

Technological Synchronism – Opportunities for Improvements In Protection, Automation and Control in Brazil

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1 INTRODUCTION

The advents of IEC 61850, Smart Grids and Wide Area Protection, Automation and Control Systems (WAMPACS) provide a unique opportunity for technical advance for the sake of effective technological synchronization in Brazil. The application of the above mentioned technologies will be really profitable, if it is implemented within an environment of revolutionary evolution in terms of reengineering as much as possible the Protection, Automation and Control (PAC) universe.

A power system which still has 70 % of its secondary systems based on analogical secondary systems demands innovations to cope with its fast growth, as well as for allowing more facilities for flexible operation while providing better and increasing security. Once power system security measures are implemented through secondary systems, such an important area of electrical engineering shall be treated under a revolutionary way of thinking, at least in Brazil.

This article is based on a Data & Information Structure [1] and [2], which lays on the intrinsic relative balance between data produced at the lowest layer and information demanded by the highest level. Summing up, Secondary Systems Modern Solutions (SSMS) [3] are those implemented as a cell of a huge digital distributed processing system that is integrated all along the operational hierarchy with the aim of improving power system security. SSMS implementation may be understood as a way to achieve technological synchronism by benefiting of all the opportunities for improvements in Protection, Automation and Control.

2 PRESENT CONDITIONS OF SECONDARY SYSTEMS AND PROTECTION IN BRAZIL

2.1 Power System Growth and Technological Synchronization

National Interconnected Power System (NIPS) has been – and will keep on – growing at significant rates to cope with the economical enlargement plus repressed demand and the interconnection of isolated systems all along the Amazon Region. The transmission lines (rated ≥ 230 kV) growth along 2002 - 2012 was from 95,500 to 116,000 km. The expected length of transmission lines (rated ≥ 230 kV) by 2019 is in excess of 132,000 km, what means an US\$ 9 billion investment.

Figure 1a presents a rough vision of NIPS and its enhancements (dotted lines) scheduled for a short term horizon. Figure 1b highlights two very large enhancements in NIPS, one (Madeira Complex) already under commissioning and the other (Belo Monte) which is scheduled for a midterm horizon:



Figure 1a: Short term enhancements (dotted lines)

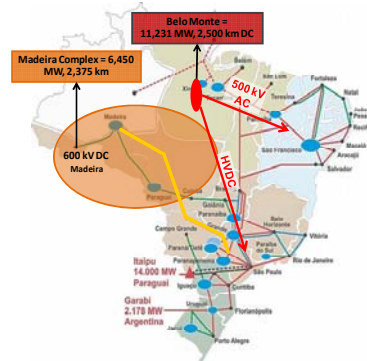


Figure 1b: – Large enhancements

Figure 1: National Interconnected Power System (NIPS) growth

Such a growth suggests that many opportunities for PAC improvements will arise by themselves, but it does not lead to any coordinated effort towards the integration of secondary systems as cells composed by the three lowest levels of the operational hierarchy. Secondary Systems Modern Solutions (SSMS) shall become a compulsory goal.

2.2 Existing Secondary Systems (SS) and Technological Synchronization

The refurbishment the existing SS is not necessarily a way to SSMS. Figure 2 states the percentages of technologies applied in the existing secondary systems:

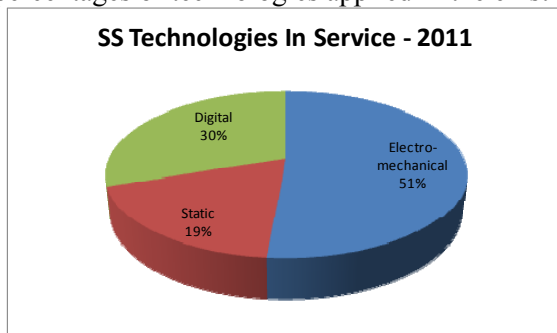


Figure 2a: Three technologies

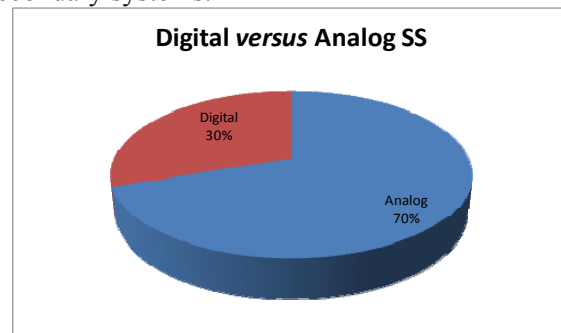


Figure 2b: Analog and digital

Figure 2: Secondary systems (bays) – technologies in service

Presently there are in Brazil more than 24,000 bays to be modernized, but the inherent trend remains being the reproduction of old secondary systems by digital means. Table 1 shows the numbers of bays corresponding to each technology:

Electromechanical	18,816	Analogical	24,507	70 %
Static	6,491			
Digital	10,560	Digital	10,560	30 %

Table 1: Numbers of bays in service (rated $V \geq 138$ kV)

2.3 Protection Performance and Secondary System Modernization

Poor protection performance or lack of spare parts and the implementation difficulties are the three usual features that lead to the best moment to modernize secondary systems. Figure 3 presents the results of statistical evaluations on protection performance in terms of power system events and accidental tripping for components rated ≥ 138 kV. Accidental tripping information shall always state those events caused by human interference. Figure 4 describes how human errors are influencing accidental tripping statistical data. Figures 3 and 4 are exposed on next page.

Indexes on poor protection performance show that the time for modernization has arrived and that it means modernizing secondary systems, but Secondary Systems Modern Solutions (SSMS) will not spontaneously stem from these motivations. Modernizing secondary systems, when moved by poor protection performance, may lead only to the reproduction of the classical features by the introduction of devices and systems available in the Protection, Automation and Control (PAC) market, without achieving everything one can get from the state of PAC art.

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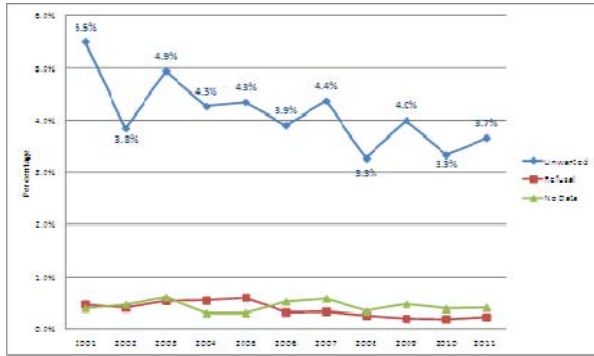


Figure 3a: Performance for power system events

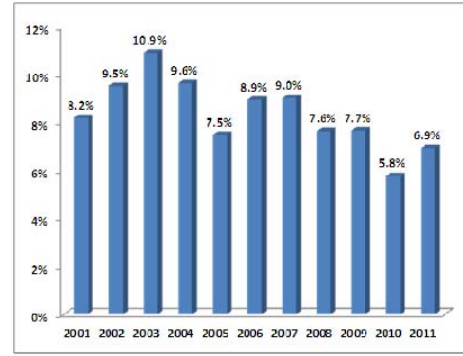


Figure 3b: Performance for accidental tripping

Figure 3: Protection performance from 2001 to 2011

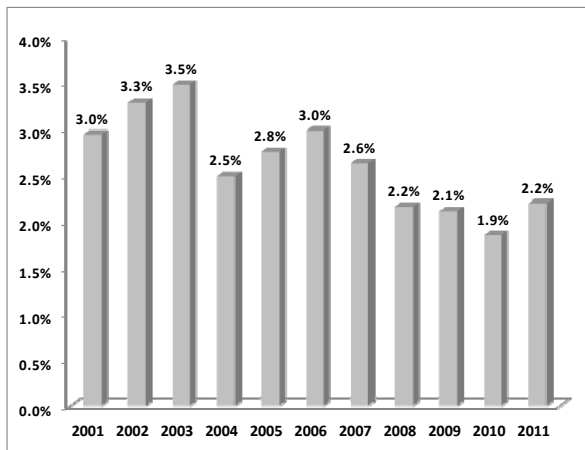


Figure 4a: Percentage of total trippings

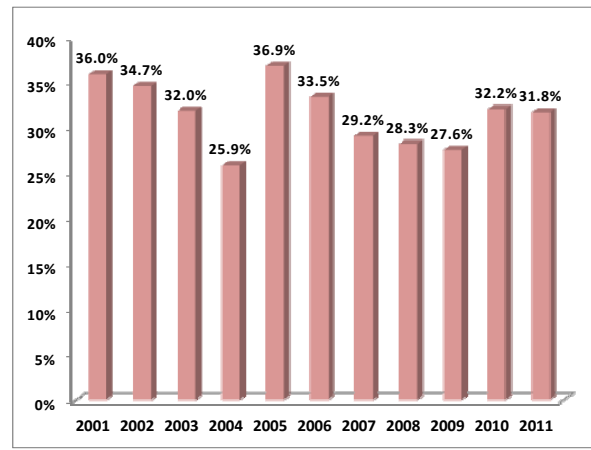


Figure 4b: Percentage of accidental trippings

Figure 4: Performance of protection schemes for accidental tripping caused by human errors

2.4 Functional Integration and Technological Synchronization

So far there still is excessive segregation among the macro-functions Real-Time Operation, Automatic Control and Protection. Even technological synchronization is not leading to an effective functional integration. For instance, Brazil has implemented the protection macro-function as described in Table 2:

	Protection of Power System Components	Protection of the Power System Itself
Protective Devices	As required by each power system component	27, 59, 68OSB, 68OST, 78, 81
Others	-	Special Protection Schemes

Table 2: Protection implementation in Brazil

Even in digital substations Special Protection Schemes (SPS) do not share steady state data and information with local and/or remote SCADA systems. This leads to incoherencies between SPS and SCADA concerning steady state measured values, raising problems during disturbance analysis. Such incoherencies are quite straightforward when there are SPS based on analog values both for arming or triggering. Primary voltages and currents are usually connected to SCADA and to SPS subsystems by two separate sets of VTs and CTs for and other TIs for SPS subsystems. Such a condition raises long and boring debates among operational teams and protection specialists.

Switchgear status information is another source of problems between SPS and SCADA. Even within SCADA itself there has been room for similar problems. Further details on incoherence issues in Brazil are addressed in [1].

There shall be more than a rough guidance for functional integration when technological synchronization imposes the modernization of a secondary system, thus avoiding the mere replication of the subsystems implemented in the past. The very same data and information shall be available to all subsystems according to the application: steady state or transient conditions. Such a way of

thinking inherently applies to Synchrophasor Measurement Subsystems and Asset Management Subsystems.

3 SECONDARY SYSTEMS MODERN SOLUTIONS – SSMS

3.1 A Way for SSMS Implementation

From chapter 2 above a few issues and questions on the near future of Protection, Automation and Control (PAC) in Brazil can be raised. There is a growing market for PAC solutions, but there is no driving force towards SSMS. There is a trend to the predominance of digital technology, but there is no schedule determining how fast modernization shall take place. The largest driving force for modernizing secondary systems remains being poor protection performance, but all secondary system macro-functions (real time operation, automatic control and protection) are not receiving adequate importance to provide easier and more straightforward implementation of power system security.

The definition of some kind of concept or philosophy for SSMS is a requirement of the utmost importance to guide the modernization of Protection, Automation and Control (PAC) in Brazil. Happily, a stronger association between the idea of SSMS and the implementation of optimized power system security issues may be used to show the way to the harmonization of SSMS priorities.

3.2 SSMS Concept and Philosophy

The following requirements summarize the Secondary System Modern Solution (SSMS) concept:

- Adequate balance between data and information for each hierarchical level:
 - Data and information logging for each hierarchical level;
- Preferably high added value information [1] shall be provided to devices, systems and operators at higher levels along the operational hierarchy:
 - Local State Estimators shall be applied at substation level, exchanging data and information with adjacent substations;
- Local devices and systems shall be parts of a distributed processing Protection, Automation and Control system [3] ranging from the IED physical level up to the National Control Center level, the highest one:
 - IEC 61850 and CIM (Common Interface Model) [2] shall be applied to allow free choice of manufacturer at each hierarchical level;
- Secondary systems – and all the higher hierarchical levels – shall be conceived to be fully tested, enhanced and optimized:
 - Most of all, secondary system shall be securely testable at anytime along their life cycles,
 - The Evergreen [4] concept shall be adapted and applied to secondary systems;
- The communication flows among substations and up to and among control centers shall be alleviated [1].

The philosophy behind SSMS lies on human attitudes [3]. Only the deep understanding of all variables involved would lead to fruitful advances in terms of coping with the challenges that stem from power system security real demands. Some examples are presented below:

- Utility engineering staff shall provide thorough specification, design (project) and bidding process;
- Engineering, operation and maintenance teams shall work closer;
- Protection, automation, control and communication specialists shall remain skilled only in a single one of these macro-functions, but to be knowledgeable on all of them;
- Protection, automation, control and communication staff, including managers shall open their minds for economical solutions based on power system security along the whole life cycle of secondary systems;
- Manufacturers shall be invited to work closer to the utilities.

4 BRAZILIAN ELECTRIC ENERGY INDUSTRY MODEL

4.1 The Industry Model

The Brazilian industry model has already been introduced to the Russian PAC Community during the presentation of [1] two years ago in the St. Petersburg Conference. Brazilian government and the regulatory bodies are more and more emphatic on the concept of responsible competition, which is intimately connected to power system electrical security. Many blackouts have been originated around the world by the disadvantages and defaults inherent to savage market rules or lack of rules. The maximization of power system security means leaving aside practically all blackout risks that may stem from the “fragmentation” of the power system. The pillars of safe power system operation are: energetic optimization and best possible electrical security conditions.

On the other hand, any industry model hardly could define how to deal with a multi-enterprise, multi-disciplinary and innovative matter as Secondary System Modern Solutions (SSMS), regardless of its comprehensive nature. It is useless to look at the model and find who would be responsible for such a task.

4.2 Attitude and Model Interpretation

Since last year the Electric Energy Regulatory Agency (EERA) and Brazilian ISO are involved in an unprecedented task concerning busbar configurations: the analysis of a blackout led to the evaluation of main grid busbar configurations under the systemic reliability viewpoint. Instead of applying penalties, EERA will provide funding for the implementation of new switchgear to improve substation security. Recently the Ministry of Mines and Energy has started to work with EERA and G&T utilities in order to check existing protection against the respective Grid Procedures. The main objective is to allow utilities to upgrade their protection systems.

The activities on busbar configurations and protection upgrade are considered as very stimulating by the industry. Above all, they show the maturity of the entities involved, which do not waste time cogitating how the actions shall fit the industry model. Things were not this way a year ago when [3] was presented in Chicago (US): lots of advancement took place in Brazil since then.

Under wider interpretation, one may say that Brazilian electric energy industry is mature for the implementation of Secondary System Modern Solutions (SSMS). Working on busbar configurations and protection upgrade, the author realized that, even within such a stimulating atmosphere, it is not enough to formulate the SSMS concept and philosophy to the authorities; it is of the utmost importance to reach some critical mass. In other words: the whole industry – all its segments – shall understand, contribute to and support the implementation of SSMS; then the concept might be formally put into practice according to the industry model proper interpretation.

Thus, the Brazilian protection, automation and control community shall be mobilized through a change in its attitude concerning secondary systems: the community shall evolve from a passive spectator to an active player attitude.

4.3 Funding Provision

Taking busbar configuration and protection upgrade activities as examples, the author expects to convince the Brazilian protection, automation and control (PAC) community to formulate a pledge for funding according to the industry model. So far, this subject has been restricted to private conversation among the community informal leaders, those active in voluntary work on PAC (CIGRÉ and IEEE).

4.4 Forum

A forum to deal with SSMS shall allow:

- Participation of all industry segments;
- Open discussion within democratic environment;
- Production of white papers and technical guides;
- Checks by the international protection, automation and control (PAC) community.

Voluntary work is precisely the path through which the community shall reach critical mass on Secondary System Modern Solutions (SSMS). Thus, a choice between two remarkable institutions – CIGRÉ and IEEE – shall take place to create the most adequate forum for the analysis and synthesis of a national approach for SSMS. In fact, such a choice is not so difficult within the Brazilian voluntary

work environment. Despite been cooperative with Brazilian CIGRÉ Study Committee B5 – Protection and Automation, the professors and researchers have dedicated more attention to IEEE, once there is a strict connection between IEEE and the academic career in the country. Recently both International and Brazilian CIGRÉ have started working to upgrade the publication policy to be even more attractive to the Academia.

All the other segments of Brazilian PAC community are significantly active within Brazilian CIGRÉ SC B5, which mean having the participation of representative from utilities, ISO, research centers, universities, consulting companies and manufacturers. The tradition of Brazilian CIGRÉ SC B5 [5] makes it the natural forum for the discussion and progress of SSMS. This tradition highlights the presentation of ideas, concepts, philosophies, etc. to the international PAC community to check the consistency of Brazilian propositions, as it is happening during the Actual Trends in Development of Power System Protection and Automation Conference in Yekaterinburg.

5 OPPORTUNITIES FOR IMPROVEMENTS IN PAC

5.1 How PS Security Is Dealt With Today

For the time being, Brazil has excelled on power system simulations to determine how to provide the best electrical security condition for the operation. Basically there are four areas involved in security maximization: Operation Planning, Special Protection Schemes (SPS), Scheduling and Risk Management. The operation planning area benefits from the N-1 criterion applied in the studies that lead to the expansion planning of National Interconnected Power System (NIPS). The operation planning studies add value to the security process both by defining the most suitable grid configurations for energetic optimization, while enhancing the capabilities for withstanding N-M criteria and by identifying the bottlenecks that may endanger NIPS security. Whenever any configuration leads to poor security conditions, SPS are conceived or reconfigured to upgrade NIPS reliability. Among the outage expectations, risk management is performed for all demands of intervention in the power system.

So far, this process is not necessarily optimized concerning secondary systems. The mere diversity of technologies is enough to impose different solutions to three similar parts of a given SPS – it would be the case of dealing with three substations that have distinct technologies respectively: electromechanical, static and digital. Another difficulty is that

SPS in Brazil are neither conceived nor implemented with full test capabilities. Test platforms are not a must. Reconfiguration and parameterization means are restricted in number and flexibility, once many SPS are implemented through different devices and systems in each substation. In new substations SPS are implemented through remote terminal units (RTUs), which are adequate in terms of processing capacity and time response, but do not cope entirely with the electromagnetic compatibility (EMC) requirements of protective devices.

As stated above, there are exceptions in that heterodox plethora of SPS, as for instance the ones in service in the 765 kV transmission system [6] and [1]. These SPS are about to be modernized and this brings very good news: the new implementation will be done through Intelligent Electronic Devices (IEDs) already in service in the substations and extra IEDs wherever necessary.

5.2 How SSMS Shall Be Improved to Cope With PS Security Optimization

A basic architecture shall be defined according to IEC 61850. Multi-substation systems such as System Integrity Protection Schemes (SIPS), Synchrophasor Measurement Systems (SMS) and Wide Area Monitoring, Protection and Control Systems (WAMPACS) shall be uniformly implemented along the whole power system, regardless of how many and which utilities may be involved.

The macro-functions (Real-Time Operation, Automatic Control, Component Protection and Power System Protection) shall share data and information among themselves. Redundancy would be welcome according to reliability criteria, but functional duplication by different devices leading to different results shall be proscribed.

Full integration and free functional allocation shall take place along the whole hierarchical operational structure, from the IED physical level up to the National Control Center. This includes full testing capabilities, both local and remote, at any level of the operational hierarchy structure. It is also implicit here that unattended substations shall benefit from flexible and reliable secondary systems, so

the presence of human beings shall be compulsory only in case of physical intervention in the local devices and systems.

5.3 Examples of Opportunities

Figure 5 depicts an example of secondary system architecture [7] that copes with the requirements of Secondary System Modern Solutions:

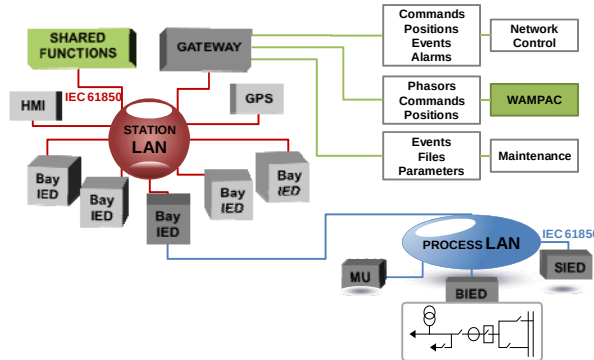


Figure 5: Example of SSMS Updated Architecture

The SSMS Updated Architecture highlights the following issues:

- Applying merging units, process bus and station bus optical devices and systems;
- Benefitting from free functional allocation, seamless communication and other facilities provided by technological evolution;
- Implementing a global structure for protection, monitoring and control data and information (D&I), for instance, accurate situational awareness systems depend on top-quality D&I!
- SSMS shall be conceived to allow easy testing:
 - oOf the secondary system (SS) itself,
 - oOf each SS function,
 - oOf SS as a cell of the huge distributed processing PCM digital system (from the process level to the National Control Center).

The implementation of hierarchical SIPS [8] is another opportunity achievable by SSMS philosophy. Figure 6 describes the concept of hierarchical SIPS:

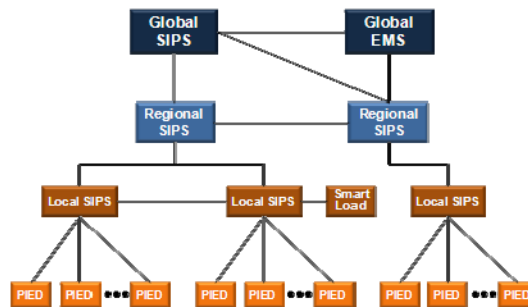


Figure 6: Example of Hierarchical SIPS Architecture

All steady-state functions that a SIPS may need already exist in or may be easily implemented by Global EMS. This will lead to full exchange of data and information, thus providing coherence between distributed processing systems and operators.

In other words: secondary systems are no longer standalone!

6 MAIN ISSUES TO BE CONSIDERED IN SSMS IMPLEMENTATION

6.1 Tuning of Practices

A few practices shall be carefully tuned when dealing with Secondary System Modern Solutions:

- SSMS specification;
- Testing of SSMS and the whole digital system from process level up to the national control center;
- Compliance with Data and Information Structure and global SIPS implementation;
- Frequent exchange of engineering solutions;
- Closing the loop through permanent SS performance evaluation.

6.2 Lifecycle Costs of SSMS

The electric energy industry model applied in Brazil led to differences on understanding and interpreting the lifecycle of secondary systems. Table 3 sums up how SS lifecycle costs are seen nowadays in this country:

Lifecycle Issues	Utilities' Ownership		
	Governmental	Private	
		Large Size	Small Size
Engineering	High, but fading away	High	Low
Acquisition Costs	A budget for SS	A budget for the station	Idem – turnkey projects
Maintenance Costs	Not computed	Effective cost approach	“What”?
Shortage of Revenue	Not computed	Imposes feedback to SS acquisition process	
Lifecycle Cost Evaluation	No regular process so far!		

Table 3: Distinct Views on SS Lifecycle Costs

The most stringent situation pinpointed in Table 3 is the “surprise” faced by small private utilities (more often small transmission utilities) on SS maintenance costs. Having low engineering qualification, the small utilities are beginning to review their organizational structures which privilege the work of lawyers and economists and are based on outsourcing all technical services.

When dealing with SSMS, Brazil shall develop processes to:

- Preserve engineering capabilities in all categories of utilities, respecting their sizes and financial peculiarities – the Electric Energy Regulatory Agency (EERA) will be of the utmost importance on the implementation of such a process;
- To weigh acquisition costs versus the importance of the secondary system for the optimization of power system security issues;
- To consider strict criteria for the quantification of lifecycle costs.

All new substations and power plants shall be provided with the adequate architecture of secondary systems, as well as their integration with the higher levels of the operational hierarchy. The secondary systems already in service shall be modernized according to priorities dictated by their importance to the power system security.

6.3 Quantification of Hidden Costs

There are a few significant costs hidden by the way secondary systems are treated in Brazil. They are summarized in Table 4, which is self explicative:

Issues	Hidden Costs
Too dissimilar SS Engineering Solutions (SSES)	Same mistake causes trouble more than once
Too many SSES	No gain with large scale application of each optimized SSES
Excessive separation between protection, automation & control and operational functions	Duplication of correlate functions & distinct results → risks of litigations
IEC 61850 implementation	Only pays off if applied in large scale
How long shall a SS last?	Poor SSES lead to poor power system security

Table 4: Examples of hidden costs

There shall be no more hidden costs, so responsible competition may take place among generation and distribution utilities within their respective industry segments.

6.4 Innovative Engineering and SSMS

Reference [1] describes the use of IEC 61850 Standard to allow the full implementation of the concepts of Model Based Automation (MBA). MBA allows complete abstraction of application layer from physical aspects of the controlled process. It offers many advantages over hardware-oriented automation systems, allowing the implementation of functional location-free and multi-supplier interoperable solutions. Figure 7 shows how the three layers shall be understood:

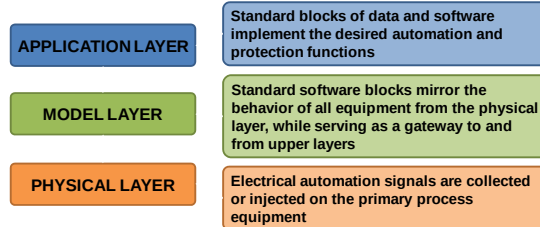


Figure 7: Three Layers' Contents

As far as data are concerned, a Logical Node (LN) can be seen as a software class, with structured data for settings, controls, measured and status information about a specific modeled behavior. Figure 8 depicts a Binary Decision Diagram (BDD) for a logical node:

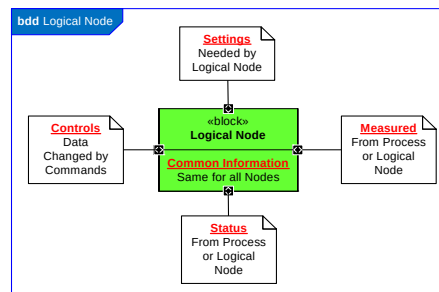


Figure 8: BDD of a Logical Node

Last but not least, an input-output view of a Logical Node (LN) can be depicted as a package of four building blocks as shown in Figure 9:

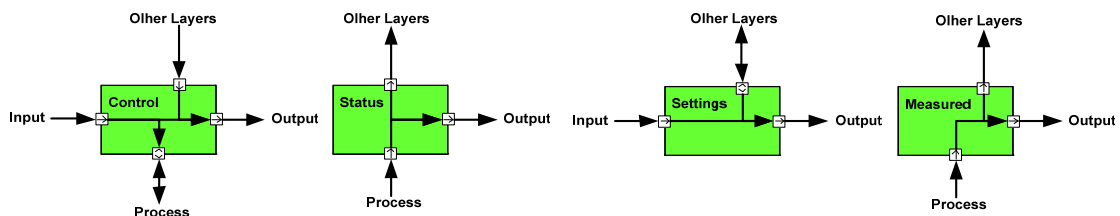


Figure 9: LN as a Package of Four Building Blocks

7 CONCLUSIONS

Secondary System Modern Solutions (SSMS) are feasible within any electric energy industry model. It is a mere question of interpreting the model and finding ways to cope with any idiosyncrasy through a forum where all industry segments may be freely gathered.

SSMS are no longer standalone. They shall become active parts of a distributed processing system that encompasses the whole operational hierarchy from the IEDs physical level up to the National Control Center Level.

The competition among utilities within each industry segment (GTD) shall only start after assuring power system security. Manufacturers shall be stimulated to acknowledge the importance of SSMS and compete with responsibility.

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