Journal of Cleaner Production 65 (2014) 202–216

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

A literature survey on Smart Grid distribution: an analytical approach

Jesus A. Cardenas [a,*], Leopoldo Gemoets [a], Jose H. Ablanedo Rosas [a], Robert Sarfi [b]

[a] University of Texas at El Paso, TX, USA
[b] Boreas Group, Denver, CO, USA

ARTICLE INFO

Article history:
Received 11 April 2013
Received in revised form
13 September 2013
Accepted 14 September 2013
Available online 4 October 2013

Keywords:
Smart Grid
Smart Grid Distribution
Smart Grid technologies
Renewable energy
Smart Grid business model
Prosumer

ABSTRACT

Many different technologies have been growing under the umbrella of Smart Grids, which can be split into three major blocks: generation, transmission, and distribution. Generation and transmission have been evolving and improving as they have been under the control of utility companies, but distribution has been lagging behind on some of these improvements, due to the number of stakeholders involved in the process. With the integration of information and communication technology into the electricity distribution, there has been a spike in research and other studies to prepare for the future. In this paper, we analyzed all papers related to the topics of Smart Grids and Distribution. Because of the novelty of the concept, the results validate the expectation of an empirical approach in papers using case studies to simulate or conduct pilot runs of the technologies before their massive implementations. Strategies are mostly driven by the USA, while other countries are focusing on quality improvements of the already strategized initiatives with an efficiency-related goal in mind. Consumer participation is going to play a key role in the near future as it requires developing a new business model with the inclusion of self-generation and selling-back of excess capacity to the utility company.

1. Introduction

For many years, nations around the world have been building huge infrastructures and generation plants to ensure provision of electricity. Unfortunately, they have been facing an expected loss of energy due to transmission and distribution interconnection ranging from 10 to 52%, depending on the advancement of technology and controls to prevent theft (Najjar et al., 2012).

Looking now to the questions of environmental impact, human activities are the top contributors of the primary gases emissions with 20% of the CO_2 coming from transportation and 40% from power generation (Lo and Ansari, 2012). These activities depend mostly on fuels or coal that when burned, emit gases swelling the greenhouse gas emissions and rising global temperature. As consumers are getting more devices for the modern world needs, these gadgets require additional electricity, so more energy is being required. It is expected that by the year 2030, consumption of electricity throughout the world will increase 76% of the current consumption (Ramchurn et al., 2012). To generate this electricity, more primary gases will also be emitted along with it. Therefore, European countries are writing directives and goals to reduce these emissions in the short term to comply to the G8 leaders' agreement adopted in Heiligendamm to reduce more than 50% of the emissions by the year 2050 (Battaglini et al., 2009).

We see the integration and growth of new sources of cleaner energy like wind, photovoltaic, natural gas, nuclear, and others. New renewable resources have been growing up to 3% while nuclear generation has reached 6% of the total produced world's energy. But, after the incident provoked by the tsunami in the Fukushima nuclear plant in Japan on March 11, 2011, the reaction of the Federal Republic of Germany was to immediately close eight nuclear sites and schedule the closure of the nine remaining plants in 10 years (Römer et al., 2012). The rest of the world is also taking precautions to reduce or even eliminate nuclear energy generation.

As scientists and engineers are facing the challenge of reducing contamination and losses inherent to the distribution and transmission processes of the traditional grid, the solution seems to be the concept of Smart Grid which is based on recent technologies: Efficient distribution of energy with the inclusion of state of the art solid state electronics; use of renewable resources to generate electricity; participation of the consumers in the process by generating and/or conserving energy; feedback to consumers and utility companies about real-time consumption via smart meters; the use of electric vehicles' batteries to store and distribute energy at homes, and distributed energy resources, among others.

* Corresponding author. College of Business Administration, Room 205, El Paso, TX 79968-0544, USA.
E-mail addresses: jacardenas3@utep.edu, cardenjetx@msn.com (J.A. Cardenas), lgemoets@utep.edu (L. Gemoets), jablanedorosas2@utep.edu (J.H. Ablanedo Rosas), rsarfi@boreasgroup.us (R. Sarfi).

0959-6526/$ – see front matter
http://dx.doi.org/10.1016/j.jclepro.2013.09.019

Table 1
General classification of SGD research papers.

Classification	Components of the classification
Research category	Empirical Research, Modeling & Analytical Methodologies, Conceptual and General, Survey and Review, and SG Education
Research focus	Theory building, theory testing, and applications
Data collection	Case study, field research, laboratory research, archival research, and surveys
Data analysis	Descriptive statistics, neural networks, mathematical modeling, regression, Crombach's alpha, game theory, DEA, time series, simulation, non-linear and linear programming, or non-data analysis
Disciplines	Physical (P), Regulatory (R), Environmental (E), Social (S), Economic (F), Information and Communication technology ICT (I)
Taxonomy of paper's purpose	Strategy, Quality Management, Supply Chain Management, Environmental Issues, Service Design, Process Design, Scheduling, Planning, and Blackout
Smart Grid Categories	Demand Response, Automated Meter Reading, Distribution Automation, Distributed Generation, Electric Vehicles, Energy storage, Cybersecurity, Vol/VAR Analysis, User friendly enhancem ents, Efficiency, and Self-healing
Originating Countries	United States, China, Canada, Germany, Italy, United Kingdom, Japan and others

All these technologies are being developed and even implemented in some countries, while others are waiting to know the results before taking solid steps toward their implementation. The United States seems to be the leader in this effort with the support of the Electric Power Research Institute (EPRI), National Institute of Standards and Technology (NIST) Department of Energy (DoE), National Rural Electric Cooperative Association (NRECA), Edison Electric Institute (EEI), and the American Public Power Association (APPA) (Lo and Ansari, 2012).

Other national governments are promoting efforts for the implementation of Smart Grids in the near future. For instance, Korea launched the K-grid project in 2002 (Son and Chung, 2009), India created the Indian Smart Grid Task Force (Mukhopadhyay et al., 2012), and China formed the Strong and Smart Grid (Uslar et al., 2012).

There are also some important efforts in promoting Smart Grids in Europe where major efforts and monies have been invested on implementing advanced meters and "green" cleaner energy. The focus in the USA, however, is targeting strategies on automation and use of solid state electronics, along with information and communication technologies (ICT) to enhance the traditional grid and shift into a new and more efficient Smart Grid.

The overwhelmingly amount of Smart Grid research investment funding comes from the United States, with 31% as reported by Bloomberg New Energy Finance. Although the USA is still the leader, analysts are predicting that China will overtake this leadership position as the Smart Grid program launched by the Obama administration comes to an end in 2015. At the same time, China is continuously growing with an investment of $3.2 billion compared to the USA that spent $4.3 billion in 2012.

The Smart Grid will result in a two-way communication and flow of energy, instead of the traditional one-way flow from traditional electricity (Ramchurn et al., 2012) and information (Fadlullah et al., 2012) systems. The U.S. government has made an important start up contribution with these investments, having released $3.4 billion in grants for the investigation of Smart Grids (Güngör et al., 2011).

As communications technology has been evolving from the typical wireline to wireless media, there are important proposals about the concept of "ZigBee smart energy" with wireless communications to remotely controlled devices. The utility company or the consumer will be able remotely to turn appliances or other devices on or off depending on their need based on the cost of energy or present environmental conditions.

With all these technologies under the umbrella of Smart Grids, we chose to focus only on energy distribution for this literature survey. Distribution is a current fast-growing area and very visible to consumers, utility companies, and governments who are trying to involve the general public in this discussion. If distribution is enhanced, the expected result is energy conservation to avoid unnecessary investments in new large generating plants by reducing energy consumption.

2. Research methodology

For this literature survey, we query ISI Web of Science using "Smart Grid" and "Distribution" as selected topics with no restrictions other than requiring the papers to be peer-reviewed. After reading the papers, each one will be classified in the 8 categories shown in Table 1, which shows the sequence and sections of the methodology for the analysis of the selected and available literature.

Once the classification process is completed, we will chart trends, distributions, and cross-matrix tables to compare percentages using the total sum of the rows and the columns. The objective of this analysis is to identify important information about the areas where the majority of efforts are being channeled, increasing this area of knowledge.

2.1. Research category

This survey classifies the articles as empirical research if they contain any real data. Papers outside this category were classified as "modeling and analytical methodologies" based on mathematical functions and/or simulated datasets, "conceptual and general category" (including papers without any data and based on comments about the topic), and the final category is called "survey and review" which consists of papers reviewing the existing literature.

2.2. Research focus

We classify the selected published papers on distribution into three main categories based on the purpose behind the research: theory building, theory verifying, and theory application (Gupta et al., 2006).

2.3. Data collection

All papers are classified by the data-collection method used. In this paper we classify the data-collection approaches for empirical research in Smart Grid's Distribution into these categories: case study, field research, laboratory research, archival research, and surveys (Gupta et al., 2006)

2.4. Data analysis

Papers are then classified based on the numerical analysis techniques used; there is a category for the papers that had no data analyzed.

2.5. Disciplines

We separate the papers by categories using the six layers presented by Giannfranco Chicco (2010) in which he identifies them on the basis of interaction between elements in the Smart Grid papers. It is important to emphasize that there are going to be overlaps as two or more layers can be addressed in a single paper. The categories are shown in Table 2.

Table 2
Categories and descriptions (Chicco, 2010).

Category	Description of category
Physical (P)	Network interconnections used for the distribution of energy
Regulatory (R)	Applying standards, rules and other types of incentives or penalties to moderate the activity in the market, control prices, and/or protect consumers
Environmental (E)	Activities to have an impact on the defense of human life and protection of the planet
Social (S)	Customers' willingness to do something by investing on devices, changing consumption habits, participating in the utility companies' programs, etc.
Economics (F)	Those activities that have an impact on the economy of the consumer or the company
Information (I)	Includes efforts to integrate ICT in the distribution of energy via management, communications, and control

Using the definitions in Table 2, we identified the papers with the six categories using the first letter as, identifier, with the exception of economics changed to financial (F) to avoid repeating (E) which was already being used for environmental papers.

2.6. Taxonomy of paper's purpose

By analyzing the general purpose of the published paper, we use several categories to sum up the intention. The categories include: Strategic, Quality Management, Supply Chain Management, Environmental Issues, Service Design, Process Design, Scheduling, Planning, and Blackouts. Strategic papers will present clearly defined strategies or guidelines for future implementation; Quality Management focuses on optimization and performance; Supply Chain Management centers on the continuous supply of inputs; Environmental Issues papers are concerned with reducing environmental impacts ("greener" planet); Service and Process Designs are very similar because energy provision is a service, but the focus on the generation, transmission and distribution process will be considered as process design, while service design is related to the activities around the process to aid and enhance the customer perception; Scheduling is related to Planning in time; while the Planning classification is used for those activities as developed beforehand; and Blackout papers concentrate on avoiding power outages.

2.7. Smart Grid technologies

There are several technologies under the umbrella of Smart Grid Distribution (SGD); the most typical ones are Advanced Metering Infrastructure (AMI), Demand Response (DR), Distribution Automation (DA), Electric Vehicles (EV), Distributed Generation (DG), System Efficiency Improvement, Self-Healing, Cybersecurity, and Distributed Energy Storage.

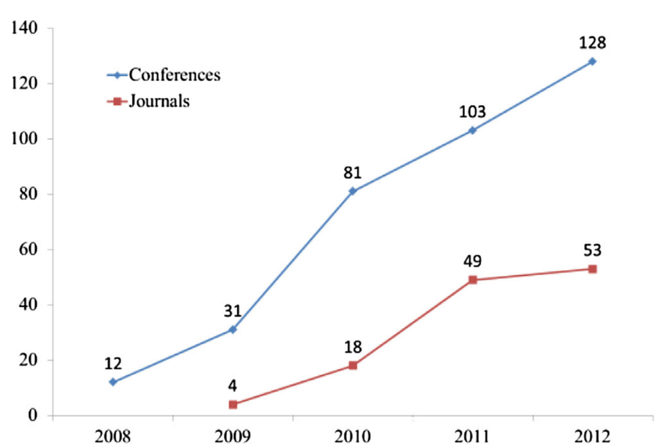


Fig. 1. Evolution of Smart Grid Distribution listed papers in ISI Web of Science.

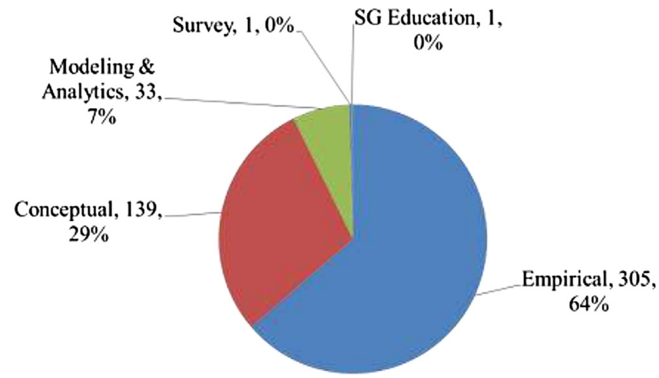


Fig. 2. Distribution of papers by research category.

2.8. Countries

The papers are also grouped by countries where they are originated, that is the home of the authors, the country referred in the paper, or the sponsor country of the publication.

3. Results

In the past five years there have been a number of important papers about Smart Grids focusing on distribution. This has not been the case in previous years. Now looking only at peer-reviewed published papers in the past five years, we are seeing a significant increase of attention to this area. For this particular research, we consulted ISI Web of Science to identify peer reviewed publications and found 479 published papers from a 5 year period from 2008 to 2012. These papers describe in detail many challenges and opportunities (e.g., Mamo et al., 2009; Chicco, 2010; Li et al., 2012): The business model for the integration of distributed generation, the charging process of electric vehicles, and the development of batteries for energy storage are some of the key topics in this research.

As we reviewed these papers, 355 of them were proceedings from conferences and society meetings, while 124 were journal papers (Fig. 1). The trend of journal and conference papers on this topic has been climbing steadily. As technologies mature, the number of journal published papers is expected to grow, so we are witnessing a maturing process for empirical research of Smart Grids distribution. There is an increase in conference papers in 2012 although there were a reduced number of conference papers compared to the prior year. The IEEE Smart Grid internet site lists 27 conferences in 2010, 44 in 2011, and only 40 for 2012. Even though there was a 10% reduction in the number of Smart Grid's organized conferences from 2011 to 2012, in ISI Web of Science the number of conference papers published was increased 24%. The number of articles increased from 103 to 128 in the period 2011–

Table 3
Row percentages of research classification versus focus.

	Applications	Theory building	Theory testing	Total
Empirical research	63	23	14	100
Conceptual & general	96	3	1	100
Modeling & analytical	58	30	12	100
SG education	100			100
Survey	100			100
Grand total	72	18	10	100

Table 4
Column percentages of research classification versus focus.

	Applications	Theory building	Theory testing	Total
Empirical research	55	84	89	64
Conceptual & general	39	5	2	29
Modeling & analytical	5	12	9	7
SG education	0			0
Survey	0			0
Grand total	100	100	100	100

2012, compared to the published 81 papers indexed in the year 2010.

3.1. Research category

Out of the 479 reviewed papers, a total of 305 fell into the empirical research category and the remaining were grouped as modeling, conceptual, survey or education-related published papers. Fig. 2 illustrates the distribution of papers in this classification where empirical research is the majority of all papers. This is expected because the different technologies under the umbrella of Smart Grid have practical applications and are being analyzed before they are implemented at macro levels. Because there are important differences among peer reviewed papers depending on the publication outlet, another important delineation is by use of their publication source. Some articles are published at conference proceedings or general meetings of engineering societies, while the others are published for academic and scientific journals.

However, many of the papers on SGD refer to simulations and pilot runs before implementation. These simulations and pilot runs prior to implementation could help prevent catastrophic events if the proposed models are not validated or even tested beforehand due to the size of the endeavor. Due to the fact that empirical studies are designed to focus on the effectiveness of proposals for new theories (e.g., algorithms to forecast electric vehicles charging process (Soares et al., 2012)), it is not surprising that 63.7% of the reviewed papers are empirical researches, with less than a third (29%) being conceptual, and only 6.9% focusing on developing new models.

When there is no information available due to cost, time, or other constraints, there is the possibility of conducting a survey to gather information and come up with conclusions. In this particular area, there was only one of these cases in the reviewed papers, where Pakonen et al. (2012) surveyed 18 Finnish distribution network operators (DNOs) about smart meters.

Tables 3 and 4 show that papers dealing with the application of SGD have the major share of published papers with a 72% contribution, followed by theory building in the modeling and analytics area. We are seeing more application papers of Smart Grid Distribution because this area is being optimized with the aid of

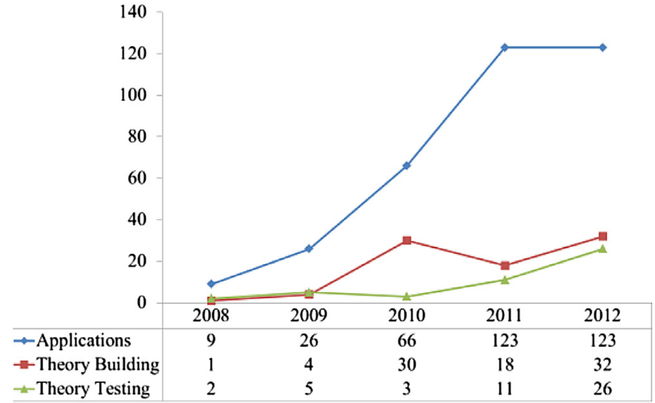


Fig. 4. Evolution of papers by research focus.

technologies already available and previously used for transmission (e.g., SCADA, D-SCADA) or in the areas of communication (e.g. wireless technologies). The empirical analysis is the largest share of the pie with 64%, followed by the conceptual papers with less than half of the empirical contribution. 96% of the conceptual papers are focused on practical applications.

3.2. Research focus

Fig. 3 shows that theory building is second in order with an 18% contribution, theory testing is third with only 10%, and application papers are identified as the major purpose of research, accounting for 72% of all analyzed papers.

Although there are 85 research papers focusing on theory building, the percentage is low compared to the overwhelming amount of the 347 application papers. Fig. 4 shows an increase of papers on theory building until 2010 when the trend reached the peak and proceeded to descend to almost half the prior level, but it picked up in the past year. Theory testing is consistently trending upwards while application papers are showing a positive trend, although the overall number of published articles in 2012 is the same as in 2011, it is much higher than 2010. Application papers focus on the practical implementation of technologies or ideas; therefore we are seeing a large number of application papers as practitioners are analyzing SG for implementation. Authors seem to be focusing on the process of implementing those practical applications around SG, based on field and lab results without proper theory supported, but with a strong pragmatic support.

We have noticed that research needs to be simulated under controlled conditions in order to be able to demonstrate the validity of the existing theories (e.g., Kurohane et al., 2010; Schneider et al., 2009). Researchers have set up field conditions in laboratories to conduct empirical research and evaluate the validity of the

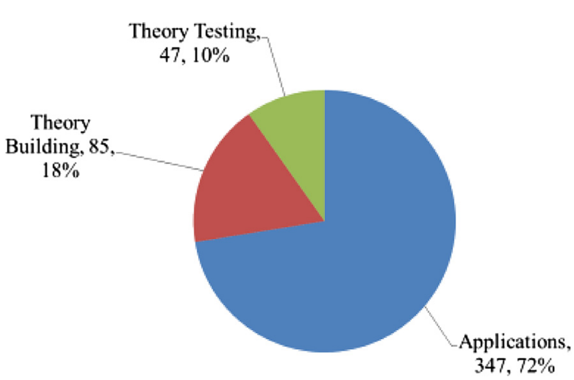


Fig. 3. Distribution of papers by research focus.

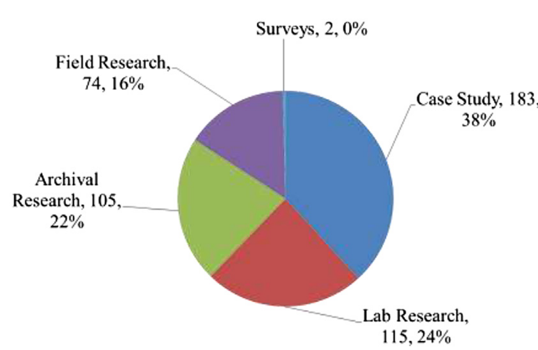


Fig. 5. Research by collection approach.

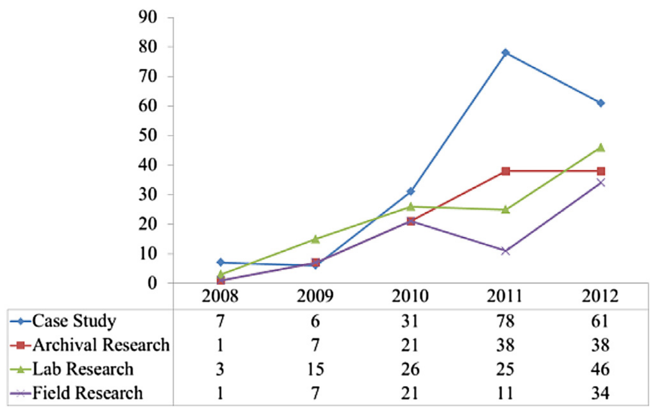


Fig. 6. Evolution of papers by data collection.

assumptions developed in the modeling process. For example, Teng et al. (2008) proposed a method to integrate distributed generation in the optimal capacitor planning process for effective and efficient operation proving it with an 11.4 kV feeder and five capacitor banks.

Regarding papers in the category of theory-building, authors develop new relationships, algorithms, or hypotheses to be confirmed in future research papers (Kleinberg et al., 2009). Although this literature survey is written from the social science perspective of Information and Decision Sciences, these papers are required to be conceptual and also contain empirical data to support the author(s)' hypotheses. For example, Tom Jauch (2009) proposes the coordination of Volt/VAR Management systems and equipment with an innovative adaptive technique to automatically adjust to changing loads, circuit changes, reverse power applications, and circuit switching and reconstruction. Sanz et al. (2009) also researched the introduction of electronic circuitry in the control of distribution to optimize the process. More recently, Dukpa and Venkatesh (2010) proposed a new model for distribution systems using fuzzy charts.

For theory-verification, the authors conduct tests to prove those hypotheses previously proposed in earlier research (Saleem et al., 2009; Vokony and Dan, 2009). For examples, Tenti et al. (2010) introduced the token ring approach to minimize the lost energy where a voltage control algorithm sets a progressive reduction of the voltage at the other end down to zero. Moreover, Li et al. (2008) examined the system configuration and control methods at the typical radial distribution network, where locations of distributed energy resources are affecting the grouping of the buses; therefore, they affect the reduced network structure and the appropriate range of the controller parameter.

3.3. Data collection

More than one third of the papers used case studies (38%); Archival research accounts for 22% of all papers; and laboratory research also accounts for 24% (Fig. 5). It is not surprising to see case studies as the majority of data collection efforts because SGD technologies are new and being fine-tuned in the field by

Table 5
Row percentages of data collection versus research focus.

	Applications	Theory building	Theory testing	Total
Case study	68	21	11	100
Archival research	95	3	2	100
Lab research	64	21	15	100
Field research	65	26	9	100
Surveys	50	50		100
Grand total	72	18	10	100

Table 6
Column percentages of data collection versus research focus.

	Applications	Theory building	Theory testing	Total
Case study	36	45	45	38
Archival research	29	4	4	22
Lab research	21	28	36	24
Field research	14	22	15	15
Surveys	0	1	0	0
Grand total	100	100	100	100

simulating and quantifying their impact to a specific selected case. Later this case is usually compared to others under different characteristics to validate the hypothesis and shape theories, that is, case studies represent a grounded reality. Fig. 6 shows that trends are positive in most cases although the 2012 results are higher in all cases compared to 2010. Field and lab research is at the highest level in the period of time analyzed, showing increased interest in collecting data at these locations as real life validations are needed.

Smart Grid Distribution (SGD) is a recent development, the focus in the past years was on energy transmission, and hence there are not many available sources for data collection. The SGD implementation process is in the early stages; therefore, we were only able to identify 183 case studies in the analyzed papers. Also, there were utilities and other companies' data collection efforts over short periods of time. The scope of case studies varies, ranging from radial distribution networks (Calderaro et al., 2011) to a proposed roadway microgrid to be deployed at Lincoln, Nebraska (Qiao et al., 2011), and a super-grid implementation at Sardinia, Italy (Purvins et al., 2011).

A field research study (15%) is similar to a case study, but it does not require many visits to the project being analyzed; only one or two visits would be enough for the data collection purpose. In other words, we only need a short period of time to gather the necessary information needed to make conclusions (Gong and Guzmán, 2012; Son and Chung, 2009). Some of the examples of field research studies include Carlson et al. (2009) review of the application of cutout type reclosers, and the work of Lindsey (2010) on the application of line sensors on the field.

The laboratory research study classification (24%) includes those simulations and experiments that are done under controlled conditions to discover new theories. Because of the newness of the Smart Grid technology, many of the published papers are about experimentation to simulate the possible conditions of circuitry, controls, and processes beforehand (Mohammed and Nayeem, 2010; Lo and Chen, 2011). Examples of laboratory studies include an evaluation of the accuracy for an islanding impedance detection system conducted by Fort et al. (2010) and the development of a

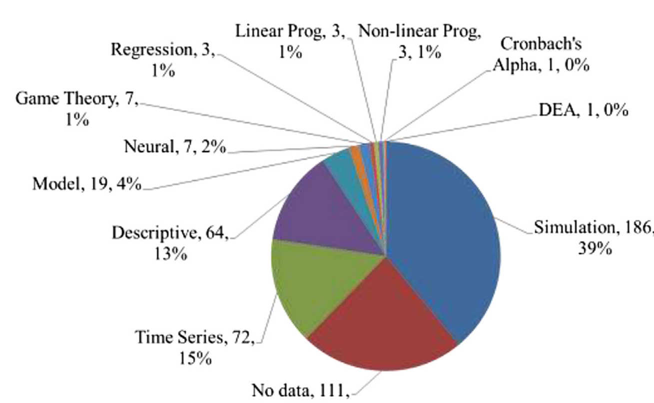
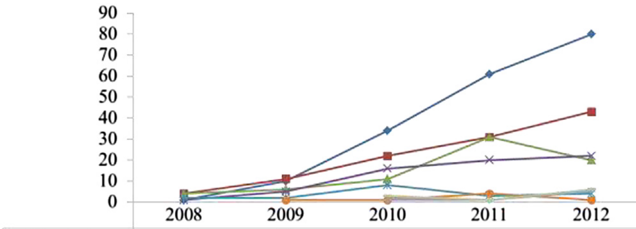


Fig. 7. Distribution of analysis techniques used.



	2008	2009	2010	2011	2012
Simulation	1	10	34	61	80
No data	4	11	22	31	43
Time series	4	6	11	31	20
Descriptive	1	5	16	20	22
Model	2	2	8	3	4
Neural net		1	1	4	1
Game Theory			1	1	5
Regression			2	1	
Others			3	1	6

Fig. 8. Evolution of papers by analysis techniques.

Smart Grid test bed using emerging technologies such as multi-agent systems written by Belkacemi et al. (2011).

Archival research (22%) refers to the use of secondary data obtained from sources other than direct data collection, for instance, the use of publicly available sources or from the companies' archives. This classification also includes general information or comments about Smart Grids that have been published and are available for reference. Because prior experiences on the Smart Grid technologies have not been documented, some papers only present comments about public information, while others use these sources of information for further researches (Liu, 2010; Bilgin and Güngör, 2011). Two examples of archival researches are the worldwide annual electrical power generation, reported from Siemens databases in the paper written by Bosselmann (2010), and the information about the McAlpine substation at Charlotte, NC as presented by Miller et al. (2012).

Tables 5 and 6 show that case studies is the data collection method used by the largest group of papers with 37% of all analyzed articles. Archival research is used mostly for applications (96%) because secondary data sources are used to represent the way things are in real life, not to build or test theory. For theory building, authors are writing 43% of the papers using case studies, followed by laboratory research with 32% of the papers. These numbers show that using implementations in the field and case studies represent 52% of all papers confirming the expected focus on practical applications for future implementation validation.

3.4. Data analysis

In this paper we discuss the analysis techniques mentioned most in the published literature. From all of the analyzed papers, 111 of them contain concepts but do not have any data analysis (e.g., Galli et al., 2011; Heydt, 2010). In most of these cases, the papers present challenges or opportunities detected by the authors and suggest possible alternatives but do not include data collection.

Table 7
Row percentages of data analysis versus research focus.

	Applications	Theory building	Theory testing	Total
Simulation	67	19	13	100
No data analysis	90	7	3	100
Time series	69	17	14	100
Descriptive	73	25	2	100
Model	74	16	11	100
Game theory	14	43	43	100
Neural networks	86	14		100
Linear programming		100		100
Regression	67		33	100
Non-linear programming	33	67		100
DEA	100			100
Crombach's alpha		100		100
Grand total	72	18	10	100

Table 8
Column percentages of data analysis versus research focus.

	Applications	Theory building	Theory testing	Total
Simulation	36	42	53	39
No data analysis	29	9	6	23
Time series	14	14	21	15
Descriptive	14	19	2	13
Model	4	4	4	4
Game theory	0	4	6	1
Neural networks	2	1		1
Linear programming		2		1
Regression	1		2	1
Non-linear programming	0	2		1
DEA	0			0
Crombach's alpha		1		0
Grand total	100	100	100	100

Simulation is the technique that is used the most in the literature, which is not surprising due to the newness of the Smart Grids in distribution and the scope of the implementation challenge (e.g., Gudi et al., 2012; Strasser et al., 2011). The next categories are time series (e.g., Acampora et al., 2011; Giri et al., 2012), descriptive statistics (e.g., Cheema et al., 2010; Ochoa et al., 2011), and mathematical modeling (e.g., Andreotti et al., 2012; Mohagheghi et al., 2009).

Smart Grid Distribution literature is evolving because the analysis technique that is mostly used is the simulation of what is going to happen when this technology is implemented. Simulation has the purpose of providing confidence for implementation, and a successful simulation shall help the scholars identify opportunities, and enhance the process before investing in a major implementation. Charging electric vehicles' batteries at certain times (Han et al., 2012), using wind power for distributed generation at homes (Wang et al., 2010), and strategies for demand response (Fuller et al., 2011) show the ample field of simulation approaches discussed there.

Although some of the published papers have no data analysis, we identified 11 techniques used in the analyzed papers. Some papers use more than one technique, but for analytical purposes we choose the one technique which is the focus of the paper.

Fig. 7 weights the relative importance of the techniques used when measured as a percentage of the total incidences (479). Simulation is the analysis technique used most frequently in the analyzed papers with a 39% contribution and continuing on an upward trend. It was expected to find such a large number of simulation papers because 53% of the case studies studying

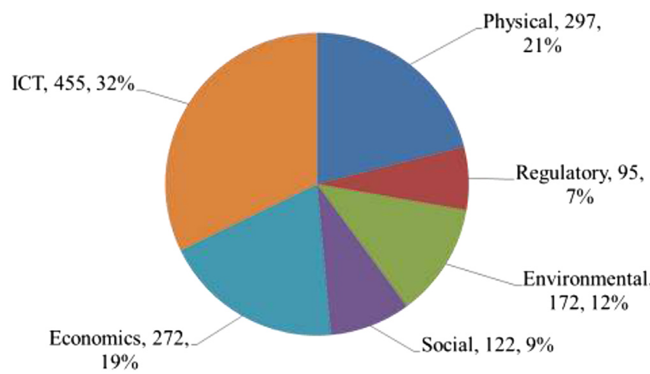
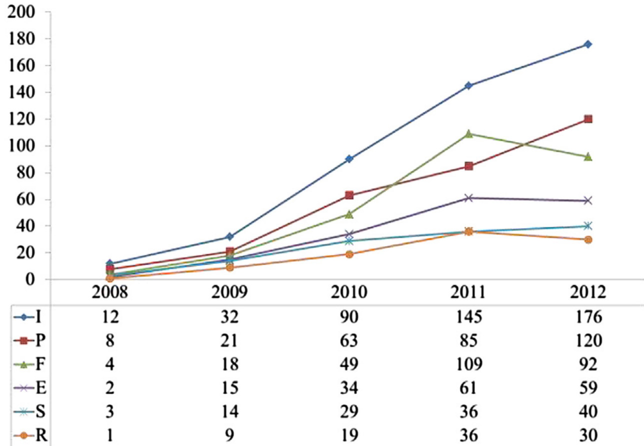


Fig. 9. Distribution of papers by category.



	2008	2009	2010	2011	2012
I	12	32	90	145	176
P	8	21	63	85	120
F	4	18	49	109	92
E	2	15	34	61	59
S	3	14	29	36	40
R	1	9	19	36	30

Fig. 10. Evolution of papers by discipline.

applications use simulation as the main tool and 17% of the simulations use the Monte Carlo method. Papers without data (23%) are also showing an upward trend as new techniques, opportunities and challenges are constantly discovered and discussed before conducting any data analysis (Fig. 8).

Tables 7 and 8 show that simulation is the technique used most often with 39% of the papers, mainly because the implementation of automation and new developments in this area in the field need prior validation to prevent catastrophic failures. Creation of algorithms to simulate consumer patterns was also used to build theory, while some other papers were simulating current or expected conditions to test already developed theory. Simulations represent a larger share for theory testing (53%), theory building (42%) and applications (36%).

3.5. Discipline

All disciplines' categories show upward trends with some of them presenting decreased numbers of papers in 2012, but they are higher than the 2010 numbers; therefore, there is a continuing positive trend to date (Figs. 9 and 10).

An important finding on this chart is the increase of economics related papers in the past three years focusing on efficiency because the energy generation and conversion process are of low efficiency (Dovì et al., 2009). This financial analysis peaked in 2011, even overtaking second place from physical interconnection papers. The papers show an increased awareness on the financial impact of SG with the appearance of a new business model based on the elements of distributed generation, electric vehicle and automated metering that are bringing a new customer behavior. The role of the

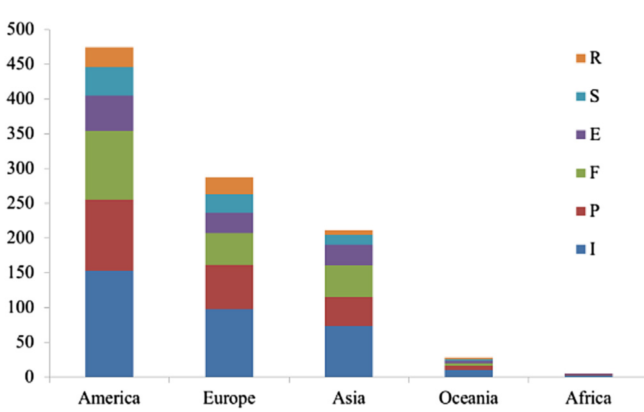


Fig. 11. Conference papers' topics by continent.

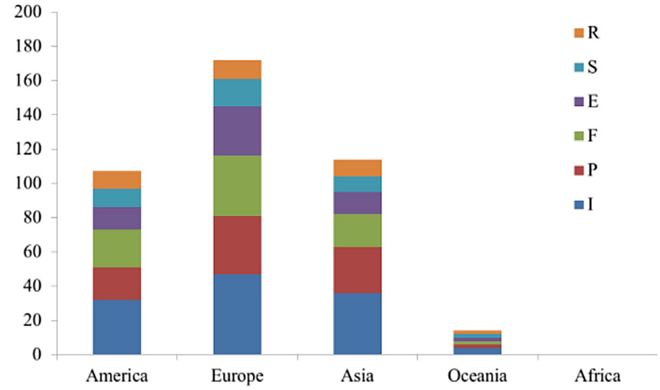
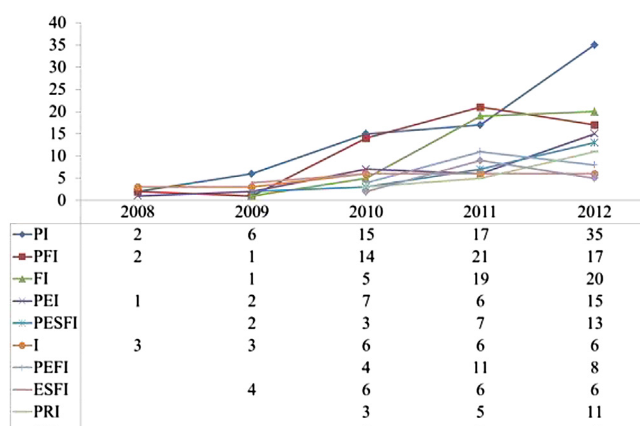


Fig. 12. Journal papers' topics by continent.

consumers and producers merging together as prosumers will bring added complexity to the commercial relationship between utilities and entities generating energy for self-consumption because they can also sell their excess capacity to the utility company. In the same way that communication and energy now are flowing bi-directionally instead of unilaterally, energy will also have different costs for the consumer and for the utility company, creating a new situation that had not been addressed before. This new model is an effect of the upward trend of economics papers related to SG because it will require participation of many stakeholders who were previously passively involved in this process. The social and cultural changes from this new business model have to be analyzed in detail before companies fail to involve consumers and implement SG with their strong opposition. On the other hand, if companies successfully involve the stakeholders in the enhancement of the generation, distribution and consumption processes, the result could bring forth a new quality of life for consumers in general (KPMG, 2013).

Figs. 11 and 12 show the distribution of Chicco's categories on the different continents separated by conference or journal papers. Journal publications are led by Europe in all categories while Asia is passing America in the Physical interconnection classification.

Fig. 13 shows that physical interconnections with ICT aid under the classification PI have the highest contribution (16%), followed closely by the same classification PI, which also includes financial analysis PFI (11%), and in third place is the financial ICT impact FI with a contribution of 9%. The SF column is completely blank, which means that the combinations of social involvement and financial results have not been used in conjunction, except when including ICT to the equation. In other words, ICT allows consumers to reduce



	2008	2009	2010	2011	2012
PI	2	6	15	17	35
PFI	2	1	14	21	17
FI		1	5	19	20
PEI	1	2	7	6	15
PESFI		2	3	7	13
I	3	3	6	6	6
PEFI			4	11	8
ESFI		4	6	6	6
PRI			3	5	11
EFI			2	9	5

Fig. 13. Evolution of papers by disciplines' mixes.

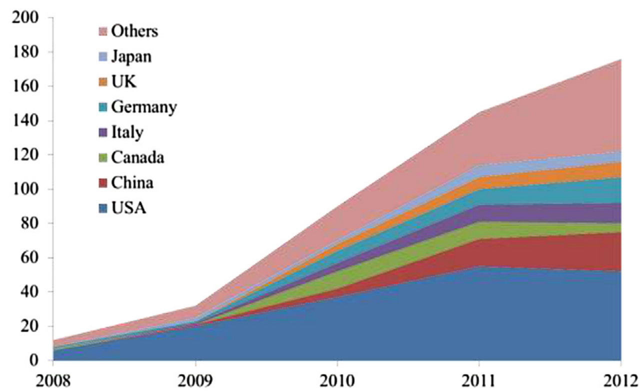


Fig. 14. ICT papers by year & country.

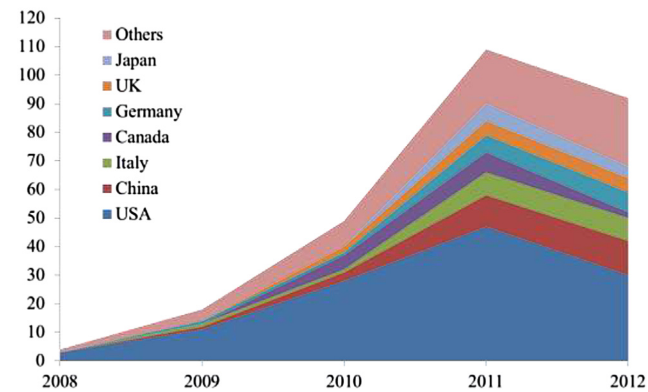


Fig. 16. Economics related papers by year and country.

costs, but without ICT it is not feasible. Adding ICT to social and financial columns, the results show the third highest column. Unexpectedly, the weakest line is the regulatory environmental, which was expected to be an important one due to the needs of renewable energy. The new clean technology should come along with political and their upcoming regulations to ensure sustainable energy development for all society (Klemeš et al., 2012). Something that is awakening for us is the importance of ICT in general SGD instead of regulatory efforts, as this shows that the Clean Tech Energy Revolution is heavily impacted by ICT, more than any other element to move towards a clean tech nation (Pernick and Wilder, 2007, 2012).

Fig. 14 also shows how most of the highest literature contributors are still growing with the exceptions of the PFI (physical-financial-ICT) classification which shows a small decrease in 2012, but still with a positive trend. Financial impact of ICT (FI) is growing. Papers show a move from physical interconnection analysis to pure ICT impact on the energy distribution process. The combination PFI (physical-financial-ICT) has migrated to either PI or FI, which is a sign of specialization of the papers as they address either the interconnection physical aspect or the financial one.

3.5.1. ICT related papers

Fig. 14 shows an upward trend in papers related to ICT even though Canada shows decreases beyond 2010's performance. USA leadership is holding strong compared to the rest of the countries in the world. The United Kingdom and China are showing growth although there were adverse conditions in the year 2012. There are 53 countries writing papers about ICT, and the top seven contribute with 70% of all literature (shown in Fig. 14). The United States is undoubtedly the largest contributor with 37% of all papers. In second place is China with a remote contribution of 9.8%, although we are seeing an increasing number of papers being written and more conferences being held in China regarding the use of ICT in Smart Grid Distribution. Data shows how DG & AMR are spread throughout the world but there is a strong leadership from the USA in regards to Volt/VAR and demand response (DR), we can infer that these two areas are technical in nature and the world is following what the USA is developing in these fields.

3.5.2. Physical interconnection related papers

Fig. 15 shows a continuous increase chart on physical interconnection related papers, with the UK being the leader on growth. Canada, Italy and Japan show decreases in physical connection papers while the USA's leadership is stabilizing after a drop in 2011. Although there are 47 countries contributing to this subject, the selected seven countries contribute with 75% of the papers. The United States is strong leader (38% of all papers), and China is a distant second place (9%). USA is publishing more than four times as much as the next highest publishing country, but the USA is writing about strategies for new developments, and China is working on improving those developments.

Fig. 15 show that papers on the physical interconnection of distributed generation has a higher number of publications around the world than in the USA. This is an area of opportunity for America because there is a strong European push towards this technology that has not being developed with the same emphasis here. Distribution automation and efficiency are important topics that have a strong push from the USA focusing on state of the art and ICT technologies to optimize processes and transferring decision making from people to automatic controls. The importance of DA and DG into the physical interconnection classification shows they are components of a new supply chain of SGD. They bring reductions to the fluctuation of energy while even reducing costs of utilities (Daim et al., 2012).

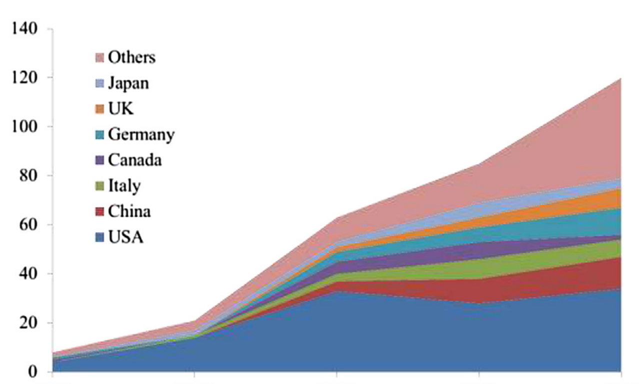


Fig. 15. Physical papers by year and country.

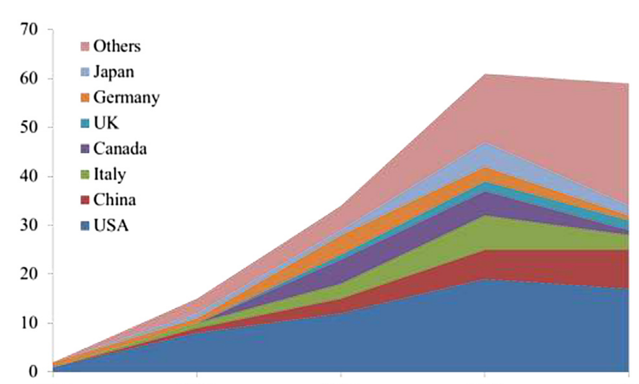


Fig. 17. Environmental papers by year and country.

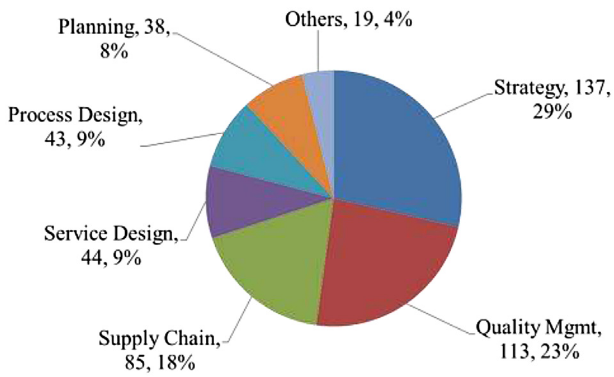


Fig. 18. Taxonomy of papers.

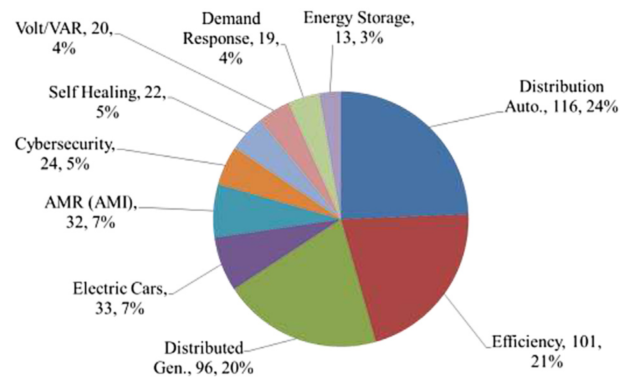


Fig. 20. Distribution of SGD technologies.

3.5.3. Economics related papers

Fig. 16 shows a deeper fall compared to the other types or layers. Economics however have to change to adapt to the real world and transform from being a part of the problem to an element of the solution (Spangenberg, 2010). The USA, Japan and Canada are showing important decreases in economics related papers. Even with that reduction, the USA is still the leader with China a distant second. The shown seven countries in the chart represent 79% of all literature, although there are 39 countries writing about this topic. The United States is stabilizing as the leader with a contribution of 44% of all papers. Second place is China with a remote contribution of 10%, that is, the USA is publishing more than 4 times as much as the next largest contributing country. It is important to emphasize that green initiatives have high initial capital requirements that have to be recovered soon (Chang et al., 2011).

Data shows that the main interest for economic analysis in the efficiency of the current practices along with the implementation of distributed generation, where a new business model will come out of this technology implementation. Third in importance is the topic of distribution automation. China is looking at DA before DG because of the national interest on automation. In China, homes' generation is not a priority under actual conditions. The cost of energy will soon become a major topic of discussion because DG is closely related to financing, so the implementation of self-generation will require contracts between stakeholders that were not involved before. The market suggests the system will soon move into a growth phase of technology diffusion towards a new economic model (Köhler et al., 2013).

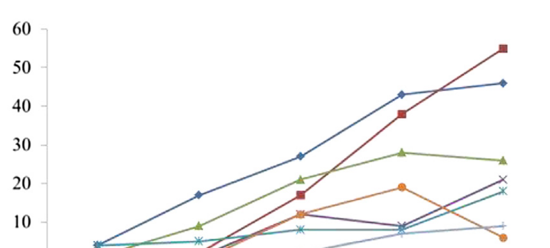
3.5.4. Environmental related papers

As shown in Fig. 17, Japan, Germany, Italy and Canada are showing important decreases on environmental related papers while the USA's leadership is stabilizing and China is quickly growing. Although there are thirty five countries that have written papers about environmental issues, the selected seven countries contribute 73% of the papers on this topic. The United States is stabilizing as the leader with a contribution of 33% of all papers. In second place is China with a remote contribution of 11%. According to the UN millennium development goal statistics in 2009 China was the largest polluter with a contribution of 7,687,114 thousand metric tons of CO_2 emission in the environment because most of their energy generation depends on coal, and 80% of CO_2 emission comes from coal (Feng and Yuexia, 2011). The USA with 5,299,563 tons of CO_2 emission is publishing more than three times as many papers as China. As expected, distributed generation is the technology more related to environmental protection, as it pertains to renewable cleaner energy and home generation to reduce and prevent contamination.

3.6. Taxonomy of purpose

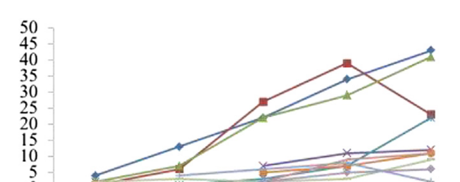
The results are presented in Fig. 18 and their trend in Fig. 19.

The three most important topics in the reviewed literature are: Strategy (29%), quality management (23%), and supply chain (18%). It is not surprising to see strategy as the leading classification because the alternatives for proper implementation are still being developed in some of the various technologies. The value in quality



	2008	2009	2010	2011	2012
Strategy	4	17	27	43	46
Quality Mgmt	1	2	17	38	55
Supply Chain	1	9	21	28	26
Service	1	1	12	9	21
Process	4	5	8	8	18
Planning	1	0	12	19	6
Others		1	2	7	9

Fig. 19. Evolution of papers by taxonomy.



	2008	2009	2010	2011	2012
Distribution Automation	4	13	22	34	43
Efficiency	1	6	27	39	23
Distributed Generation	2	7	22	29	41
AMR/AMI	2		7	11	12
Electric Vehicle		1	3	7	22
Cybersecurity	1		5	7	11
Volt/VAR		4	6	8	2
Self Healing			2	9	11
Demand Response	2	3	2	3	9
Energy Storage			2	5	6

Fig. 21. Evolution of papers by SGD technologies.

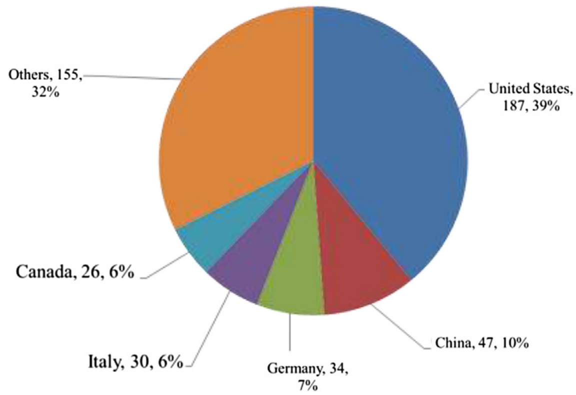


Fig. 22. Distribution of papers by country.

management is increasing due to the growing importance of using resources efficiently. The efforts to optimize energy distribution are aiming to save some of the typical loss of generated energy due to transportation losses (Görbe et al., 2012) which in the USA account for 5–12% (Lauby, 2010) and 15–20% in India (Sinha et al., 2011). The third important classification is the supply chain, which describes how energy users have changed from only being consumers to now becoming “prosumers” who generate and consume cleaner energy (Zhabelova and Vyatkin, 2012).

Fig. 19 shows how Quality Management has over taken strategy in 2012 on a number of papers, which confirms the increasing notion of a SG definition as a way to look for efficiency (Wissner, 2011). Strategy is still strong because some areas of SG have not been fully developed, such as electric vehicles. EVs bring new and expensive interactions including driving range and recharging time (Silvester et al., 2013) vehicle charging, which still needs to be

Table 9
Row percentages of conferences' SG category versus taxonomy of purpose.

Conferences	Strategy	Quality mgt.	Supply chain mgt.	Service design	Process design	Planning	Blackouts	Green issues	Scheduling	Total
Distribution automation	37	28	5	8	11	9			1	100
Distributed generation	18	13	59		3	2	1	3	1	100
Efficiency	39	30	2	9	4	15		1		100
Automated meters	19	34		31	9	6			6	100
Electric vehicles	9	21	24	24	9	6			6	100
Cybersecurity	38	38		8	4	13				100
Self-healing	27	13	9	14	5		32			100
Vol/VAR	20	25	10	5	35	5				100
Demand response	42	5		5	26	11	5		5	100
Energy storage	15	8	38	8	15	8	8			100
User friendly	33	33			33					100
Grand total	29	24	18	9	9	8	2	1	1	100

Table 10
Column percentages of Conferences' SG category versus taxonomy of purpose.

Conferences	Strategy	Quality mgt.	Supply chain mgt.	Service design	Process design	Planning	Blackouts	Green issues	Scheduling	Total
Distribution automation	31	29	7	20	30	29			20	24
Distributed generation	13	12	71		7	5	10	75	20	21
Efficiency	27	26	2	20	9	37		25		20
Automated meter reading	4	10		23	7	5				7
Electric vehicles	2	6	9	18	7	5			40	7
Cybersecurity	7	8		5	2	8				5
Self-healing	4	3	2	7	2		70			5
Vol/VAR	3	4	2	2	16	3				4
Demand response	6	1		3	11	3	20		25	4
Energy storage	1	1	6	2	5	3	10			3
User friendly	1	1			2					1
Grand total	100	100	100	100	100	100	100	100	100	100

Table 11
Row percentages of journals' SG category versus taxonomy of purpose.

Journals	Strategy	Quality mgt.	Supply chain mgt.	Service design	Process design	Planning	Blackouts	Green issues	Total
Distributed generation	11	18	64		4	4			100
Efficiency	43	29		11	4	11		4	100
Distribution automation	32	27	9	14	9	9			100
Electric vehicles		9	18	45	18	9			100
Cybersecurity	44	33		11		11			100
Vol/VAR	29	43			29				100
Self-healing	17	33		17			33		100
Automated meter reading		20		40	40				100
Demand response	50	25			25				100
Energy storage			100						100
User friendly					100				100
Grand total	25	24	20	12	10	6	2	1	100

Table 12
Column Percentages of Journals' SG category versus taxonomy of purpose.

Journals	Strategy	Quality mgt.	Supply chain mgt.	Service design	Process design	Planning	Blackouts	Green issues	Total
Distributed generation	10	17	72		8	13			23
Efficiency	39	27		20	8	38		100	23
Distribution automation	23	20	8	20	17	25			18
Electric vehicles		3	8	33	17	13			9
Cybersecurity	13	10		7		13			7
Vol/VAR	6	10			17				6
Self-healing	3	7		7			100		5
Automated meter reading		3		13	17				4
Demand response	6	3			8				3
Energy storage			12						2
User friendly					8				1
Grand total	100	100	100	100	100	100	100	100	100

considered before massive implementation can be accomplished (Shuaib et al., 2012).

3.7. Smart Grid category

Looking at the 479 papers, we classified them into 11 categories and Figs. 20 and 21 show the distribution and trends. Only efficiency and Volt/VAR analysis show a reduction of papers lower than the level from 2010, all others are showing positive trends as these techniques are becoming more popular and important to our society (Fig. 22).

The three most important technologies based on the number of papers are: Distribution Automation (24%), System Efficiency (21%), and Distributed Generation (20%). These three areas show the current trends of SGD. There is an important effort to automate the distribution process with the use of ICT devices and state of the art devices. The automation process will allow quicker and better responses on energy consumption that will result in efficient use of cleaner energy, thus reducing the negative impact on environment (Koroneos and Nanaki, 2012). Additional methods to make energy distribution more efficient vary from replacing transformers with new more efficient ones (Grigoras et al., 2010) to the identification of the most probable configuration of the wind to locate mills (Chertkov et al., 2011). The third technology, Distributed Generation, is a growing area, mostly in Europe, where there is a major effort to move to self-generation using renewable resources that could reduce 2–4% of the energy losses in Europe (Lasseter, 2011).

Tables 9–12 show the relationship between the Smart Grid technology and the focus of the conference and journal papers. Tables 9 and 10 show the relationship for conference publications only. As shown in Table 9, strategy is the most published paper focus followed closely by quality management and supply chain. Strategies for distribution automation (31%) and efficiency (27%) represent 58% of all published strategies because of the new definition of Smart Grid as the automation of distribution with the inclusion of ICT for optimized results.

The focus of conference papers for distributed generation is most importantly related to supply chain (59%), as this concept of home generation of own cleaner energy is growing rapidly in some countries. Planning papers are focusing on achieving efficiency (37%) and distribution automation (29%), but the approach is beyond strategy and moving into the "how to" mode. The process design papers focus mainly in distribution automation (30%), Volt/VAR control (16%) and demand response (11%) because these are the practical papers; "the nuts and bolts" of the Smart Grid implementation.

Tables 11 and 12 show the relationship between the Smart Grid technology and the focus of journal papers. As shown in Table 11, the order from conference paper's contribution remains the same for journals because strategy and quality are the most published paper focuses here, which is followed closely by supply chain. Strategies at journals changed the order between distribution automation (23%) and efficiency (39%) and they are 62% of all published strategies. Quality related paper focus mostly on efficiency (27%) and distribution automation (20%). The focus of journal papers for distributed generation is most importantly related to supply chain (64%). Planning papers are focused on achieving efficiency (38%) and distribution automation (25%). Service design papers focus mainly on electric vehicles (33%), distribution automation (20%), efficiency (20%), and advanced metering (13%). Journal and conference papers show technologies reaching maturity as they emphasize strategy, although journals are paying more even attention to strategies than quality management and supply chain management.

3.8. Originating country

Almost half of the papers are from the USA which generated 39% of all literature, followed by China with 10%, Germany with 7%, and Italy and Canada with 6% respectively.

Fig. 23 shows the continuous increase of papers coming from other countries not listed in the top five; the diverse composition of this classification shows a worldwide interest in this area that the USA is leading, while other countries are making smaller contributions. Something to notice is the important growth of literature from other countries. Even though the top five represent 68% of all papers analyzed, the number of other countries is increasing as there is a worldwide attention on this subject. Some countries are specializing in certain technologies. For instance, Portuguese authors are writing more papers about electric vehicles than most countries with focus on particle swarm for vehicle to grid

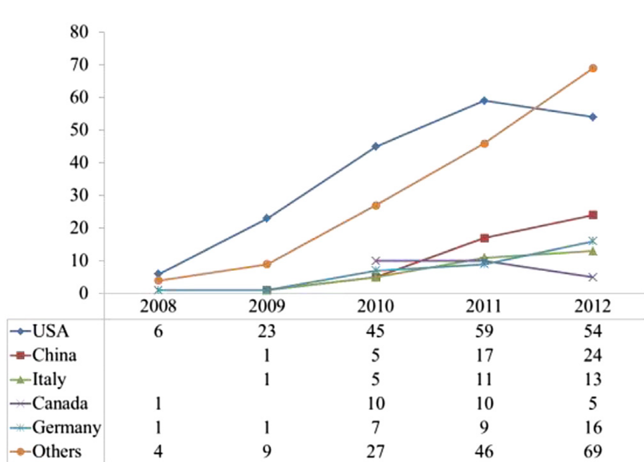


Fig. 23. Evolution of papers by country and time.

Table 13
Row percentages of originating country versus taxonomy of purpose.

	Strategy	Quality mgt.	Supply chain mgt.	Process design	Planning	Service design	Blackouts	Green issues	Scheduling	Total
USA	31	20	17	11	10	7	2	1	1	100
China	26	32	11	2	13	13		4		100
Germany	24	35	9	6	9	12	6			100
Italy	30	30	20	3	3	12	3			100
Canada	19	19	23	12	8	15			4	100
Japan	29	12	41			12			6	100
UK	15	35	15	15	10	5				100
Australia	17	17	17	17	8	25				100
Korea	43	29	21			7				100
India	33	33	11		11	11				100
Others	31	19	20	14	11		2	1	1	100
Grand total	29	24	18	9	9	8	2	1	1	100

Table 14
Column percentages of originating country versus taxonomy of purpose.

	Strategy	Quality mgt.	Supply chain	Process design	Planning	Service design	Blackouts	Green issues	Scheduling	Total
USA	42	34	38	45	42	37	40	40	25	39
China	9	13	6	2	14	16		40		10
Germany	6	11	4	5	7	11	20			7
Italy	7	8	7	2	2	8	10			6
Canada	4	4	7	7	5	11			25	5
Japan	4	2	8			5			25	4
UK	2	6	4	7	5	3	10			4
Australia	1	2	2	5	2	8				3
Korea	4	4	4			3				3
India	2	3	1		2	3				2
Others	19	14	20	27	21		20	20	25	18
Grand total	100	100	100	100	100	100	100	100	100	100

Table 15
Row percentages of originating country versus SG category.

	DA	DG	Eff.	Electric vehicle	AMR/AMI	Cyber Security	Self-healing	Vol/VAR	DR	Energy storage	User friendly	Total
USA	23	21	17	6	6	6	6	5	4	4	1	100
China	34	23	19	4	9	9			2			100
Germany	15	3	41	9	9	9	9		3	3		100
Italy	27	30	13	10	3		10	7				100
Canada	19	23	12	12	8	4	8	8	8			100
UK	25	20	10	5	10	10		5	5	10		100
Japan	18	41	6		6	12	6		6	6		100
Australia	8	8	33	17	17		8	8				100
Korea	14	36	29			7	7		7			100
Portugal	10	20	20	40					10			100
India	44	11	22		11		11					100
Others	31	19	26	4	7			5	4	3	1	100
Total	24	21	20	7	7	5	5	4	4	3	1	100

Table 16
Column percentages of originating country versus SG category.

	DA	DG	Eff.	Electric vehicles	AMR AMI	Cyber Security	Self-healing	Vol/VAR	DR	Energy storage	User friendly	Total
USA	37	40	33	36	34	46	50	50	42	54	67	39
China	14	11	9	6	13	17			5			10
Germany	4	1	15	9	9	13	14		5	8		7
Italy	7	9	4	9	3		14	10				6
Canada	4	6	3	9	6	4	9	10	11			5
UK	4	4	2	3	6	8		5	5	15		4
Japan	3	7	1		3	8	5		5	8		4
Australia	1	1	4	6	6		5	5				3
Korea	2	5	4			4	5		5			3
Portugal	1	2	2	12					5			2
India	3	1	2		3		5					2
Others	20	14	20	9	16			20	16	15	33	15
Total	100	100	100	100	100	100	100	100	100	100	100	100

scheduling (e.g. Soares et al., 2012; Sousa et al., 2012). It is interesting to note as many as 53 countries have participated in the generation of literature. We see a technological wave throughout the world to meet the upcoming challenges and to be prepared for implementation. Environmental protection and cleaner energy sustainability are two of the many subjects addressed globally and their importance is critical for SG.

Tables 13 and 14 show the relationship between the focus of the papers and the country where the document was generated. The USA is the leader in strategy, quality, and supply chain. As shown in Table 13, strategy is the most published paper focus with 29%, and followed closely by quality (24%) and supply chain (18%). Although the USA is the leader in all categories, it is important to emphasize the contribution of China on planning (14%), quality (13%) and service (16%), while Canada has an important 11% of contribution to the service design related papers.

Tables 15 and 16 show the relationship between the SG technologies and the countries publishing articles. The leadership of the USA in the Volt/VAR (50%), Demand Response (42%), and energy storage (54%) shows the interest on developing these technologies while the rest of the world is following the example. Germany is writing more papers on efficiency (41%) than the rest of the countries, which shows the interest in migrating to efficient ways of generating energy, as they have a plan to go green without nuclear power. The UK follows the USA in energy storage with 15% of all papers on this subject. In general, we can see that USA is leading over all SGD technologies with China as a distant second. Based on this analysis we conclude that the USA has the leadership of most clean energy efforts at this time.

4. Conclusions

Our conclusions are based on the analysis of 479 peer reviewed papers listed at ISI Web of Science in the period from 2008 to 2012 with the Smart Grid and distribution topics. Overall, we observed that there is an increasing trend in the number of published papers over the past five years. Over 60% of the articles were related to empirical research, which is not surprising because Smart Grid Distribution efforts require a high level of analysis before its implementation in the field.

The increasing trends in papers suggests that Smart Grid is not a fad because the trend has been upwards for over three years, so even though there was a decrease on conferences in 2012 due to the economic situation around the world, journals and conference papers are still increasing. The planned number of conferences for 2013 is higher, so the upward trend is expected to continue in 2013.

Journal papers are clearly following the trend of the number of conference papers, so if these publications continue growing, we are expecting journals to continue publishing about Smart Grids.

334 of the papers related to Smart Grid Distribution are published by IEEE and they represent 70% of the total papers analyzed; therefore it was expected to have more empirical papers than conceptual ones because this is mostly an engineering area of study.

The focus on proving the applications on the field can also be noticed as more case studies are used than lab or archival research studies because SGD can hardly be simulated under controlled conditions, so field work is necessary.

We discovered that the choice of the method of analysis is simulation as it appears in 39% of all analyzed papers. As there are so many expectations in the field of Smart Grid Distribution, simulating the new technologies and theories is an important tool for success.

Strategy, quality, and supply chain papers are topics with positive trending, and they alone represent 71% of all papers. The quality focus of the papers is based on a popular new definition of Smart Grid as an effective way of distributing energy, so efficiency can be related to achieving quality in the technologies. This approach is supported worldwide.

The relationship between Smart Grid and ICT is very strong, as one of the modern definitions of Smart Grids is the use of information and communication technologies to transmit and distribute energy; therefore it is not surprising that 95% of all analyzed papers refer to ICT in some way.

The top category of the SGD technologies is distribution automation, considering the enhancements to eliminate or reduce dependency on operators with the use of computer and information and communication systems. In second place, we have system efficiency effort, as authors are clearly stating that by improving quality of the current process, we can overcome the need for more generation, as distribution losses are reduced or even eliminated.

The USA is the clear leader in all areas showing the important role that it is taking into the third millennium leading all global efforts toward clean tech energy. China is a distant second in most categories and we do not foresee them taking this leadership anytime in the very near future.

It is interesting to see how the strategic papers are being replaced by quality assurance ones because strategic is prevalent among distribution automation, efficiency, self-healing, and demand response because these technologies are being strategized towards implementation. Distributed generation and electric vehicles papers' focus is on supply chain as more efforts are taken to new forms of energy generation, and in general a new business model where stakeholders will be generating and consuming energy.

The next step from this research should be focused on identifying applications that are being implemented and compare them to the simulation numbers to determine if these actions are effective and if so, recommend them for future technologies validation prior to implementation.

Another recommended research is the analysis of Smart Grid Transmission papers to compare the results and determine if they are running in parallel or if transmission was the early focus that has now moved to distribution.

A new business model can be developed in this research. The authors are now developing a model that describes the elements, sequence and relationships for SGD. The model is a business model in nature that includes the technical aspects of these technologies to provide cleaner energy to consumers throughout the world.

Information and details about the 479 papers used for this survey are available by contacting the writer.

References

Acampora, G., Loia, V., Vitiello, A., 2011. Exploiting timed automata based fuzzy controllers for voltage regulation in Smart Grids. In: IEEE International Conference on Fuzzy Systems (FUZZ-IEEE 2011). IEEE, pp. 223–230. http://dx.doi.org/10.1109/FUZZY.2011.6007617.

Andreotti, A., Carpinelli, G., Mottola, F., Proto, D., 2012. A review of single-objective optimization models for plug-in vehicles operation in Smart Grids part I: theoretical aspects. In: IEEE Power & Energ. Soc. Gen. Meet, pp. 1–8. http://dx.doi.org/10.1109/PESGM.2012.6345381.

Battaglini, A., Lilliestam, J., Haas, A., Patt, A., 2009. Development of SuperSmart Grids for a more efficient utilisation of electricity from renewable sources. J. Cleaner Prod. 17 (10), 911–918. http://dx.doi.org/10.1016/j.jclepro.2009.02.006.

Belkacemi, R., Feliachi, A., Choudhry, M.A., Saymansky, J.E., 2011. Multi-agent systems hardware development and deployment for Smart Grid control applications. In: IEEE Power & Energ. Soc. Gen. Meet, pp. 1–8. http://dx.doi.org/10.1109/PES.2011.6039822.

Bilgin, B.E., Güngör, V.C., 2011. On the performance of multi-channel wireless sensor networks in smart grid environments. In: 20th International Conference on Computer Communications and Networks (ICCCN), pp. 1–6. http://dx.doi.org/10.1109/ICCCN.2011.6006029.

Bosselmann, T., 2010. A paradigm change in energy: the new electricity Age. In: Santos, J.L., Culshaw, B., López-Higuera, J.M., MacPherson, W.N. (Eds.), Fourth

European Workshop on Optical Fibre Sensors, vol. 7653, pp. 765302–765302–4. http://dx.doi.org/10.1117/12.867071.
Calderaro, V., Hadjicostis, C.N., Piccolo, A., Siano, P., 2011. Failure identification in Smart Grids based on Petri Net modeling. IEEE Trans. Ind. Electron 58 (10), 4613–4623. http://dx.doi.org/10.1109/TIE.2011.2109335.
Carlson, N., Asgeirsson, H., Lascu, R., Benaglio, J., Ennis, M.G., 2009. Application of cutout type reclosers on distribution lateral circuits — a field study. In: Power & Energ. Soc. Gen. Meet. IEEE, pp. 1–4. http://dx.doi.org/10.1109/PES.2009.5275172.
Chang, N.-B., Rivera, B.J., Wanielista, M.P., 2011. Optimal design for water conservation and energy savings using green roofs in a green building under mixed uncertainties. J. Clean. Prod. 19 (11), 1180–1188. http://dx.doi.org/10.1016/j.jclepro.2011.02.008.
Cheema, J., Clark, A., Kilimnik, J., Pavlovski, C., Redman, D., Vu, M., 2010. Intelligent rating systems for the Smart Grid. In: Proceedings of the World Congress on Engineering and Computer Science 2010 Vol. II. WCECS 2010, October 20–22, 2010, San Francisco, USA.
Chertkov, M., Stepanov, M., Pan, F., Baldick, R., 2011. Exact and efficient algorithm to discover extreme stochastic events in wind generation over transmission Power Grids. In: IEEE Conference on Decision and Control and European Control Conference, pp. 2174–2180. http://dx.doi.org/10.1109/CDC.2011.6160669. IEEE.
Chicco, G., 2010. Challenges for smart distribution systems: data representation and optimization objectives. In: 12th International Conference on Optimization of Electrical and Electronic Equipment, pp. 1236–1244.
Daim, T.U., Amer, M., Brenden, R., 2012. Technology Roadmapping for wind energy: case of the Pacific Northwest. J. Clean. Prod. 20 (1), 27–37. http://dx.doi.org/10.1016/j.jclepro.2011.07.025.
Dovì, V.G., Friedler, F., Huisingh, D., Klemeš, J.J., 2009. Cleaner energy for sustainable future. J. Clean. Prod. 17 (10), 889–895. http://dx.doi.org/10.1016/j.jclepro.2009.02.001.
Dukpa, A., Venkatesh, B., 2010. Smart reconfiguration using fuzzy graphs. In: IEEE Power & Energ. Soc. Gen. Meet, pp. 1–5. http://dx.doi.org/10.1109/PES.2010.5589534.
Fadlullah, Z., Kato, N., Lu, R., Shen, X., Nozaki, Y., 2012. Toward secure targeted broadcast in Smart Grid. IEEE Commun. Mag 50 (5), 150–156. http://dx.doi.org/10.1109/MCOM.2012.6194396.
Feng, Z., Yuexia, Z., 2011. Study on smart grid communications system based on new generation wireless technology. In: International Conference on Electronics, Communications and Control (ICECC), pp. 1673–1678. http://dx.doi.org/10.1109/ICECC.2011.6066343. IEEE.
Fort, A., Mugnaini, M., Rocchi, S., Vignoli, V., Simoni, E., 2010. Accuracy evaluation of a grid islanding impedance detection system. In: IEEE International Instrumentation and Measurement Technology Conference, pp. 2–5.
Fuller, J.C., Schneider, K.P., Chassin, D., 2011. Analysis of residential demand response and double-auction markets. In: IEEE Power & Energ. Soc. Gen. Meet, pp. 1–7. http://dx.doi.org/10.1109/PES.2011.6039827.
Galli, S., Scaglione, A., Wang, Z., 2011. For the Grid and through the grid: the role of power line communications in the Smart Grid. Proc. IEEE 99 (6), 998–1027. http://dx.doi.org/10.1109/JPROC.2011.2109670.
Giri, J., Parashar, M., Trehern, J., Madani, V., 2012. The situation room. IEEE Power Energ. Mag. (october), 24–39.
Gong, Y., Guzmán, A., 2012. Advanced fault location solution for distribution systems using IED information and the Detailed feeder model. In: Power and Energy Engineering Conference (APPEEC), 2012 Asia-Pacific.
Görbe, P., Magyar, A., Hangos, K.M., 2012. Reduction of power losses with smart grids fueled with renewable sources and applying EV batteries. J. Cleaner. Prod. 34, 125–137. http://dx.doi.org/10.1016/j.jclepro.2011.12.021.
Grigoras, G., Cartina, G., Bobric, E.-C., Rotaru, F., 2010. Evaluation of the performances of efficient transformers in distribution networks by fuzzy techniques. In: 12th International Conference on Optimization of Electrical and Electronic Equipment, pp. 1281–1284. http://dx.doi.org/10.1109/OPTIM.2010.5510405. IEEE.
Gudi, N., Wang, L., Devabhaktuni, V., 2012. A demand side management based simulation platform incorporating heuristic optimization for management of household appliances. Int. J. Electr. Power Energ. Syst. 43 (1), 185–193. http://dx.doi.org/10.1016/j.ijepes.2012.05.023.
Güngör, V.C., Sahin, D., Kocak, T., Ergüt, S., Buccella, C., Cecati, C., Hancke, G.P., 2011. Smart grid technologies: communication technologies and Standards. IEEE Trans. Ind. Informa. 7 (4), 529–539.
Gupta, S., Verma, R., Vitorino, L., 2006. Empirical research published in production and operations management (1992–2005): trends and future research directions. Prod. Oper. Manag. POMS 15 (3), 432–448. ISSN:1059-1478 06 1503 432.
Han, P., Wang, J., Han, Y., Zhao, Q., 2012. A novel coordinative resident electric vehicle charging mechanism. In: Asia-Pacific Power and Energy Engineering Conference, pp. 0–3.
Heydt, G.T., 2010. Future renewable electrical energy delivery and assessment of FREEDM systems. In: IEEE Power & Energ. Soc. Gen. Meet, pp. 1–4. http://dx.doi.org/10.1109/PES.2010.5589348.
Jauch, E.T., 2009. Volt/var management — an essential "SMART" function. In: IEEE/PES Power Systems Conference and Exposition, pp. 658–664.
Kleinberg, M., Miu, K., Chiang, H.-D., 2009. Service restoration of power distribution systems incorporating load curtailment. In: IEEE International Symposium on Circuits and Systems. IEEE, pp. 1709–1712. http://dx.doi.org/10.1109/ISCAS.2009.5118104.
Klemeš, J.J., Varbanov, P.S., Huisingh, D., 2012. Recent cleaner production advances in process monitoring and optimisation. J. Clean. Prod. 34, 1–8. http://dx.doi.org/10.1016/j.jclepro.2012.04.026.
Köhler, J., Schade, W., Leduc, G., Wiesenthal, T., Schade, B., Espinoza, L.T., 2013. Leaving fossil fuels behind? an innovation system analysis of low carbon cars. J. Clean. Prod. 48, 176–186.
Koroneos, C.J., Nanaki, E., 2012. Life cycle environmental impact assessment of a solar water heater. J. Clean. Prod. 37, 154–161. http://dx.doi.org/10.1016/j.jclepro.2012.07.001.
KPMG Global Energy Institute, 2013. A New Energy World, New Business Models. KPMG Global, Industry: Energy & Natural Resources, Power & Utilities. Date: 1/29/2013 http://www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/Pages/new-energy-world-new-business-models.aspx (accessed 28.08.13.).
Kurohane, K., Senjyu, T., Uehara, A., Yona, A., Funabashi, T., Kim, C.-H., 2010. A hybrid smart AC/DC power system. In: 5th IEEE Conference on Industrial Electronics and Applications. Ieee, pp. 764–769. http://dx.doi.org/10.1109/ICIEA.2010.5516936.
Lasseter, R.H., 2011. Smart Distribution: Coupled Microgrids. In: Proceedings of the IEEE, vol. 99 (6), pp. 1074–1082. http://dx.doi.org/10.1109/JPROC.2011.2114630.
Lauby, M.G., 2010. Reliability considerations for application of Smart Grid technologies. In: IEEE Power & Energ. Soc. Gen. Meet, pp. 1–4. http://dx.doi.org/10.1109/PES.2010.5589411.
Li, HaoYang, Ge, S., Liu, H., 2012. Analysis of the effect of distributed generation on power grid. In: Asia-Pacific Power and Energy Engineering Conference. IEEE, pp. 1–5. http://dx.doi.org/10.1109/APPEEC.2012.6307248.
Li, Huijuan, Li, F., Xu, Y., Rizy, D.T., Kueck, J.D., 2008. Interaction of multiple distributed energy resources in voltage regulation. In: IEEE Power & Energ. Soc. Gen. Meet, pp. 1–6. http://dx.doi.org/10.1109/PES.2008.4596142, 1-11.
Lindsey, K.E., 2010. Practical aspects of using line sensors in the field. In: IEEE Power & Energ. Soc. Gen. Meet. IEEE, pp. 1–4. http://dx.doi.org/10.1109/PES.2010.5589557.
Liu, X., 2010. Combined heat and power dispatch with wind power: a Stochastic model and solutions. In: IEEE Power & Energ. Soc. Gen. Meet, pp. 1–6. http://dx.doi.org/10.1109/PES.2010.5589287.
Lo, C., Ansari, N., 2012. In: The progressive smart grid system from both power and communications aspects. IEEE Communications Surveys & Tutorials, vol. 14 (3), pp. 799–821.
Lo, W., Chen, S., 2011. Advanced metering the signal activity of combined signal in sparse data condition. In: IEEE International Instrumentation and Measurement Technology Conference, pp. 0–4.
Mamo, X., Mallet, S., Coste, T., Grenard, S., 2009. Distribution automation: the cornerstone for Smart Grid development strategy. In: Power & Energ. Soc. Gen. Meet, pp. 1–6. http://dx.doi.org/10.1109/PES.2009.5275540.
Miller, M.T., Johns, M.B., Sortomme, E., Venkata, S.S., 2012. Advanced integration of distributed energy resources. In: IEEE Power & Energ. Soc. Gen. Meet. IEEE, pp. 1–2. http://dx.doi.org/10.1109/PESGM.2012.6345573.
Mohagheghi, S., Mousavi, M., Stoupis, J., Wang, Z., 2009. Modeling distribution automation system components using IEC 61850. In: IEEE Power & Energ. Soc. Gen. Meet. IEEE, pp. 1–6. http://dx.doi.org/10.1109/PES.2009.5275841.
Mohammed, O.A., Nayeem, M.A., 2010. A laboratory based microgrid and distributed generation infrastructure for studying connectivity issues to operational power systems. In: IEEE Power & Energ. Soc. Gen. Meet, pp. 1–6. http://dx.doi.org/10.1109/PES.2010.5589693.
Mukhopadhyay, S., Soonee, S.K., Joshi, R., Rajput, A.K., 2012. On the progress of renewable energy integration into Smart Grids in India. In: IEEE Power & Energ. Soc. Gen. Meet, pp. 0–5. http://dx.doi.org/10.1109/PESGM.2012.6344933.
Najjar, M.B., Ghoulam, E., Fares, H., 2012. Mini renewable hybrid distributed power plants for Lebanon. Energ. Procedia 18, 612–621. http://dx.doi.org/10.1016/j.egypro.2012.05.074.
Ochoa, L.F., Keane, A., Harrison, G.P., 2011. Minimizing the reactive support for distributed generation: enhanced passive operation and smart distribution networks. IEEE Trans. Power Syst. 26 (4), 2134–2142. http://dx.doi.org/10.1109/TPWRS.2011.2122346.
Pakonen, P., Vehmasvaara, S., Pikkarainen, M., Siddiqui, B., Verho, P., 2012. Experiences on narrowband powerline communication of automated meter reading systems in Finland. In: Electr. Power Qual. and Supply Reliab, pp. 1–6. http://dx.doi.org/10.1109/PQ.2012.6256242.
Pernick, R., Wilder, C., 2007. Clean Tech Revolution: the Next Big Growth and Investment Opportunity. Harper Business.
Pernick, R., Wilder, C., 2012. Clean Tech Nation: How the US Can Lead in the New Global Economy. Harper Business.
Purvins, A., Wilkening, H., Fulli, G., Tzimas, E., Celli, G., Mocci, S., Pilo, F., et al., 2011. A European supergrid for renewable energy: local impacts and far-reaching challenges. J. Clean. Prod. 19 (17–18), 1909–1916. http://dx.doi.org/10.1016/j.jclepro.2011.07.003.
Qiao, W., Sharma, A., Hudgins, J.L., Jones, E.G., Rilett, L., 2011. Wind/solar hybrid generation-based roadway microgrids. In: IEEE Power & Energ. Soc. Gen. Meet. IEEE, pp. 1–7. http://dx.doi.org/10.1109/PES.2011.6039884.
Ramchurn, S.D., Vytelingum, P., Rogers, A., Jennings, N.R., 2012. Putting the "Smarts" into the Smart Grid: a grand challenge for artificial intelligence. Commun. ACM 55 (4), 86–96.
Römer, B., Reichhart, P., Kranz, J., Picot, A., 2012. The role of smart metering and decentralized electricity storage for Smart Grids: the importance of positive

externalities. Energ Policy 50, 486–495. http://dx.doi.org/10.1016/j.enpol.2012.07.047.
Saleem, A., Heussen, K., Lind, M., 2009. Agent services for situation aware control of power systems with distributed generation. In: IEEE Power & Energ. Soc. Gen. Meet. http://dx.doi.org/10.1109/PES.2009.5260219.
Sanz, A., Garcia-Nicolas, J.I., Estopiñán, P., Miguel, S., 2009. PRIME from the definition to a SoC solution. In: IEEE International Symposium on Power Line Communications and Its Applications, pp. 347–352.
Schneider, K.P., Chassin, D., Chen, Y., Fuller, J.C., 2009. Distribution power flow for smart grid technologies. In: IEEE/PES Power Systems Conference and Exposition, vol. 1–3, pp. 1–7.
Shuaib, K., Zhang, L., Gaouda, A., Abdel-Hafez, M., 2012. A PEV charging service model for smart grids. Energies 5 (12), 4665–4682. http://dx.doi.org/10.3390/en5114665.
Silvester, S., Beella, S.K., Van Timmeren, A., Bauer, P., Quist, J., Van Dijk, S., 2013. Exploring design scenarios for large-scale implementation of electric vehicles; the Amsterdam Airport Schiphol case. J. Clean. Prod. 48, 211–219.
Sinha, A., Neogi, S., Lahiri, R.N., Chowdhury, S., Chowdhury, S.P., Chakraborty, N., 2011. Smart Grid initiative for power distribution utility in India. In: IEEE Power & Energ. Soc. Gen. Meet. IEEE, pp. 1–8. http://dx.doi.org/10.1109/PES.2011.6038943.
Soares, J., Canizes, B., Lobo, C., Vale, Z., Morais, H., 2012. Electric vehicle scenario simulator tool for smart grid operators. Energies 5 (6), 1881–1899. http://dx.doi.org/10.3390/en5061881.
Son, S.-Y., Chung, B.-J., 2009. A Korean Smart Grid architecture design for a field test based on power IT. In: Transmission & Distribution Conference & Exposition: Asia and Pacific. IEEE, pp. 1–4. http://dx.doi.org/10.1109/TD-ASIA.2009.5356842.
Sousa, T., Morais, H., Vale, Z., Faria, P., Soares, J., 2012. Intelligent energy resource management considering vehicle-to-grid: a simulated annealing approach. In: IEEE Transactions on Smart Grid, vol. 3 (1), pp. 535–542. http://dx.doi.org/10.1109/TSG.2011.2165303.
Spangenberg, J.H., 2010. The growth discourse, growth policy and sustainable development: two thought experiments. J. Clean. Prod. 18 (6), 561–566. http://dx.doi.org/10.1016/j.jclepro.2009.07.007.
Strasser, T., Stifter, M., Andren, F., Burnier de Castro, D., Hribernik, W., 2011. Applying open standards and open source software for smart grid applications: simulation of distributed intelligent control of power systems. In: IEEE Power & Energ. Soc. Gen. Meet, pp. 1–8. http://dx.doi.org/10.1109/PES.2011.6039314.
Teng, J.-H., Chen, C.-Y., Chen, C.-F., Liu, Y.-H., 2008. Optimal capacitor control for unbalanced distribution systems with distributed generations. In: IEEE International Conference on Sustainable Energy Technologies, pp. 755–760. http://dx.doi.org/10.1109/ICSET.2008.4747107.
Tenti, P., Trombetti, D., Costabeber, A., Mattavelli, P., 2010. Distribution loss minimization by token ring control of power electronic interfaces in residential micro-grids. In: IEEE International Symposium on Industrial Electronics. IEEE, pp. 2377–2381. http://dx.doi.org/10.1109/ISIE.2010.5637489.
Uslar, M., Rohjans, S., Specht, M., 2012. Technical requirements for DER integration architectures. Energy Procedia 20, 281–290. http://dx.doi.org/10.1016/j.egypro.2012.03.028.
Vokony, I., Dan, A., 2009. Examination of smart grids in Island operation. In: IEEE Bucharest Power Tech Conference, pp. 1–7.
Wang, S., Yang, H., Zuo, S., Xu, W., 2010. Optimal Dispatch of power system with Stochastic wind generation. Appl. Mech. Mater. 37-38, 783–786.
Wissner, M., 2011. The Smart Grid – a saucerful of secrets? Appl. Energy 88 (7), 2509–2518 http://dx.doi.org/10.1016/j.apEnerg..2011.01.042.
Zhabelova, G., Vyatkin, V., 2012. Multiagent smart grid automation architecture based on IEC 61850/61499 intelligent logical nodes. IEEE Trans. Ind. Electron. 59 (5), 2351–2362.