Information System for Smart Grid:
Systemic and UML combined approach

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Abstract - The effective management of large and complex systems depends on the presence of all relevant information describing system within the reach of the actors and decision makers. To this extent, we propose in this paper a combined methodology for information system design based on a participatory approach that brings together several parts to ensure better result juxtaposed with an object-oriented process based on Unified Modeling Language diagrams to design the database of the information system following a spiral development cycle. This methodology is implemented through the systemic method: PPPO, the Simplified Unified Process and the spiral development cycle. It allows us to model the smart grid and develop an information system that describes all information necessary for its good management.

Keywords: Smart Grid, Systemic methods, Information System, Participatory Planning of Project by Objectives, Simplified Unified Process.

1.INTRODUCTION

The use of information systems in the company has become a daily reality. Therefore, the management and design of information systems represent today a major problem of organizations. To meet this need, several studies and attempts are developed to facilitate and even automate the information system development process.

This paper describes a systemic methodology combined with an object-oriented modeling and design tool for analysis, modeling and planning projects and systems and designing their information systems. This methodology is based on systemic approach and follows a participatory method juxtaposed with an object-oriented development process. The system analysis and modeling are made by the Participatory Planning of Project by Objectives method (PPPO) and the Simplified Unified Process (SUP).

2.METHODOLOGIES & TOOLS

Based on the key characteristics of the smart grid namely its complexity, extended and heterogeneity [6], we chose to analyze the system and develop its information system a systemic approach for the first step (modeling of the problem). For the second one, we opted to use a development process based on UML diagrams through an iterative cycle.

2.1. Systemic approach (Methodology)

The world phenomenon known as "systemic movement" and the large number of ideas and practices that can be classified under "systemic approach" are keys to the implementation of a solid methodology that considers the following systemic aspects [7]:

- The consideration of "systems" as abstract objects for building a better understanding and a shared vision of a complex system.
- The identification of the essential dimensions and high priority issues.
- The predominant importance given to the study of relationships between elements of the system and the system with its environment.
• The interest in collective and participatory reflection and group work.
• The need for autonomy and integration into decision making.
• The possibility to use images and graphics in the development of specific actions and the information system.

The systemic approach in the analysis and design of information systems allows also being conscious of the future world in which the treaty system should be located. It allows thus to spend a major weakness of the organizations that is the resistance to changes in their environments therefore secure their sustainable development [8].

2.2. Systemic used method

We used to analyze the control problem of smart grid and develop a coherent and faithful to reality information system the method: Participatory Planning of Project by Objectives (PPPO).

PPPO’s goal is to collect the knowledge and expertise of experts and stakeholders in order to reach a broad consensus and a collective solution to the questions related to the Smart Grid [3]. It serves to mobilize the efforts and know-how of different stakeholders around a structured and systematic approach by linking them in workshops and structured meeting of “brainstorming” to generate the maximum of ideas that will later be the subject of analysis, classification and modeling [3], [8].

PPPO has the capacity during its exercise to motivate stakeholders who may have different repositories to be active, influential and participate in the analysis and design process to be part in decision-making process and have a strategic reflection on future actions [8]. The method tries to find a compromise land between the different actors through an iterative negotiation process for the exchange of views and even debates around some critical situations [8].

It is widely flexibilized by its instigator (German Cooperation Agency "GTZ") to avoid its mechanicistic, rigid and falsely participative use. So, it has become just a general framework counselor rather than a series of tools and prescribed mandatory steps. This flexibility puts the actors and their perceptions of the problems, needs, interventions, etc. at the center of a non-deterministic planning process, an iterative negotiation and not final process [8].

PPPO is based on a very linear approach to reality (cause produces effect). It starts with a negative reading (reverse) of this reality, i.e. a succession of problems [8].

Like many modeling tools, PPPO provides possible simplifications [8]. In short, we limit ourselves at this stage to some problems and causal links, and we choose some prospects to prove our solution.

The method is based on five methodological steps; identification of stakeholders, developing a problems tree, developing an objectives tree, defining strategies and developing the planning matrix (logical framework). This approach is retroactive as a spiral process, i.e., each step used for supplying the previous steps (addition of new actors, problems, goals, etc.).

2.2.1. Stakeholders Identification

The first step is to identify the individuals, groups and institutions that are relevant to the system. Determine their interests and views on the issues. The relations and the positioning of these players are also subjected to analysis in order to properly master the debates between them and understand the “contradiction” of their viewpoints sometimes. For example debates between economists on the one hand and naturalists and environmentalists on the other hand [8].

Stakeholders meet in workshops for a common reflection and shared discussion of different points of view.

2.2.2. Development of problems tree

The first phase is to identify problems in bulk (brainstorming). This collective exercise is done using small cards by annotating one problem per card. Thereafter, prioritize and organize the cards problems according to causality relations (cause gives effect) to build a problems tree [3], [8].

The tree can have one or more roots (one / many major problems). Each node of the tree represents a problem cause while his descendants (branches) are the negative consequences.

2.2.3. Development of objectives tree

The issues identified in the previous phase are translated into objectives insofar the resolution of these issues results the desired future state. i.e., negative states are translated into positive desirable states. An objectives tree is automatically built by translating causality links into end-means links. Only solutions of possible problems are retained [3], [8].

2.2.4. Definition of strategies

The objectives tree helps bring up several possible alternatives and strategies that can help in solving the posed problems and issues. One or more potential alternatives are selected to form adequate strategies and policies according to well-defined and carefully selected criteria defined by domain experts such as skills, priorities, available resources (human, financial, etc.), economic and political climate, etc.

2.2.5. Development of the planning matrix (logical framework)

Once the objectives and strategies are well defined, indicators and tools to measure, verify and evaluate the result of the planned activities will have to be specified. These activities are determined according to the strategies defined to achieve the desired objectives.

All these information are transposed and summarized in a matrix that attempts to answer the following questions [3], [8]:

• The why of the project?
• What are the results (objectives)?
• What are the external factors of importance to project success (hypothesis / risks)?
• How to evaluate the success / failure of the project (objectively verifiable indicators)?
• Where to find the data needed to evaluate the project?
• How much the project will cost (means)?
2.3. Development Process

To design the solution of the Smart Grid control problem and the development of its SI, we have chosen as a development process a reduced and simplified derivative of the unified process.

A unified process is a software development process built on UML. It is iterative and incremental, focusing on architecture, driven by the use cases and piloted by risk. The management of such a process is organized in four phases presented as follows: pre-study (inception), elaboration, construction and transition. Its development activities are defined by six fundamental disciplines that describe business modeling, requirements capture, analysis and design, implementation, testing and finally deployment [30].

The adopted simplified unified process comprises the following nine steps [30]:

2.3.1. Development of use cases

This step is very important, in fact, these diagrams explain clearly the expected application services and the needs it must satisfy.

2.3.2. Development of System Sequence Diagram

This diagram shows the interactions between actors and the system.

2.3.3. Implementation of Human Machine Interface (HMI) models

The models give the possibility to work on the design appearance before delivery of the final version of the software and discuss his critics from the start of work.

2.3.4. Development of the domain model

This is a first class diagram to identify the entities and their attributes and associations.

2.3.5. Development of participating class diagram

It is a diagram that includes the three types of classes; dialogs, controls and entities, it is based on the domain model.

2.3.6. Development of the navigation diagram

Two diagrams can fulfill this task, the activity diagram and the statechart. They complement the sequence diagram.

2.3.7. Development of interaction diagram

It is a detailed diagram of sequences, it reflects the communication between the different implemented objects.

2.3.8. Development of the design class diagram

It is obtained by the enrichment of participating class diagram by adding functions from detailed sequence diagrams.

2.3.9. Implementation

This step consists in generating the database (classes). It ends by filling the code completely, test and validate it.

2.4. Development Cycle

In order to increase productivity and to estimate development time, it is imperative advised to follow a development cycle. It turns out that several approaches and methodologies exist and can meet this need.

After a comparative study of these methodologies and cycles, we felt that the spiral cycle is the most suitable for our case.

It is a software design procedure that want more pragmatic than traditional methods. This model enables highly responsive to its requests. It aims to real satisfy the needs. The spiral model is distinguished compared with conventional methods by its principles that present its strengths [1]:

- Giving more importance to individualities and foster communication than following fixed processes to ensure communication and serious discussion between the project participants.
- Perform iterative tests to ensure having fully tested software at the end.
- Involve all participants in development in order to avoid possible misunderstandings.
- Instead of following an exact plan, develop and evolve the project while responding to any changes identified during work.

This software development cycle model includes the different steps of cycle V. By implementing successive versions, the cycle starts by offering a product more complete and robust. However, it puts more emphasis on risk management in the cycle V. There are four phases in the course of the spiral cycle [1], [31]:

i. Determining objectives, alternatives and constraints.
ii. Analysis of risks, evaluation of alternatives.
iii. Development and verification of the solution.
iv. Review of results and verification of the next cycle.

3. Case Study of a Smart Grid (RESULT)

3.1 Application of PPPO

The PPPO method is used in order to model the problem of management and control of the Smart Grid to identify the needs of the system that are used later in the design of the solution. In short, these needs present the starting point for use cases diagrams.

The result of the application of this method is presented in the following in this section.

3.1.1 Identification of Stakeholders

The Smart Grid is a complex system [5], [6] that affects many parties. To ensure the identification of all individuals and groups interested in energy system and that can contribute to the completion and success of the Smart Grid project, we chose to identify stakeholders layer by layer of the Smart Grid Architecture Model “SGAM” (Component Layer, Communication Layer, Information Layer, Function Layer, Business Layer) [9].

Some stakeholders are included in several layers, namely the Manager of the grid which is involved in the physical chain (production, transmission and distribution of electricity) and in the logic chain and grid control.
3.1.2 Problems tree

After brainstorming workshops, and the classification of identified Smart grid problems, a main problem is unveiled: the implementation and control of smart grid based on the existing aging infrastructure. We partitioned the problems that arise from this main problem into four groups (Management problems, Technical problems, economic problems and Environmental problems).

3.1.2.1 Management problems

The first part concerns the real-time management of energy production, transportation from fields, turbines and power plants to customers through a transport and distribution network. The power management also extends to cover energy consumption. Indeed, one of the benefits of smart grids is the inclusion of the user in the management process.

Logical management issues are classified as a sub-part dealing with data flow management, the taking of adequate and timely decisions and the management of resources (human, financial, etc.).

3.1.2.2 Technical problems

As the first part, the second one is divided into two categories, physical and other logical problems. The first correspond to the power system namely issues related to the equipment and installations especially cohabitation between new technologies and equipments and existing infrastructure.

One of the most relevant issues in this part is the distributed generation through the introduction of renewable and intermittent new energy resources [10].

The explosion of the demand and the new arrival (electric vehicle (EV)) [11], [12], the automatic incident detection and resolution of faults [13], [14], [15] are also predominant issues in the implementation of Smart Grid.

The second category in this part concerns the logical problems: security of the energy system against cyber-attacks and confidential data hacking threats of customer and all parties included in the energy chain [16].

Among posed technical problems, we identify the issues of standardization and legislation whose role is so important that they must be answered before any efforts in the implementation of Smart Grid [17], [18], [19], [20].

Besides the energy network traffic, a data traffic system is essential for rapid collection of information and reliable communication between consumers and regional centers of conduct and parties concerned by this information [19], [21], [22], [23].

Technical problems also include backup and archiving problems of electric grid characteristic values and history of the entire energy system for a possible electric network analysis.

3.1.2.3 Economic problems

The economic problems are linked mainly to the financing and investment, the stress of the energy market, the speculation problem and economic balance income / expenses.

The dynamic billing [18], [24] and prices of energy use affect the economic side especially with the increase of distributed generation and consumer participation in energy production (e.g. providing excess energy produced locally by its solar panel).

The loss of jobs presents also a very critical social and economic problem. In fact, the use of new intelligent control and management technologies and the automation of many parts of the energy system may eliminate a lot of jobs [25].

3.1.2.4 Environmental problems

The obvious first problem is related to the pollution issues (emission of greenhouse gases, waste of nuclear activities, etc.). The second problem is the resources depletion mainly those based on fuels due to its overexploitation. The third one, which is very serious and dangerous, is the health problem and environment damage from radiofrequency (RF) and electromagnetic frequency (EMF) radiation from new information and communications technologies (ICT) and Smart Meter installation [25].

3.1.3 Objectives tree

The objectives present the resolution of the previously mentioned problems and the response to the relevant questions. In short, the same structure characterizes the two trees (problems tree and objectives tree).

3.1.3.1 Management objectives

The Smart grid allows to maintain balance between supply and demand by developing an effective real-time work plan, optimizing decisions in terms of time and efficiency and using intelligent management of stocks of raw materials (fuels, nuclear resources, etc.) to satisfy customers and supply new needs (electric vehicles) and reduce energy consumption especially during peak hours and avoid falls of the electricity grid. This will help to reduce damage and bad impacts to incidents and organize the relationships between parts of the smart grid.

3.1.3.2 Technical objectives

In the technical level, the smart grid aims to upgrade existing infrastructure by adding new technologies, increase the estimation and analysis capacities of climate changes and their impact on the energy system balance. It improves techniques and energy storage means and secures the communication network. It is necessary also to ensure the interoperability of different parts of smart grid by standards and different parties by adequate laws and appropriate legislations.

3.1.3.3 Economic objectives

Economic objectives affect both clients whatever their kind (industrial, commercial, individual) by rationalizing consumption and consequently billing and increase local energy production and society as a whole (the state) by reducing energy costs and make economic gains, founding a robust economy and limit the loss of jobs.

3.1.3.4 Environmental objectives
3.1.4 Definition of strategies

The search for solutions to achieve the desired objectives permits to classify them into groups. Each group allows the appearance of many alternatives to satisfy those goals. These alternatives form the Energy Policy and the strategies leading to the success of the smart grid.

The strategies adopted are:

- Diversify and distribute energy resources and improve the use of renewable resources to reduce dependence on fuel-based resources that have unstable prices [10].
- Decentralizing the management and control [24].
- Inform the consumer of his consumption and introduce him in the control process.
- Securing the exchange and sharing of data between control centers [16].
- Facilitating investment in the energy market with adequate decisions and legislations.
- Evolving the energy storage technologies.
- Adjusting the production program in real time according to supply and demand.

3.1.5 Development of logical framework

In this step, we limited ourselves to the definition of control units and their activities which allow us to simulate the Smart Grid and implement our solution in the rest of the work. Four units are defined (inspired from [17], [2], [28]) to manage the Smart Grid in order to rationalize consumption and local energy production. In short, the Smart Grid is divided into three compartments based on the seven domains of National Institute of Standards and Technology (NIST) model. The first compartment is the Production (Generation), the second encompasses the energy delivery grid and the parts affecting the system such as markets managers, operations and service providers. Third, the consumption compartment. Each compartment is managed by a type of logic units. The fourth one is responsible for the management of information flows circulating in the system.

This step has enabled us to develop a set of specifications containing functional and technical requirements of the solution. The functional requirements are used to set the activities and uses of each identified unit (agent).

3.2 Application of simplified unified process

The simplified unified process starts up with the needs identified by the application of PPPO.

The second modeling phase of the Smart Grid enables the design of an IT solution to the problems mentioned above and the development of a coherent IS for the Smart Grid.

As mentioned, the proposed solution is based on four types of units (agents):

- Consumer Agent: responsible for the management of energy consumption (consumption compartment).
- Producer Agent: responsible for the management of energy production (production compartment).
- Control Agent: manages the entire energy system including the management and coordination of other agents (control compartment).
- Database Agent: responsible for data management and present the access point to the database for other agents.

Each agent is considered as an autonomous, independent and application that communicates with others parts.

The output of the simplified unified process is presented as a design class diagram enabling the development of the source code of the solution. The IS presents the direct projection of this class diagram.

The diagrams elaborated specify the characteristics (attributes) of each agent, its tasks (methods), interactions (associations) with its environment and with its neighbors (agents).

4. DISCUSSION

4.1 Choice of systemic methodology

Several techniques are developed for the analysis and modeling of IS, most of which are part of two major classes "Cartesian methods" and "systemic methods" [4].

We chose a systemic class method given to the nature of Smart Grid system. Indeed, the electrical system is among the widest and complex human systems [5], [6], [24]. It encompasses several subsystems (power subsystem, management subsystem, and human subsystem [24]) and brings together many and various stakeholders. Such a system requires great coordination among its heterogeneous parts for its better management. That is why we felt that the Cartesian methods are unable to meet our needs for analysis and modeling of the Smart Grid as asserted C. FLOYD "Cartesian methods are applicable to medium-sized systems with little human-machine interaction and when the features of the system are relatively clear in advance" [4].

The table TABLE I shows a comparison between the two classes of methods:

<table>
<thead>
<tr>
<th>Systemic methods</th>
<th>Cartesian methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd generation [4]</td>
<td>1st generation (appeared in the 60s) [4]</td>
</tr>
</tbody>
</table>

- large and complex systems [27]  
- systems with heterogeneous parts [27]  
- small and medium systems [4]  
- existing systems [4]  
- known system functions [4]
We excluded the analytical approach also because it aims to reduce the system to its smallest elements [29] in contrast to the systemic approach that addresses the system in the whole of its components and its internal interactions [26]. The analytical approach applies the rule "divide and rule" so that each element of the system becomes an independent problem, smaller and easier to solve. Thereafter, evaluate all solutions and use compensatory algorithms to mutually compensate the resulting values of different dimensions. Therefore, the use of analytical methods entails many, lengthy and intensive calculations [29].

For these reasons, the analytical approach is reserved for easy problems and its use as a problem solving process does not always result solutions when the system studied is complex [29].

The TABLE II illustrates an opposition of Joel de Rosnay of the two approaches (systemic and analytical) [29]:

TABLE II. COMPARISON BETWEEN SYSTEMIC AND ANALYTICAL METHODS

<table>
<thead>
<tr>
<th>Systemic approach</th>
<th>Analytical approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connects : focuses on the interactions between system elements</td>
<td>Islands : focuses on the elements</td>
</tr>
<tr>
<td>considers the effects of interactions</td>
<td>considers the nature of interactions</td>
</tr>
<tr>
<td>is based on the global perception</td>
<td>is based on the precision of details</td>
</tr>
<tr>
<td>insufficiently rigorous models as a basis of knowledge, but, usable in the making decision and action</td>
<td>precise and detailed models, but difficult to use in action</td>
</tr>
<tr>
<td>effective approach when interactions are important and nonlinear</td>
<td>effective approach when interactions are low and linear</td>
</tr>
</tbody>
</table>

Systemic methods have some gaps too. For example, the method adopted (PPPO), although it is used by many funders, and that it benefit of a systemic and participatory approach, it admits shortcomings. One of the risks of the method lies in the disproportionate importance that can be given to planning to the detriment of reflection and constant questioning of the changing context. It can become demotivating and disempowering [8]. But PPPO allows benefiting from other tools and juxtaposing other techniques to overcome its limitations. In fact, it represents just a counselor [8].

4.2 Utility of PPPO

The SUP starts from needs and based on use cases. In our case, we do not have tender specifications that contain these requirements and functional and technical needs and we are invited to identify them. Hence the need for a tool that precedes the SUP to make the problem analysis.

We believe that the systemic approach is the most appropriate class as explained previously.

We used the systemic approach PPPO given the clarity of its principle and the simplicity of its application.

4.3 Implementation of PPPO

4.3.1 Meeting stakeholders and brainstorming workshops organization

A Smart Grid is a wide and complex system [5], [6] that affects several stakeholders from different fields. Thus, the meeting of all these parties is a non-obvious mission. Indeed, it requires the availability of these parties and their agreement to share their knowledge and expertise. This phase also requires significant budgetary and human resources not all currently available. However, we have exploited existing ones and we have benefited from the meeting and workshops organized to analyze Smart Grid and design a minimal IS that can be enriched afterwards and assist in decision making.

4.3.2 Logical framework development

This step requires even more coordination between participants in the project. Indeed, the establishment of a complete logical framework and plan for the implementation of a national Smart Grid requires more financial and human resources. That's why we are limited in this step to the definition of solution actor’s and the definition of their tasks to identify the use cases of the proposed solution.

4.4 Choice of Unified Process Simplified

PPPO is insufficient to realize the SI in a support usable for decision making. So it is necessary to complete it with another tool to design and implement the IS.

We chose the SUP because it is an object-oriented method that represents the market trend toward. It plays a dual role. It models the IS as a set of diagrams finalized by a design class diagram to realize the IS and develop a database in the first hand. On the other hand, it allows the passage to the development of decision-making system in the future based on the same elaborated design.

The SUP benefits from the power and completeness of Unified Process (UP) and speed of the extreme programming, of course while reducing the cumbersome of standard UP [30].

4.5 Choice of the spiral cycle

We opted to use the spiral model because it is the most suitable for new applications, and it allows benefiting from several advantages of which we mention [1]:

- Allows catching up if we miss one or more use cases.
- Practical and safe solution validation.
- Validation as early as possible.
- Upward design.
- Identify possible changes early.
- Make variants iterations (sprints) to give time to code. Each sprint has a specific goal or "backlog".

5. Conclusion

This paper presents a methodology for the study and modeling of complex systems to develop an information system. The systemic method PPPO and the simplified unified process based on UML are used to analyze the smart grid and develop its information system in a
participatory process that brings together all stakeholders in order to identify problems and challenges of implementation of the Smart Grid, classify and structure them in the form of a tree that will be converted into an objectives tree that reflects the strategies and the planning of Smart Grid implementation activities. It is proved that these steps are very important and sensitive. They greatly affect the following steps. Indeed, the design of solution of all these issues in the form of UML diagrams developed as part of the unified process and refined in each iteration (sprint) following a spiral development cycle are deducted from this analysis and modeling performed.

The proposed approach enabled to design a minimal IS that can be enriched permanently and will serve the decision system.

In the future, it is important to treat the hosting and access to data to complete a logical framework.

6. REFERENCES


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