmission, maximum loadability, energy management systems, independent system operators.

INTRODUCTION

Modern utilities are discovering the side effects of the open access paradigm the hard way: today their transmission networks must sustain MW transfers that can be quite different from those for which they had been planned. This is because energy transactions take place within and/or across the boundaries of vast multi-area systems and may cause parallel flows, excessive network loadings and low bus voltages.

Under certain conditions, such degraded states may lead to blackouts – but how to measure the risk of blackout? And how to compute it quickly enough to support on-line decision-making? The first question leads to the need to define a "metric" for assessing the risk of blackout. Such a metric has been around for a long time – it's the *distance* to steady-state instability, also referred to as steady-state stability reserve. The second question refers to the need to perform fast stability calculations and has been answered, too, both off-line and in real-time, by QuickStab®.

Need to Look at the Risk of Blackout from a Different Angle

Until now, the industry has taken for granted concepts such as the Available Transfer Capability (ATC), Total Transfer Capability (TTC), Transmission Reliability Margin (TRM) and Capacity Benefit Margin (CBM), but stopped short from adopting fast stability computations in real-time dispatch and short-term operations scheduling. Why not?

According to NERC [20], the TTC is given by:

TTC = Min {Thermal Limit, Voltage Limit, Stability Limit}

Conceptually, the thermal and voltage limits are well known and understood. They are relatively constant, thus predictable, and can even be violated for short periods of time. But how about "stability limits"? How to define and quantify them? Can they be "violated"? And, if they can, by how much and for how long?

Intuitively, it is clear that stability limits *do* exist. They are not fixed, though, and *change* with the system conditions. And since instability develops rapidly and leaves no time to react, in addition to the need to define a *metric* for the stability limits one must also reevaluate these limits for each new system state -- after each state estimation and / or load-flow calculation.

In fact, NERC's Policy 9 [24] requires Reliability Coordinators to compute the "stability limits" for the current and next-day operations processes to foresee whether the transmission loading progresses or is projected to progress beyond the operating reliability limit. Is this being done?

The wide and fast spreading August 14 2003 blackout suggests that this may not be the case – perhaps because detecting thermal and voltage violations is straightforward and can be executed on-line, whereas performing real-time stability assessment is a difficult proposition. But operating a power system without knowing its actual stability limit is like walking on thin ice -- and since conventional stability methods cannot be used in real-time, a new way to define and solve the problem must be identified.

IN SEARCH OF THE STABILITY LIMIT

Transient and Voltage Stability Limits

Sophisticated stability assessment tools are currently available to determine "whether a given condition is stable or unstable, but have not been efficient in quickly and automatically determining the stability limits, that is, how much a system, or part of a system, can be loaded before instability occurs" [10]. Two different tracks have been followed in the industry: transient stability and, respectively, voltage stability.

On the transient stability venue, much work was done to develop "transient stability indices" that would provide the "degree of stability". Regardless of the specific details, these methods follow the same scenario: derive an "index" for a severe contingency; compute new power flows; and repeat the process until an unstable case has been obtained [22]. Their limitations are similar, too: computational burden, non-convergence of load-flow calculations near instability, and the need to examine huge sets of possible disturbances.

Voltage stability procedures, on the other hand, are capable of finding the point of voltage collapse at individual buses by making certain assumptions about the nature of the load [2], [9] – but the process needs to be repeated to evaluate as many buses as feasible or, at least, a minimum set of buses known *a priori* to be critical.

The Steady-State Stability Reserve

The Steady-State Stability Limit (SSSL) of a power system is "a steady-state operating condition for which the power system is steady-state stable but for which an arbitrarily small change in any of the operating quantities in an unfavorable direction causes the power system to loose stability" [23]. As shown in the following, approaching the search of the stability limit of a power system from this perspective brings promising results.

First and foremost, SSSL is mathematically definable, therefore it can be quantified. Then, it *does* represent an operating limit, albeit one that is unsafe, and can be defined in terms of the MW loading of the transmission system under certain voltage conditions.

Therefore, a metric is also definable to determine "how far from SSSL" is any stable operating state. In fact, such a metric existed and has been used in Europe under the name of *steady-state stability reserve* since early 1950s [4], [5], [15].

Relatively recent papers [11], [17] have theoretically proven the connection between voltage stability, which is predominantly load instability, and steady state, or angle stability. Simply stated, the SSSL and Voltage Stability Limit (VSL) are given by the same mathematical condition and depict the *maximum loadability* state.

On the other hand, a Transient Stability Limit (TSL) *does* exists even if it can't be found easily. Intuition suggests that SSSL and TSL are interrelated. They change in the same direction: if SSSL is high, TSL is also high, and vice-versa. For a given set of relay settings, TSL depends on the same factors that affect SSSL: topology, voltage levels, etc. We do not know if a mathematical formula relating TSL and SSSL can be found, but we believe that the TSL/SSSL *ratio* can be approximated empirically.

In other words, it is possible to find a "safe" MW system loading, referred to as *security margin*, such that, for any state with a steady-state stability reserve smaller than this value, no contingency, no matter how severe, would cause transient instability. The security margin is expressed as a percentage of the SSSL. As a matter of fact, Paul Dimo [4] [6] used to recommend, for the power system of Romania in the 1960s and 1970s, a 20% security margin, which means that maintaining the system load below 80% from the SSSL, i.e., 80% below the maximum transfer capability, would ensure that no transient instability would occur.

TSL, TTC and the Stability Envelope Concept

It should be clear by now that the TSL is actually the same as NERC's TTC – and the security margin, i.e., a "safe system MW loading limit" that can be interpreted as a *stability envelope* (Figure 3), corresponds conceptually to NERC's definition of TRM.

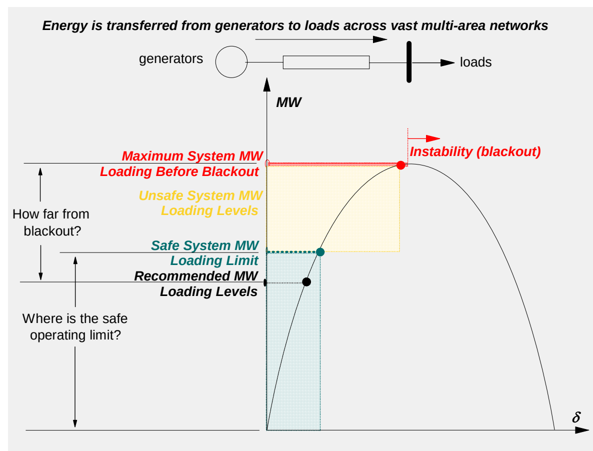


Figure 1. The "stability envelope"

SOLUTION TECHNIQUE

Operating states near SSSL are obviously not safe and, as we have already seen, the TSL (TTC) is an elusive target -- but now we can replace an otherwise unsolvable problem with the computation of a *stability envelope* as follows:

- First: starting from a state estimate or solved load-flow, determine the steady-state stability reserve, i.e., the distance to SSSL
- Then: for a given x% value of the security margin, determine the corresponding safe system MW loading below the SSSL.

This can be accomplished both by detailed analysis, which is appropriate for off-line studies but not (or ... not yet) suitable for fast simulations, or by fast approximate methods, the latter approach being perfectly suited for real-time and for quick off-line decision making.

Such a fast, yet reasonably precise, solution technique was developed by Paul Dimo [4], [5], [6] in Europe. Its validity and usefulness for real-time applications was demonstrated in the EPRI Research Project RP2473-43 [19] and presented in various US and international publications [8], [12], [13].

Paul Dimo's Simplified Steady-State Stability Approach in a Nutshell

Paul Dimo's field-proven method, first published in France in 1961 [4], used in production-grade studies in Europe for many years, and awarded the Prix Montefiore in Belgium in 1981, is predicated on the:

- Short-circuit currents and a radial network of short-circuit admittances
- Practical steady-state stability criteria that entail simple algebraic computations instead of eigenvalues
- Simplified representation of generators, modeled by constant e.m.f. behind the transient reactance x'_d
- Fictitious load-center obtained by aggregating the loads via a Zero Power Balance Network
- *Case worsening procedure* used instead of a succession of load-flow computations.

Paul Dimo's solution technique was extensively published. Further details regarding his methodology go beyond the scope of this article, but can be found in many publications, e.g., [4], [5], [6], [8], [12], [13], [19], and so on.

Two-Step Stability Limit Evaluation Paradigm

A fast stability assessment method such as the one developed by Dimo can help develop a *two-step computational model*, which begins with a quick check aimed at:

- Determining "how far from instability" is the current system state
- Identifying the "stability envelope" based on a user-defined "x% security margin"

The SSSL and the *total system loading for a specified security margin* are determined with an enhanced version of Dimo's method. When evaluating MW transfers across multi-area systems, both the maximum loading of specific sub-areas and the capabilities of interchange interfaces can be assessed.

The second step, consisting of a full analysis performed with detailed small signal stability software, is executed only if needed, i.e., only if the case under evaluation is situated outside the stability envelope.

PRACTICAL IMPLEMENTATION

The solution technique described in [12] was tested, on an experimental basis, in 1993 in Southern Company Services, USA and IREQ d'Hydro-Quebec Canada [8]. Further algorithm refinements and usability features were subsequently added and resulted in the *QuickStab® Professional* computer program that is currently used in real-time, off-line and from the Web in multiple SCADA/EMS installations in US, Europe, Latin America and Asia [12], [21].

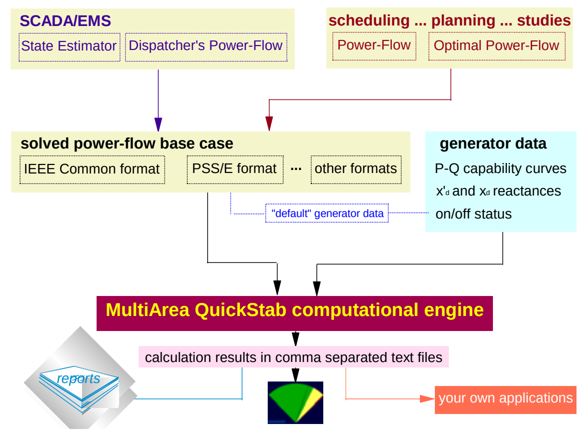


Figure 2 QuickStab® interfaces with real-time and off-line applications

QuickStab® interfaces with real-time and off-line programs are shown in Figure 2. A simplified flow-chart depicting Areva T&D real-time implementation of QuickStab® on *e-terra*™ SCADA/EMS solution delivered to Transelectrica is depicted in Figure 3.

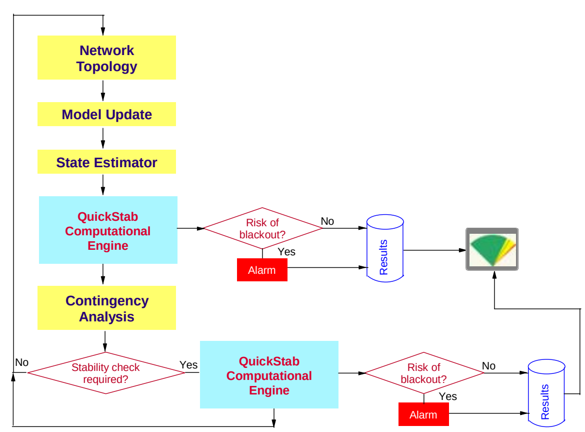


Figure 3 Integration of QuickStab® Professional in the real-time analysis sequence

USING QUICKSTAB TO EVALUATE THE STEADY-STATE STABILITY RESERVE OF THE NATIONAL TRANSMISSION SYSTEM

In early 2003, the National Dispatching Center (DEN) of Transelectrica started to use QuickStab® Professional to evaluate the steady-state stability reserve of the National Transmission System (*Sistemul Energetic National SEN*). Initially, the program was used off-line in operations scheduling. At the time when this paper was written, QuickStab® Professional, already seamlessly integrated by Areva T&D on DEN'S new SCADA/EMS, was under Factory Acceptance Testing (FAT) and scheduled to go in production-grade operation in real-time in mid 2004.

The following pictures illustrate actual study cases conducted at DEN in 2003, and depict the look and feel of the graphical output provided by QuickStab® Professional. The speedometers shown in these pictures visualize the *distance* (in MW) between the system state in the base case and the state of maximum transfer, i.e., the SSSL. The target security margin was set at 20%, but the computation stops when a security margin close enough to the target has been found.

Figure 4 shows the output for a morning peak. The total generated real power in SEN plus the tie-line imports is 7860 MW. The steady-state stability reserve for this case is 14%. The average system voltage is 0.996, i.e., 1% smaller than the average voltage at the security margin.

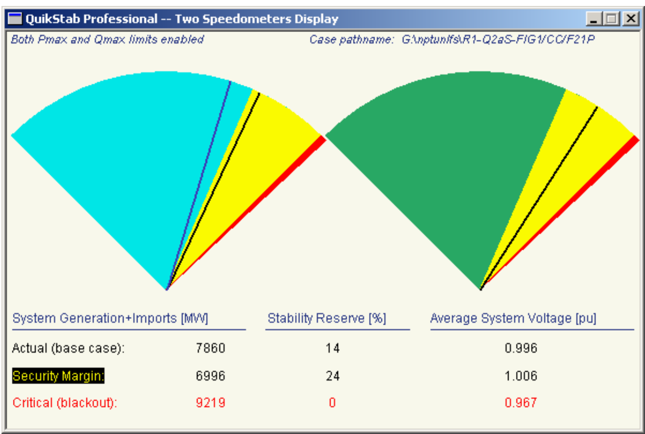
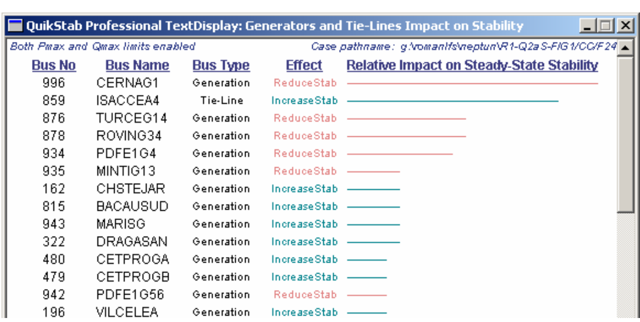


Figure 4 Morning peak – full system

Let's note that the blue speedometer's black needle, which uses the non-linear scale of the dQ/dV derivative, is farther away from red (critical state) than the black needle in the green speedometer, which uses the linear scale of MW system loading. This indicates that the system excursion towards the critical state is relatively fast paced.


QuikStab Professional TextDisplay: Generators and Tie-Lines Impact on Stability

Both Pmax and Qmax limits enabled — Case pathname: g:\romanlfs\neptun\R1-Q2aS-FIG1/CC/F24

Bus No	Bus Name	Bus Type	Effect	Relative Impact on Steady-State Stability
996	CERNAG1	Generation	ReduceStab	
859	ISACCEA4	Tie-Line	IncreaseStab	
876	TURCEG14	Generation	ReduceStab	
878	ROVING34	Generation	ReduceStab	
934	PDFE1G4	Generation	ReduceStab	
935	MINTIG13	Generation	ReduceStab	
162	CHSTEJAR	Generation	IncreaseStab	
815	BACAUSUD	Generation	IncreaseStab	
943	MARISG	Generation	IncreaseStab	
322	DRAGASAN	Generation	IncreaseStab	
480	CETPROGA	Generation	IncreaseStab	
479	CETPROGB	Generation	IncreaseStab	
942	PDFE1G56	Generation	ReduceStab	
196	VILCELEA	Generation	IncreaseStab	

Figure 5 Unit and tie-line ranking -- morning peak -- full system

The active injections' impacts on the stability conditions of the system, shown in Figure 5, are ranked as follows: Cernavoda 1, Isaccea 400 (tie-line injection) and the units 1 and 4 in Turceni, and, respectively, units 3 and 4 in Rovinari.

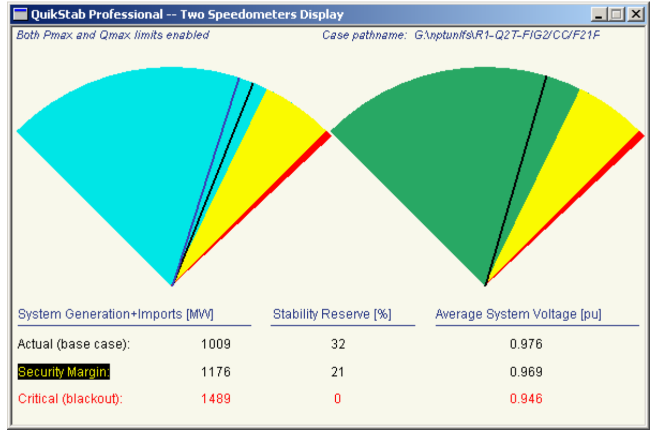


Figure 6 Morning peak – Northern Region Section S4

Figure 6 shows the output for a morning peak in the Northern Region (Section S4). The total generated real power plus the tie-line imports toward this region equals 1009 MW (720 MW internal generation and 389 MW import). The steady-state stability reserve for this case is 32%, with an average system voltage of 0.976, i.e., 0.7% higher than the average voltage at the security margin that was found at 21%. In this case, the black needle in the blue speedometer is closer to the critical state than the black needle in the green speedometer, which could be an indication that the system excursion towards the critical state would be relatively slow. The most impacting active injection is Iernut 400 (LEA end of tie-line Iernut-Sibiu).

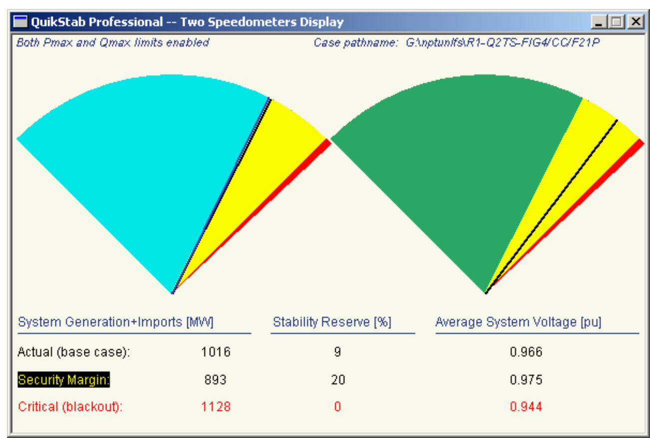
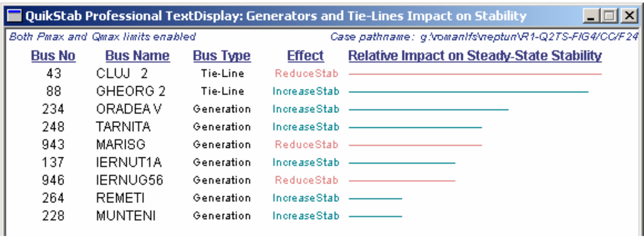


Figure 7 Morning peak S4 -- LEA Sibiu-Iernut outaged

Figure 7 shows the output for the morning peak in Section S4 but with LEA Sibiu-Iernut out of service. The total generated real power plus the tie-line imports toward this region is 1016 MW (720 MW internal generation and 396 MW import). The steady-state stability reserve now is much smaller (9%) for a security margin of 20%. Figure 8 depicts the ranking of the tie-line injections (CLUJ 2 and GHEORGHIENI 2) and, respectively, the generating units.


QuikStab Professional TextDisplay: Generators and Tie-Lines Impact on Stability

Both Pmax and Qmax limits enabled — Case pathname: g:\romanifs\neptun\R1-Q2TS-FIG4/CC/F24

Bus No	Bus Name	Bus Type	Effect	Relative Impact on Steady-State Stability
43	CLUJ 2	Tie-Line	ReduceStab	
88	GHEORG 2	Tie-Line	IncreaseStab	
234	ORADEA V	Generation	IncreaseStab	
248	TARNITA	Generation	IncreaseStab	
943	MARISG	Generation	ReduceStab	
137	IERNUT1A	Generation	IncreaseStab	
946	IERNUG56	Generation	ReduceStab	
264	REMETI	Generation	IncreaseStab	
228	MUNTENI	Generation	IncreaseStab	

Figure 8 Unit and tie-line ranking - morning peak S4 -- LEA Sibiu-Iernut outaged

Figure 9 depicts an hypothetical case were it was assumed that the MVA loading limits of the lines connecting to the buses CLUJ 2 and GHEORGHIENI 2 in the case "morning peak S4 with LEA Sibiu-Iernut outaged" were relaxed.

The purpose of this experiment was to determine the impact on stability of the units situated only within S4. It can be seen that for the same 1016 MW base loading, the stability reserve jumps to 32% with a security margin of 20%.

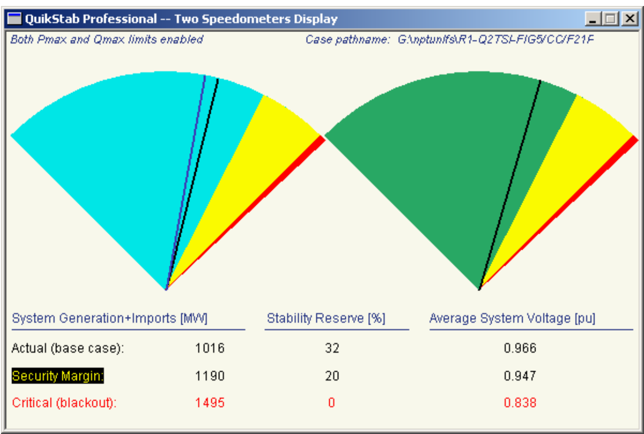


Figure 9 Morning peak S4 -- LEA Sibiu-Iernut outaged and MVA tie-line limits into CLUJ 2 and GHEORGHIENI 2 relaxed

Figures 10, 11, 12 and 13 show the PV-Nose curves for the cases analyzed in this paper. The "speed of approaching the stability limit" depicted by these curves is fully consistent with the relative positions of the black needles in the blue and, respectively, green speedometers.

CONCLUSIONS

This paper describes the utilization of QuickStab® Professional to compute the steady-state stability reserve of the National Electric System (SEN) as required in system dispatching and operations planning.

Theoretical and practical aspects of computing the distance to instability, the transmission reliability margin and the maximum transfer capability are reviewed and analyzed.

In addition, a number of actual examples taken directly from operations planning studies performed at DEN in 2003 are illustrated and briefly discussed.

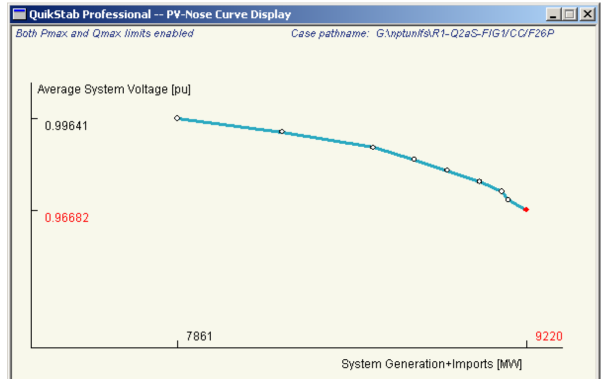


Figure 10 PV-Nose curve morning peak -- full system

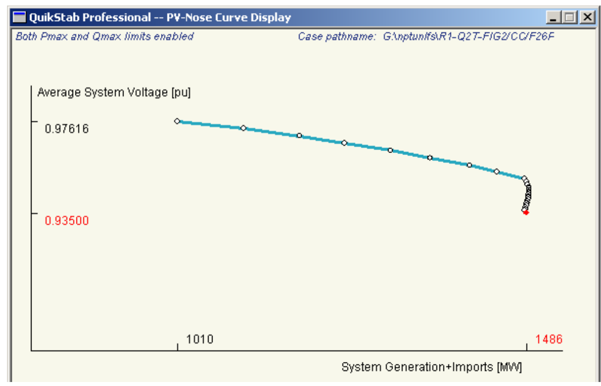


Figure 11 PV-Nose curve morning peak Northern Region S4

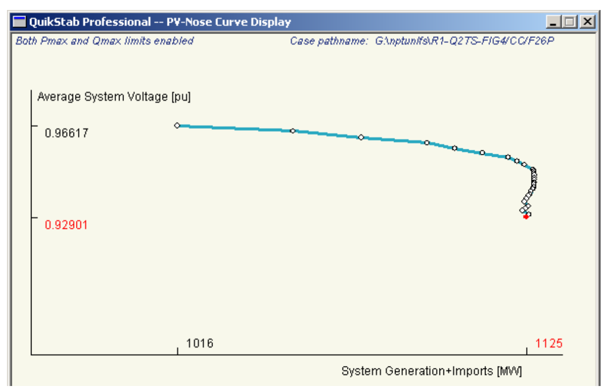


Figure 12 PV-Nose curve morning peak S4 Sibiu-Iernut outaged

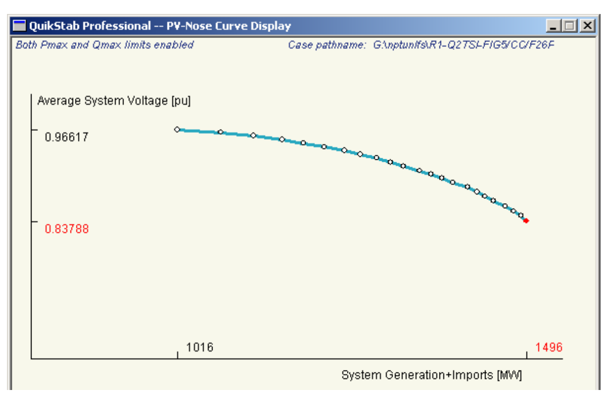


Figure 12 PV-Nose curve morning peak LEA Sibiu-Iernut outaged and MVA tie-line limits into CLUJ 2 and GHEORGHIENI 2 relaxed

The conclusions derived from these examples are in line with the pattern of behavior of the SEN, as system dispatchers and operations personnel know it.

QuickStab® Professional's computational speed and unique ability to determine and visualize the distance to instability, i.e., to quantify the risk of blackout, recommend it for daily use in system operations and transmission planning.

This application is currently used in operations planning at DEN – and, with its seamless integration on the company's SCADA/EMS provided by Alstom's *e-terra*™, it will provide the system operators with the knowledge needed to minimize risk while maximizing the use of the transmission network.

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