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## **Outline on situation-system energy togetherness: case-studies and open issues**

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**Abstract:** Our feedback through practice and training over time on multidisciplinary systems engineering has leading us to question on what forms the tangible togetherness of a man-made wholeness to control multiple situations examined as a simplex system of systems. We examine the essence of the energy togetherness that makes tangible the anchoring onto “reality” of a phenomenologically framed situation-system “in engineering” by an interdisciplinary orchestration process of multidisciplinary knowing-how and knowledge. The energy togetherness of the connectedness dynamics of a system-situation wholeness depicted in form of stock-flow models is checked by multidimensional analysis of the power bond continuity with respect to fields and engineering multidomain realities. We first apply this scientific *situation and system thinking* corpus to maintain the energy togetherness of the situation-system wholeness in the discrete processes domain to examine the lack of energy bonds between production, logistics and consumption on the one hand and between product-driven control including human in the loop on the other hand, to satisfy cyberphysical consistency. A second case-study domain relates to comfort at work to point out the oxygen-driven energy bond in order to maintain the physico-physiological connectedness between the human energy factory and the indoor air factory at a contained situation-system scale. A third case-study deals at the broader scale of the electric generating domain with the cyberneconduction-driven controllability of the reticular connectedness of the many upstream and downstream discrete energy situation-system in order to maintain a grid power togetherness between consumption and production. Innovative perspectives are given from each case study before emphasizing in conclusion the necessary congruence between the energy togetherness of a field situation-system and the interdisciplinary harmony of the responding engineering situation-system.

**Keywords:** situation-system, energy togetherness, cyberneconduction, interdisciplinary orchestration, systems thinking, systems engineering, system of systems.

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## 1. Introduction and context

Our practice and training of man-made multidisciplinary systems engineering has been aligned over time both in academy and industry on technology-enhanced architectural patterns to control a manufacturing plant as well as a power plant as a whole system (Morel et al. 2019). Many feedbacks have questioning us, as addressed by (Sauser et al. 2010), on “what forms a tangible togetherness of the wholeness of these structures and behaviors exhibiting more and more systems of systems (SoS) characteristics of technological, human and natural interoperating components to control situations perceived as complex” (Penalva 1997). Recurrent systemic failures (Boardman and Sauser 2008; Hollnagel and Fujita 2013) exhibiting togetherness damage strengthened our belief to look inwards the energy essence of a wholeness tangibility for understanding and responding to the meaning of “why humans make systems?” (Lawson 2010) and furthermore on “what can be automated or not?” to control a situation-system (Millot et al. 2011). This raises the question of the congruence between two realities (Giré 1986; Claeys 2013); on one hand, the {experiential (operational) reality} requiring an energy togetherness of a responding wholeness architecting by an {engineering (systems) reality}, on another hand. Next sections deal with our findings about the meaning of the reticulation process (Paynter 1961) of three units - situation, togetherness, and system - of conceptualization, architecting and ontological commitment of a wholeness reality to be controlled.

We address in section 2 our scientific corpus committing situation and system, each being in its own a conceptualization unit of a portion of reality (Kuras 2006), for bringing an added value to the notion of situation-system in order to better state on the energy nature of the togetherness of a respondent wholeness. We apply this *situation and system thinking* corpus to point out energy togetherness issues in the discrete process domain from our recent historical survey (Morel et al. 2019) for cyberphysical issues.

We experiment then in two other domains the relevance of this corpus:

- Section 3 deals with oxygen-driven energy bond forming the togetherness of a physico-physiological situation-system at the contained scale of comfort at work.
- Section 4 deals at a broader scale with the cyberneconduction-driven reticular connectedness of a power grid to maintain the energy togetherness of the many involved upstream and downstream situation-system.

Innovative perspectives are given from each case study before emphasizing in conclusion the necessary congruence between the energy togetherness of a field situation-system and the interdisciplinary harmony of the responding engineering situation-system.

## 2. Situation-system togetherness framing statement

Following influential works of (Lawson 2010), we make of situation-system the precept of our scientific corpus for addressing, with simplex rules (Berthoz 2012), physics analogies (Fuchs 2010) and systems dynamics precepts (Forrester 1994), the phenomenological essence of the energy togetherness of a multidisciplinary framed situation-system in the form of stock-flow models whose consistency with reality is checked by a power continuity multidimensional analysis (Sonin 2001). We revisit then with this *situation and system thinking* corpus the product-driven control of a business-to-manufacturing system-of-systems to point out, within this information-intensive interoperability wholeness, the lack of energy-driven connectedness on which to focus the framing interdisciplinary orchestration of the related situation-system dynamics togetherness for cyberphysical issues.

### 2.1. Situation-System physics-driven framing

For our domain-of-interest of man-made systems, framing a system-of-interest is an artful act for construct as safe as possible emergences while being able to check those which are tolerated or redoubted and to remain aware others asserted as being true may occur (Bombed 2014) as revealed to us by systemic failures. Currently, the underlying assumption for architecting this system is to consider the connectedness of visible properties of objects-of-interest to form a feasible respondent wholeness to meet a required purpose under human and artefactual control. With the possibility, however, that a subordination of this framing process to an information-intensive requirement template driven may restrict the visibility of the physical causation bonds forming the architectural “mortar” between the system, its environment, and the surrounding reality. Thus, the physics assumption of what (Paynter 1961) termed a reticulation process points out the necessary energy causations that the situation reality in which the system resides must itself exert to form the energy togetherness of a required wholeness (figure 2.1). This implies to consider, among the relations and bonds of interaction between the elements (which can be systems) and between these elements and their surroundings, the transformation, and the transfer of matter-energy to service flowing (in purple) as the finalizing causality putting into being a system (or system-of-system) in space-

time. The resulting dependence of the system content on energy transactions (in red) between discrete locations (in red) through intermediate places underlies a dynamic framing of its boundary with its surrounding world-of-interest. That led us to make the assumption of an energy togetherness causation bringing into congruence within a situation-system the many powering situations exerted by {experiential reality} onto the system and the multidisciplinary situations to be exerted in response by {engineering reality}. This intent underlies an interdisciplinary focus through the situation-system framing process on what reality may reflect as essential but not too as in case of caustic<sup>2</sup>. So that we apply, by some extent, an abductive reasoning to form the energy togetherness of a wholeness from an essential *thing of interest* revealed by the surrounding situation-system in order to connect other *things of interest* by respecting, for example, power binding. Conversely, the system boundary depends on the many living situations both of operation and engineering examined at relevant energy moments as a system.

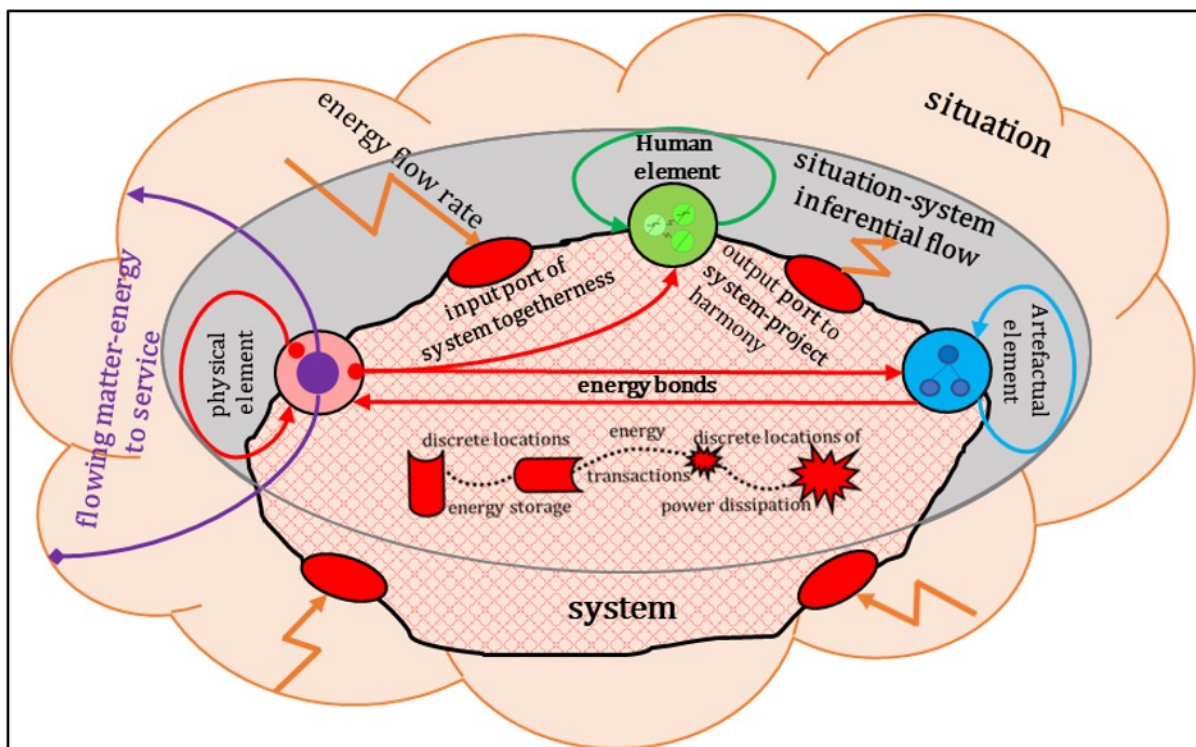


Figure 2.1: Situation-System framing focus

This justifies our proposal of a scientific corpus to see more from the essential of reality than what is usually subordinated to design<sup>3</sup> issues in systems thinking and engineering. This corpus

<sup>2</sup> As wrote by (Grothendieck 1986), "*things of the Universe never tire of speaking for themselves and revealing themselves, to the one is sensitive to hear them*"

<sup>3</sup> Even though changes have been recently highlighted to meet *design for resilience* and *design for the unexpected* issues (see in Morel, et al, 2019).

points out that togetherness can be embodied by the notion of causal closure, stated by (Rosen 1991; Louie 2011; Ellis 2020) as the grounding of phenomenological features making autonomous, in a relational sense, the wholeness of situations of a reality of interest to meet a purpose.

These features are related to causality (Rosen 2012) which are ontological (Pearl 2009) describing requested phenomenological effects which their propagation forming the togetherness anchoring the wholeness of situations whatever are the external influence. If this propagation or any of its effects were to be altered, then they would damage the balance of the togetherness, even to the point of breaking-off it and thus its related wholeness. So that, we designate a situation as occurring at a moment during which a causal relation between its committed elements triggers a phenomenological effect, leading to a result subject to a purpose or, alternatively, a goal and external conditions (adapted from (Zask 2008; Girin 2011; Nadin 2012; Declerck and Lenay 2017)). It should be noted that the composition and the change of the observable properties of these elements depends on the situation evolution of both {experiential and engineering reality}. According to the causal relation logics, the wholeness constructed by at least two situations occurs when a phenomenological effect produced by a first one exerts an influence for triggering the production by the second one of a phenomenological effect, itself exerting an influence the first, in a form of a reciprocal action interaction. Nevertheless, we perceive of the tangibility of this essential interaction (Brier et al. 2004; Declerck and Lenay 2017) between situations only those phenomena effects which are directly apparent to us or indirectly through their measurements. However, a logic of effects as demonstrated by (Ducrocq 1996), outlines that phenomena effects involved in the essential interaction are not enough sufficient by themselves to produce the complete phenomenological regime of the togetherness of their wholeness. Moreover, the combined exploration of the logic of effects with the popularization of quantum mechanics by (Gell-Mann 1995) allows us to point out the reified nature of the interaction revealing a third phenomenon that drives an energy bond anchoring situations to each other to form their togetherness and whose resulting energy nature will de facto maintain the integrity of their wholeness over time. It must be noted that togetherness damages are de facto the proof of the existence of this "anchoring" phenomenon which may remain hidden to us because even if we have a form of awareness of it, its effect is not measurable or because not being aware of it, we do not know of what this togetherness is "physically" made by its own and thus we do not perceive it<sup>4</sup>. Here, in the context of our

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<sup>4</sup> « We only perceive the world as we are prepared to perceive it » (Weber 1993).

scientific corpus, framing a situation-system as the fact to examine situations as a system involves to investigate the causal phenomenological closure where togetherness of situations take place due to an energy bond forming de-facto their wholeness.

When exemplifying such congruent perspective between {experiential and engineering reality} in manufacturing (below), indoor air quality (section 3) and electric generating (section 4) domains, we observed that system-oriented languages<sup>5</sup> did not enable the necessary interdisciplinary abstraction to designate the causal phenomenological closure with which a situation-system is concerned. We have also found that this limitation is also true when it must be expressed that it should be energy-focused to form any cyberphysical {SoS} togetherness balancing de facto Human, artefactual and physical intricate causations loops.

So that we made of system dynamics with added modelling rules based on dimensional analysis (Sonin 2001) a means to interdisciplinary power continuity checking the energy bond connectedness between the interacting domains (physical, mechanical, physiological, ...) of our project-system. So that dimensional the power-oriented checking result is transitioned in system dynamics as an {energy-driven force} to form the multidisciplinary nature of the situation-system togetherness by keeping into integrity a {Flux} and {Flow} connectivity. The main rule is to make of a flowing matter-energy quantity the energy togetherness synchronizer of system interoperability causations at relevant discrete-energy locations prior to space-time steady-states. A complementary rule is based on physical analogies (figure 12 in (Fuchs 2010)) to check the powering equation  $\{P = \frac{\Delta X}{\Delta T} \times \Delta \varphi\}$ <sup>6</sup> resulting from a variation of an intensive observable  $\{\varphi\}$  and a time derivative of an extensive observable  $\{X\}$  playing respectively the role of a {energy pushing force} and the role of a {substance-like} (fluid like). Another rule may be substituted for better considering moving effects between discrete energy states into a bounded domain situation as well as across energy conversion domains. Typically, because neither energy nor power can be located in electromagnetic fields, a time derivative energy equation  $\{P = \Delta \eta / \Delta T\}$  enables to check a certain power continuity resulting of the product of an energy exitance  $\{\pi\}$  by a pondered cavity surface  $\{\Sigma\}$  crossed by an energy flux.

## 2.2. Situation-system physico-logical togetherness issues

Let's consider for illustration in the discrete process domain some power continuity restriction issues of matter-energy flowing to meet a physico-logical togetherness. The

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<sup>5</sup> <https://sysml.org>; <https://modelica.org/>

<sup>6</sup> <https://www.showme.com/sh/?h=r2BYfBI>

situation-system we deal with involves heterogeneous enterprise systems aiming to interoperate together as a {SoS} to manufacture, to supply, to deliver a common product as requested by consumption for own using. We depict in (figure 2.2) in the abstracting form of an executable stock-flow model the dynamics of such generic situation-system to point out what makes tangible or not, i.e., with physically some {energy} (in red), the togetherness of the targeted {SoS} wholeness. Manufacturing, distribution, and consumption systems are depicted by the means of a system dynamics architecting tool<sup>7</sup> as {stocks} (in red) which accumulation from {input pipes} or depletion by {output pipes} which content flowing (in orange) is weighting by {directional valves}. Service-oriented (in blue dashed arrow) and material-oriented (in orange solid arrow) content moving results from unidirectional cross-systems causations exerted as {force} on input and output pipe-valves of respective stock-flows according to their diachronic dynamics. Content interoperability checking {^} between {good ^ service} as a whole-product is currently planned at relevant situation-systems (diagrammed in dark dashed rectangle) during which circular causations exert synchronizing informing and forming actions (in blue dashed arrow through converter) at space-time driven steady-states (in red converter) making thus balancing loops {B} or reinforcement loops {R} if not.)

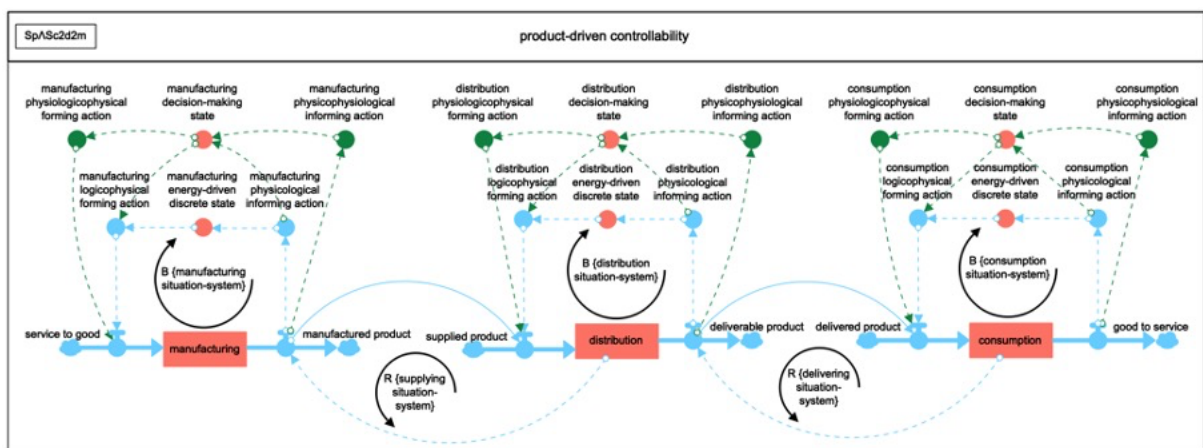


Figure 2.2: SoS business-to-consumption situation-systems togetherness issues

The anchoring controllability as {good ^ service} of the targeted product-wholeness can result in practice of a read-write energy interaction with an embedded digital technology to directly (instead of indirectly through instrumentation) observe space-time locations from manufacturing (in left) to consumption and use (in right). Notwithstanding the term of a fully standardization<sup>8</sup> of data-driven connectedness between the service-oriented enterprise level and the resource-oriented multi-plant level, the resulting enterprise architecting paradigm change is

<sup>7</sup> Stella architect, <https://www.iseesystems.com/>

<sup>8</sup> OPC foundation (<https://opcfoundation.org>)



making of a flowing active product termed intelligent product the synchronizer of local control loops through the many situation-systems encountered, sometimes unexpected. Nevertheless, the overall IT-intensive systems-architecting process discretizes locations of matter or service (in blue), without sufficiently considering the exergy quality of information increasing along with the product flowing to check its {good  $\wedge$  service} togetherness (end-user must digitally accept a packaged product delivery of which the material content is not allowed to be checked). Another connectedness weakness may be wireless communication channel energy robustness issues as addressed by (Koubeissi 2015), even if the less energy-contingence of discrete processes enable fault tolerant routing alternatives of downstream and upstream flows, The resulting non-direct energy anchoring between SoS components in {experiential reality} may restrict the control of the powering forces exerted by the many encountered situations as well as those which should be exerted through {forming actions} and {informing actions} by the flowing product itself at {discrete energy states} synchronizing locations instead of only at {event-driven steady-states} places. In a complementary way in {engineering reality}, another promising holarchy architecting to cope with part-whole dilemma has making of a flowing holon-product the synchronizer of its space-time transformational resource-holons under order-holons local supervisory and staff-holons global advisory to reflect on-the-fly its changing environment for facing unexpected situation-systems. However, the many prototyping based on multi-agent technology architecting remain addressing practical (industrial) issues on how services-oriented emergent routings of importance for resilience issues could be robust enough in reality at the plant level matter-energy oriented by essence. That may indicate that the self-consistent of an energy-holon should addressed in the holonic paradigm, as given by (Giré 1986) with an added cybernetics value termed organon for its operationalization. It is therefore possible to admit a paradigm change making an energy-togetherness of cyber-physical SoS rather than only an information-intensive interoperability wholeness.

### 2.3. Situation-system physico-physiological togetherness issues

Notwithstanding those physico-logical balancing loops are moreover under human controllability of which energy-driven togetherness (knowing-how harmony) must be also examined for circular causality (in green) issues. Certain situations, even contained as a situation-system, require that an operator perceive well to act well what a material or technical element may afford to him, maybe beyond what is known procedurally or whatever suggested affordance is (Masoudi et al. 2019). By combining some relevant precepts of the Mathematical Theory of Integrative Physiology (MTIP) (Chauvet and Chauvet 2002) and of the Theory of

Perception-Action (Berthoz and Petit 2006), we pointed out in previous works (Dupont et al. 2019) an anchoring prerequisite of the human sensory system onto the surrounding situation-system before any decision-making. Namely that a source of the sensory perceptual stimulus must send a certain physical amount to the human sensory system dedicated to the nature of sensation, as for example a visual signal of a tag emitting an energy flow (photon) to the ocular system to enable the right checking  $\{\text{good} \wedge \text{service}\}$  of a composite product. Indeed, an important precept, among others, is the assumption that any physiological mechanism is a set of elementary mechanisms consisting of the triplet  $\{\text{source, interaction, sink}\}$  with a sink that can potentially become a source (Figure 2.3, in right). The interaction qualified as functional is representing an event causality carrying a physical quantity between one structure and another across other structures, called structural discontinuities. This propagation at finite speed with some transmutation is depending on available action potentials at time involving at a space lower level what is called structural propagator. We made at our applicative scale-factor an abstracting analogy with a thyristor of our understanding of the non-linear behavior of a physiological process from the originating field theory formalism aiming to report for computational issues the multiscale complexity of the three-dimensional (space-time-level) hierarchy of a biological system<sup>9</sup>. This pattern highlights thus the prerequisite physical nature (in orange) of a source  $\{\Psi P\}$  triggering a first “gate” (1st perception potential  $\{\Uparrow P\}$ ) and then a second one to physiologically propagate a sensing information for perceiving and understanding  $\{\Psi P U\}$  a situation-system from acquired knowledge (2nd understanding potential  $\{\Uparrow U\}$ ), and so on with non-local propagating from understanding to resolution  $\{\Psi U R\}$  and from resolution to solving  $\{\Psi R S\}$  to action  $\{\Psi A\}$ . Looking inwards such illustrative  $\{\text{perception-action}\}$  pattern points out that  $\{\Psi P\}$  may coming from another physiological source (in green) and resulting to a physical (in orange) or a physiological sink action. It is therefore possible to admit the anchoring input potential that situation-system reality (in orange) may exert on a control team to physically (ontologically) focus the many individual’s detours with some harmony (togetherness) on an output wholeness feasible solution (in grey). We depict by some extent in (Figure 2.3, in left) a dynamics illustration of a human-driven controllability loop to point out the many detours involving  $\{\text{decoding}\}$ ,  $\{\text{decision-making}\}$  and  $\{\text{encoding}\}$  functional interactions which ontological togetherness is depending first on a physical anchoring onto the situation-system to be aware of its affording potential.

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<sup>9</sup> The goal of an integrative biology ([www.admiroutes.asso.fr/gilbertchauvet/en/index.htm](http://www.admiroutes.asso.fr/gilbertchauvet/en/index.htm))

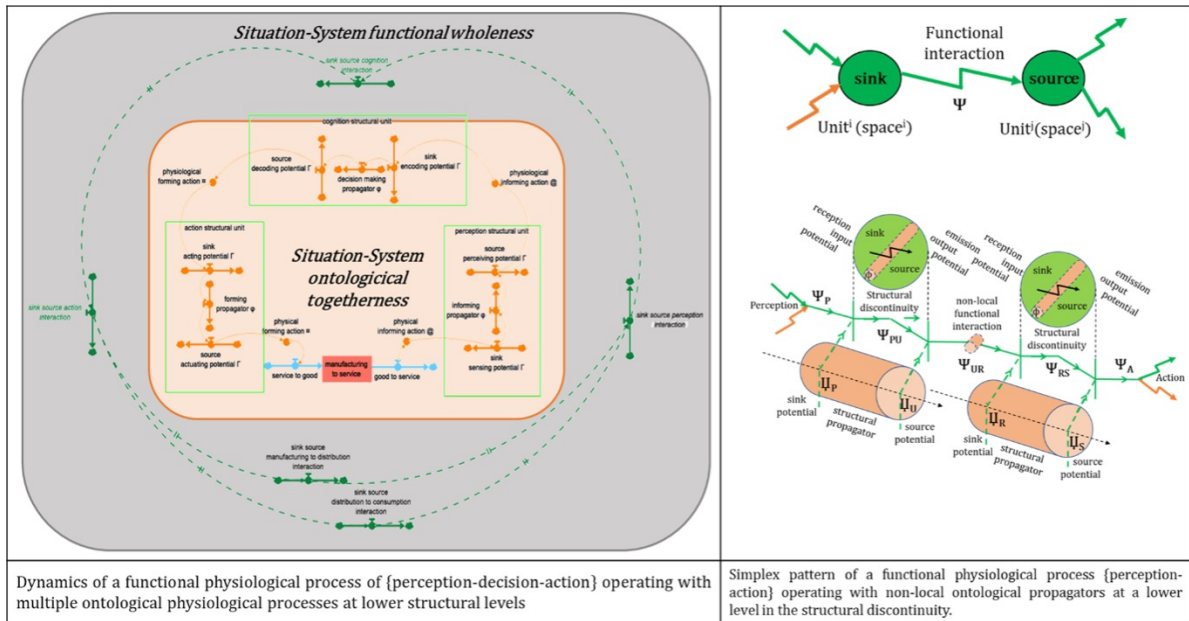


Figure 2.3: Controllability-loop physico-physiological anchoring onto situation-system

#### 2.4. Situation-System simplicity-driven framing

The orchestration metaphor points out in practice that the “system partition”, i.e., thinking and acting to wholeness, is written in the course of the multidisciplinary engineering process itself. By having in mind that information as “that which changes us” or “the difference that makes a difference” (Bateson 1972) is depending on multiple intrinsic and extrinsic influential effects inferring multiple knowledge “by detour” trajectories, it is therefore possible to admit the contingency of this human-orchestrated multidisciplinary process to acquired {cognitive} knowledge blocs to meet by “detours” a feasible solution  $\{\Psi_A, \text{in orange}\}$  from multiple informal percept’s  $\{\Psi_P\}$ . All the more the first awareness source of a situation is human-orchestrated (Figure 5, chapter 10, (Millot et al. 2011)) (Wilber, holonic paradigm in (Mella 2009)), when requiring a respondent wholeness to recover a certain togetherness in case of not direct solving to a problem-situation. While agreeing with the evidence of the Lawson’s coupling concept, we nevertheless wondered on the relevance of the well-established *situation-system thinking and acting* process since we became convinced by experimental knowledge gained of its physico-physiological nature enabling an energy framing bond  $\{\Psi_P, \text{in orange}\}$  between {experiential reality} and {engineering reality} situations examined as a system. Thus, the abstracting rules above relate to the biologically inspired principle of simplicity suggested by (Berthoz 2014) for orchestration issues *by detour* by enabling human-to-human congruence to form a situation-system togetherness.

Technology-enhanced orchestrating techniques are becoming available to enable a data-continuum across {experiential  $\wedge$  engineering} reality in the form of a common bus, i.e. a togetherness conductor, and the intertwined situation-systems of interest, as depicted in (figure 2.4). Various domains of interest are promoting such scope making available by the increasing performances of model-based execution and simulation technologies to cope with a posteriori system life cycle coupling concerns between operation and design (Galara et al. 2012). Correctness (job-right in (Fanmuy et al. 2011)) of each solution was verified according to domain best practices and multidisciplinary checked in the understandable form of test-cases scenario-results in return of some wholeness request. The interdisciplinary commitment consistency (right-job in (Fanmuy et al. 2011)) of these verified solutions in system togetherness consisted of a model-based wholeness co-execution on-the-fly with a physical platform emulating a plausible reality. As hereinafter case-studies deal with de-facto a system-of-systems cyberphysical scope, the interdisciplinary commitment consistency of their reality in situation-system togetherness consists of a power continuity checking of stock-flow models from multidisciplinary results. A common computer tooling has supported at distance our interdisciplinary collaborative process where authors have played the role of a system architect (in grey) orchestrating an enabling situation-system thinker (in orange) and two specialists in integrative physiology (in red-green) and integrative cyberphysics (in red-blue). It should be however noted that the overall situation-system reality understanding has been facilitated by our knowledge integrative base in physics as well as by the common systems dynamics language which been proven to be well-suited to capture and modelling in a simplex manner of the phenomenological essence of multiple causations. For example, both Paynter's and Chauvet's works refer to *field theory* but share with Forester's works a common {force-effect} abstraction of system interactions dynamics.

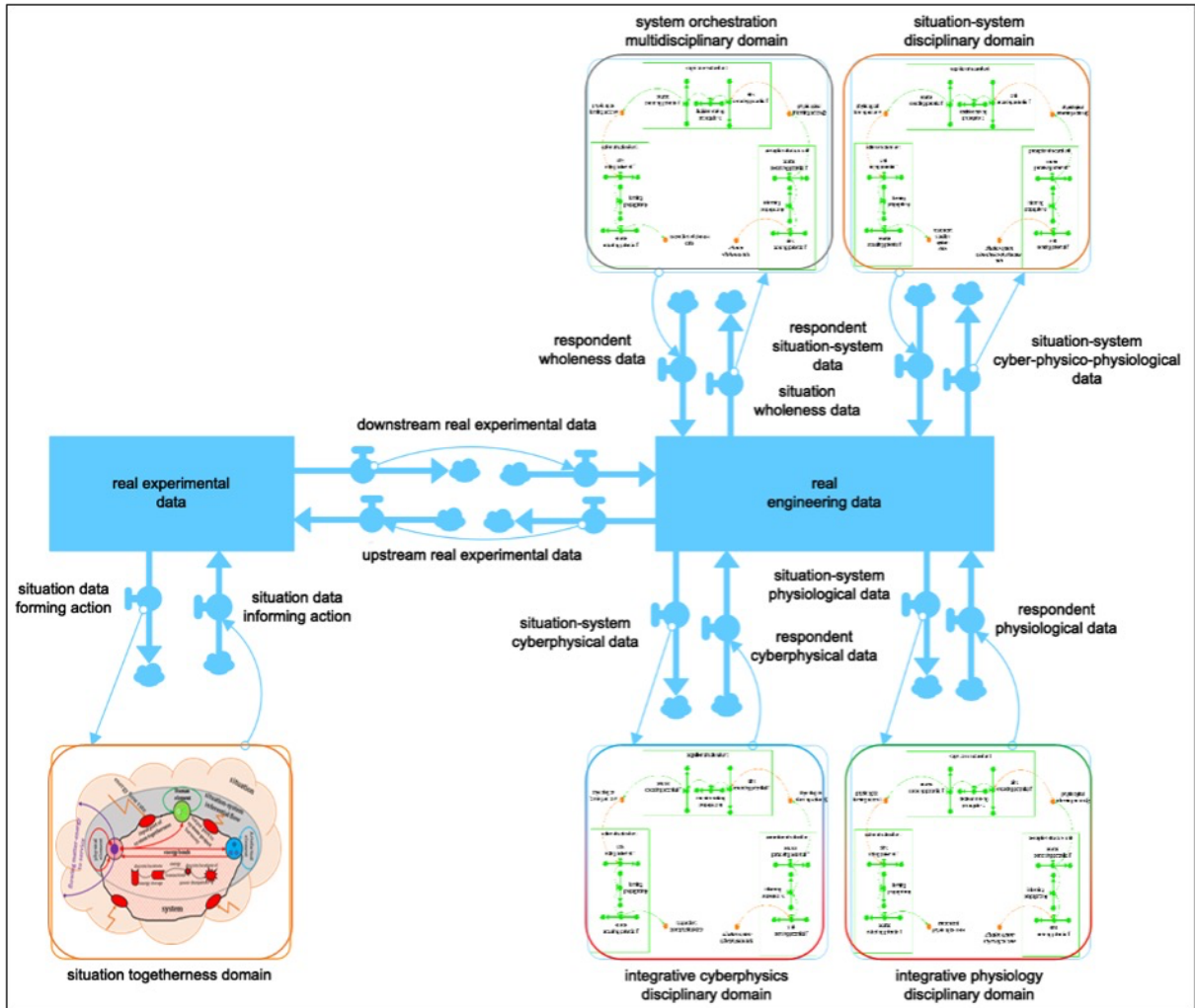


Figure 2.4: Situation-system dynamics togetherness framing interdisciplinary orchestration

### 3. Case-study on the energy-togetherness of a situation-system at a contained-scale

The growing importance of indoor air quality (IAQ) for performing work activities in a confined space is given us the opportunity to apply our *situation and system thinking* corpus (subsection 2.1) to a suitable situation-problem in order to bond into energy the resulting situation-system togetherness vis-à-vis of its milieu. We first apply systems thinking percepts to form a feasible wholeness of this situation-problem to meet a required service level agreement (SLA). We then decipher beyond this necessary but non-sufficient wholeness the essential physico-physiological energy-bond on which the situation-system togetherness may be experimentally grounded. So that on we deepen the essential oxygen-driven energy-bond enabling to form the togetherness dynamics of the targeted situation-system before to point out some innovative features for IAQ purpose.

### 3.1. Wholeness-oriented situation-system framing

Confined spaces are monitored by a wide range of indicators, guidelines and standards as well as applications made more efficient by the maturity of technologies in order to improve the feeling of indoor air quality of occupants along with their comfort in their daily work activities (Li 2020; Korsavi et al. 2021).

The precepts of systems thinking allow, in the reality of engineering, to contextualize from a system completeness perspective the stakeholder requirements (table in Figure 3.1) that an IAQ monitoring system must satisfy in order to compliant with a service level agreement (SLA). As recently addressed by (Baron and Daniel-Allegro 2020) for such intensive ICT system, framing the situation-problem as a situation-system to extract the technical system of interest (Figure 3.1 in blue) consists in navigating in a non-linear way through the roots and branches of the *system-thinker tree*, suggesting the attitudes he must adopt to think “system”.

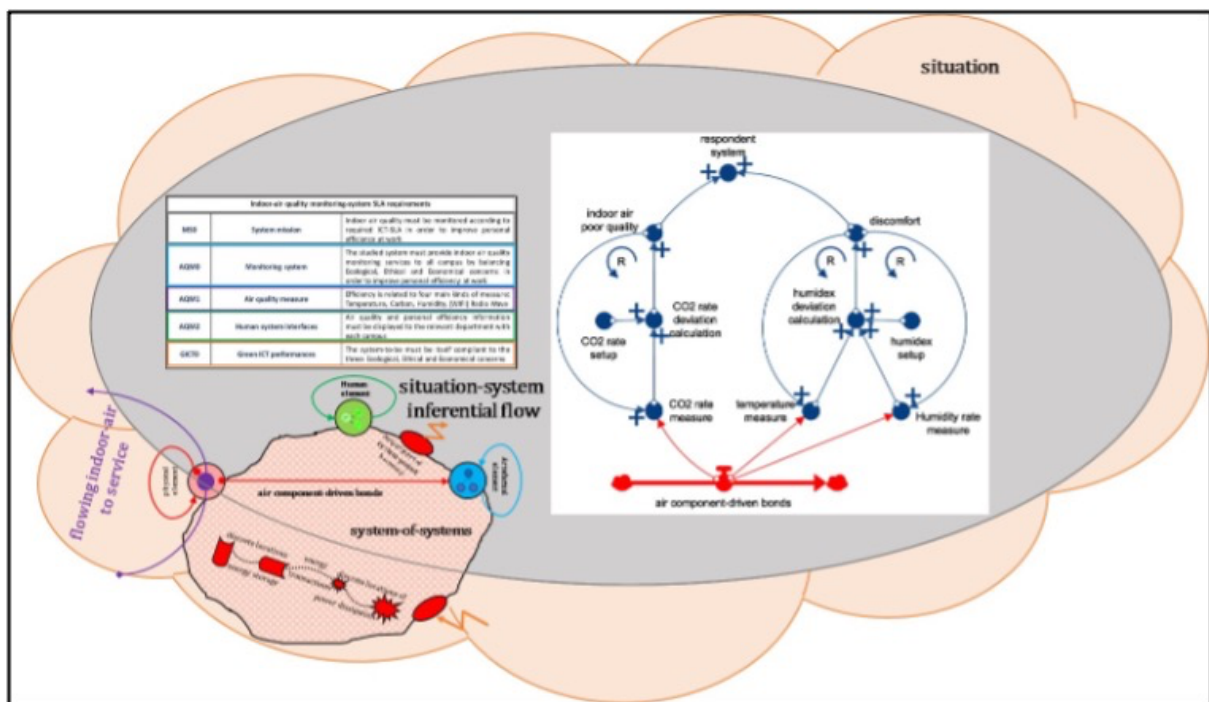


Figure 3.1: requirements-driven situation-system wholeness framing

Thus, a first attitude, for example for formative purposes<sup>10</sup>, is to explore the root "context" and the branch "perceive" to discern the circumstances of indoor air quality degradation and its effects on occupants in order to understand the context in which the stakeholders' requirements

<sup>10</sup> « Systems engineering » course of EMJMD Pervasive Computing and Communications for Sustainable Development, related to a Complex Systems Engineering master's degree (<http://fst.univ-lorraine.fr/formations/master-ingenierie-des-systemes-complexes>)

were expressed. The boundaries of the situation-system wholeness are so given. Anticipating these effects leads then to progress along the “detect the influences” branch for sketching the outline of the sufficient causes as being air components-driven bonds events (Figure 3.1 in red) that precede a IAQ damage event, and with which this damage event occurs or no (Rothman and Greenland 2005).

A knowledge exchange with a QSE expert is therefore needed to designate these IAQ components, their properties and their bonds by the mean of the roots “structure”, “relationships” and “behavior”. QSE good practices leads first to identify the CO<sub>2</sub> component as the main polluter released by occupants, justifying so to monitor its rate in indoor air as a normative intensive measured property for IAQ issues.

This first frame does not, however, allow to state on the wholeness completeness between indoor air quality and the implicit needs of comfort of the occupants for efficiency at work (Pereira et al. 2014; Dong et al. 2021; Haddad et al. 2021). Inquiring beyond the SLA requirements about this missing link is then a pretext to continue navigating in the system tree for discerning others related hidden influences. Reassessing the wholeness of the situation-system relies now on the “conceptagon” (Boardman and Sauser 2013) as an architectural pattern for system wholeness completeness issues. Focusing on the “function-structure-process” triad suggests the humidex index as an indicator candidate to objectify the impact of the air quality on the human subjective comfort sensation, and so and. This extensive property indirectly qualifies the correlated impact of the released CO<sub>2</sub> rate and other intensive properties such as indoor humidity rate resulting of the release in the air of H<sub>2</sub>O by occupants perspiration and indoor temperature influenced by the occupants one.

Finally, closing the system-loop with the “communication-command-control” triad lead to prescribe a refined requirements-driven situation-system wholeness diagram in a form of causal loops diagram (in Figure 3.1) highlighting the indoor air components bonds to be monitored by a humidex-driven monitoring system (Rondeau et al. 2015). Further orchestration steps with requested specialists lead to translating in SysML language for executable model-based<sup>11</sup> issues a preliminary architecting of a respondent monitoring system.

Wholeness-oriented situation-system framing revealed the entanglement of air components-driven bonds that should be unified in an integrative physics perspective, which goes beyond the traditional mental schemes, as in the case of the systemic thinking. It should be however noted that this wholeness boundary doesn't take enough into account the available energy

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<sup>11</sup> IBM® Rational® Rhapsody®

transactions enabling human in the loop anchoring (Figure 3.1 in green) onto the situation-system as pointed out in sub-section 2.3. and rather reducibly addressed by only human factors. So that we address in next sub-section the situation-system togetherness energy anchoring of what reveals to be de facto a physico-physiological system of systems.

### 3.2. Experiential-oriented situation-system framing

Now we address the {experiential reality} of indoor air flowing physiological requirements onto situation-system (Figure 3.2) beyond the technical ones previously satisfied.

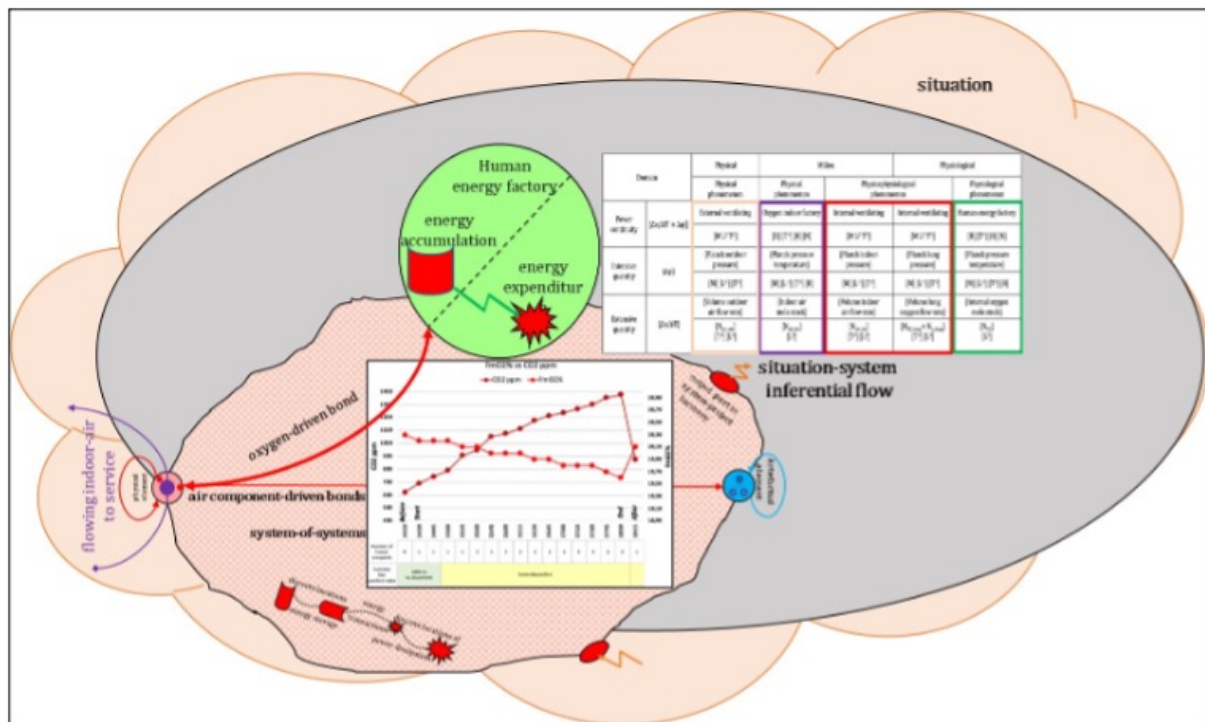


Figure 3.2: phenomenon-driven situation-system experiential framing

#### 3.2.1. Physico-physiological oriented-framing of the experiential situation-system

We focus first mainly on the indoor air flowing requirements (figure 3.2, red curve) of the human energy factory situation (figure 3.2, in green). Sanitary crisis as well as literature and exchanges with a physiologist make us aware that these requirements are related to at least two situations: an energetic situation and a physico-physiological situation. The first situation refers to the physiological phenomenon of energy factory to produce, from intake physical energy, physiological energy to be accumulated to meet our energy expenditure for performing working activities. The second situation refers to the physiological phenomena of consumption of the requested energy to meet the previous energy requirements. One of the phenomena satisfying these needs is the absorption of nutrients contained in our food. The other is the breathing of



the required energy put at our disposal by the physical phenomenon of indoor energy factory. The dependence of occupants on these energy transactions with the indoor milieu outlines a situation-system in the {experiential reality} framed by this primary energy-driven boundary of a psychophysiological system of systems (SoS).

Following our scientific corpus, we deepen then the complete energy phenomenological regime of this SoS in order to make visible the energy causation bonds that anchors the two previous phenomena. The feedback of the physiologist specialist in this respect allows us to designate oxygen as the requested oxidant for the production of our physiological energy by combustion of the nutrients fuel with, at the same time, a release of waste products, such dioxide of carbon (CO<sub>2</sub>) and thermic dissipation. In fact, (Martin et al. 2017) underline the importance of this oxygen role by showing, through predictive models, the impact that the atmosphere deoxygenation might have on human energy requirements. Moreover, (Lador et al. 2006) gave the experimental proofs of a direct relation between energy quantity requirements and intake oxygen quantity at the breathing level. In all logics, we assume then that oxygen-driven bonds plays the role of the architectural “mortar” of the energy transactions connectedness of this extended physico-physiological system of systems, keeping into energy integrity both human and indoor air. According to our precept, the dimensional analysis (table in figure 3.2) aims finally to *power continuity checking* this oxygen-driven bond energy (figure 3.2 in red) connectedness causing by a pression variation (intensive quantity in red in the table of figure 3.2) between the milieu and the physiological lung making flowing oxygen (extensive quantity in red in the table of figure 3.2) from indoor milieu to occupants. According to our precept, this oxygen-driven internal ventilating phenomenon between physical and physiological energy factory locations (respectively in violet and green in the table of figure 3.2) forms de facto the energy togetherness of the resulting situation-system wholeness in section 3.1.

### 3.2.2. Checking of the resulting situation-system vis-à-vis of the {experiential reality}

We now focus of the dynamics of the internal ventilating physico-physiological phenomenon onto the situation-system togetherness in the {experiential reality} of a confined space.

#### *Experiment protocol*

So that parameters trends can be measured in short working times (for example half a day), we carried out an experiment in a confined space of 200 cubic meters with occupants flowing

inside and outside according to their working activities, indeed our own office. We decided to check the oxygen-driven internal ventilating phenomenon by the measurement of the evolution of the indoor milieu oxygen molar fraction using an oxygen meter. We complete experience with an IAQ meter measuring the molar fraction of CO<sub>2</sub>, the indoor temperature, the molar fraction of H<sub>2</sub>O (related to humidity) as well as the speed of air circulation in the indoor air. In our case, we continuously measure these parameters with a value capture frequency every 15 minutes during half a day with 3 flowing occupants. Such protocol is checked with a Quality-Security-Environment specialist.

### *Experiment results*

Resulting recording in figure 3.2 clearly depicts a significant molar oxygen molar fraction decreasing (in red) calling us on what the indoor air must provide to produce our physiological energy. Reading of these measurements with a physiologic specialist states that oxygen molar fraction value at the beginning of the experiment is far from 21% demonstrated by numerous studies to be the optimum quantity for the human energy factory to produce the required energy for our activities. The physiologic specialist concludes then that the value of the oxygen mole fraction at the end of the experiment is very close to the safe threshold (an oxygen mole fraction of 19.5%<sup>12</sup>), synonymous of a possible damage of our physiological energy production. The calculation of a humidex index (in green and yellow) recently adapted to indoor air (Rana et al. 2013) enables us to correlate this decrease in the mole fraction of oxygen with the subjective feeling of discomfort (appearance of headaches, feeling of dampness, sweating) of occupants. Finally, the physiologist specialist helps us to discern at the intersection curves that the internal ventilating phenomenon correlated to the breathing are the facts at the origin of the variation of the O<sub>2</sub> and CO<sub>2</sub> (in dark red) molar fraction and indirectly of the variation of the indoor temperature and humidity rate.

This experiment allows us to evoke, in our work, the oxygen as a principal source of energy transactions to anchor the human onto the situation-system and that, of its rate depends on the good functioning of the human energy factory. It should be noted that paradoxically humans are first responsible for its decrease by rejecting CO<sub>2</sub>, the main pollutant of the indoor air.

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<sup>12</sup> Site canadien du travail

### 3.3. Dynamics-oriented framing of an energy bond of the situation-system togetherness

After having experimentally checked the role of flowing oxygen to energy anchoring human onto situation-system togetherness, we first give it a mathematical background in order to achieve the situation-system togetherness dynamics consistency according to the dimensional analysis table in figure 3.2.

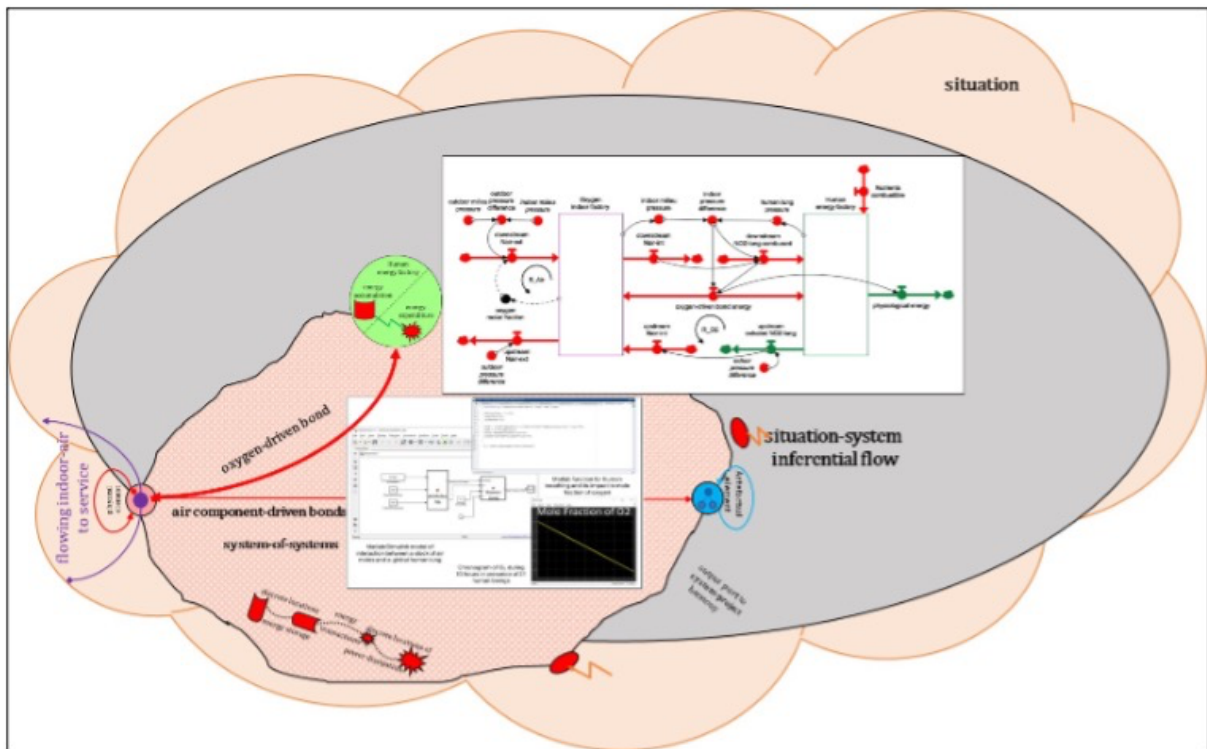


Figure 3.3: energy-driven situation-system togetherness framing

#### 3.3.1. Framing of the flowing oxygen-driven energy-bond

Previous works (Mayer et al. 2020) focused on the model-based interdisciplinary specification process of a physico-physiological situation-system wholeness termed hybrid homeostasis but not on its resulting energy togetherness as developed in this following work. For this purpose, we reassess this wholeness by deepen the physico-physiological aspect of the oxygen-driven energy bond with the physiologist before to express it mathematically. Within the *integrative physiology framework*, the oxygen-driven energy bond may constitute one of the paths of a functional interaction (sub-section 2.3) and so can be identified through the carried inhaled physical quantity of oxygen under a molar form. The physical assumption of (Paynter 1961) leads us then to posit that, associated to this energy bond, are a physical lung-like (drawing the indoor internal ventilating phenomenon) and a physiological lung (drawing

occupants breathing as a global human internal ventilating phenomenon). A bio-inspired approach allows us finally to define these two lungs as forming a unique physico-physiological lung on which a global physico-physiological internal ventilating phenomenon exerts an influence in the form of oxygen-driven energy bond. Then, we rely on the force balance equation given by (Herman 2016) to estimate the evolution of the indoor oxygen mole quantity yielding by this energy bond. On average, each human being typically inhales  $\sim 6L/$  of min air expressing the inhalation rate ( $d_{Inhaling}^{Air}$ ) that we can consider as expressing the physico-physiological phenomenon of internal ventilating. And 5% of inhaled oxygen is consumed for energy factory requirements, 4 % of carbon dioxide and about 0.5 kg water vapor/day are released in the exhaled air while Nitrogen remains constant.

As we consider the milieu at a contained scale, the evolution of the quantity of indoor oxygen  $n_{O_2}^{Ind}(t)$  as the extensive quantity of our dimensional analysis (in red in the table in figure 3.2) results only from the human breathing in terms of consumption according to:

$$(1): \quad n_{O_2}^{Ind}(t) = \frac{n_{O_2}^{Ind}(t=0)}{\left(1 + nbH \times \left(\frac{5}{100}\right) \times \left(\frac{d_{Breathing}^{Air}(t)}{V_{Ind}}\right) \times t\right)}$$

With  $V_{Int}$ ,  $nbH$ ,  $d_{Breathing}^{Air}$  respectively the physical volume of the indoor milieu, the number of occupants and the inhalation rate bounded to the physico-physiological lung.

This mathematical expression of the oxygen-driven energy bond now allows us to formulate the flowing oxygen quantity in the form of a molar fraction  $f_{O_2}^m$  (in violet in the table in figure 3.2) located in the indoor milieu at occupants disposal to meet their own energy requirements. It should be noted that this fraction is proportional to these of CO2 and H2O, being other mixed elements active in the indoor air as well as this of the Nitrogen passive element. For this, we use ideal gas law (2)  $PV = nRT$  as simplex rule suggested by (Nazaroff 2013) where P, V and T are respectively the indoor pressure, volume and absolute temperature before human occupants incoming; n is the number of total moles (indoor air); and R is the universal constant of the ideal gases (8,314 J/K.mol).

$$(3): \quad f_{O_2}^m = \frac{n_{O_2}^{Ind}(t)}{\sum_i n_i^{Ind}(t)} = \frac{n_{O_2}^{Ind}(t)}{n_{O_2}^{Ind}(t) + n_{CO_2}^{Ind}(t) + H_2O^v + n_{N_2}^{Ind}(t)}$$

For physiological issues, the value of this oxygen molar fraction must be between 19% and 21% in the indoor air. In some extend of PAAS defined by Chauvet as "*a principle of construction and organization of a biological system*", this molar fraction is an invariant reflecting the supply of the requested amount of oxygen to the occupants by the indoor milieu, exercising phenomenologically the required oxygen-driven bond connectedness to form the energy togetherness of the situation-system. Transitioning the mathematical model into an multiphysics model<sup>13</sup> (Figure 3.3) with scenario-based state cases aims to given an executable proof of this oxygen-driven bond connectedness between energy storage and factory locations for IAQ issues.

### 3.3.2. Dynamics-oriented transitioning of the resulting energy-bond behavior

We now transition the previous dimensional power continuity checking into an executable stock-flow diagram (Figure 3.3) in order to highlight the role of the oxygen-driven energy bond as an {energy-driven force} triggering the dynamics of the situation-system energy togetherness.

First of all, the moving of the oxygen extensive quantity involving the energy togetherness is diagrammed by valves and flaps. According to equation (1) in sub-section 3.3.1, their opening makes flowing the « downstream  $N_{O_2-lung}$  comburant» flow (illustrated by a red valve) as the requested comburant taken (illustrated by a black connector) in the “downstream  $N_{air-int}$ ” flow (illustrated by a red valve) produced by the “indoor milieu oxygen factory” (stock in violet). In return, always according to previous equation, their opening makes flowing the “upstream exhaled  $N_{O_2-lung}$ ” flow (red valve) released by the “energy human factory” (stock in green) in the indoor milieu through the “upstream  $N_{air-int}$ ” flow (red valve). According to physical processes conceptualization principles (Fuchs 2010), the opening of the several valves occurs when it exists a variation of pressure within the physico-physiological lung that we depict in the stock-flow diagram by converters (circles in red) connected to valves flaps stating on the pressure difference between the “indoor milieu oxygen factory” and the “energy human factory”. By some analogy with case study developed in section 4, this first “physico-physiological circuit” dynamics framing results in the materialization of a “physico-physiological air-oxygen gap” as the causal phenomenological closure with which the situation-system is concerned.

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<sup>13</sup> Matlab®/Simulink®, <https://fr.mathworks.com/>

According to our scientific corpus, the dynamics of the flowing oxygen and of its related pressure results in the supply of an oxygen-driven bond energy flow (illustrated by a red valve) to the energy human factory in order that it delivers the required physiological energy flow (illustrated by a green valve) for performing working activities. This energy continuity (depicted by a black connector linked the two energy flows) through the two factories is however contingent on the amount of oxygen available in the stock “indoor milieu oxygen factory” (according to equation (2) in sub-section 3.3.1). As we have experienced in subsection 3.2.2, this quantity decreases over time due to human breathing, until it reaches a certain threshold causing the imbalance (R\_O2 counterclockwise loop) perhaps even the breakdown of the oxygen-driven energy bond with the consequence of causing a systemic failure of the situation-system energy togetherness, impacting the physiological energy production (as illustrating by the connector between the two energy valves). The system dynamics precepts then suggest to make of the indoor oxygen molar fraction (equation (3) in sub-section 3.3.1) a variable depicted as a converter (in black) to achieve an oxygen-driven controllability (black dotted connector) of the supply of outdoor air to renew the indoor oxygen in order to recover the balance (B\_Air clockwise loop) of the situation-system energy togetherness.

#### 3.4. Situation-system togetherness innovative perspectives

As far as the human energy factory is concerned, it can be noted that, while the IAQ devices did not know whether the well-being is, the human energy factory *knew* about that situation-system. So that our *situation and system thinking* corpus is in contradistinction with IAQ current practices which limits have been revealed by the pandemic crisis. In fact, this period has allowed to point out some possible drawback on indoor-air renewability subordinated to multiple influential factors to coping each to technology-enhanced situations, but which physico-physiological energy togetherness may be questionable. For example, the indoor-air natural renewal as legacy recommended to cope with diffusion viral effect may be in contradistinction with airborne recycling effect of dual stream mechanical ventilation for energetic issues among others. Recent renewed feedback with successively a "60 students' lung" performing cognitive activity of collaborative innovation in the same University teaching space (amphitheater) confirms the recorded cross trends between CO<sub>2</sub> and O<sub>2</sub> making of the later a suitable IAQ controllability candidate. Especially since the right human oxygenation is manifestly the vital combustive effect for energy human factory energetic to facing any disturbance situation. It should be noted in the same environment others concerns from multiple engineering and operation in-silo acts along the life-cycle of the as-is air-quality control-system,

such as the moving of sensors for esthetic concerns, the change of air renewal for pedagogical or building retro-fitting concerns as well as for the attraction of newer available technologies, and so and. So that the interdisciplinary focus on the situation-system energy togetherness to be maintained is candidate for multidisciplinary framing orchestration of the many surrounding situations, as for example thermal comfort related to H<sub>2</sub>O.

So that it is no longer suitable to not considered the dynamics of energy togetherness of IAQ systems which some failures and weaknesses are repeatedly reminding us that they exhibit de facto a behavior of physiological system of technical systems. This implies an architecting paradigm shift to ensure a data-driven connectedness continuum (figure 3.4) between the in-situ reality of a contained situation (at left) and the in-silico reality of a remote (or not) multidisciplinary systems engineering situation (at right). A formative scenario onto our working situation of learning in our training building<sup>14</sup> points out some interdisciplinary moments (multi-colored circles) to orchestrate a synergetic togetherness between multidisciplinary wholeness assets. Some well-being damage reported by learners {L} and teachers {T} to the systems engineering staff (at right) is giving the opportunity of a training project through research to innovative practices. One of them play the role of system architect (A) to frame with a system thinker {S} the dynamics of the situation-system to be controlled (figure 3.3). The contained scale of such project situation makes easier the knowledge appropriation by the many involved educational assets (students, engineers, researchers, teachers, ...) of the simplex framing guideline inquiring on *which matter-energy must flowing to maintain in well-being energy-togetherness such situation-system while analysing and synthesizing a respondent to-be system*. Ambient computer technology enables the measurement of air-component driven bonds (Rondeau) with the extended measurement of the oxygen molar fraction, to reflect on the fly through a digital bus (in blue) the {experiential reality} (at left). At another project stages, physiology {Ψ}, physics {φ} and control {C} specialists may exchange directly between them for integrative issues, such as thermal comfort (at middle, on top) or human-energy control (at middle, on bottom) as well as with the systems engineering staff (at right) by the means of the *SysML* languages of any means facilitating cross understanding. We argue that such innovative architecting paradigm would contribute to efficient well-being occupant service in many domains, in a broader dynamic perspective of Human-infrastructure togetherness, by taken better into account the integrative air-water contribution to the human energy factory.

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<sup>14</sup> Systems Manufacturing Academics Resources Technologies (<https://aip-primeca.univ-lorraine.fr>)

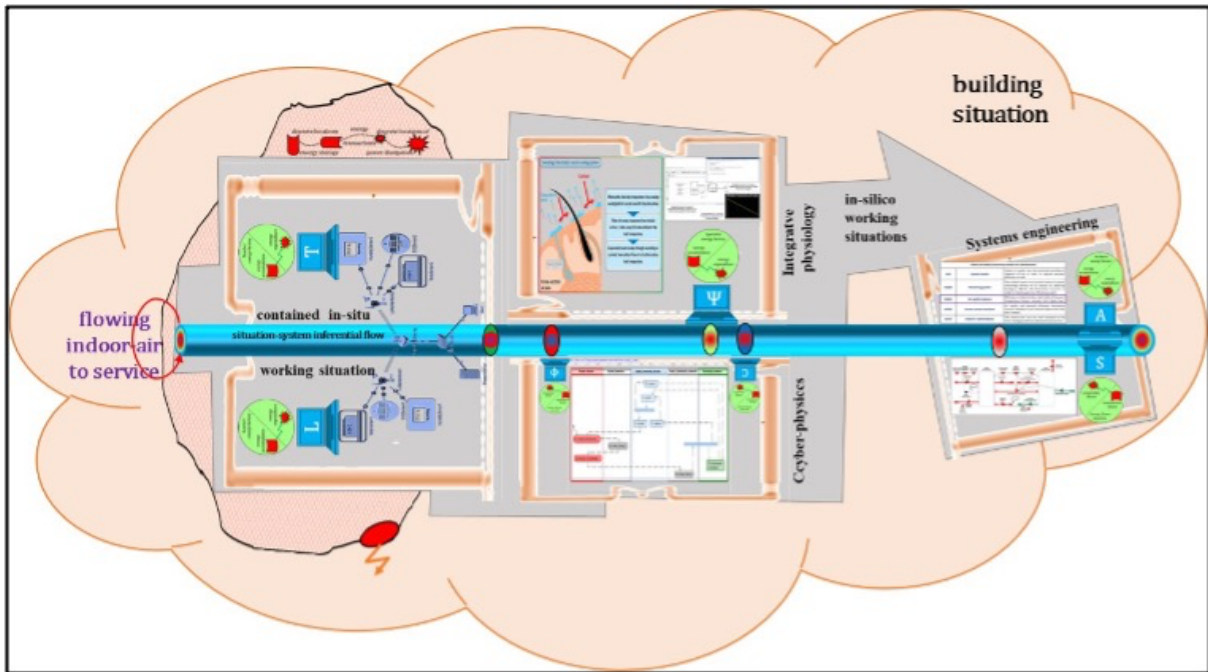


Figure 3.4: Togetherness and wholeness architecting pattern for a working situation-system dynamics

#### 4. Situation-system togetherness qualitative case-study at large-scale

Conversely to information-based SoS in the manufacturing domain, the connectivity of a power grid relies with the direct synchronizing role of the flowing matter-energy itself. We base first in {experiential reality} on specialist expertise the framing of the situation-system togetherness damage and recovering resulting of a European power grid systemic disturbance. We base then in {engineering reality} on simplex interdisciplinary orchestration of Systems Dynamics and Multiphysics Integrative Cyberneconduction<sup>15</sup> the perspective of a control paradigm change to form the togetherness of such situation-system examined as a cyberneconduction-driven  $\{\Omega\}$  system of energy  $\{\eta\}$  systems  $\{S_{\Omega} \wedge S_{\eta}\}$ .

##### 4.1. Togetherness context of a system of power component systems

The quality-of-service (QoSe) of a power grid is related first to the phenomenological essence of electricity as man-made energy increasingly consumed in a variable way. This QoSe is contingent on belonging best-practices to a whole system to control flowing matter-energy

<sup>15</sup> Underlying an in-progress Mathematical Tooling of Integrative Cyberneconduction (MTIC) from registered term la cyberne conduction by (<https://marques.expert/hennebicq-jean-pierre/la-cyberne-conduction-3698283.html>)



resulting from the multi-systems conversion of a variety of natural energy sources, renewable (hydraulic, wind, solar, marine, ...) or not (fossil including nuclear), throughout a variety of enabling energy forms (thermal, mechanical, magnetic, ...). The evolution of not-planned power production practices is increasingly adding the necessary deployment of storage systems to accumulate this variable power in an enabling form (gravitational, thermodynamic, kinetic, electrochemical, chemical) to make its planned controllability. This phenomenon of production-consumption variability is increasing the risk of a major incident when main cascading overloads, voltage collapse, frequency variation and loss of synchronism phenomena occur consecutively or simultaneously overcoming reliability standards<sup>16</sup>. Looking inwards the systems connectivity of a power grid exhibits properties that characterize the overall behavior of a system whole of heterogeneous technological, human, and natural systems. The recurrent feedback from various expert committees on what makes or breaks the wholeness of this {SoSe} focus mainly after togetherness damage and recovering on the improvement of steering rules of multi-stakeholders having to mitigate the effects of the emergence of disturbance intertwined situations to recover the right service of active power delivering at right frequency with a certain constituent systems autonomy. Moreover, the literature (Li 2009; Pannatier 2010; Ngoc 2011; El-Sefy et al. 2019; Guilbert and Vitale 2021) and many reports remain looking inwards the future of power-energy grid<sup>17</sup> with a technology-enhanced in-silo approach rather than with a multidisciplinary systemic perspective to look outwards its multi-scale energy dimension (Bouscayrol 2003) to assess in return each impact on the grid togetherness (for example reactive power stiffening effect of a storage component). The physics nature of togetherness appears us as an integrative resilient means, so that we have exploring how making of the flowing power-energy the synchronizer of the multiple systems involved in consumption, planification, distribution, transport related to tangible service on one hand and production, allocation, supply, accumulation related to tangible good on another hand.

#### 4.2. Togetherness framing of a disturbance situation-system

We depict by some extent in (figure 4.2) an emulated form of record from real state-event recorders reflecting a plausible reality of the disturbance situations chronology relying with the European grid service loss in 2006 November. We focus mainly on the operating state-event situations which phenomenological entanglement has not enabled operators to decipher on-the-

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<sup>16</sup> RTE reliability report 2020 ([www.services-rte.com](http://www.services-rte.com) )

<sup>17</sup> RTE future pathways to 2050 (<https://www.rte-france.com/analyses-tendances-et-prospectives>)

fly some “structural steady state” (Galara and Hennebicq 1999) to construct “by detour” a mental scheme to recover locally or globally a known situation-system with regards to an acquired knowledge. As some not visible phenomena has remaining a posteriori misunderstood or unexplained, we apply a domain physics-oriented analysis from visible facts to point out cyberneconduction causations on grid togetherness which result of powering control deterministic actions (controllable energy) or not (variable energy) and localized (at a certain site) or not (by resonance).

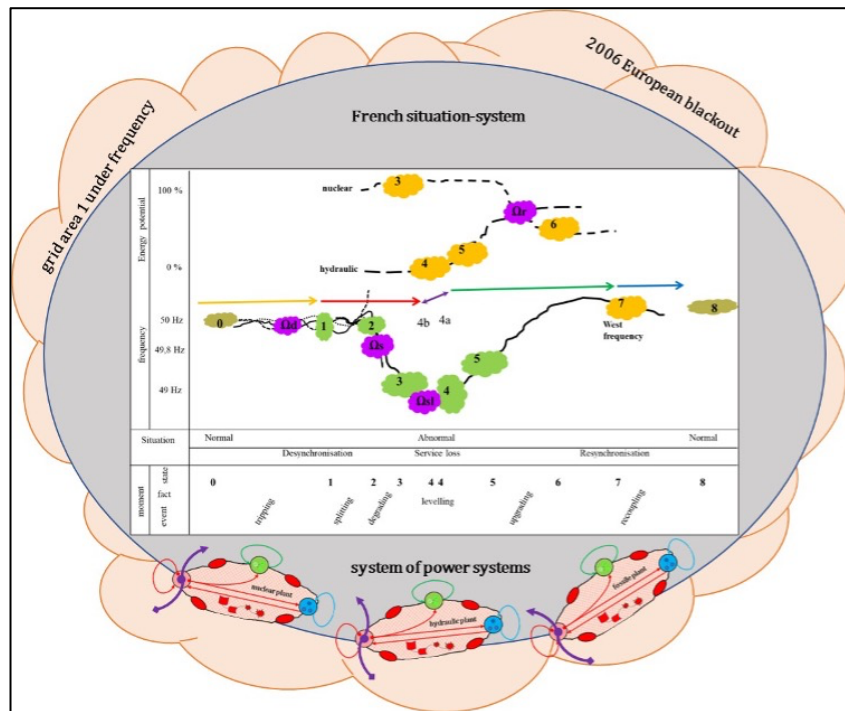


Figure 4.2.1.: Situation-system togetherness disturbance framing

#### 4.2.1. Physics-oriented framing

A factual reporting of the physical separation of the synchronously interconnected grid pointed out as root cause at moment {0} a manual action of line opening without fulfilment of best practices regulation criteria resulting in automated cascade of lines tripping in Germany. A frequency variation at moment {1} appeared between three geographical zones emanating from the critical zone which ended with the splitting of the grid into three at moment {2}; an over-frequency surplus zone in the North-East, a slightly under-frequency deficit zone in the South-East, and a strongly deficit zone in the West of Europe for which the frequency dropped sharply. Considered the importance of East-West powering transfers prior to the incident, a few generation units were disconnected from the grid on frequency or voltage criteria, unable by design to maintain themselves in a disturbed situation because of additional wind power and

cogeneration. So that the use of primary and secondary energy reserves within the West-European grid revealed not sufficient to contain the frequency dropping at moment  $\{3\}$ . We continue this fact-oriented analysis with physics-oriented knowing-how on the operating modes of plants to synthesize visible causations of French situations of power frequency-control disturbance (in green and orange) resulting from state-event triggering between constituent systems at a nuclear plant scale. We frame then some phenomenological causations (in violet) at moments  $\{\Omega_d, \Omega_s, \Omega_{sl}, \Omega_r\}$  making visible by applying qualitative knowledge on Integrative Cyberneconduction  $\{\Omega\}$ .

#### 4.2.2. Cyberneconduction-oriented framing

We frame then some phenomenological causations (in violet) at moments  $\{\Omega_d, \Omega_s, \Omega_{sl}, \Omega_r\}$  making visible by applying qualitative knowledge on Integrative Cyberneconduction  $\{\Omega\}$ .

##### *Desynchronization*

Today, the dynamics of a grid is mainly driven by the physical behaviour of power plants alternators to convert rotational mechanical energy in pulsative electrical energy. An early phenomenological understanding of the divergent instability of the frequencies of the 3 zones just before the separation should have stated that the French generation units remained interconnected together on the West European grid and not in separate mode as some control plant operator (CPO) may have believed.

$\{\Omega_d\}$ : The redistribution of power-energy flows points out extrinsic and intrinsic effects on each turbo-alternator characteristics (launch time, electromagnetic coupling between rotor and stator, and line inductance, ...) impacting in return plant reactive power and voltage control but without un-anchoring highlighting a certain robustness.

##### *Service loss*

The resulting effect on nuclear plants of the abnormal frequency deviation is an entanglement of three disturbance situations of dropping, levelling, and rising at moments  $\{\Omega_s\}$ ,  $\{\Omega_{sl}\}$  and  $\{\Omega_r\}$ . The loss of synchronism due to separation produced a power discontinuity event between generation and consumption resulting in a frequency dropping perceptible by the French transmission system operator (TSO).

{ $\Omega_s$ }: The rise to maximum power of the generation plants points out a transient overshoot observed in first time but later remained phenomenologically misunderstood.

That led at moment {3} to the switch to forced manual power-frequency control (CMAD) of nuclear plant when the frequency drops to less than 49.8 Hz which corresponds to a certain increase of the local production to the resorb the global unbalance between the actual consumption and the global production. The automatic triggering of interruptible load shedding<sup>18</sup> resulted then to a 49 Hz levelling at moment {4} with frequency rising at moment {5} with nuclear power decreasing. What is revealed by analysis feedback in figure (4.2.1) is the powering (orange arrow) and energy (red arrow) coupling at moment {4b} et {4a}) between the extrinsic parameters of the situations of the mechanical domain of rotation (and situations of the other upstream production domains) and the extrinsic parameters of the electrical domain of pulsation of the AC current (and the situations of the other downstream consumption domains) when service loss.

{ $\Omega_{sl}$ }: The generation/consumption imbalance that causes the frequency dropping to stop points out a physical self-powering frequency control manifested itself by spatially decentralized effects aggregating at the speed of the power phenomena in the middle of the mechanical-electrical conversion domain highlighting a certain resilience (charges self-control).

### *Resynchronization*

Energy variation reveals phenomenological causation on frequency-control after nuclear units became again locally regulating at moment {5}. The French (TSO) who just had using hydraulic reserves has no longer known then how to balance together hydraulic and nuclear reserves from resynchronization at moment {6} to stabilization at 50 Hz at moment {7} and recoupling conditions checking with the 3 zones at moment {8}.

{ $\Omega_r$ }: Cascading energy causations from dropping to additional energy calling at resynchronization point out a loosely powering control before tightly recovering for recoupling (power deficit too large to use only hydraulic plant as pilot plant for recovering power balance).

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<sup>18</sup> Feedback from 1978 black-out which cause has been relied to lack of intervention in due time for manual load shedding decision-making when facing frequency collapse.

### 4.3. Situation-system togetherness dynamics-oriented framing

The state-event situation-system togetherness manifested itself indirectly and mainly in the form of power-balance frequency-control to any (TSO) and (CPO) at different moments and different European sites scales. Above phenomenological causations at the French scale manifestly centers well the togetherness closure of all the situations in the electricity generating domain, where electromagnetic forces should exert the anchoring or not of the multiple heterogeneous involved systems.

#### *As-is situation-system*

We depict its dynamics in the form of an executable stock-flow diagram (Figure 4.3.1.) to point out first the frequency-driven controllability (in top) of active and reactive power balance between plant production and grid consumption of which we examine the  $\{Sg^{\wedge}S\eta\}$  wholeness as a whole-alternator (in middle). The airgap power togetherness is based on (Moreschi and Sparling 1984) works involving the mass with the electric charge and the magnetic charge to admit an electromagnetic charge which moving through an electromagnetic circuit by analogy with an electrical circuit enable us to state of an electromagnetic power. Notwithstanding electromagnetics deepening studies, we assume that a certain upstream and downstream power continuity within airgap is dimensionally resulting of the wavelength-driven moving of an electromagnetic charge quantity which acts (in green) through the  $\{\text{surface}\}$  of a “valve flap” to carry a vectorial  $\{\text{electromagnetic exitance}\}$  yielding a conductive energy transfer with sliding and dissipation effects. From a preliminary excitation electrical DC current of the rotating  $\{\text{electromagnetic field}\}$ , available electric charges are put into downstream moving by a pulsating energy to supply to grid and thus to deliver to consumption respectively an  $\{\text{active power}\}$  and an  $\{\text{apparent power}\}$  characterized by  $\{\text{voltage}\}$  and  $\{\text{intensity}\}$  quantities under  $\{\text{frequency set-up}\}$ . In practice, four regulation loops  $\{\text{voltage, angle, mechanical power, electrical power}\}$  enable to push from production a relevant  $\{\text{pulsating electrical energy}\}$  to counter the  $\{\text{stiffening effect}\}$  relating to upstream  $\{\text{inertia reactance}\}$  and downstream  $\{\text{electricity reactance}\}$  of power circuits from which a reactive portion contributes to making the electromagnetic fields. A  $\{\text{synchronizing power}\}$  tooling (in dotted info-converter) is operating by TSOs and CPOs from power observables under setting-up rules to maintain a damping ratio of  $\{\text{frequency/active-power}\}$  to consumption and of  $\{\text{voltage/reactive-power}\}$  to production. Back to above situation-system togetherness damage, it can be considered at  $\{R_{\Omega d}\}$  that only a quarter of the connected generating systems effectively participated to

frequency/active power self-adjustment to counter the tripping effect on {transmission angle} as well as from {variable power} effect on grid synchronizing power and thus on that of each plant. So that calling to shedding at  $\{R_{\Omega_s}\}$  and later to energy contributed to stabilize frequency dropping and then to recover right frequency at  $\{R_{\Omega_r}\}$ . Direct calling to energy at resynchronization  $\{B_{\Omega_r}\}$  or not enough between TSOs and CPOs at desynchronization  $\{R_{\Omega_d}\}$  and dropping  $\{R_{\Omega_s}\}$  point out a certain architecting weakness of the information-enabled controllability paradigm (in blue) of such  $\{S_g \wedge S_\eta\}$  to maintain a powering togetherness (in orange) of situation-systems intricating de facto physical, logical, and Human domains.

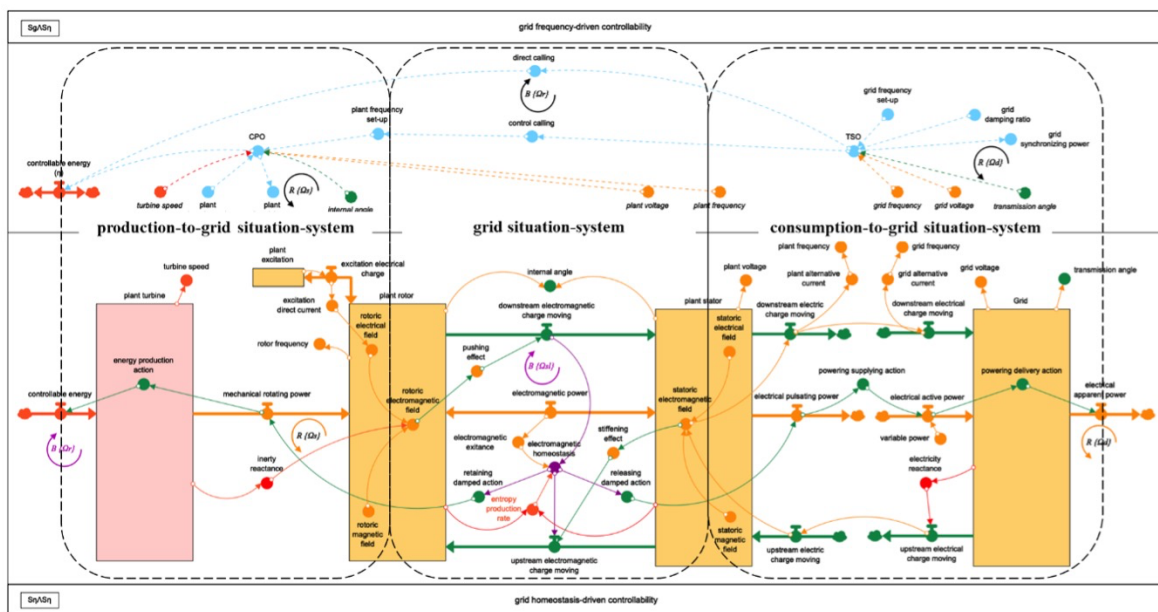


Figure 4.3.1: As-is situation-system dynamics-oriented framing

### To-be situation-system

Even more than a homeostasis-like controllability effect  $\{S_\eta \wedge S_\eta\}$  of powering recovering has manifested by itself at levelling moment by some balancing dynamics  $\{B_{\Omega_{sl}}\}$  of pull-push causations between variable consumption and respondent production. Having in mind the “hysteresis” role of the two respective ferromagnetic parts of the stator and rotor (seat of iron permeability) connected by the air-gap (seat of an air permeability), we make an analogy with a {memory effect resistor} from (Chua 1971) works to reflect the electromagnetics entanglement having mitigated “naturally” the power upstream and downstream effects. This sixth link invoked between electrical charge and magnetic flux among the various pairings bringing together the four basic variables {voltage, current, charge, magnetic flux} of electric circuits points out a hysteresis loop whose two branches crossing at the origin reflect some

information storing capability from past. So that a nonlinear ratio as  $\{M=V/I\}$  is reflecting some dynamical shifting of the boundary between what energy to be retained or released throughout power flow pipes. It is therefore possible to consider that the memristive ohmic dimension  $[V.I^{-1}]$  be a constitutive observable of the balancing  $\{\text{conduction}\}$  role with a  $\{\text{cyberne}\}$  added value played by the matter-energy flowing for  $\{S_{\Omega} \wedge S_{\eta}\}$  controllability issues, by some extent analogy with the product-driven control paradigm in discrete process domain, By making a dimensional homogeneous translation of  $[M]$  as  $[\text{Planck}/\text{charge squared}]$ , we reflects in (figure 4.3.2) the dynamics role that this  $\{\text{cyberneconduction}\}$  property  $\{\Omega\}$  (converter, in violet) of the matter-energy could playing, by flowing from a  $\{\text{discrete energy state}\}$  to another one (converters in red), along a  $\{\text{cyberneconductor}\}$  (pipes in orange) where energy informing-actions and forming-actions (converters in green) would enable intra and inter domain space-time situational changes. For example, to maintain a grid powering balance  $\{B_{\Omega g}\}$  under TSO's controllability activities of the global situation-system togetherness (in middle) when allocating the circular causations to synchronize a power continuity at relevant power generation  $\{B_{\Omega g 2 p i}\}$  and  $\{B_{\Omega g 2 p j}\}$  from various plants under CPO's local situation-system togetherness controllability activities (in left) in order to satisfy variable situation-systems of powering consumption  $\{B_{\Omega g 2 c k}\}$  and  $\{B_{\Omega g 2 c l}\}$  (in right). Nevertheless, it should be noted that the  $[\text{cyberneconduction unit}]$  must be recursively specialized as  $[\text{Planck}/\text{local displacement squared}]$  to any not electrical domain, such as a generating domain  $\{B_{\Omega p i}\}$  and  $\{B_{\Omega p j}\}$  where power conversions depend on the nature of controllable energy source for which we envision a cyberneconduction-driven turbo-alternator control paradigm change for practical and theoretical issues in next sub-section. That makes also of  $\{\text{cyberneconduction}\}$ , among other possibilities, a candidate property to observe more from the matter-energy flowing for human-in-the-loop constructs of discrete energy steady-state throughout the many involved situation-systems. Towards cyberneconduction-based unifying interoperability  $\{S_{\Omega} \wedge S_{\eta}\}$ , and even  $\{S_{\Omega} \wedge S_{\Omega}\}$  one, possibly enhanced by digital twin technology.

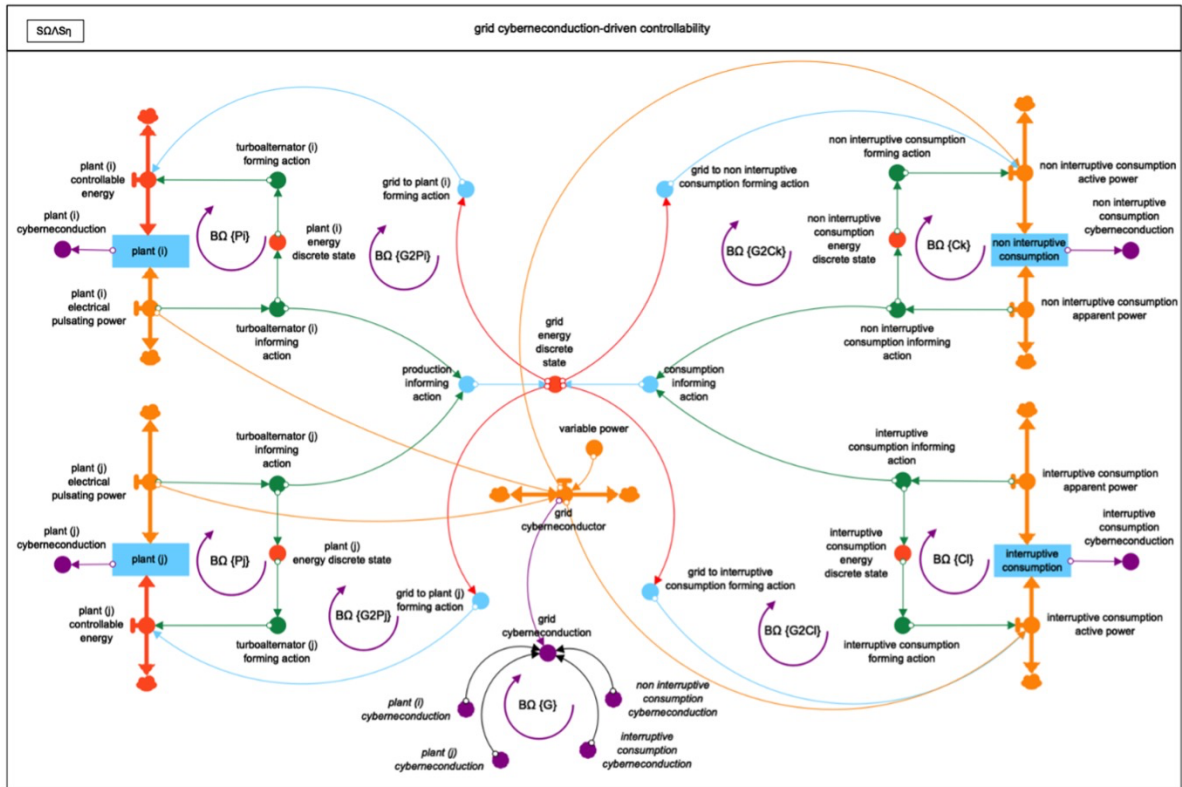


Figure 4.3.2: To-be situation-system dynamics-oriented framing

#### 4.4. Situation-System togetherness cyberneconduction-driven control

The framing of multiple situational behaviors in (figure 4.2) has revealed cascading causations which main effect led to the synchronization damage of grid connectivity examined as a managed  $\{Sg \wedge S\eta\}$  and thus of the as-is situation-system, pointing out a togetherness dependency between them. We localized then the phenomenological togetherness damage in (figure 4.3.1, violet) at the air-gap of the grid examined as a whole-alternator aggregating the operation of the interconnected alternators. We next outline in (figure 4.3.2.) the balancing  $\{\text{conduction}\}$  role with a  $\{\text{cyberne}\}$  added value played “naturally” by the flowing matter-energy to reveal a certain remanent togetherness which memory effect is inherited upstream from various types of plants that produce the mechanical rotational energy to and from the rotor, and downstream from various types of consumption that consume the electrical energy to and from the stator (input and output impedance matching). So that by extensively acting for power synchronizing purposes onto the twin-faces (figure 4.4.1.), TSO’s and CPO’s triggered phenomenological variations onto flowing cyberneconduction which return  $\{\text{cyberneconduction}\}$  and  $\{\text{conduction-cyberne}\}$  effects which may form reinforcement loops instead of balancing ones  $\{B_{\Omega, pi, j,}\}$ . Domain best-practices energy flow diagrams (Tyran 1984; ISO



10628 1997) focus mainly in a functional way on state-event operation sequences to be implemented to make flowing matter-energy throughout space-time by the use of a logical hierarchy of structural means. A major drawback may be to not sufficiently make visible phenomenological causations triggered by matter-energy flowing itself, as for example, the interaction between two mechanico-magnetic and magneto-electric coupling resonances via the transport of magnetic energy in air gap which has manifested by itself at  $\{\Omega d\}$  by a narrow-time (3,3s) of instability period but which not has not been decoded although encoded (recorded). This diagnosis, among others, has led us to note that the connectedness of a power grid should rely with the direct synchronizing role of the flowing matter-energy itself and to envision a situation-system transition which togetherness would be maintained by a cyberneconduction-driven controllability of the rotating effect of each turbine on related alternator and conversely by phenomenological aggregation to power-plants wholeness examined as a  $\{S_{\Omega} \wedge S_{\Omega}\}$ . So that looking inwards a plant situation-system dynamics ( $\{\Pi\}$  in top left, figure 4.3.2) lead us to formally exhibit main artifacts of an going Mathematical Tooling of Integrative Cyberneconduction framework (Figure 4.4.1) whose simplex-oriented drawing underlies a formal graph-oriented notation based by on a system of rules and units by some extent natural as a Planck's based one.

#### 4.4.1. Modelling and theoretical framework

We consider first in (figure 4.4.1,) that the framing of phenomenological recording is resulting of antinomic pairings pointing out the power-service synchronizing of  $\{\text{production-consumption [2-6]}\}$ ,  $\{\text{distribution-supply [5-3]}\}$ ,  $\{\text{planification-allocation [7-1]}\}$  functional pairings enabling the functional  $\{\text{accumulation-transport [8-0]}\}$  pairing forming the grid togetherness. This underlies the reticular entanglement of energy transactions, storages, and dissipations of the total discrete energy in two-fold: one as accumulative (potential energy) and second as transported (kinetic energy). That suggests in (figure 4.4.1, right) generalized relations and variables of Paynter's tetrahedron making of  $\{\text{accumulation [\#]}\}$  and  $\{\text{transport [\sim]}\}$  the constitutive operators of the basic  $\{\text{power [\&-£]}\}$  bond to satisfy the required  $\{\text{service [\$/-§]}\}$  one. However, it should be noted that this diagramming is well suitable for togetherness modelling between space-time steady-states of some physical systems by means of a bond-graph tooling (Dauphin-Tanguy, 2000) (Hennebicq, 2007) applying domain-oriented compulsory rules to direct resistive effects which may be combined with systemic precepts for architecting physico-functional process patterns (Feliot 1997). Even when paying additional

attention to the missing {memristive [%-^]} bond addressed by Chua's works (Chua 1971) of which we above pointed the informing interest, this planar diagramming is not sufficient to reflect the cyberneconduction propagating dimension [4] resulting of the {flowing matter-energy [ $\Omega$ ]} between discrete energy locations as discussed in section 2 for situation-system togetherness issues.

For this purpose, it is necessary to describe higher level pairings in each direction of the graph-diagram and to explicit their role:

- {togetherness [%-\$] [2-6] [HvL]} pairings refer to space-time bond, standing for the {Hamilton [H]} conservation of energy and for the {Liouville [L]} arrow of time in an irreversible direction.

- {Connectedness [£-^] [5-3] [XcN]} pairings refer to matter-energy flowing, considering that we have to take into account the order and the causalities (linear, circular, and recursive) putting { $S_{\Omega} \wedge S_{\Omega}$ } into being.

- {Wholeness [%-&] [7-1] [EψS] ad [#-~] [8-0] [UζP]} pairings refer to { $S_{\Omega} \wedge S_{\Omega}$ } evolution as well as to its architecting, for instance the whole storage of energy is two-parts: accumulation and transport, the service whole is two-parts: planification and allocation.

We can now introduce in term of graph other {cybernetics [w □ a] ad [h @ i]} pairings for {powering to acting} and {actioning to informing} controllability issues through the anchoring role of the {cyberneconduction property [ $\Omega$ ]} in two parts that we termed {conduction-cyberne [@]} and {cyberne-conduction [□]} triggered from by the flowing matter-energy along a cyberneconductor. We argue {matter} relies with space-structuration in form unit { $\delta$ } related to {[1-4] [S- $\Omega$ ] and [2-4] [H- $\Omega$ ]} pairings while {energy} relies with space-evolution in energy unit { $\eta$ } related to {[2-4] [H- $\Omega$ ] and [7-4] [E- $\Omega$ ]} pairings. So that {synchronization} relies with time-structuration in period unit { $\tau$ } related to {[1-4] [S- $\Omega$ ] ad [6-4] [L- $\Omega$ ]} pairings while {quality of service} relies with time-evolution in frequency unit { $\nu$ } related to {[6-4] [L- $\Omega$ ] and [7-4] [E- $\Omega$ ]} pairings. Starting from the natural matter, we have to consider that the matter contents energy, that this energy has to be synchronized by the means of cyberneconduction, from which its results usable exergy. So that along the quantitative matter-energy flowing, the quality increases with an exergetic usable part (forming part of {cyberne-conduction □}), and an anergetic part (which delivers negentropic {conduction-cyberne @} before returning to the entropic environment). The diachronization and synchronization of energy producing an anchorage effect results from the resonance between the transport part and accumulation part

of energy, the difference (Lagrangian) integrated over time consisting of action, with a damping effect controlled via cyberneconduction.

Having in mind that {control}, i.e. {cybernetics [w □ a] [h @ i]}, is the major asset to direct the respondent flowing matter-energy. i.e. {connectedness [X ∫ N]}, a proof of evidence may be given of this framing relevance at {Ωd} onto situation-system damage. The situation-system of islanding (or not) would have required some {evolution-structure [EψS]} reconfigurability enabler when a section of the electrical grid became disconnected from the main electrical grid because of the incidental tripping of a large circuit breaker. This broader phenomenological architectural asset of {wholeness [U ∫ P]} life cycle is fundamental in the airgap when one passes from the interconnected network to the separate network, and more generally for any intermediate situation (e.g., due to lightning strikes or short circuits in the grid). Our interpretation of Paynter's theory aims to enable the power synchronizing and acting controllability of any cyberneconduction-driven intermediate combination rather than to be relatively fixed by a {junction bond [∫-∫]} for only power continuity issues.

However, the manifest entanglement of {Ωd, Ωs, Ωsl, Ωr} energy discrete-state situations point out propagating remote causations suggesting some conservation of wave-vectors summation at the corpuscular level of the flowing matter-energy (Prigogine and Stengers 1996), including neutronic (e.g., xenon effect) source causations as well as the sink ones of variable powering. So that, for {togetherness [H ∨ L]} issues, we have to take into account some energy factor {K= H + Δh / ΔT} of irreversibility, e.g., related to constraints hysteresis, dissipation, diffusion, ... These cyberneconduction causations refer to {wholeness and togetherness} global descriptions which have to be refined at a Lagrangian intermediate level and at a Eulerian lower level for implementation issues. Without load shedding and notwithstanding safety devices, a self-regulating dropping stabilization {Ωsl} would have occurred at another lower frequency level by some cyberneconduction effects, depending on launch time and consumption self-regulating. So that for practical modelling purposes, after having described the intermediate level (Paynter global variables and total derivation according to time) and the upper level (in terms of matter-energy and synchronization for service), it is necessary to describe the local lower level. This local level may be reached with partial derivation according to space {divergence and curl} and to time interpretation based on (Paynter 1961; Tonti 1976; Vieil 2012) works.

Generic graph	Grid function	Diagram description	Pairing framing	Graph description	Cyberneconduction description				
	production	dynamic time integral	\$	2-6	HoL	H Hamiltonian	togetherness	situation	flowing matter-energy property $\Omega$
	consumption	cinematic time integral	\$	5-3	XcN	L Liouville			
	distribution	generalized flow	f	7-1	EψS	N input	connectedness		
	supply	generalized impulse	^	8-0	UψP	X output			
	planification	generalized displacement	%	1-4	w = a	E Life cycle	wholeness	system	cyberne-conduction = and conduction-cyberne @
	allocation	generalized effort	&	4-5	h @ l	S architecture			
	accumulation	constitutive operator	#	7-4	h @ l	U whole	cybernetics		
	transport	constitutive operator	~	4-3	i	P part			
	Power synchronizing and acting	resistive bond	& = E	1-4	w = a	w power			
		memristive bond	% @ ^	7-4	h @ l	a act			
			4-3	h @ l	h action				
			4-3	i	i information				

Figure 4.4.1. Cyberneconduction-driven modelling and theoretical framework

#### 4.4.2. Modelling and practical framework

It must be noted for situation-systems controllability issues that these three levels of modelling, from the global time derivation to the local space derivation, correspond to the levels of operation of the plant, from the goal and set-point definition to the system local component, corresponding at our abstraction level to the choice of exitance actuating and measuring means by the control room and field operators (figure 4.4.2., left). Modelling understanding of cyberneconduction as composition and change of extrinsic and intrinsic characteristics for perception of phenomena which reveal themselves in the process enables to guide at the different levels the definition of junction structures with respect to power continuity law and stages of evolution with respect to less action principle referring in theory to  $\{S\psi E\}$  pairing (Delattre 1971) to boundary, initial and final conditions which must be considered by wholeness for energy togetherness checking. Especially we must keep in mind that, for the whole plant, it is of most importance to consider the airgap of the electric generator and the thermo-neutronic effect of heat exchange of the steam generators as key point for operation and control analysis. From physical point of view, we can remark that the magnetic kinetic energy transports by itself (electron spin) but cannot accumulate by itself because it needs support of electrical charges; on the contrary, in steam generator production, the potential thermal energy accumulates by itself (thermal capacity) but cannot transports by itself as it is supported by the kinetic energy of water and steam. So that by acceptance of cyberneconduction in  $[I.V^{-1}]$  dimension of admittance (inverse of memristance) and not resistance, a proof of measurability may be given to path the way to a  $\{S_{\Omega}\}$  controllability perspective, and thus of an  $\{S_{\Omega} \wedge S_{\Omega}\}$  one. We end up (figure 4.4.2, right) with quantities of the type  $[\text{pulsation}^2/\text{puissance}]$  and  $[\text{angle}^2/\text{action}]$ . If we compose the admittances of the antagonistic faces, we have differences in the squares of pulsations (acts) and angles (information), each of which can be factorized into a sum and a difference. In the European case of incident of November 4, 2006, the difference in pulses of

the networks before separation at  $\{\Omega d\}$  corresponds to the visible stroboscopic beat of period 3.3s and the difference in angle corresponds to the internal angle of the generators. For synchronizing, power and action are linked, as are act and information, by the fact that angle is the temporal integral of angular velocity. Stator periodic deviations of angular velocity  $\{Fs\}$  are manifested by the perception of the phenomenological manifestation of an amplitude  $\{\gamma\}$  of pulsation  $\{\omega\}$ , and periodic deviations of angle  $\{as\}$  are manifested by the perception of a phase shift  $\{\phi\}$  of the same phenomenon. Propagating to turbine control, (figure 4.4.2, right) clearly shows the decoupling between the stator electrical power linked to the downstream airgap and the rotor mechanical power related to the upstream airgap. The appearance of instability with a period of 3.3s suggests favoring the mechanical power control and to decouple the electrical power control by setting the feedback loop to a response time higher than these 3.3s.

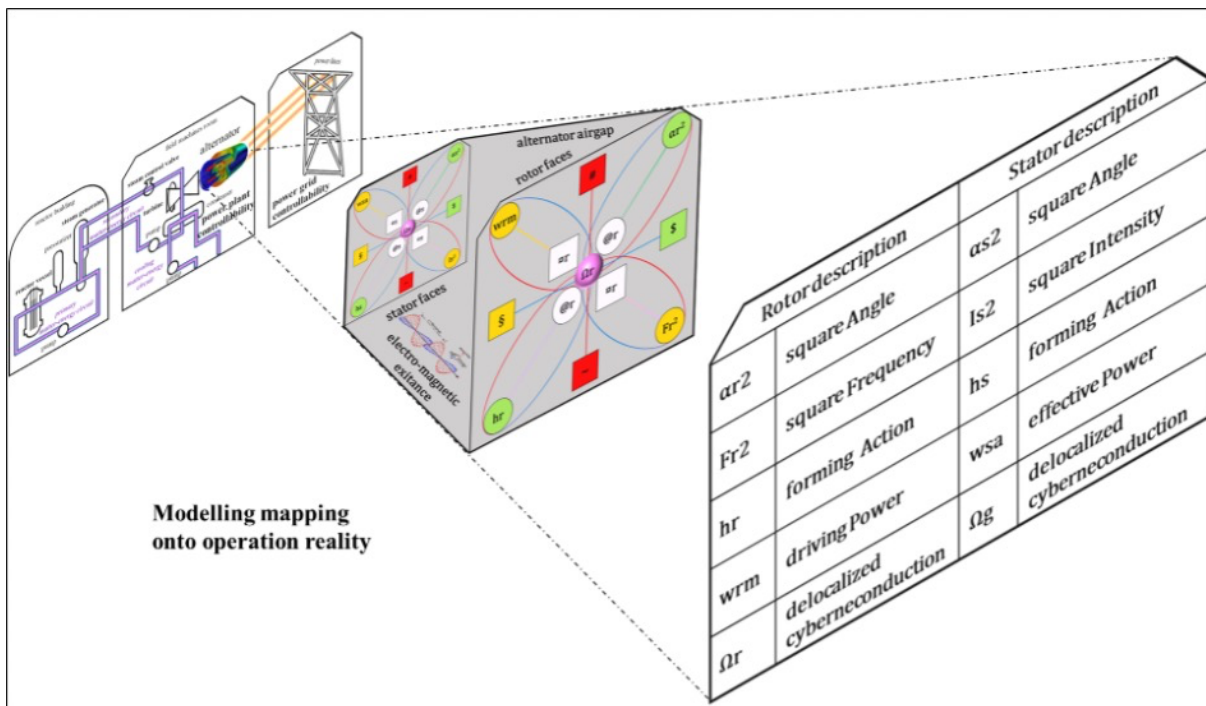


Figure 4.4.2. Cyberneconduction-driven modelling and practical framework

#### 4.4.3. Transitioning practical process

(Figure 4.4.3.) depicts the main pillars of the transitioning mapping of a to-be situation-system as addressed in (figure 4.3.2., right up) onto an as-is representation of a nuclear power plant controllability, documented with engineered mechanical and electrical schemes, process Plant Flow Diagrams (structural Paynter variables), Plant Instrumentation Diagram (logical part of causal loops) and nomenclatures reflecting the wholeness  $\{P\zeta U\}$  of components (in left,

bottom). The operating teams needs added data corresponding to Paynter evolution variables (states and actions) displayed in the control room and documented in the operating procedures. As maneuverability is concerned, the parameters corresponding to the given service consist, in addition to the daily power program, of primary active power reserves {RP}, secondary active power reserve {RS}, and tertiary active power reserve {RT} classified by phenomenological delay of mobilization (RP from 1 to 10s, RS from 10s to 1mn, RT beyond the minute). The grid program of reserves {RPg}, {RSg} and {RTg} are planned ({%} in figure 4.4.1, right), the expected consumption for the day after is allocated (& in figure 4.4.1, right) by the dispatcher to the power plants in terms of specific reserves ({RPP}, {RSp}, {RTp}, {spinning}) available ready to start, e.g., reflecting in (Figure 4.4.3, left up) the situation-system of 2006, November 6<sup>th</sup>. Considering the situation-system of the plant is induced by the grid connectedness situation-system, if one is in a local outer space insulation, the excitation current determines the alternator voltage, and the frequency is determined by the ratio required electrical power versus supplied mechanical power; if one is in a large space interconnected grid, the frequency is determined by the grid, and the excitation current determines the {power factor} (injected or absorbed reactive power). Middle space interconnexion area leads to intermediate sharing between the active and reactive power, and the partition of control frequency by different plant performance checking tests which can be apprehended by standard ones (A°, B°, C°, D°). From acceptance and performance tests point of view, we refer to the know-how return of experience with engineering and operational test teams, and on a project mock-up experimentation<sup>19</sup>. Thus, the response of the factory generating power-energy is deduced taking into account the possible behavior conditioned by the extrinsic and intrinsic characteristics. From a process point of view, the energy source of RP is in the mechanical rotational energy stored in the rotating masses of the turbo-alternator group, If we draw from the storage of the steam generator (accumulation + transport), we obtain the secondary reserve in the medium-term RS, the source of RS being in the latent heat of the water in the steam generator. If we rely on the RS, we reconstitute it by calling the RT, the thermal storage and neutron production of the reactor being in the efficient section of uranium. The thermodynamic conversion occurring at the intrados and extrados of the turbine blades (enthalpy/active/reactive entropy diagram) which enable the commandability and maneuverability of production via the turbine valve, the volume of steam between them and the blades, and the rotating mechanical masses leading to the control of the rotational speed of the rotor {Fr}, of the accumulation capacity of the steam generator and of the thermal inertia

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<sup>19</sup> <https://www.osti.gov/etdeweb/biblio/31350>

of the primary circuit (identifiable by test-type), and the operating limitations of the various devices. It is therefore possible to agree that such acts can modulating cyberneconduction effects  $\{\square\}$  and  $\{@\}$  on the flowing matter-energy through the different conversions operated to change the physical domain from fuel to electricity (neutronic / thermal / thermo-hydraulic / rotation mechanics / electricity).

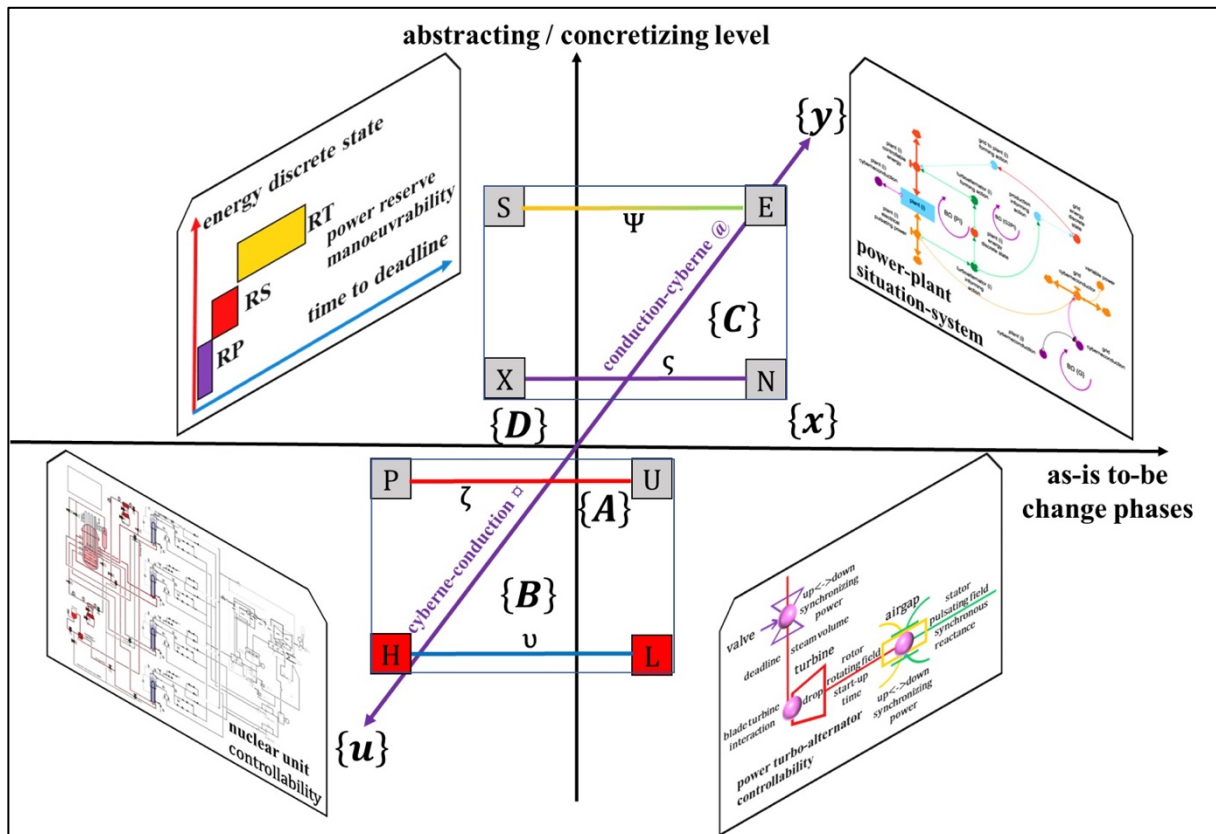


Figure 4.4.3. Cyberneconduction-driven situation-system controllability transitioning process

#### 4.4.4. Towards a power turbo-generating system controllability paradigm change

The current design of the turbine control system is based on a very fast {frequency-power} control loop that replaces the {speed-load} control system, which acts directly on the valve opening setpoint in the case of a start-up and separate network. Switching is done by a manual-automated-direct device (CMAD) from one mode to the other on a frequency criterion (49.8 Hz). During the incident of November 4, 2006, this design made it impossible to modulate the load of the non-hydraulic power plants from the dispatching center. By modifying the current design principle of substitution in favor of a principle of superposition, it is possible to manage the switching differently and to relax the current stiffness of the power loop, in order to push its undamped natural frequency beyond the resonance pulsations where instability is at risk. The static and dynamic optimization of the valve control (linearization, response time) currently

provided by the electrical power servo can be done as well by a direct open loop and/or automatic closed loop control of the mechanical power which does not need to be switched on a network frequency decrease criterion since it respects the natural decoupling of the physical phenomena and impedances between the upstream and downstream of the airgap as we have seen in (4.3.1.). Thus, this is of importance to consider both the coupling and decoupling upstream and downstream cyberneconduction movements to maintain the energy togetherness of such power system-of-systems  $\{S_{\Omega} \wedge S_{\Omega}\}$  far beyond best-practices regulation  $\{S \wedge S_{\eta}\}$  rules.

As far as the airgap is concerned, it can be noted that, while the plant operators did not know whether they had remained on the interconnected network during the incident, or whether they had switched to a separate network, the airgap *knew* about that situation-system. It should be noted thus the simplex orchestrating powerful of the situation-system framework to decipher inwards the airgap the cyberneconduction source resulting from a work of scientific deepening on a return of experience of about fifteen years. So that, at an industrial scale (Devic 2018), an intermediate stage of document-to-model translation remains necessary to preserve decades of knowledge and know-how (e.g., Lilliput models in (Tyran 1984)).

Our intent has been to open the mindset for practical transitioning on some  $\{MTIC\}$  artifacts aligned with (figure 4.4.1.) enabling a situation-system controllability paradigm change driven by the energy discrete-states triggered by the matter-energy flowing. Compared with state-space representation in process control, we point out in (Figure 4.3, middle) the directing role of the feedforward matrix  $\{D\}$  with respect to the time-variant formulation  $\{\dot{x} = Ax + Bu\}$  and  $\{y = Cx + Du\}$  (with  $x$ ,  $u$ ,  $y$  called respectively state, input, output vector and  $A$ ,  $B$ ,  $C$  corresponding matrix). A prospective alternative as Intelligent proportional-derivative-regulator would be a model-free control (Fliess and Join 2021), at least for local cyberneconduction controllability at relevant discrete energy state moment. Its simplex formulation  $\{y(n) = F + \alpha u\}$  points out a time-varying data-driven quantity  $F$  given by the past values of  $u$  and  $y$  including not only the unknown structure of the system but also any disturbance ( $\alpha$  is chosen by the practitioner such that the three terms in equation have the same magnitude; derivative order ( $n$ ) is 1 or 2 in applicative practices (Lafont et al. 2020)). Compared with the discrete product-driven control paradigm, we argue the cyberneconduction could play the role of product synchronizer as  $\{\text{power} \wedge \text{service}\}$  to close a data-driven controllability loop in operation. Cyberneconduction, by its “intelligent natural property” to mitigate power upstream and downstream effects., enables us to extend an architectural pattern (Dobre 2010) resulting of long-time R&D works (Pétin et al. 1998; Morel et al. 2009) to distribute as close



as possible to the process some “man-made intelligent capabilities” into smart actuation and measurement components (IAMS) to form an integrated control, maintenance and technical management system (CMMS). Thus, connectedness between multidisciplinary assets of operation reality and engineering reality, through a data-driven channel, could enable a continuum of information along product-life cycle as patterned by (Galara et al. 2012). We prototyped at TRL5 maturity a system co-specification platform based on executable multi-models interacting with a data-driven physical mock-up to iteratively validating on-line the multidisciplinary wholeness (but not the energy togetherness) emulating an emergency situation-system of steam generator water supply (Bouffaron 2016).

## 5. Conclusion and perspectives

We made of {situation} and {system} a *situation and system thinking* corpus to put the multidisciplinary respondent {wholeness} of an engineering reality in interdisciplinary congruence with the requiring {energy-togetherness} of the *experiential reality* related to three applicative domains, i.e. manufacturing, cyberphysical and electricity power.

We argue that the matter-energy flowing is the modulating causation of the boundary dynamics between its environment and a system, de facto a system-of-systems by the exhibited characteristics, as addressed by ((Paynter 1961), page 35) in the energy domain and recently by ((Bures et al. 2018), figure 1) in the smart-cyberphysical domain. The product-driven control paradigm from the manufacturing domain has inspirated applicative case-studies. At a contained scale, we show that the human energy-factory is knowing what molar fraction of oxygen is required for its energy-expenditure at work. At a large-scale, we demonstrate from return-of-experiments that the airgap of a whole-alternator knew that the energy-togetherness of a power grid was damaging from the manifestation of a *cyberneconduction* property for which is given a theoretical and modelling framework.

From the simplicity of this abductive orchestration of multidisciplinary knowledge and knowing-how driven by the matter-energy flowing, we induce through mainly analogy with physics the related dynamics of a targeted situation-system as a higher level of abstracting of the experiential reality energy-togetherness. Practical concretization is discussed in each section by applying disciplinary modeling tooling from the unifying situation-system representation.

Our formative intent is to open the mindset of *systems thinking and engineering* to the energy-togetherness of a wholeness which should better be aware of what the matter-energy flowing is revealing of the surrounding experiential reality.

### **Acknowledgement**

The authors wish to express thanks and gratitude to Doctor Dominique Galara, R&D retired engineer, for his inspiring inputs over time to improve plant operation control by field operators in order to master the complexity of nuclear power plant automation. He managed several European projects in which we have been involved in the area of Integrated Control, Maintenance and Technical Management Systems based on distributed intelligent field devices. He also published some relevant papers and books on this topic.

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