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Wide Area Protection Systems in Brazil

FROM REAL SPS TO A DREAM ON WAMPACS

The article from Brazil presented in the PAC World Summer 2009 issue mentioned how large is – and will be even larger – the National Interconnected Power System (NIPS). Such a wide power system brings along many hydro energy benefits through seasonal power exchange among its regions, but it also demands intensive care to cope with risks of electromechanical or voltage unstable conditions.

Biographical Sketches

Jorge Miguel Ordacgi F. took his Electrical Engineer degree from Universidade Federal Fluminense. During his career as a protection engineer (1974 – 1998) with FURNAS, ITAIPU Hydro and ELETROBRAS he worked on setting calculations and analysis of G&T systems. He later joined Brazilian ISO managing the implementation of SPSs and now he is involved with Control Center automation, SCADA and EMS. 1975 – 1992 he taught Power System Protection at Universidade Veiga de Almeida. 2004 – 2008 Jorge was the Brazilian Member of SC B5 – Protection and Automation. He received a CIGRÉ TC Award in 2006. He is Advisor of PAC World Magazine.

Alexandre Garcia Massaud took his Electrical Engineer degree from Universidade Estadual do Rio de Janeiro. During his career as a power system engineer (1971 – 1995) with LIGHT, ELETROSUL and ELETROBRAS he worked on dynamic system analysis of Brazilian power systems. He later joined Brazilian ISO dimensioning and aiding the implementation of SPSs. He is individual member of CIGRÉ since 1995.

THE THREE TOPICS BELOW SHOW how Brazil is pragmatically handling Wide Area Protection Systems (WAPS) nowadays. Brazilian main WAPS aim to prevent mostly the occurrence of electromechanical unstable conditions.

In fact, Brazil has a long experience with the so-called Special Protection Schemes (SPS), both for NIPS alternate current part, as well as for its 7,000 MW ± 600 kV HVDC link. Even before the creation of WAPS concept in the international scenario, Brazilian engineers noticed that SPS application in a 7,000 MW 765 kV AC interconnection needed something designed and tested with extra care. So far, the

table 1 Brazilian WAPS & SPS Summary

Types of WAPS and SPS	Number	Percentage (%)
Generation rejection	69	22.55
Load rejection (transformer overload control)	12	3.92
Under frequency load shedding	1 (*)	0.34
Load shedding	54	17.64
Automatic load restoration	3	0.98
Controlled opening of lines	109	35.62
System separation	12	3.92
Generator to synchronous compensator	9	2.94
Busbar segregation	10	3.27
Insertion/Reinsertion of voltage control equipment	25	8.17
Others	2	0.65
Total	306	100
*	<i>System - wide</i>	



need for a SPS was identified during operating planning studies and simulations, leading to a rush in the SPS engineering. Bearing in mind that power plants and substations had analog secondary systems, one can imagine what kind of race against time was put on and how pragmatic some solutions had to be. All those initial problems were overcome by digital technology and earlier identification of the need of a WAPS

Up to now NIPS has 306 WAPS and SPS (Special Protection Schemes) in service. Table 1 summarizes how many systems and schemes are in service for each macro-function.

Right now Brazil has a country-wide on-going project for a Wide Area Measurement System (WAMS) for NIPS. Brazilian WAMS is based on synchrophasor measurement technology and aims to provide better input data for the

State Estimators running at the Regional Control Centers and a post-mortem disturbance analysis system. The disturbance analysis system will lead the experts to improve models, SPS and WAPS. The application for improving State Estimator performance, by providing the phase angles and trying to make the algorithm as linear as possible, is taking place under the ISO coordination. The idea behind Brazilian WAMS is to give freedom to the utilities to buy their PMUs from a wide range of manufacturers, so tests were performed at the National Institute of Standard Technology (NIST) in Washington DC (US) to check how the PMUs of many vendors cope with the technical requirements. The great challenge of this WAMS is the Super Data Concentrator which is necessary to be on top of

Brazil is prone to improve its WAPS as long as its percentage of substations with modern secondary systems (IEC 61850) grows.

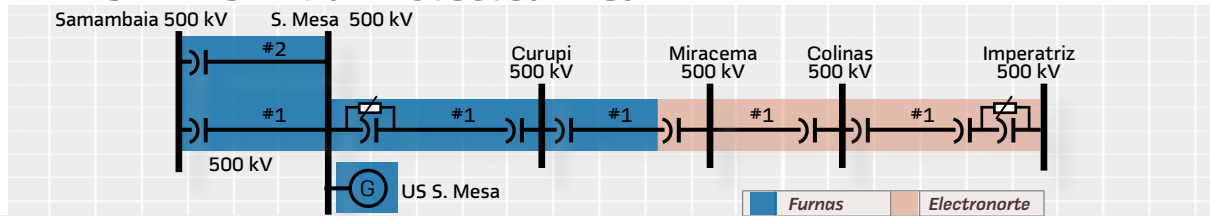
the pyramid of data concentrators belonging to G & T utilities.

A stimulating fact for getting along with Brazilian WAMS is the evolution of the Supervision and Control Systems now in service in the Regional and National ISO Centers towards a unique and revolutionary SCADA/EMS based on the Evergreen concept

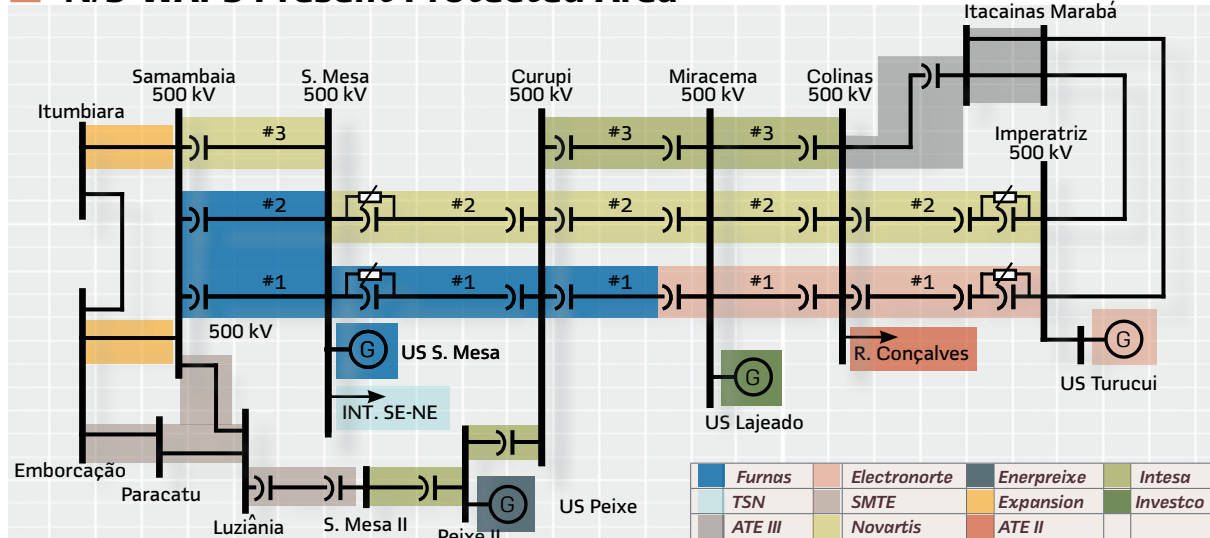
Fast inter-connection growth with increased utilities number.

WAPS must be prepared to parameterize as required by short-term operation planning to cope with seasonal conditions and particular generation or transmission conditions.

1 N/S-WAPS Initial Protected Area



2 N/S-WAPS Present Protected Area





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and designed to be in service and permanently updated until 2020 or more. The features conceived for the new SCADA/EMS are so interesting that they deserve an exclusive paper to describe them. But the fact is that there will be one single (fully backed-up) State Estimator running for the whole NIPS. This requires top quality input data, so accurate snapshots shall be taken for improving the output of Real-Time Applications, such as power system security assessment. Such an assessment – similar to a “radar system” – is already running in the ISO Regional Centers with fair steady state performance, but its dynamic improvement depends on the State Estimator, which claims for data from a WAMS. The “radar system” works by showing the operating point and how close or far it is from the limits (a polygon) pre-determined by operating planning studies. In reality, due to accuracy issues, the operating point should be a spot and the polygon sides (straight lines) should be areas, but their sizes are yet unknown. The WAMS’ two initial products plus some deep metrological studies will pave the way for the accurate representation of the operating point and the limit straight lines.

For the moment, at least as far as the authors are aware, there is no specific Wide Area Control System (WACS) in Brazil. The expectations are that the experience with the

WAMS will be a turning point to start working with WACS.

For the near future, all systems mentioned above shall be joined in a Wide Area Monitoring, Protection and Control System (WAMPACS), as long as experience and confidence is being gained with WAMS, WAPS and WACS. NIPS is quite prone to wide area applications, because it has five hydro-generation areas with different hydrological regimes. The most tempting advantages of WAMPACS envisioned by Brazilian engineers are adaptive, protective and control systems. In that way, all changes eventually needed by protection and control systems will be executed automatically according to particular operating conditions.

WAPS In Service – Two Main Examples

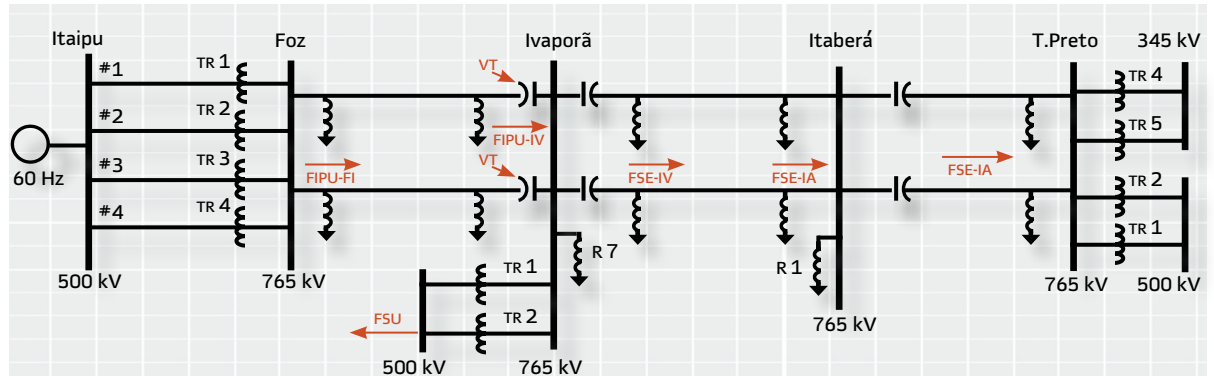
Figure 9 shows where these two WAPS are installed and reminds how wide and long NIPS is. North-South trunk is 800 km long and South-Southeast trunk is 1,000 km long. An interesting peculiarity of WAPS is their need to be enhanced accordingly to the power system growth, as well as WAPS must be prepared to be parameterized as required by short-term operation planning to cope with seasonal conditions, special generation or transmission conditions and so on. As time goes by, WAPS may have their area and complexity increased – sometimes they even may become less important or useless,

WAMS are the turning point to deal with WACS.

depending on power systems’ growth. North-South WAPS is one example of such increase in area and complexity. As shown in Figure 1, its initial protected area required five programming logics and had only two utilities involved. With two more series compensated 500 kV lines, the transmission limit grew from 1,000 to 4,000 MW. So N/S-WAPS had to evolve to cope with new transmission limits and multiple contingencies, in order to assure fair dynamic performance between N/SE and N/NE subsystems, avoiding overloads and minimizing overvoltages in the remaining line(s). Nowadays N/S-WAPS area has 11 utilities, 19 lines and 4 power plants, with 17 programming logics to face all the contingencies (overload; single, double and triple losses) that may affect these transmission trunk components. Figure 1 is more eloquent than words to describe the protected area. The same happened with South-Southeast WAPS, which aims to identify transmission component losses and/or transformer overload in order to have compatibility between Itaipu generation and transmission capacity immediately

To face the challenges of evolution and parameterization along time, WACS demand testing platforms compliant with hardware and software installed in the field.

3 S/SE-WAPS Initial Protected Area





after disturbances along the 765 kV transmission trunk. Figure 3 shows the initial protected area, for which there were eight schemes to cope with all contingencies. Nowadays, as per Figure 4, twenty schemes are necessary to handle the contingencies along the transmission trunk fed by up to ten generating units rated 700 MW each.

S/SE-WAPS and N/S-WAPS started their operation during the mid and late nineties, respectively. They were implemented by remote terminal units (RTUs) with processing capacity which were upgraded to the protection level concerning electromagnetic compatibility. The RTUs along the interconnections send information to a Master RTU, where the main processing work is done. Tripping commands (200 ms operating time) are sent back to the specific RTUs in order to shed generation. Risks of misoperation and corresponding consequences for NIPS security include failures to operate when required, incorrect operations and accidental operations.

To face the challenges of evolution and parameterization along time, there are testing platforms implemented by same equipments installed in the field. All future software and/or hardware modifications are developed and thoroughly tested before field implementation. The platforms also benefit maintenance teams, which

are permanently updated to act with efficiency and in time.

Hardware obsolescence issues and restrictions imposed by proprietary communication protocols limit further enhancement of existing WAPS. New communication systems and IEC61850 are most welcome by Brazilian engineers. These WAPS will clearly benefit from the WAMPACS philosophy.

Power System Studies And Simulations

Hydro plants very far away from the load centers are typical for NIPS' configuration. Its transmission trunks are long and subject to frequent contingencies. Thus, NIPS dynamics is highly impacted by sudden losses of transmission lines or even large generating units. The two transmission trunks mentioned in the topic above demand permanent care through power system studies and simulations.

Presently, the loss of one line of N/S interconnection overloads the two remaining lines. The overload is controlled by N/S-WAPS, which is armed by the interconnection state before any contingency, and sheds generation at the chosen power plants. Double and triple losses are also taken into consideration, once they lead to loss of synchronism among the subsystems around the trunk. Simulations allow fair quantification of how much generation must be shed to control overloads and to keep NIPS within

Maintenance teams also benefit from testing platforms.

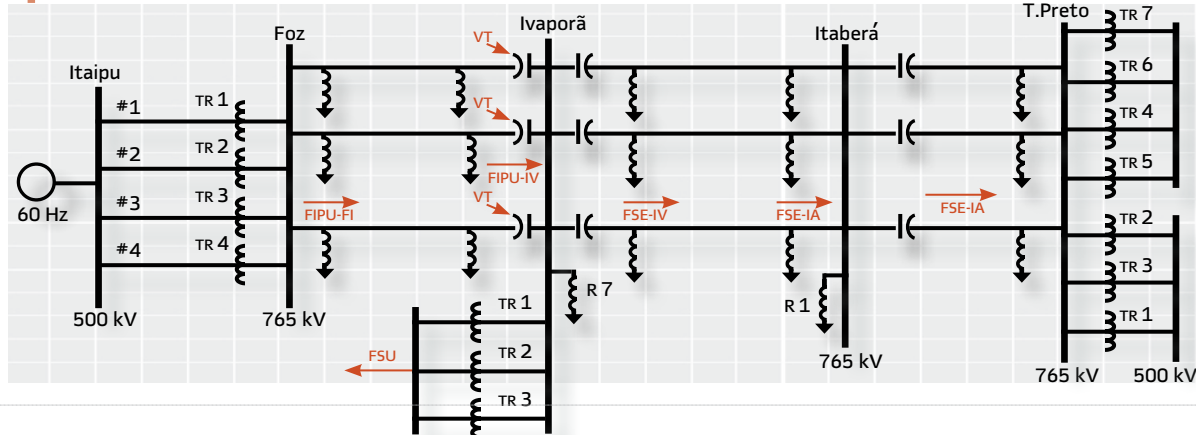
secure dynamic stability margins. Depending on the location of the line loss, generation shed up to 2,300 MW may be done at Tucuruí, Lajeado, Peixe Angical and/or Serra da Mesa power plants. The energetic benefits obtained by this WAPS are quite significant, fully justifying the installation and maintenance costs.

Figures 5 and 6 show why N/S-WAPS is necessary, after a double line loss in the trunk, previously loaded at 4,500 MW measured at the Serra da Mesa power plant. Figure 5 demonstrates that synchronism is lost without N/S-WAPS action. Figure 6 presents how synchronism is kept when generation shed is commanded at Tucuruí plant, not leading to load shedding or any other adverse consequence. Figure 5 states that Tucuruí plant loses synchronism in 1.5 seconds, which causes the formation of two islands: N/NE and S/SE subsystems. The blue and pink curves correspond to Tucuruí oscillation related to S/SE area (two power plants). The red curve shows Tucuruí oscillation related to NE subsystem equivalent.

Fernando Aquino Viotti received his Electrical Engineer degree from Universidade Federal de Minas Gerais in 1970. He started working in 1971 at Companhia Paranaense de Energia Elétrica, applying protective relaying and doing disturbance analysis. In 1976 he joined IESA, a Morrison Knudsen Company, as a project engineer. In 1979, he joined ELETROBRÁS, doing relaying setting calculations and disturbance analysis. From 1991 to 1996, he was the Chairman of Protection WG of GCOL, a Group for coordinating interconnected operation. In 1999 he joined Brazilian ISO (ONS) as the P&C Manager. He is a Regular Member of Brazilian CIGRÉ SC B5.

Roberto Campos de Lima took his Electrical Engineer degree from Universidade Federal Fluminense in 1980. He has been working at FURNAS Centrais Elétricas S/A since 1980 in protection and in development, implementation and operation of Wide Area Protection. Currently, he is the Manager of Power System Protection Division.

4 S/SE-WAPS Present Protected Area



Hardware obsolescence and proprietary protocols limit further enhancement of existing WAPS. IEC 61850 is most welcome as a solution for these issues.

The PMU tests performed at NIST demonstrate that vendors shall be ready to improve their products here and there, so they may fit the requirements imposed by a multi-vendor project, as the Brazilian WAMS will be.

As per Figure 6, N/S-WAPS has tripped four generating units (1,400 MW) at Tucuruí. The green curve shows Tucuruí oscillation against one SE subsystem power plant. The blue curve shows Tucuruí oscillation related to another plant in the same subsystem, which is close to the electrical center for this contingency. The red curve is the same as in Fig. 5.

The studies put into practice to support S/SE-WAPS are basically dynamic simulations to evaluate NIPS performance in case of losses along the respective transmission

trunk. The envisioned consequences are overloads or loss of synchronism of Itaipu 60 Hz generating units. Simulations show that single contingencies lead to overload in the remaining lines, preserving stability. According to the statistical report of S/SE interconnection, double contingencies are quite frequent, because two lines share the same right-of-way. To avoid loss of synchronism in such cases, mainly when the dispatch is high, generation shedding is implemented in Itaipu power plant. Though being

The effort to specify, bid and buy a super data concentrator is being put forward right now.

a contingency of low probability, triple loss has already happened, so there is a scheme to cope with the most serious consequences of such an event. They lead to out of step conditions among NIPS areas and intentional or under frequency load shedding by a system wide underfrequency scheme. All take into consideration the operative state before the contingencies, so the appropriate ones may be previously armed.

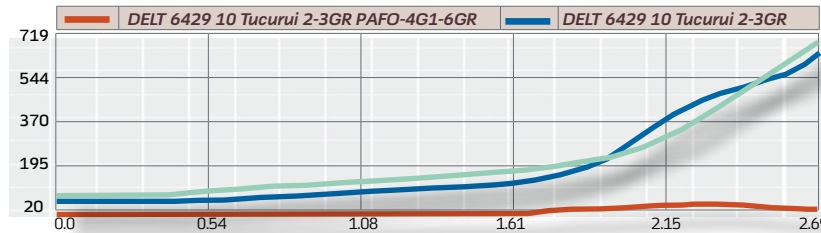
WAPS Performance Analysis

During the last ten years, most of transmission trunks and lines added to NIPS were designed to strengthen the network in response to demand growth or to connect generation resources within distinct subsystems. Some major transmission reinforcements have been made specifically to strengthen the bulk transmission system, such as the examples presented in this article. The open transmission access has resulted also in increased energy transfers over long distances, resulting in NIPS operation closer to its security limits.

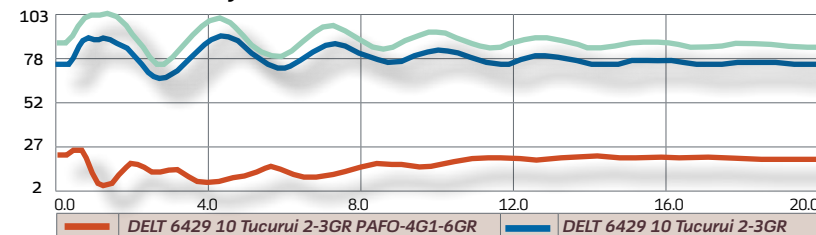
Brazil benefits from keeping protection behavior and automatic tripping statistical data since the early eighties. Such a statistical universe naturally includes WAPS and SPS. Figures 7 and 8 show N/S and S/SE-WAPS performance over the last years. The incorrect operations of N/S-WAPS were 5 % from total with 2 % hardware failures and 3 % not found.

The incorrect operations of S/SE-WAPS were 8 % from total and were caused by 1 % hardware failures, 1 % software errors, 1 % wiring errors, 2 % maintenance errors and 3 % operation errors. ■

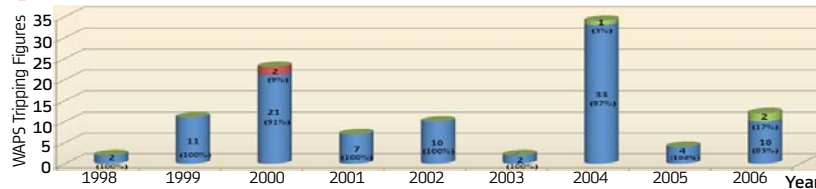
5 Tucuruí Hydro Performance without WAPS



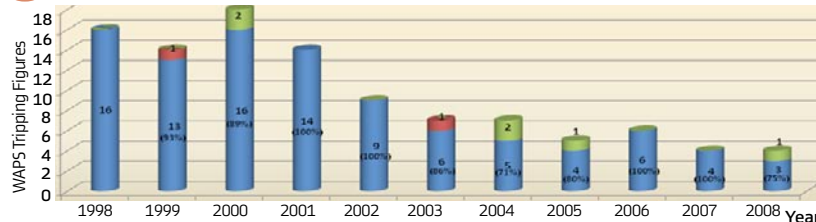
6 Tucuruí Hydro Performance with WAPS



7 N/S-WAPS Performance 1998 - 2006

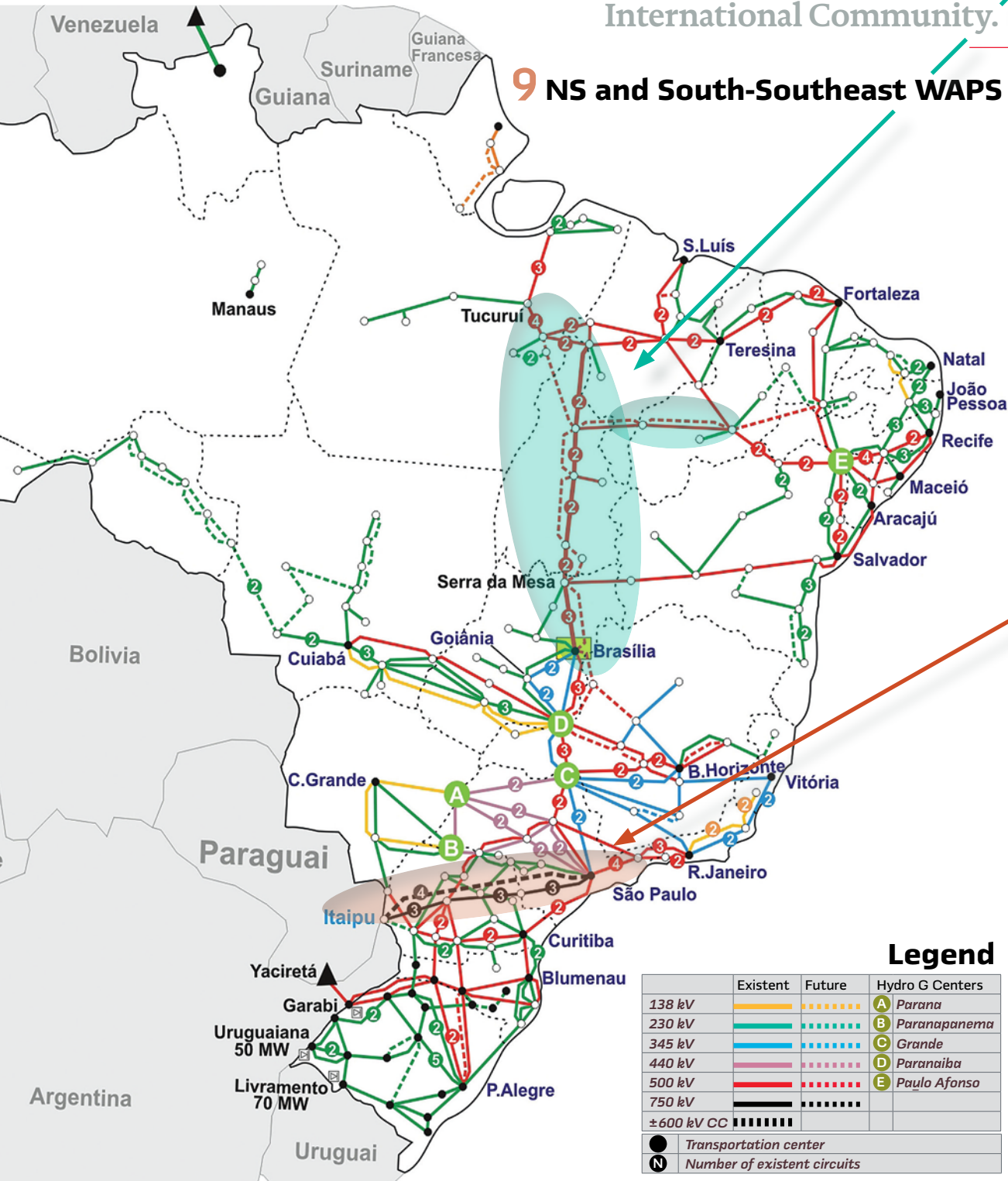


8 S/SE-WAPS Performance 1998 - 2008



Brazil will soon have good news to share with the PAC International Community.

9 NS and South-Southeast WAPS



N / S WAPS

- Installed 1999
- Stations:
 - 8 Transmission
 - 5 Generating
- Device:
 - 9 Controllers
- Technology:
 - digital
- Language:
 - (FBD)
- Communication:
 - Fiber-optic
 - 19,200 bps

S / SE WAPS

- Installed 1996
- Stations:
 - 4 Transmission
 - 1 Generating
- Device:
 - 6 Controllers
- Technology:
 - Digital
- Language:
 - Ladder diagram
- Communication:
 - MicroWave -
 - voice 9,600 bps

Legend

	Existent	Future	Hydro G Centers
138 kV			A Parana
230 kV			B Paranapanema
345 kV			C Grande
440 kV			D Paranaiba
500 kV			E Paulo Afonso
750 kV			
±600 kV CC			
	Transportation center		
	Number of existent circuits		