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Formal Requirements for Microgrid Using Kaos and Reference Architecture

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ABSTRACT-| *This paper presents a method for specifying requirements, applied to the operation of a microgrid. The challenge is to model Smart Grid systems requirements using formal methods based on schematic representa-tions that will allows analysis, veri cation and validation, improving the reliability and performance of the design cycle. Considering the inherent complexity of these systems - generally heterogeneous, open and distributed - formal modeling is a key issue for the design of automated electrical systems to t user experience expectations. In this article we propose a systemic approach that combines consolidated reference architectures and modern goal-oriented requirements engineering methods in the early steps of microgrid design. The formalism proposed is intended to obtain formal requirements models associated with standards and reference models proposed and accepted by the scienti c and practitioner community.*
Keywords*|Requirements Engineering, KAOS, IEC 61850, Microgrid.*

I. INTRODUCTION

Electricity is a key element to improve the quality of life of the population. However, according to the Brazilian Institute of Geography and Statis-tics, about 729 thousand Brazilian families have no access to any energy resources, mainly because they live to far from the available resources and distributed network.

The implementation of Smart Grid (SG) sys-tems with renewable energy generation has proven to be a viable alternative to diversify and rational-ize energy supply needs, especially if it is based on the integration of di erent renewable sources.

In addition, SG systems have inherent com-plexity because they are eminently heterogeneous, open and distributed systems, demanded in dif-ferent situations and application environments. Therefore, it implies knowledge domains that combines general and local information, making the design process quite complicated.

In this context, the life-cycle of the SG sys-tems has an important initial phase, character-ized by incomplete knowledge in the requirements speci cation. On the other hand, in the early re-quirements phase it is strategically easier to deal with di culties and physically easier to introduce changes. That turns the requirements phase sig-ni cantly important to the success of of the whole design, and must be treated as a necessary condi-tion to the a good design performance.

In fact, the introduction of a structured re-quirements phase that anticipates formalization in the life-cycle of SG. systems is a recent trend in electrical systems and has attracted the atten-tion of researchers and implementers. Some ex-isting methods consider a requirements phase in the life-cycle, but do not fully meet the require-ments phase, they only satisfy some preliminary steps informally (Silva and Silva, 2015).

Several researches related to the design of en-ergy systems have recently been carried out in the academy, searching for new, more robust, consis-tent and exible methods, as shown in the litera-ture:

In this context, some models and reference architectures have recently been proposed, such as IntelliGrid, an architecture proposed by the Electric Power Research Institute (EPRI, USA) (Commission et al., 2008) or the SGAM architec-ture (Uslar et al., 2012). Both architectures rec-ognize the importance of the requirements phase, which includes requirement elicitation, based on IEC / PAS 62559 and modeling, using (UML) Uni ed Modeling Language. A repository of De-sign Cases of requirements for Smart Grid systems was built, including features to transmission, dis-tribution and integration.

Although there are other design methods for systems in general or speci cally for SG, it turns out that the initial stage usually does not receive the attention it deserves. Requirements speci ca-tion and analysis lack speci c treatment methods and, consequently, result in di culties and unnec-essary costs in the rest of the life cycle (Mazzolini et al., 2011).

In addition, working with informal require-ments seems to facilitate the design process but can lead to undetected failures during require-ments speci cation (where error costs are lower) and compromises the project as a whole.

The complexity involved in dealing with a dis-tributed arrangement of subsystems (not all done at the same time) is another important factor in justifying the use of formally closed and consistent methods that can be analyzed and veri ed before implementation.

In this paper we present a proposal for a for-mal modeling of microgrid systems requirements speci cation. The proposal is based on systems of systems approach that anticipates formaliza-tion through a schematic representation, associ-ated to the Model Driven Engineering (MDE) scope, (Cretu and Dumitriu, 2014).

II. CONCEPTUAL DESCRIPTION OF THE METHOD

A conceptual description of the method is depicted in Figure 1.

Figure 1: Method owchart

Initially, a scenario is de ned where the method will be applied, consisting of operational, geographic characteristics, environmental restric-tions and local details that should be veri ed. In this step a reference architecture is selected to guide the process. For the proposed method we choose the IEC 61850.

Next, requirements are speci ed based on the chosen reference architecture. Therefore, the op-eration of the microgrid will follow the recommen-dations of the standard IEC 61850. Here, it is necessary to delimit the application domain, and development scope, that is, de ne the systems of interest, inputs and outputs, interface and forms of communication. In fact, this is one of the most complicated steps, since important informa-tion may not be available.

In the next step, it is made the modeling of system requirements based on objectives, opera-tions and agents responsible for meeting the ob-jectives. The GORE (Goal Orientated Require-ment Engineering) method is used, speci cally the KAOS tool (Knowledge Engineering Object System). The use of this method introduces a more direct approach, collapsing aspects of func-tional and non-functional requirements. Follow-ing, the formal requirements speci cation is gen-erated, both by KAOS diagrams and to a formal representation based on Linear Tree Logic (LTL).

The nal step is the validation with stake-holders, through the analysis of LTL properties to check process properties like Security and Life-ness, associated to the control solution for the mi-crogrid, considering also its constraints.

III. PROPOSED APPROACH

The proposed method combines a new approach of the Objective-based Requirements Engineer-ing (ER) with the reference model approach fre-quently used in energy system design, applied to the operation of a microgrid considering its tech-nical peculiarities.

3.0.1 Microgrid System

Technically speaking, a microgrid is a low voltage distribution network, located downstream of a dis-tribution substation through a Common Coupling Point (PCC). The microgrid consists of a set of components, including Intelligent Electronic De-vices (IEDs), for sensing and control, as well as charging and monitoring tools for energy quality, a Control system that allows rapid diagnosis and accurate solutions for interruptions in the network or disconnections.

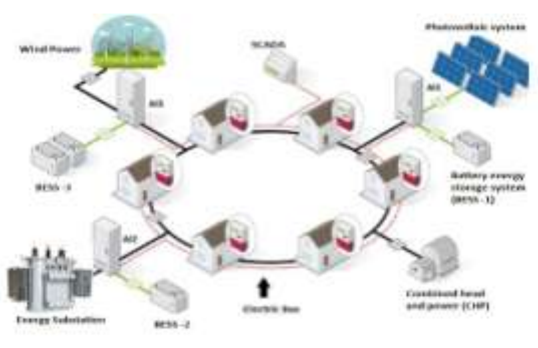

Figure 2: Proposed scenario for the microgrid

Therefore, a microgrid is a multi-source sys-tem consisting of conventional Renewable Energy Sources (RES), storage systems and controllable loads. The interface between the service network and the microgrid is used to interact with the SG; it provides voltage control, power balancing, load sharing. A communications infrastructure, us-ing communication networks that propitiated the transfer and exchange of data, in real time, Figure 2.

Therefore, microgrids play a key role in the in-tegration of Distributed Generators (DG) and, in particular, RES (Sechilariu and Locment, 2016). However, the intermittent and unpredictable na-ture of the power supply continues to be a problem for integration with the service network, resulting in voltage and / or frequency uctuations, har-monic pollution, and di culty in charge manage-ment , etc.

In Brazil, there is great potential for the devel-opment of technologies for sustainable generation based on wind, solar, biomass and hydroelectric energy, among others. The integration of these technologies has become a priority in microgrids, not only for presenting DERs, but also for the need to integrate IED devices, sensing and mea-surement systems, network nodes with computing capacities, actuation systems with con guration and adjustment capability that allows integration with new devices.

3.0.2 Architecture IEC-61850

The IEC 61850 architecture was developed with the aim of being a communications architecture, that facilitated the design of electric systems of power for protection, control, monitoring and diagnostics functions in substations (Naumann et al., 2014).

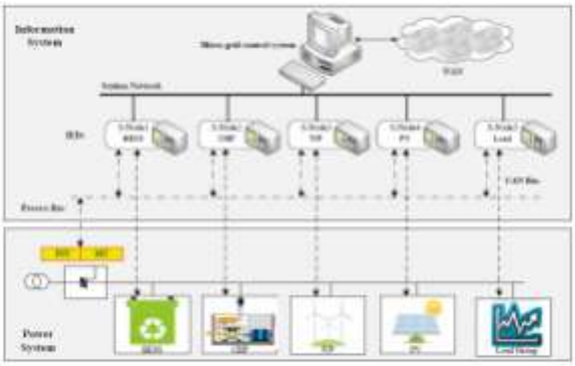

Figure 3: Architecture Microgrid based IEC 61850

The architecture is not only deal communica-tion, but also about the modeling of information tailored to the needs of the electric power industry (Berger and Iniewski, 2012), Figure 3.

Although the IEC 61850 originally addressed only substation automation, however, there are already additional information models de ned based on the IEC 61850 architecture for other domains such as renewable energy (Berger and Iniewski, 2012). In 2010, the US National Insti-tute of Standards and Technology (NIST) recog-nized IEC 61850 as a major facilitator of the im-plementation of SG systems.

One of the main goals of this IEC 61850 ar-chitecture was to solve interface problems and standardize communication to avoid the use of manufacturer-speci c protocols. Also, provides a mechanism for future automation and control functions that will allow electrical systems to evolve into SG (Naumann et al., 2014). Currently, there are extensions and additional information models for microgrids domains, so IEC 61850-7-420 provides the information model and logical node (LNs) for DERs at the process level, including (ECPs) power converters, con-trollers, generators, power converters, DC con-verters, and auxiliary systems (such as as mea-suring devices). IEC 61850 7-1, 7-2, 7-3 and 7-4 provide the principle of modeling equipment infor-mation. IEC 61850 also provides object-oriented models for inverters, power storage systems, and others (Hongwei, 2014).

3.0.3 GORE:Goal Oriented Requirements Methods

Goal-orientation, is a recent ER approach used to capture requirements. GORE refers to the use of objectives for de ning requirements, eliminating the traditional dichotomy between functional and non-functional requirements. The former is more intuitive and generally associated with services to be provided to customers while the latter is related to quality, sometimes performance or resources re-quired for service, and also related to external de-mands such as safety requirements, performance, safety, aspects, etc. Here, a requirement is a nec-essary condition to reach a given goal in a speci c application domain (Horko et al., 2017).

Therefore, since in the direct approach non-functional requirements are usually neglected or fail to compose a complete set, goal-oriented methods are becoming an interesting alternative to large systems. (Dardenne et al., 1993).

3.0.4 KAOS Graphic Representation

KAOS, is an ER method that covers the identi-cation of requirements in the form of objectives whose graphical part is represented by diagrams, in order to build a formalizable model for the re-quirements. It is designed to adjust descriptions, analyze problems, clarify responsibilities, and al-low stakeholders to communicate.

Requirements analysis with KAOS provides traceability, completeness, and unambiguity. On the other hands, the KAOS requirements model consists of four submodels: objectives, objects, agents, and operations.

The goal model, represented by a graph or tree in which the main objective is (the root), where to the abstraction of the problem, can be re ned into sub-objectives and re ned until mod-eling requirements or expectations (tree leaves), which are the most basic objectives in the diagram hierarchy, and always associated with the agents.

If the agent is part of the system to be devel-oped, it is a requirement, whereas the objective is an expectation if it is linked to an agent of the context.

3.0.5 Formal Representation (LTL)

An objective can be described as a valid nal state, derived from the general behavior of the sys-tem. Separately, each sub-goal can emerge from di erent courses of action, but converge to the pri-mary goal. Such behaviors can be represented as paths in a graph or as a combination of di erent automata.

The formal representation prescribed by the KAOS method is based on LTL, but can also be represented by a formal state transition represen-tation. A transition can be represented formally in terms of LTL sentences, such as:

$$C \quad \Rightarrow T$$

where C is a current condition, T is a target condition and is one of the LTL operators repre-sented in Table 1.

Table 1: Temporal Logic Operators

Operator	Description
[	In the next state
Â	Eventually in the future
2	Always in the future
0d ≤	Hold until is true

ER tools, such as ObjectivER, can help for-malize the requirements speci cations that come from the KAOS diagrams in LTL formulas. How-ever, these formulas specify each process and it is not so easy to express distributed dynamics. In or-der to confront, several papers propose the trans-lation of LTL representation for Petri nets (Silva and Silva, 2015).

IV. APPLICATION OF METHOD

In this section, the proposed method for the op-eration of a microgrid, based on GORE and the reference model IEC 61850 is described. Initially, are extracted the minimum requirements for the operation of the microgrid based on the IEC 61850 reference model. Thus, Figure 4 shows the dy-namics of the operation, also the control strategy is veri ed on each RSD, like all combinations.

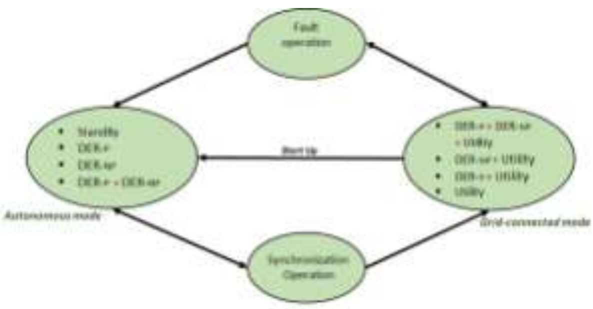

Figure 4: Operation Microgrid based IEC 61850

Therefore, based on the context of the stan-dard the DERs were grouped into programmable DER (DER-P) and non-programmable DER (DER-NP) (Postigo, 2018). The battery energy storage system (BESS) and Combined head and power (CHP) are part of the DER-P. On the other hand, renewable energy sources such as PV and WP belong to the DER-NPs, this is due to their uncertainty of power generation, and randomized in the production of energy, a ected by natural factors. The Control system will be responsible for the automation and switching of the DERs.

Each DER accesses the microgrid bus through a circuit breaker. The microgrid connects to the service network by a PCC. When the turn o the PCC, closes the microgrid it accesses the electrical network and switches to the Connected Network Mode. When the switch it is open, the micro-grid is disconnected from the service network and switches to Autonomous mode.

Autonomous Mode: It happens when the mi-crogrid supplies power to the load only with the GD, that is, every time have some abnormal sit-uation in the main network or happen a manual operation.

Synchronization mode: Whenever network power is reestablished, additional transition modes are required to synchronize distributed gen-eration (DG) with the main network.

Network Mode Connected: Normal operation occurs when the microgrid is connected to the main network and distributed energies (DER).

Fault Mode: Whenever a fault is detected, the PCC switch opens, and MSG is separated from the service network and switches to autonomous mode.

The next step in the method is to model the requirements in the form of objectives using the objectives diagram. Figure 5, shows the KAOS model using the ObjectivER tool. It is observed how the main objective is re ned in sub-targets, that is, the target Control of Operation of the mi-crogrid, is re ned in the submit Automatic Op-eration and Grid Operation connected. Also in

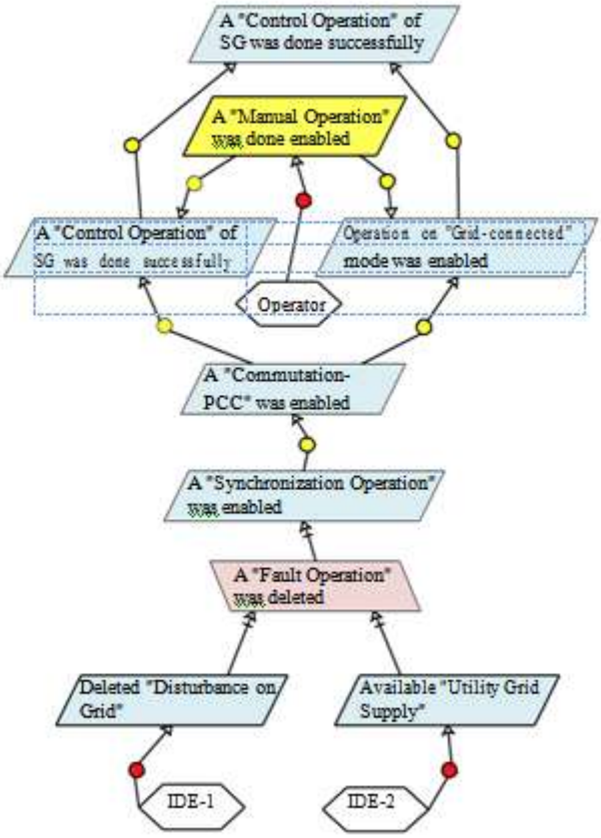

Figure 5: Goal Model

this model, each subroutine is re ned into require-ments and obstacles considered relevant to the eld of microgrid operation, they are used to prove that the re nements are complete.

Available

Sinal IDE-2

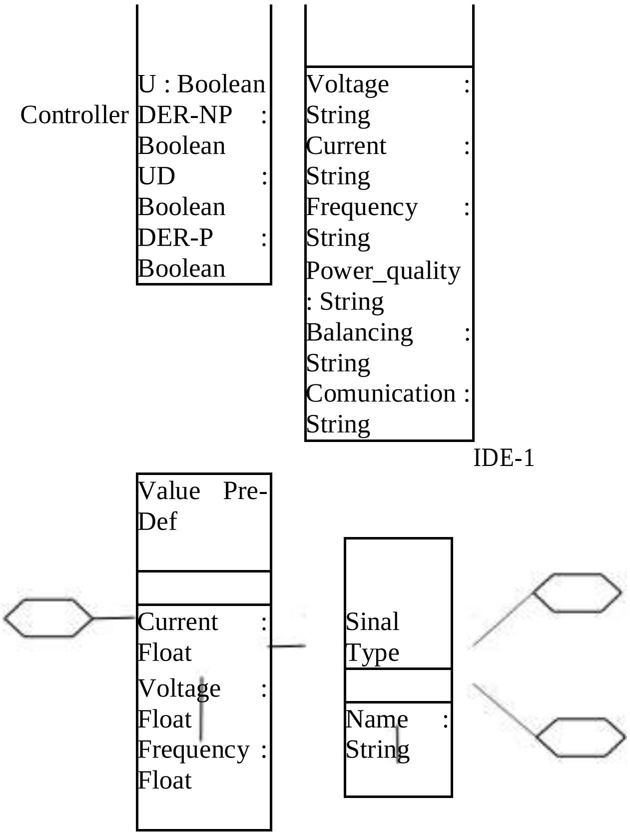

Figure 6: Object Model

Figure 6, shows the KAOS object model, which is an equivalent diagram with the UML class diagrams. They have characteristics such as inheritance and, is available for all types of objects (including associations).

In this diagram the objects (Available and Signal Type) are quali ed with attributes, which captures the relevant vocabulary to express the objectives for microgrid control.

Figure 7, shows the operations diagram that represents all the behaviors agents need to have to meet their requirements. Thus the behaviors are expressed in terms of operations performed by the Controlling agent.

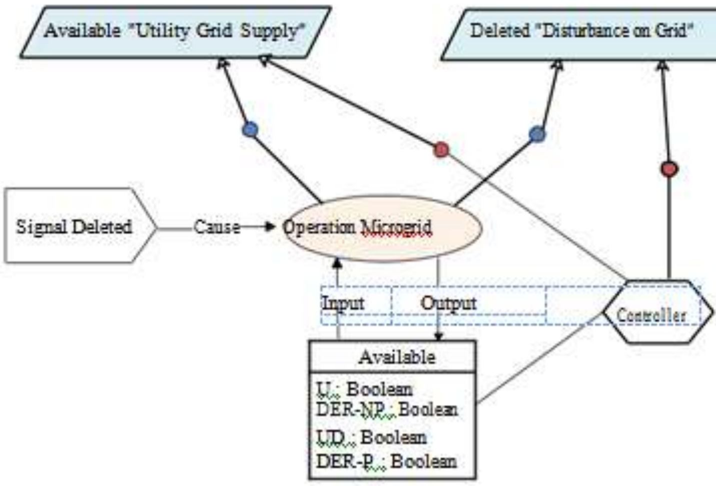

Figure 7: Operation Model

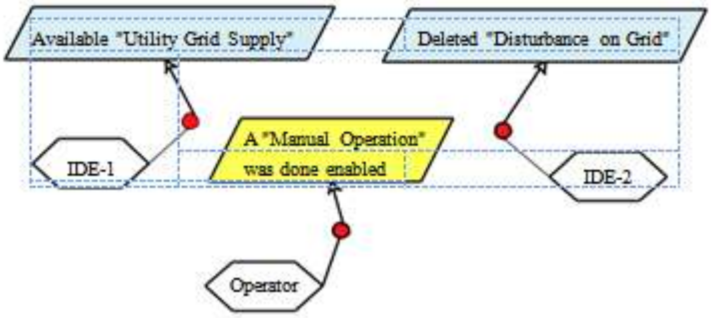

Figure 8: Responsibilities Model

Operations work on objects described in the object model (Available), which will allow objects to be created, object state transitions, or trigger other operations through events and signals sent and received by the IEDs.

Figure 8, shows the responsibilities diagram, which describes the responsibilities for each agent, the requirements and expectations for which they are responsible or that have been assigned to the Controlling agents and IEDs. Here, we check the di erent requirements and expectations in the ob-jectives model and assign an agent to each of them.

The nal step of the process is the formal-ization of requirements where KAOS is also used. Therefore, the process described so far is based on the hypothesis that the requirements must be formalized before they become speci cations. Thus, the requirements are introduced as disci-plined semi-formal declarations (since we are using reference models) and must be formally analyzed, using the LTL of the KAOS tool. This process is very important for the automation system that interacts with the SG system.

Goal	LTL Sentences
A \Control Operation" of SG was done successesfully.	pcc PCC, grid Grid); on(pcc) grid:mode=true; ∀(→ A
Operation on \Automous Mode" was enabled.	pcc PCC, grid Grid); Of(pcc) autonomousMode(grid); ∃(→ A
Operation on \Grid-connected mode" was enabled.	∃(op Operator, grid Grid); On(grid) ∧ Available(op) → A manualOperation(op; grid);
A \Commuta-tion" was en-abled	sinal Sinal, com Commutation); ∃(enabled (com) disturbance(sinal) ¬ enabled(com) supply(sinal) ; → A ∧
A \Synchro-nization" was enabled.	∃(sinal Sinal); ¬ disturbance(sinal) ∧ suply(sinal) → A synchronized(sinal) ;
A \Fault op-eration" was detected.	∃(sinal Sinal, pcc PCC,); ¬ disturbance(sinal) ∧ ¬ supply(sinal) of(pcc) ; → A
Detected \Distur-bance" on Grid.	ide-1 IDE-1, sinal Sinal.); On(ide-1) disturbance(sinal); ∃(→ A
Available \Utility Grid Supplye".	∃(ide-2 IDE-2, sinal Sinal.); On(ide-2) → A supply(sinal) ;

Table 2 shows LTL sentences associated with each goal.

V. CONCLUSION

This work is based on the hypothesis that in order to achieve good performance, SG systems must be automated and therefore their design should no longer be based on good practices and experi-ence based on intuitive and / or tacit knowledge. Automation can also introduce autonomy into the control systems, which could be a source of prob-lems rather than advantages, if not well managed.

Thus, the proposal presented here combines consolidated reference architectures with modern objective-oriented requirements modeling, speci - cation and analysis methods, aiming to provide re-liable microgrid design, capable of managing from simple urban problems until sophisticated cases in remote locations.

In addition, using GORE, KAOS and refer-ence model, the proposal introduces LTL-based (formal) requirements analysis and validation. However, it is observed there are not signi cant numbers of cases with this method developed to support direct comparison with traditional meth-ods such as UML. Although, the case study pre-sented in this paper clearly shows the advantage and reliability of the GORE approach.

The drawback of the proposal is associated with the formal presentation in LTL, which is not approapriated to distributed systems. Future steps of this research will investigate the use of Petri nets to provide a dynamical modeling and formal veri cation in these systems.

Finally, this work shows a method for formal speci cation of requirements that allows the syn-thesis of control and operating modes for a micro-grid based on the IEC 61850 architecture. The use of GORE methodology eliminates problems with the equilibrium between functional and non func-tional requirements that are present in the con-ventional approach based on UML, besides being traceable and easy to reuse.

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