COMPARING THE INTEGRATION OF INNOVATIVE ASPECTS IN SMART GRID DEMONSTRATION PROJECTS

Stijn VAN LOO
G2Elab - Université Grenoble Alpes - France
Stijnvl1991@gmail.com

Damien PICAULT
G2Elab - Université Grenoble Alpes - France
damien.picault@g2elab.grenoble-inp.fr

ABSTRACT

This paper describes a methodology to assess the broadness of innovation in smart grid demonstration projects. The proposed methodology extends previously published methods by using a single indicator which evaluates relevant smart grid criteria. In this work, additional criteria have been added to the indicator in order to enhance the smart grid concept. The customization of the smart grid scope indicator (SGSI) to focus on specific aspects of smart grid projects is also proposed. Further improvements described in this paper concern a method to account for the reliability of reference material used for analytic purposes. Finally, results of the evaluation method will be presented, based on an independent survey of the current major smart grid demonstration projects throughout the world.

INTRODUCTION

The increasing need for sustainability and carbon-free energy use has led to a recent boom of smart grid demonstrators throughout the globe. Smart grids have been presented as an important component to develop the future energy system, a system with a reduced carbon footprint. In Europe, these improved energy systems are also a crucial tool to reach the European Union's 20-20-20 targets. Smart Grid demonstrator projects include innovative technologies and aspects from the entire electricity chain, from the generation of electricity to its transport, distribution and consumption. Where the majority of these projects try to experiment technologies in a certain field, more ambitious demonstrators try to integrate several aspects to test the electrical system of the future. Prior publications have proposed methodologies to analyze and compare these projects. A smart grid can be described using the following key performance indicators [1]:

- Enable informed participation of customers
- Accommodate all generation and storage means
- Provide power quality for the 21st century
- Operate resiliently to disturbances, attacks and natural disasters

Projects can then be evaluated by the presence of such indicators in the project scope. Similar approaches use four functional projects in which different technologies are mapped [2]. These functional projects concern the integration of smart customers, integration of smart metering, integration of distributed energy resources (DER) and new users, and smart distribution networks.

Previous work has been proposed using an increased number of criteria to define a smart grid [3], by considering 36 items classified into six groups. These groups are: generation, transmission, distribution, storage & electrical vehicles, consumer service and business models. This method differentiates itself by attributing scores to smart grid demonstration projects. The score does not intend to evaluate the performance of a demonstrator, nor the depth of its research but it quantifies the amount of innovative aspects studied in the smart grid. To calculate the score, referred to as Smart Grid Evaluation Indicator (SGEI), binary scores are attributed to each smart grid criterion depending on their presence in the project: one if considered and zero if not. These scores will then be used to calculate sub-scores, for each of the groups, using the following equation:

$$S_j = \frac{10}{n_j} \cdot \sum_{i=1}^{n_j} I_i \qquad (1)$$

where S_j the sub-score of a given group is, n_j the amount of smart grid criteria in a group and I_i the binary evaluation of a criterion.
The SGEI can then be calculated using:

$$SGEI = \frac{1}{N} \cdot \sum_{j=1}^{N} S_j \qquad (2)$$

where N is the number of groups and $SGEI$ is the smart grid evaluation indicator previously described to assess the integration of different aspects in the project.

This paper pursues the work initiated in the SGEI methodology [3], by addressing the exposed limitations of the approach. First, further smart grid criteria has been added to better define the smart grid concept. Later, improvements of the calculation method are proposed to enable a customization and interpretation of SGSI results. Finally, an information reliability indicator will be introduced which takes into account the references used to evaluate the smart grid criteria.

IMPROVEMENTS TO THE METHODOLOGY

Implementation of New ICT

According to the French energy regulator (CRE), a smart grid is "an electrical grid to which new features are added using new information and communication technologies". These technologies are considered for the various actors

in the electric system. The purpose of a smart grid is to assure a balance between supply and demand with added flexibility and reliability, and optimizing the performance of the electricity grid. [4]. A crucial role of information and communication technologies (ICT) for smart grids is to support bidirectional energy and rapid information flow, facilitating the integration of renewable energy sources into the grid, and empowering the consumer with tools for optimizing their energy consumption [5][6].

While current power systems are based on a solid information and communication infrastructure, the smart grid needs a different and more complex one, as its dimension is much larger. Recently, new ICT technologies such as Zigbee and power line communication are being tested and optimized [7][8]. Furthermore, energy management systems (EMS) are intensely being developed on different geographical scales. For example, building energy management systems (BEMS) are being implemented as a critical part of the future smart grid in South Korea [9]. In Japan, studies to cluster energy management systems (CEMS) are presented as next generation energy-systems. CEMS monitors and adjusts energy supply and demand in real-time to form the best combination of them [10]. These new communication technologies and their applications are present in almost each before-mentioned smart grid group, to the exception of business models, such as balancing the distribution network with the transmission network or the smart metering communication infrastructure, yet they are currently not considered in the calculation of the SGEI.

The New ICT will accordingly be added as an additional group to better define smart grids. The two additional smart grid criteria related to this group are:

- **New communication technologies:** improvement of the technologies used to communicate power grid related information such as Power-Line Communication, 3G, Internet, etc.

- **Smart Energy Management Systems:** systems used to manage energy from small to larger areas: Building EMS, Community EMS, etc.

Smart Grid Scope Indicator (SGSI)

One of the limits identified in the initial SGEI method is the absence of weights for each group to ponderate the final indicator. Currently, each group has the same contribution towards the final score. In order to adjust the importance of groups towards a user's needs, weights have been added to the formula. The SGSI can now be calculated as :

$$SGSI = \frac{\sum_{j=1}^{N} \alpha_j \cdot S_j}{\alpha_j} \qquad (3)$$

where α_j are the weights attributed to each of the groups. By doing so, different values of these weights enable different interpretations of the formula :

- **All weights equal:** the formula reverts back to equation (2) and all of the groups contribute equally to the SGSI.
- **Each weights equal to the number of criteria in a given group:** each smart grid criterion has an equal importance, groups with more criteria (for example consumer service) become thus more dominant in the calculation of the SGSI
- **Only one weight of a certain group set to 1:** The indicator illustrates the scope of a smart grid project in a given group (Generation, Transmission, Distribution, Storage & Electic Vehicles, Consumption, New ICT, and Business models). This configuration can help compare projects based on a customized of smart criteria.

The proposed method enables the users to customize the SGSI according to their needs.

Information Reliability Indicator (IRI)

Interpretations of the SGSI results tend to show that smart grid projects with high SGSI scores demonstrate a wide integration of smart grid aspects. Whereas, a low SGSI does not necessarily mean the project does not integrate a wide range of aspects. It can also indicate a lack of reliable reference material in which the information to evaluate the project has not yet been accessed. To separate these two causes, an Information Reliability Indicator, later referred to as IRI, will be introduced to evaluate the quality of the reference material used in the survey process. This indicator contains four values:

- **Reliable:** the information used to evaluate the project is numerous and of good quality.
- **Acceptable:** the information used to evaluate the project is decent and reflects the project well. Searching for more references might provide complementary information.
- **Questionable:** there is a lack of information and/or the references used are of inadequate quality. Searching for more reference material is highly advised.
- **Unreliable:** Searching for more references is mandatory to achieve a better view on the demonstrator.

The proposed approach to determine the value of the IRI depends on the amount of references available and their quality. First, different document categories have been

defined and divided in two classes: primary references and secondary references, as presented on Table 1. The primary references are those which emanate from the project itself. These are reports, presentations, flyers, newsletters, press kit, etc. The secondary references on the other hand are documents made by external observers of the project. These include journalistic articles, case studies, external databases, etc. Each of these document categories will later be evaluated on the available amount and the magnitude of information that can typically be extracted out of a category.

Primary		Secondary	
A complete report describing the entire project	**S**	A summary paper on smart grids	**S**
A status report or scientific article	**S**	A website on smart grid projects	**C**
A presentation made by the project manager or one of the partners	**S**	Presentation by people indirectly involved (e.g. educational purposes)	**S**
A flyer or brochure about the project	**C**	Video clip about the project (e.g. a review)	**C**
The projects website	**C**	Journalistic articles about the project	**C**
Website of the partners or articles written by partners	**C**	Case study (consulting or expert study by people not directly involved)	**S**
Promotional movie	**C**	Database of the government about Smart Grid projects	**S**
Review of score by a party directly affiliated with the project	**R**		

Table 1. Definition of document categories

Quality of a document category

Table I also presents the types of documentation to which groups each document category belongs: S(cientific), C(ommercial) or R(eview). "Scientific" documentation considered refers to publications within the scientific community such as journals and conference articles in the smart grid domain. "Commercial" documentation refers to documents such as brochures and websites, which inform the public of keystones in the project but many times do not contain sufficient information to fully evaluate the implemented smart grid criteria. Finally, the "Review" category refers to the verification of the smart grid criteria attributions by a party directly implicated in the smart grid demonstration project.

To take into account the fact that some document categories provide more information than others, weights β and γ have been attributed to each document category according to the documentation type, as presented in equation (4) and (5).

$$\beta = \begin{cases} \boldsymbol{\beta_1}\ for\ a\ personal\ \boldsymbol{R}eview \\ \boldsymbol{\beta_2}\ for\ a\ \boldsymbol{S}cientific\ reference \\ \boldsymbol{\beta_3}\ for\ a\ \boldsymbol{C}ommercial\ reference \end{cases} \quad (4)$$

$$\gamma = \begin{cases} \boldsymbol{\gamma_1}\ for\ a\ \boldsymbol{S}cientific\ reference \\ \boldsymbol{\gamma_2}\ for\ a\ \boldsymbol{C}ommercial\ reference \end{cases} \quad (5)$$

The attribution of weight values have been chosen empirically, resulting in the approximation that three times more information is available in scientific references (*S*) than in commercial references (*C*). The personal review (*R*) receives an even higher weight due to relevant information obtained. The proposed method of attributing weights is a first approach that can be improved by studying the influence of each separate document class.

Quantity of a document category

The more references, the better the reliability of information becomes, but the repetition of information must also be taken into account. Using more references of the same document category decreases the chances of finding new information. Assuming that the first used reference of its category has full value, subsequent references of that category will thus decrease in new information. This effect of reduction of novel information with reference accumulation has been modelled using equation (6) presented below.

$$S_{cat} = \log_2(1 + N_{cat}) \quad (6)$$

where: S_{cat} is the score attributed to a certain category and N_{cat} are the amount of references in that category.

The logarithmic decrease has been chosen to ensure that the added value of a new reference for a certain document type will never become zero but will decrease as more references of the same category are used.

Calculating the IRI

After determining the quality and quantity of each document category, a score can be calculated each of the two classes, the primary and secondary references, using the following equations :

$$S_{pri} = \frac{\sum_{i=1}^{N_{cat}} \beta_i \cdot S_{cat,i}}{\beta_i} \quad (7)$$

$$S_{sec} = \frac{\sum_{i=1}^{N_{cat}} \gamma_i \cdot S_{cat,i}}{\gamma_i} \quad (8)$$

where S_{pri} is the score for the primary references, S_{sec} the score for the secondary references and N_{cat} the

number of document categories in that class.

Once the primary and secondary reference scores are calculated, they are compared to reference values in order to the IRI value. Primary sources have utmost privilege, as they are created by partners directly involved within the project. The secondary references become important when there is a lack of primary references. The reliability indicator uses threshold values for the primary and secondary scores to determine its value, as presented in Table 2.

	Primary score	Secondary score
Reliable	$>\boldsymbol{P_1}$	
Acceptable	$>\boldsymbol{P_2}$	$>\boldsymbol{S_1}$
Questionable	$>\boldsymbol{P_3}$	$>\boldsymbol{S_2}$
Unreliable	$<\boldsymbol{P_3}$	$<\boldsymbol{S_2}$

Table 2. Threshold values to determine the information reliability indicator

Application

The SGSI methodology has been applied to a database containing references of 165 smart grid demonstration projects that have been initiated worldwide since 2006. The weights α_j in formula (3) were chosen according to the amount of total smart grid criteria in a given group, ie. each criterion has the same impact on the SGSI final score. Concerning the IRI indicator, weights in (5) and (6) were chosen by the authors as follows :

$$\beta_1 = 5$$
$$\beta_2 = \gamma_2 = 3$$
$$\beta_3 = \gamma_3 = 1$$

The threshold values for primary and secondary sources in table II were also determined experimentally:

$$P_1 = S_1 = 4$$
$$P_2 = S_2 = 2.5$$
$$P_3 = 1$$

Figure 1 shows the results for the evaluation of these projects using the SGSI methodology and presenting results from the IRI.

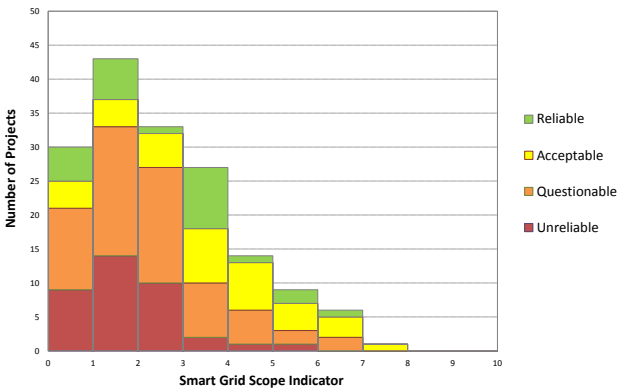

Figure 1. Analysis of 165 smart grid demonstration projects using SGSI and IRI

Results show that only seven ongoing demonstration projects have SGSI scores above six, which tends to illustrate projects with a wide spectrum of smart grid criteria implementations. The information concerning these projects are for the most part *acceptable* which confirms the reliability of the information retrieved. Moreover, most of the identified projects tend to have SGSI scores between 0 and 4, which shows a trend in addressing specific issues of the smart grid rather than having a holistic approach. IRI values for these projects tend to be lower, with a major part ranging from *questionable* to *unreliable* information. This lack of information may mostly be caused by lack of available information on specific issues, for example to respect ongoing intellectual property requirements. It should be noted that generally, demonstration projects with wide scopes of applications tend to have solid information available to the public, whereas more scope-limited projects seem to be more confidential.

CONCLUSION

This paper describes improvements to a procedure to analyze the integration of smart grid aspects in ongoing demonstration projects. Smart grid demonstrators are studied and compared based on the implementation of relevant smart grid criteria, defining a smart grid and described in previous work. These criteria each belong to a sub-set of the energy chain, ranging from generation to consumption, new business opportunities and developments of new ICT adapted for smart grid applications. Another improvement described in this article, deals with the information reliability indicator, which aims to quantify the accuracy of assessed information on projects. The aim of the proposed methodology is not only to assess the range of integration of smart grid aspects in demonstrators, but also to enable users to customize their analysis on selected smart grid criteria. Application results, based on a survey containing over one hundred and sixty demonstration projects throughout the world, show that today few projects have a holistic approach.

ACKNOWLEDGMENT

The authors gratefully acknowledge the partners of the GreenLys (www.greenlys.fr) project consortium and its financial partner ADEME (French Environment and Energy Management Agency) for their contributions to this work.

REFERENCES

[1] B. Dupont et al, 2010, *Measuring the "Smartness" of the electricity grid*, 7th International Conference on the European Energy Market (EEM), vol., no., pp.1,6, 2010

[2] H. Brunner et al, 2012, “Mapping & Gap Analysis of current European Smart Grids Projects”, Austrian Institute of Technology, *Report by the EEGI Member States Initiative: A pathway towards functional projects for distribution grids*

[3] R. López et al, 2014, “Assessing and comparing smart grid demonstration projects”, 5th *IEEE ISGT Europe, October 12-15*

[4] Commision de Régulation de l’Energie, 2014, « Définition des Smart grids », available at http://www.smartgridscre.fr/index.php?p= definition-smart-grids

[5] B. Panajotovic et al, 2011, “ICT and Smart Grid”, *Telecommunication in Modern Satellite Cable and Broadcasting Services (TELSIKS), 2011 10th International Conference on* , vol.1, no., pp.118-121

[6] OECD, 2011, “ICT Applications for the Smart Grid”, *OECD Digital Economy Papers No. 190,* available at http://www.oecd-ilibrary.org/

[7] V.C. Güngör et al, 2011, “Smart Grid Technologies: Communication Technologies and Standards”, *Industrial Informatics, IEEE Transactions on* , vol.7, no.4, pp.529-539

[8] V.C. Güngör et al, 2013, "A Survey on Smart Grid Potential Applications and Communication Requirements," *Industrial Informatics, IEEE Transactions on* , vol.9, no.1, pp.28-42

[9] K. Park et al, 2011, "Building Energy Management System based on Smart Grid," *Telecommunications Energy Conference (INTELEC), 2011 IEEE 33rd International* , vol., no., pp.1,4

[10] Y.Kamiyoshi et al, 2010, "Construction of energy measuring system in a University for Cluster Energy Management System," *IECON 2010 - 36th Annual Conference on IEEE Industrial Electronics Society* , vol., no., pp.2423-2429