

Strategic asset management: a system driven approach on electrical transmission systems

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Abstract - This paper explains why a Systems of Systems approach is the most appropriate method to measure, predict and optimize costs on a reliable electrical transmission system and optimize strategic asset investment and maintenance plans of electric transmission utilities. Following, a case study on the French transmission network details a concrete application. The document finally highlights the main system and tool requirements needed to implement such an approach.

Keywords - complex systems; electric transmission utility; electricity; optimization; maintenance and investment; asset investment planning; AIP; cost optimization

1. THE NEW CHALLENGES OF TRANSMISSION SYSTEM OPERATORS

Electric transmission utilities, such as Transmission System Operators (TSOs) are responsible for the operation, the maintenance and the investment of electrical transmission networks. Their mission is to design and implement the right maintenance and investment strategies in order to ensure grid performance, reliability and security, as well as low electricity prices.

A large part of electrical assets in OECD countries was implemented more than 50 years ago, through short, successive and intense development phases. Consequently, these assets will reach the end of their expected life span simultaneously, while creating a “wall of maintenance/investment” for TSOs which will need to renew and repair all of them at the same time. In a context where TSOs have to operate with restrained budgets and an aging workforce, this situation represents a big challenge.

Given the complexity of this challenge, traditional approaches- based on individual know-how and expertise coupled with simple modeling tools- are showing their limits. Indeed, those tools, methodologies and processes only provide

TSOs with a local, in-silo and static view of the grid, while a more global, systemic and dynamic methodology would be required in order to face this challenge.

2. A NEW HOLISTIC APPROACH TO MEASURING GRID RELIABILITY AND PERFORMANCE

In order to measure reliability and quality of service, TSOs have developed a new risk analysis matrix applied to the field of electrical networks. This risk analysis matrix has been studied in more detailed technical brochures ([1], [2], [3], [4]) from CIGRE. The basic idea of this new approach is to adopt a holistic view of risk by calculating the various and heterogeneous consequences of an event on the system. Each event is assigned a risk index and then associated with a frequency range.

Those consequences are measured on a set of heterogeneous Key Performance Indicators (KPIs) that can include: Financial Impact, Quality of Service/Non delivered Energy, Safety, Public Image, Environmental Impact, Regulator Rules Compliance, Legal and Law Compliance ([5], [6]).

The results are combined in a risk acceptability matrix that reflects the global risk of a particular maintenance or investment strategy and enables TSOs to conduct risk and reliability analysis.

3. PREDICTING EVENTS ON AN ELECTRICAL NETWORK: A SYSTEMIC CHALLENGE

In order to be able to implement this new approach of risk and grid reliability, TSOs need to be able to predict the impact of their decisions on the frequency and severity of events occurring on the system. This requires being able to represent numerically an electrical grid as it behaves in real life with all its couplings (A) and dynamics (B). It also requires being able to create and simulate different maintenance scenarios and investment strategies and to measure their impact on the KPIs

(C). This process can be considered as the adoption of a System of Systems (SoS) approach (D) ([7], [8]).

A. Representing the asset management system

In order to represent an asset management system “as it is in real life”, the representation of the following 4 main sub-systems and their couplings is necessary:

- Representation of physical assets including their degradation curves (if available) and criticality (which can be based on assumptions) in the network.
- Representation of renewal and maintenance asset management strategies of these physical assets (type of operations, cost, human resources, duration, ...)
- Representation of the network’s electric constraints (outage management) to ensure a certain level of customer supply quality (Respect of condition N-1, No Asset Derating, No impact on Energy Delivery, etc.)
- Representation of corporate organization and resources: human resource constraints, whether internal (e.g. maintenance teams) or external (e.g. suppliers), supply chain, financial resources (mainly at the level of budget forecasts), geographic and administrative organization.

B. Integrating the dynamics

To fully represent an asset management system as it is in real life, those 4 sub- systems and their couplings should be able to adapt in time and space. In order to do so, TSOs must include in their initial representation the dynamic interactions between equipment, processes, resources and constraints. For example, accelerating the execution of a particular strategy may lead to a delay in executing other policies, due to constraints related to outage planning or resource limitations.

C. Measuring Impact

Finally, TSOs should be able to configure different scenarios of maintenance as well as investment strategies and simulate their impact on the frequency and severity of events on the system. From this simulation, TSOs could perform Reliability and Risk analysis, and better understand the systemic impact of their decisions on the KPIs. Additional reliability analysis indicators could be extracted from those simulations. For example, the number of failures, the number of conflicts between operations or the ratio between Operating Expenses (OPEX), corresponding to the ongoing cost of running the operations of the utility, such as repairing assets or performing inspections on those and Capital Expenditure (CAPEX), corresponding to the cost of the acquisition or the upgrade of the assets. The collected information will enable the TSOs to build a solid Systemic Asset Investment plan. Dynamic simulation is interesting in that it provides an estimation (possibly rough) of all of the indicators as well as their evolution in various time and space scales. Moreover, it enables to reveal transitory situations that are not acceptable (such as failure peaks).

D. A system of systems approach

What we notice is that in order to be able to predict the number of events on the system, TSOs need to approach their systems with a different and more holistic view that shows all of the characteristics of a SoS approach [9]:

1. A large number of interacting agents or systems;
2. Which progress dynamically at different space and time scales;
3. And whose emergent behavior does not result from the existence of a central controller.

If we refer to IEEE-RS Technical committee SoS whitepaper [10], electrical networks can be considered as SoS with the following characteristics:

- A large number of interacting entities (equipment: substations, overhead lines, underground lines, transformers; technical teams; asset management policies; budgets; business planning rules; geographic constraints).
- A structure linking the entities and their interactions (electrical network).
- A composition of heterogeneous and coupled subsystems (physical network and asset management business processes).
- A hierarchical administrative organization.
- Behaviors that can be described through evolution rules (operations: corrective/prescriptive maintenance, renewal; aging and deterioration of equipment; budget allocation).
- Emerging phenomena (impact on business capital gains, network reliability...).

Strategic asset management on electrical networks can be analyzed as a SoS in interaction:

- **System 1:** Electrical Transmission Network.
- **System 2:** Corporate Resources and Organization (Finance, Supply Chain, Human Resources, Administrative and Geographical organization, Suppliers, etc.).
- **System 3:** Asset Management Strategies and Processes.

As we have seen in this section, Electrical Networks and Strategic Asset Management practices can theoretically be represented with a SoS approach. In the next section we will study a practical example of such an approach.

4. CASE STUDY: OPTIMIZATION OF AN ASSET MANAGEMENT STRATEGY THROUGH A SOS APPROACH

A. Introduction and context

To study SoS, it is necessary to use adequate tools and methodologies. The CoSMo Company has developed a unique modeling and simulation platform dedicated to complex systems. This platform is currently being used together with RTE (the French TSO) to develop MONA, a disruptive systemic asset investment planning solution, dedicated to optimizing maintenance and renewal strategies for electrical grids.

RTE owns and operates the largest electricity grid in Europe:

- 100 000 km of lines from 50 kV to 400 kV.
- 2600 substations (3900 connected) and their 100 000+ equipment.
- 1200 power transformers.

		Scenario 1	Scenario 2	Scenario 3
Disconnectors	Failures per year	4	3	3
	NDE (M€)	4,5	1,8	0,8
	CAPEX (M€)	4,1	5,5	5,7
	OPEX (M€)	2	1,4	0,2
Circuit Breakers	Failures per year	5	4	10
	NDE (M€)	12,8	10	78
	CAPEX (M€)	4,9	6,7	6,7
	OPEX (M€)	6,9	4	2,4
Overhead lines	Failures per year	21	23	23
	NDE (M€)	17,6	22,8	22,5
	CAPEX (M€)	37,2	28,8	28,8
	OPEX (M€)	3,8	3,9	3,8
Total	CAPEX (M€)	46,2	41	41,2
	OPEX (M€)	12,7	9,3	6,4
	NDE (M€)	35	35	101
Total	(M€)	93,9	85,3	148,6
Total conflicts	Nb operations	953	750	733

Table I. Comparison of scenario results

The global annual asset management budget (maintenance and renewal) is close to €700M.

MONA is the first tool that allows strategic planners and Executive Committees to take better and more informed decisions by applying a SoS approach to strategic maintenance and investment. MONA integrates all constraints into a single model: assets (from power transformers down to pylons), power grid constraints (outages, non-delivered energy), human resources (skillsets, tools, availability) and finance (including impact on rates). This tool can be used to simulate decades of network operations using various scenarios, to test different strategies and to optimize strategies more globally.

Early results demonstrate the benefits of simulating the SoS as a foundation for risk and reliability analysis tool. The first results clearly demonstrate that the non-inclusion of dynamic interactions leads to a systematic misvaluation of the risk taken.

B. Comparison of three scenarios

The following example shows the simulation results and comparison between three scenarios of maintenance and investment, realized on a portion of the French network and for three categories of assets: Overhead lines, Circuit breakers and Disconnectors.

- **Scenario 1** is a baseline that simulates the global impact of current asset management strategies on the network.
- **Scenario 2** reallocates budgets between asset classes and between CAPEX and OPEX (compared to scenario 1). Part of the Overhead Lines CAPEX renewal budget is reallocated to Circuit breakers and Disconnectors CAPEX.

Scenario 3 changes the maintenance strategy on the Circuit Breakers and Disconnectors, going from a “replace when it fails” strategy to a “replace when it fails for the second time”.

Performance indicators are:

- CAPEX and OPEX: cumulated spending (net present value).
- Average quantity of assets failing per year.
- Financial loss due to Non Delivered Energy (NDE)
- Conflicts: number of delayed operations.

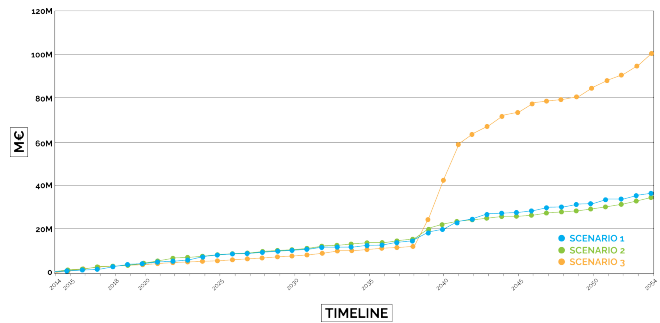


Fig I. Comparison of cumulated NDE over time

The results of the scenarios are detailed in the table here below:

C. Outcome

This brief example demonstrates the value and relevance of SoS approach in optimizing the maintenance and renewal strategies of an Electric Transmission grid. Indeed, we can clearly see that scenario 2 has a cost result that is overall better than scenarios 1 and 3. We can also see that despite having lower CAPEX and OPEX, scenario 3 is much risky overall, with NDE costs that increase significantly over time. Finally, scenario 2 also reduces the stress on the system (-20% of delayed operations due to resource access conflicts compared to scenario 1) as constraints on resources (Budget, lock out, teams, stocks...) are alleviated thanks to a better planning.

One of the major benefits of using a SoS approach in this particular case is to capture emergent phenomena that will be invisible to traditional approaches in silos.

For example, non-SoS solutions used to assess investment planning performance could be blind to tipping points (such as cascading effects when one event induces a sequence of uncontrolled consequences), a mode where you fall into the following vicious circle:

- Recurring failures from the over-aged equipment requires acceleration of pace of operations.
- Lock out constraints required to maintain high quality of service and repairing in priority the asset affected by these failures creates new deferrals in renewals.
- Assets impacted by the deferrals will become over-aged, increasing the size of the wall of investment.

This situation can get worse in the two following conditions:

- Outage planning stress, preventing the operator from shutting down an asset as another critical asset have already been locked out and having the two equipment in lock out at the same time would violate network security rules.
- Corporate resource conflicts, preventing the recovery of a delay by temporarily providing additional resources.

The SOS approach enables to predict this potentially devastating evolution of the system and therefore its dramatic impact. However, the emergence of a tipping point proves to be a very sensitive phenomenon to small variations of the initial conditions (e.g.: budget constraints) or to the way

different parts of the system interact with one another. Capturing those transitions necessarily requires a simulation of the entire SOS.

5. CONCLUSION

We have seen in this paper that using a SOS approach in the context of optimizing maintenance and investment strategies could bring a lot of value to TSOs by enabling them to get a more systemic and accurate view of the impact of their scenarios on OPEX and CAPEX but also on the Risk and Reliability of their systems.

More generally, our experience has shown that adopting a SOS approach is particularly relevant if the systems at stake have the following features:

- The real-life system is composed of heterogeneous parts;
- The real-life system includes hierarchies, i.e. some parts of the system are themselves composed of subsystems, which can themselves be composed of subsystems, etc.;
- The different parts of the real-life system (heterogeneous or not, hierarchical or not) are coupled together: the behavior of one part depends on the situation of the other parts;
- The different parts of the real-life system represent different dimensions (times and space);
- The different parts of the real-life system progress at different time and/or space scales.

For systems that have three or more of these characteristics, it is highly recommended using a modeling and simulation tool that will allow to describe the different parts of the system and their interactions.

The modeling and simulation tool must be able to:

- Represent (i.e. model) each part of the system using the relevant formalism (which might not be the same for all parts, depending on their characteristics);
- Interconnect these parts with potentially different kinds of interactions;
- Define, if necessary, the relevant time and space scale for each part.

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AUTHOR BIOGRAPHY



Thomas Lacroix is the CTO of CoSMo. He is in charge of the development of CoSMo Modeling Platform and CoSMo Applications (such as MONA). CoSMo Modeling platform’s (that has been used to create MONA) singularity is that it offers a very flexible formalism, which can differ from one part of the model to another and thus permit to handle heterogeneity in space and time scales, as well as hierarchies and network structures. In addition, it enables easy evolution in the model, either by coupling two or more models together, whatever their time and space scales, or conversely by refining parts of the model through decomposition into interacting sub-models. These options make it possible to adapt the model to address new needs that could emerge during the study.



Pierre Stevenin received a Master’s Degree in Engineering from the “Ecole Centrale de Lille”, Lille, France, in 2002. In 2003, he joined RTE, the French TSO, as a regional dispatcher in Nancy, France. In 2007, he joined the National Center for Grid Expertise (CNER) of RTE in La Défense, as an engineer working on electrical overhead line characteristics. In 2013, he filed a patent on a “method and device for monitoring a high-voltage electric current transmission lines”. Since 2014, he has been working as a research engineer in the Research, Development and Innovation Division of RTE. His main areas of research interest are asset management methodologies and tools for TSOs.