# Grid2Onto: An Application Ontology for Knowledge Capitalisation to Assist Power Grid Operators

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Abstract
The development of real-time decision-making AI virtual assistant systems requires semantic artefacts such as taxonomies, controlled vocabularies, and ontologies. These artefacts assist human operators in dealing with heterogeneous information. This paper presents Grid2Onto, an application ontology that leverages agent-oriented AI recommendations to aid power grid operators in solving future problems based on past observations stored in a knowledge database. The main contribution is a unified semantic model that formalises Grid2Op's output, a realistic simulation environment for electrical supervision. The proposed Grid2Onto ontology enhances a real-time power grid recommender system by automatically generating a knowledge graph and reasoning capabilities. This paper highlights the added value of the proposed ontology.

**Keywords**
Application ontology, ontology engineering in industrial domain, AI virtual power assistant system, real-time simulation

## 1. Introduction

Power grids, such as the one managed by the French transmission system operator RTE have always been complex artificial systems. Their complexity keeps increasing due to the current energy transition. The integration of more intermittent renewable energies on the production side and the emergence of prosumers on the demand side, coupled with the globalization of energy markets, have made power grids more interconnected and challenging to operate [1]. Additionally, the grid is also ageing, but grid asset developments are facing social opposition. As a result, operators must operate closer to the grid's limits, deal with greater uncertainty, and manage increasing grid automation.

In power grid control centres, AI assistance for real-time decision-making has emerged as a promising solution to improve the efficiency, reliability, and safety of the electric grid [2]. AI assistance and real-time decision-making can improve the performance of power systems,

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reduce the risk of blackouts, and improve the overall resiliency of the grid. In particular, managing congestion over power lines is critical. In the form of remedial action recommendations, assistance is becoming utterly needed to deal with more numerous and complex events. More precisely, the operator needs to be assisted during his operations to improve his performance and reactivity to complex or unexpected situations. This assistance goes through the recommendation of actions to be deployed and through the contextualization of the situations and the explainability behind the recommended actions. Such assistance is explored through the training of artificial agents [3, 4, 5], but gaps in terms of Human expert knowledge integration and transparency remain for such solutions to be better aligned and fully adopted. By focusing on energy management recommender systems, we can identify the lack of recommendation systems which adopt the recent trends of explainable AI [6]. One of the main purposes of ontologies is to capture knowledge about a domain and represent them in a machine-readable and interpretable form. Here, the purpose is to help grid operators find the most relevant actions to deploy regarding the contextual observations and the expected KPIs.

For that purpose, we propose a real-time ontology-based recommender system that can assist operators in finding the relevant actions to operate to regulate and manage the power grid with the help of the semantic Web techniques and knowledge graphs. We believe that using ontologies facilitates the parsing, reasoning, sharing and reusing of knowledge to assist grid operators in finding the most appropriate actions to regulate power grid-related issues. In power grid management, ontologies and knowledge graphs are usually used to model higher power grid concepts, their topology, physical components and their relationships, and the logical rules governing these concepts' functioning, constraints and requirements and their relationships [7, 8]. It will also help improve the quality and personalisation of results via recommendation systems and the understanding of these results.

This work describes the proposed Grid2Onto application ontology and showcases its usage in a real-time power grid recommender system. The paper is organised as follows: Section 2 presents a brief overview of the research background and related works. Section 3 describes the methodological and technological choices we considered in the development process of the Grid2Onto application ontology. Section 4 details the main ontology development steps, i.e., requirements formalisation, conceptualisation, implementation, and evaluation, followed by the development of the underlying ontology. Section 4 presents the results of a scripted incident management scenario and demonstrates its usage. Finally, conclusions and directions for future study are illustrated in the last section.

## 2. Background and Related Work

Recommender Systems are information filtering systems designed to assist users in finding content, products, or services by collecting their preferences either implicitly or explicitly or by analyzing their behaviours. In recent years, there has been a growing interest in semantic and knowledge-based recommenders that suggest items based on specific domain knowledge about how certain features meet users' needs, preferences, and usefulness. Knowledge bases can be used to build intelligent and explainable systems, and methods based on description logic can provide new information through deductive reasoning in mathematically proven ways.

In literature, several ontologies and knowledge-based recommender systems have been developed for various domains, such as e-learning [9], entertainment [10], nutritional and healthcare [11], manufacturing [12], and driver assistance systems [13]. However, most recommender systems are either collaborative or content-based in the power grid energy domain [14, 15]. Ontologies have primarily been used to develop task or event ontologies for Energy Management Systems (EMS) in the power systems domain [16, 17].

OntoPowSys [18] is an ontology-based management system within a Knowledge Management System (KMS) for a virtual Eco-Industrial Park (EIP). It uses an ontology to demonstrate Optimal Power Flow (OPF) in the electrical network and Cross Ontology Domain Interactions. The knowledge base is implemented in OWL and is populated automatically from J-Park Simulator data. Open Energy Ontology (OEO) [19] is an open OWL ontology that covers all aspects of the energy modelling domain and has three modules covering models and data, social and economic aspects, and the physical side of energy systems. The OEO-model module is for entities related to data and models, OEO-social is for socio-economic entities, and OEO-physical includes all entities related to the physical world of energy systems.

Ontologies have the capability to receive real-time data from various sources, including IoT devices, sensors, logs, and virtual environments such as simulators, emulators, and virtual reality. Raw data from underlying systems can be calibrated and simulated in practical industrial scenarios with real data. For our study, we acquired data from the Grid2Op power grid simulator and used it to develop the Grid2Onto ontology. This ontology captures the relationships and concepts relevant to power system operations and covers electrical grid components, observations, actions, and KPIs. By creating a knowledge graph and semantic model, Grid2Onto serves as decision-making support for operators, allowing them to establish effective action strategies based on current observations and expected KPIs. Gird2Onto has a well-specified role within the Grid2Op framework, and the usage scenarios are restricted and very specific. Considering this, we decided to implement the first version of grid2onto based only on the experts' and application needs, then extend it using existing standards such as the Common Information Model [1] (CIM), mid-level ontologies such as the Sensor, Observation, Sample, and Actuator (SOSA) Ontology [20] or initiatives such as the OEO.

The following section will describe the methodological approach used to construct the proposed ontology. Our goal is to cover the key simulation outputs of Grid2Op, including recommendations for actions based on observed situations and desired performance metrics.

## 3. Used Methodologies and Tools

In this study, we applied the realism-based approach [21, 22] to design and conceptualise the proposed application ontology. By adopting such an approach, Gid2Onto can accurately represent the entities, properties, and relationships observed in the electrical grid. Moreover, we followed the Linked Open Terms (LOT) ontology engineering methodology [23] as a basis to develop our ontology for capitalising the power grid observations. We selected this approach because it is a specialised method for developing ontologies and vocabularies in industry. LOT describes a main workflow composed of four major steps aligned with the

[1] https://www.dmtf.org/standards/cim

software development practices, namely (i) ontology requirement specification, (ii) ontology implementation, (iii) ontology publication, and (iv) ontology maintenance and recommends a list of tasks and tools for each step. We are considering the FAIR (Findable, Accessible, Interoperable, Reusable) principles [24] to facilitate the reuse and interoperability of the proposed application ontology via the metadata properties curation.

Referring to LOT recommendations, we reused the Ontology Requirements Specification Document (ORSD) templates [2] for collecting and formalizing the functional and non-functional requirements, diagrams.net for the graphical conceptualization of the major classes and relations of the proposed ontology schema, the Protégé ontology editor tool for the implementation of an ontology in an OWL format, Pellet OWL-DL reasoner [25] for consistency checking and validation, WebVowl (Web-based Visualisation of Ontologies) [3] for semantic network visualization, WIDOCO (WIzard for DOCumenting Ontologies) [4] for generating HTML ontology documentation, and Git system for ontology versioning and issue tracking.

As our goal is to automatically reason on the different Grid2Op[5] simulation data, we developed an end-to-end reproducible pipeline using the Owlready2 Python library [26] for handling data RDFisation, knowledge graph generation and SPARQL querying in the developed power grid operator's recommender system. The main stakeholders for the ontology design, development and integration within the virtual assistant system are:

- The Grid2Op and industrial power system experts contribute to defining the use case scope and specify the specifications of the ontology.
- The ontology developers implement and test the ontology.
- The architect software engineers develop a real-time supervision framework referring to the Grid2Onto application ontology.

Figure 1 depicts the main steps and I/O of the capitalisation pipeline within the assistant platform and how the knowledge base is continuously enriched with new RDF triples (e.g., grid state, context, actions, etc.) associated with an n+1 observed experience.

# 4. Development of the Grid2Onto Application Ontology

## 4.1. Ontology Requirements Specification

To elaborate on the ontology requirements, the ontology developer team interviewed Grid2Op and industrial power system experts to specify the use case specifications, the documentation needed, the purpose and scope of the ontology, and its requirements. The major purpose of developing the Grid2Onto ontology is to provide a semantic description of observed actions in a power network and a recommendation of future actions for optimizing some specific Key Performance Indicators (KPIs). It will first cover two aspects, pointing to the relevant context for applying an action, second, retrieving similar past situations for action. Thus, we identified the following intended uses regarding the flow congestions in lines on a power grid: (i) Use 1:

[2] https://github.com/oeg-upm/LOT-resources
[3] https://vowl.visualdataweb.org/webvowl.html
[4] https://github.com/dgarijo/Widoco/
[5] https://github.com/rte-france/Grid2Op

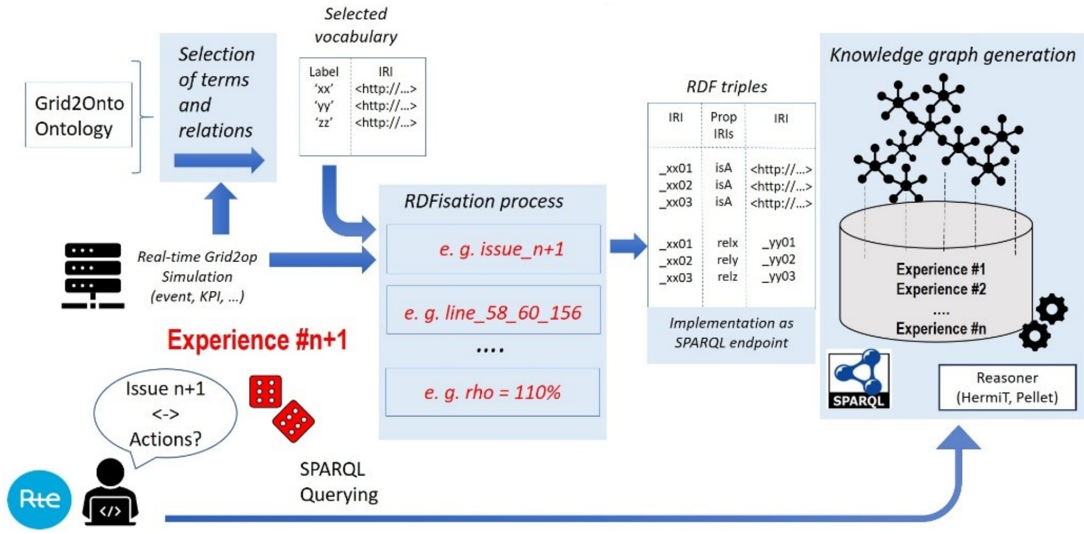

**Figure 1:** The knowledge capitalisation process for assisting power grid operators within the recommender system and its use of the Grid2Onto ontology

provide an “appropriate” recommendation using KPI: Given an identified action, add context from observations associated with it to make a recommendation for the operator. (ii) Use 2: Search for associated actions: Identify other related actions from a given action in this context. (iii) Use 3: Rank a list of actions based on KPI value(s): Suggest to the operator ones with similar or better KPI values among those actions. Ranking the actions. (iv) Use 4: Seek for similar situations: Given an action and context, identify other situations in the past that were similar to help the operator get “trust”.

Additionally, we collected the specification in the form of Competency Questions (CQs); in total, we gathered a set of 34 CQs (sprint 1) and formalized them in an ORSD file. And we defined a pre-glossary of main terms included in the CQs and calculated their frequencies. Here-after some examples of CQs examples:

- CQ1: What is the current status of the power network grid?
- CQ2: What is the category of a specific detected issue?
- CQ3: What is the measurement unit of a specific parameter?
- CQ4: How many powerline issues are observed at a specific time interval?
- CQ5: What is the list of actions that should be conducted to optimise KPI values for a specific context?
- CQ6: At what time was the highest value of the measured flow of each line?
- CQ7: What past situations best match the current context?

### 4.2. Conceptualisation

For the modelling part, a typical power system is considered as a set of power generators and loads connected through an electrical network consisting of buses and lines. It also has

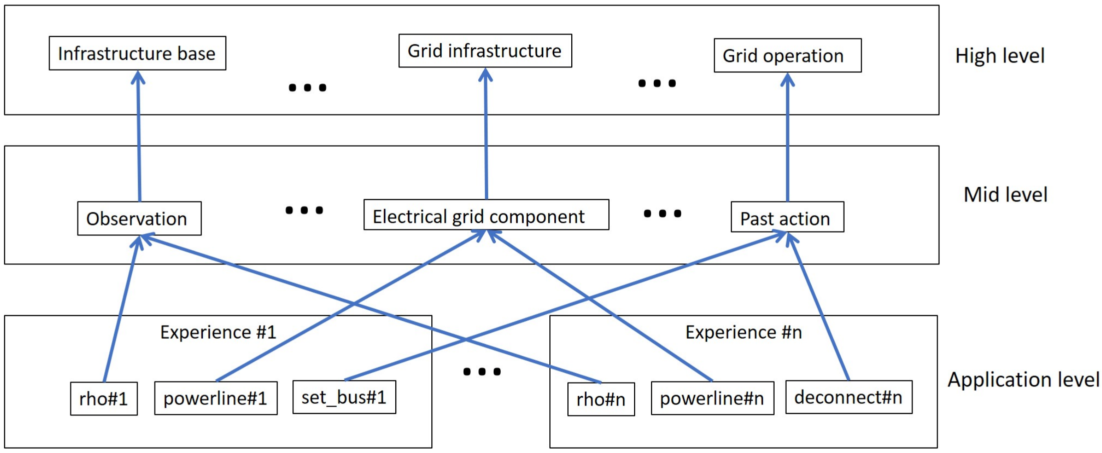


**Figure 2:** The meta-hierarchy of the Grid2Onto ontology (release V1.2)

devices like power converters to manage the quality and quantity of power flow and the voltage level. In addition, inclusion axioms are defined to introduce the subsumption relations between concepts, whereas role inclusion axioms are defined as subsumption relations between role names. Finally, relations between individuals are established using concept and role names (individual assertions). The results showcase the advantages of using ontologies in developing decision support tools.

In particular, we followed a three-step process to develop the Grid2Onto ontology and establish subsumption relationships between concepts. Firstly, we examined the technical documentation of Grid2Op, with a focus on entities related to powerline flow congestion, such as "rho," "powerline," "bus," and others. Secondly, we interviewed three experts in Grid2Op and industrial power systems. Thirdly, we expanded our analysis by reviewing existing ontologies, including the Information Entity Ontology, Agent Ontology, Quality Ontology, Units of Measure Ontology, Event Ontology, Relation Ontology, etc., to incorporate mid-level content. Figure **??** depicts the structure of the provided in the ontology.

## 4.3. Ontology Coding, Evaluation and Publication

We coded the class and relation hierarchy (including the top-level relationships shown in Figure 2, and then we formalised their definitions into the ontology using axioms (i.e., logical assertions):

- HasPart(x,y): electrical_grid x hasPart electrical_grid_component y
- HasQuality (x,y): electrical_grid x has quality y

The current version (grid2onto-owl-v1.0) of the Grid2Onto has 121 classes, 25 object properties (with the inverse relations in count), 7 data properties, and 16 annotation metadata; the ontology content is structured into five modules: infrastructure module (consists of 7 classes), Grid infrastructure module (consists of 23 classes), Grid operations module (consists of 30 classes), stakeholders module (consists of 6 classes), environment module (consists of

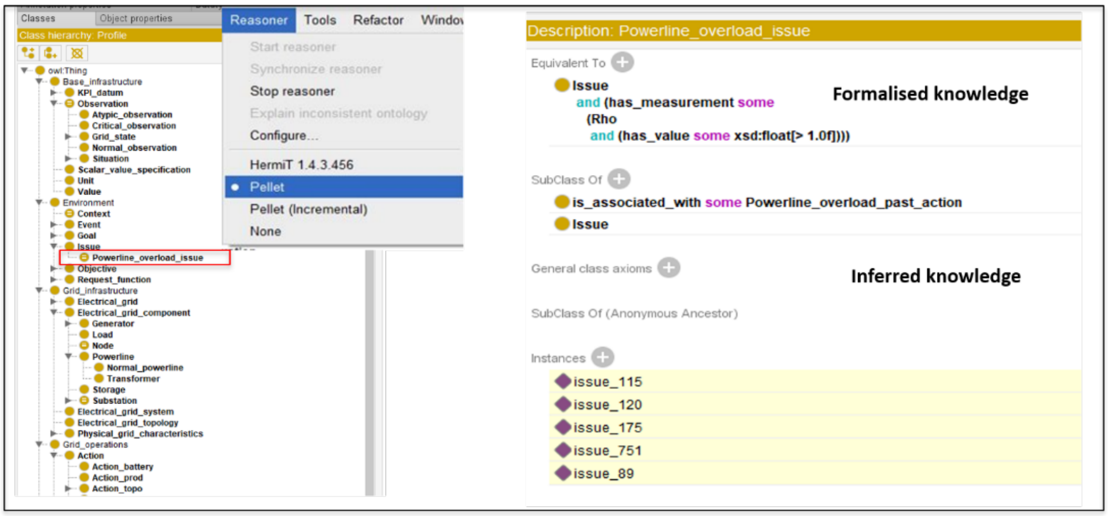


**Figure 3:** A screenshot of automatic classification process of issue instances as a powerline overload issue class using the equivalent class axiom definition (Protégé implementation)

23 classes). Following the W3C best practices, Grid2Onto adopts the HTTP namespace for the URIs of all classes, properties, and individuals to facilitate the RDF querying. Each word is lowercase and joined by underscores (e.g., electrical_grid). Thus the URIs are as follows: http://www.semanticweb.org/emna.amdouni/ontologies/2023/1/Grid2Onto/electrical_grid

We formalised Grid2Onto knowledge using axioms, for example, the concept *Powerline_Overload_Issue = Issue and (is_about some powerline) and (has_measurement some (Rho and has_value some xsd:float[>1]))*. Figure 3 illustrates how the resulted from ontology automatically infers the category of a list of new issues based on their minimal asserted features.

During the evaluation step, we first checked the consistency of the ontology schema using the Pellet reasoner as a Protégé plugin. Second, the populated ontology via the same reasoner but the owlrady2 library. We validated its completeness/coverage regarding the defined set of CQs associated with the current release of the power grid recommender. Grid2Onto (owl version 1.2) is online and shared in the IndustryPortal [6], an ontology repository for industrial semantic artefacts. We aim to allow other users to reuse the ontology once we produce the final release as decided internally in the ongoing French ANR CAB (Cockpit and Bidirectional Assistant) project [7].

## 5. Demonstration: Grid2Onto Application Scenario in the Power Grid Recommender Platform

To perform real-time virtual assistance of RTE power grids based on Grid2Onto ontology, we developed a Web application based on JavaScript, Angular, and Python technologies. Figure

[6]http://industryportal.enit.fr
[7]https://www.irt-systemx.fr/en/projets/cab-cockpit-and-bidirectional-assistant

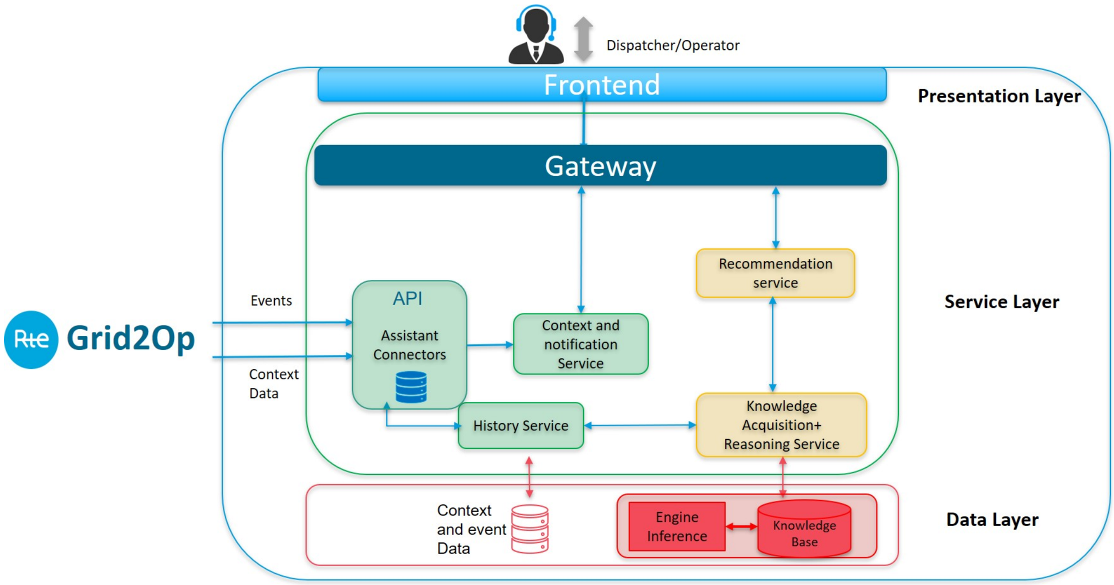


**Figure 4:** An overview of the power grid recommender system enabling semantic reasoning and recommendation for RTE power grid operators

4 details the architecture of the power grid recommender system, which is composed of five major parts:

1. Assistant connectors that implement the entry points used to receive context data and events from the Grid2Op simulator,
2. Context and notification service that displays the electrical grid with its current line status and the reported notifications about issues such as powerline overload,
3. History service that tracks all events and contexts received from the simulator and used to populate the ontology,
4. Knowledge acquisition and reasoning service that stores the new/updated RDF triples that are automatically generated according to the Grid2Onto model and performs semantic requesting using SPARQL,
5. Recommendation service that returns a list of recommendations based on the knowledge and reasoning service in the case of an observed issue.

As illustrated in Figure 4, retrieving recommendations from the RDF triple store is part of the data layer. The sequence diagram in Figure 5 details the whole process from the overload alarm notification to the RDF data retrieved from collected JSON-LD information.

The selection of relevant recommendations based on the observed context relies on the defined SPARQL queries that are handled by the knowledge acquisition and reasoning service, an example is provided hereafter:

```
Select distinct ?similarIssue ?line ?rhovalue ?pastAction
{
  ?similarIssue a Grid2Onto:powerline_overload_issue .
```

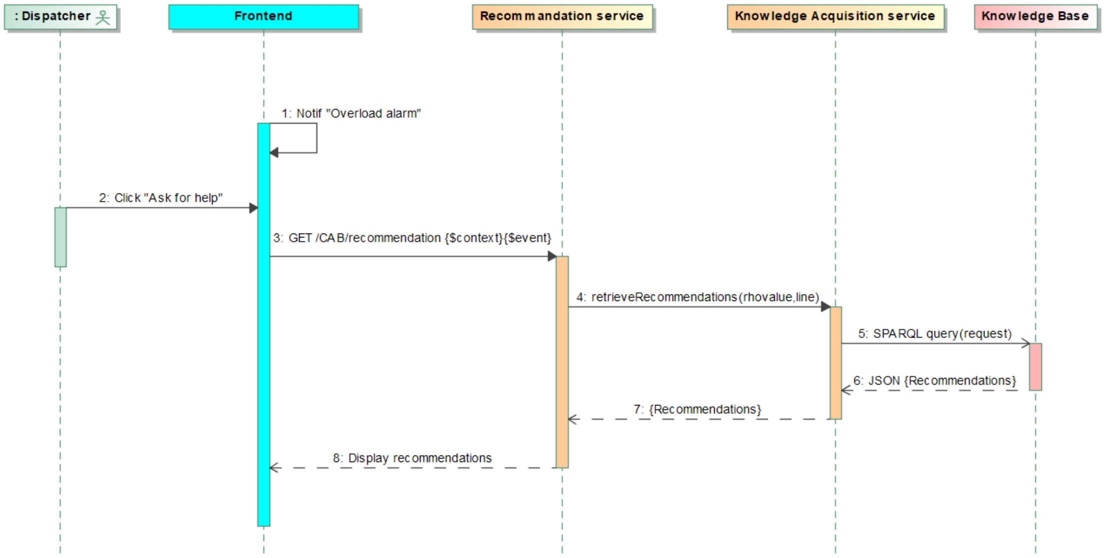


**Figure 5:** Sequence UML diagram for RDF data retrieved from collected JSON-LD information

```
    ?similarIssue Grid2Onto:is_associated_with ?pastAction .
    ?rho a Grid2Onto:Rho .
    ?rho Grid2Onto:has_value ?rhovalue .
    ?rho Grid2Onto:is_about ?line .
    ?similarIssue Grid2Onto:has_measurement ?rho .
}
```

**Listing 1**: A SPARQL query example to retrieve similar powerline issue and their associated number of the line, rho value, and past action from the acquired knowledge in the RDF triple store.

This section describes a demonstration of a powerline incident management scenario. We launch the Grid2Op simulator to push context and event data to the recommender system. As displayed in Figure 6, the assistant allows us to visualise the real-time state of the grid network. When an overload is detected, an alarm notification is raised to inform the operator about a powerline issue (a). The operator clicks on the notification for more details. The grid network plots the observed overload with a red line and information related to the line identifier and the rho value (b). The operator can ask the recommender system for help to resolve this issue. The assistant then displays recommendations for the observed powerline issue (c).

## 6. Conclusion and Perspectives

This work introduces a promising application ontology called Grid2Onto, conceived to be a semantic reference model for the grid2op RTE simulator, and aims to capitalise on the power grid operator's knowledge. The proposed ontology is integrated into an assistant platform showcasing the industrial use cases identified during interviews.

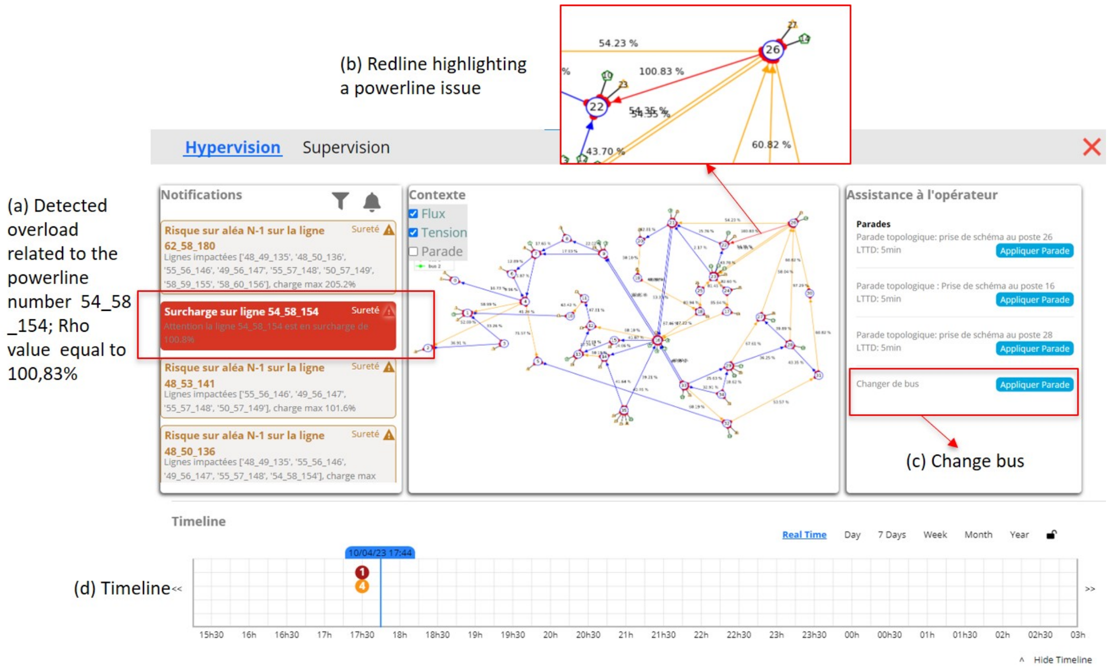


**Figure 6:** The role of Gird2Onto ontology in the assistance platform and its usage in the real-time recommendation process for RTE power grid operators, (a) ranked list of powerline overload issue notifications, (b) current grid network plot highlighting the observed powerline status, (c) list of returned AI recommended actions for resolving the selected issue, and (d) timeline of issues management

The preliminary results demonstrate some reasoning advantages of using semantic web technologies in developing real-time decision support tools in power systems. The industrial use case experts validated the current ontology recommendation results.

The proposed Grid2Onto is an ongoing French ANR RD project output, and the model is under frequent updating. In the future, the ontology modules will be based on existing relevant open ontologies, such as SOSA ontology, to cover specific domain knowledge (agent, event, quality, units of measure, etc.). And we will follow an upper-level ontology, for example, Basic Formal Ontology (BFO)[27] to harmonise the different representations and assess the FAIRness using specific tools [28] to improve the quality of our proposal. Additionally, efforts to expand the recommender system's reasoning capabilities are needed to fully cover the Grid2Op simulation parameters and generate more appropriate recommendations based on a given observed power grid context.

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