Uddin *et al. Hum. Cent. Comput. Inf. Sci. (2018) 8:2*
https://doi.org/10.1186/s13673-018-0126-9

Human-centric Computing and Information Sciences

REVIEW
Open Access

Recent advances of the signal processing techniques in future smart grids

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Abstract

Smart grid is an emerging research field of the current decade. The distinguished features of the smart grid are monitoring capability with data integration, advanced analysis to support system control, enhanced power security and effective communication to meet the power demand. Efficient energy consumption and minimum costs are also included in the prodigious features of smart grid. The smart grid implementation requires intelligent interaction between the power generating and consuming devices that can be achieved by installing devices capable of processing data and communicating it to various parts of the grid. The efficiency of these devices is greatly dependent on the selection and implementation of the advance digital signal processing techniques. This paper provides a comprehensive survey on the applications of signal processing techniques in smart grids, plus the challenges and shortcomings of these techniques. Furthermore, this paper also outlines some future research directions related to applications of signal processing in smart grids.

Keywords: Smart grid, Signal processing techniques, Wireless communication, Control, Security

Introduction

Smart grid is a network of electric supply that manages power demand in reliable and economic manner by detecting and reacting to local changes in usage. The infrastructure comprises of smart meters, appliances, and resources with a combination of modern technologies like, control, power, instrumentation, and communication. In such a complex scenario, signal processing techniques are essential to understand, plan, design and operate the complex future smart electronic grids [1]. In addition to this, signal processing has wide variety of applications and is becoming an important tool for electric power system analysis. This is due to the fact that measurements retrieved from numerous locations of the grid can be used for data analysis. These measurements can also be used for a variety of issues such as voltage control, power quality and reliability, power system and equipment diagnostics, power system control and protection, etc [2–6].

Power quality is one of the main issue of the smart grid research where voltage, current and frequency deviations in the power system are the main concerns of the system operator [7]. The characterization of the incompatibilities caused by these deviations requires an understanding of their principal cause. Other possible aspects that need inspection are the efficient representation of the voltage and current variations in various electrical equipment. Moreover, the signal processing of the power patterns leads to better understanding the behavior of these equipment. Continuous monitoring is also required to capture various events and variations. To meet future demands, methods and techniques must be developed to explore the full range of signals derived from the complex interaction between suppliers, consumers and network operators [8].

A smart grid performs measurement, monitoring and processing of waveforms based on acquisition, analysis, detection and classification techniques [9]. Furthermore, these techniques can be utilized for the identification of the system events, phenomena and load characteristics [10]. A key aspect of signal processing in power systems is signal processing methods which provide the best characterization and analysis of the signals to be investigated. For instance, many methods only demand the voltage measured for an acceptable evaluation, but in some cases current, frequency or active and reactive power of the system is required. Furthermore, an understanding of electrical system behavior is needed to study digital signal processing techniques for control, protection and monitoring of the smart grids [11].

Related work

In the literature, different surveys are performed. In [12, 13], the authors discussed the applications of time frequency analysis, wavelet packet transform and the filter banks in the future smart grids. In [14], a short survey of some advance signal processing techniques used in smart grids are presented. These techniques include sparse representation, real time re-sampling, and the wavelet applications. Technological advancements of the transmission and distribution networks in smart grid are discussed in [15]. The survey presented in [16] gives an analysis of the applications of communication technologies and their requirement in smart grids. In [17], the authors reviewed the issues of electric vehicle while implementing the smart grids. The applications and characteristics of the communication networks [18] and the communication infrastructures are surveyed for smart grids in [19]. Review on the security threats in communication networks is presented in [20]. The smart grid technologies and standards are reviewed in [21]. The demand response of the smart grids is reviewed in [22]. These surveys are summarized in Fig. 1.

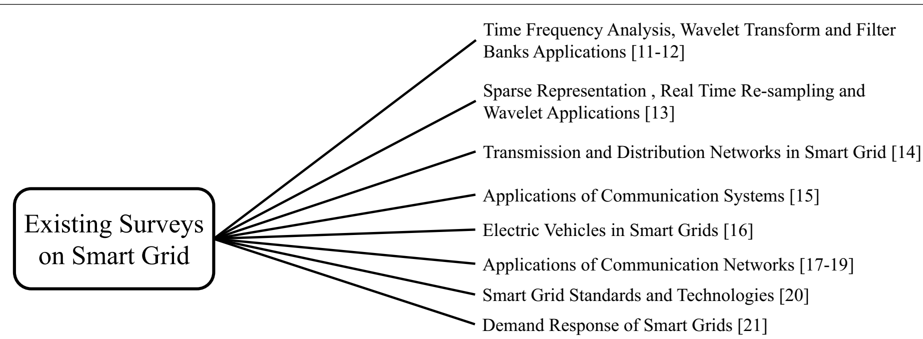

Fig. 1 Summary of the existing smart grid surveys

Case studies and service scenario

The smart grid has numerous advantages as well as technological challenges concerning its practical implementation. Throughout the world researchers contributed to the smart grid challenges. Due to the availability of modern technological tools and contributions of researchers toward smart grid, practical implementation of this grid becomes possible. The signal processing techniques contributed much more toward implementation of this grid. Challenges like security, communication, and control are outstripped with various signal processing techniques. Furthermore, smart grid is a complex system that incorporates a variety of other systems like communication system, power system, stability analysis, load management system, and the interconnected systems. The analysis of these systems and detection of certain conditions is a burdensome task in such a challenging scenario. Advance signal processing techniques are required to perform this job. Some advance signal processing techniques reported in the literature and used to overwhelm the smart grid challenges are time frequency analysis, wavelet transforms, filter banks, sparse signal processing, and real time re-sampling. The time frequency analysis and the wavelet transforms are used to overcome the limitation of the Fast Fourier transform (FFT) i.e., the time frequency analysis and the wavelet transform are more efficient than the FFT. They are also applicable in case of non-stationary scenario where within the window the data are assumed stationary. Moreover, the filter banks are used to improve the efficiency of the DSP system. Sparse signal processing and real time re-sampling are also used to process the data for various tasks in the smart grid scenario. All these signal processing techniques are surveyed in [12–14]. In addition to this, various advancements of the transmission and distribution networks are surveyed in [15]. The applications of communication technologies and their requirements in the smart grid scenario are discussed in [16]. Furthermore, communication networks also play a vital role in the implementation of the smart grid. Various communication networks and their infrastructures are surveyed in [19] in the smart grid scenario. Security of the communication networks is also a challenging issue in the smart grid scenario. Numerous techniques are presented in the literature regarding the security of the smart grid which are summarized in [20]. Due to the complex nature of the smart grid various technologies are used in the development of the smart grid and various standards are defined which are discussed in detail in [22].

Motivation and contribution

In power systems, signal processing provides the best characterization and analysis of the signals to be inspected. Signal processing also determines the correct parameter to be measured and its level of accuracy. Also, the time invariant analysis of the smart grid requires signal processing techniques. These techniques comprises of digital filters, moving average, and trapezoidal integration. Special digital systems like estimation of the differentiator, time-domain harmonic distortions and the notch filters are also included. Moreover, spectral analysis is an important application of digital signal processing that determines the frequency of current or voltage signal. The applications of signal processing in power systems can also be found in power quality analysis, protection and control. Furthermore, signals in electrical power systems are time and frequency dependent where frequency domain analysis is used to extract features and information for possible transient conditions associated with the presence of high frequency harmonics and other disturbances. Finally, the complexity of the future smart grid will require not only advanced signal processing that can identify specific parameters, but also intelligent methods for identifying particular patterns of behavior.

Several reviews published in recent years addressed limited signal processing algorithms [12–14]. Therefore a thorough and detailed review of the applications of signal processing techniques in smart grids will be beneficial for the research community. In this paper, we concentrated on different areas of the smart grid where various signal processing techniques are used. These areas mainly include the smart metering, vehicular transportation, power quality, fault diagnosis, and modern instrumentation and control. Main contributions of this paper are listed below:

- This paper highlights the importance of signal processing techniques in smart grids due to their large number of applications.
- The smart grid technologies and implementation issues are discussed while implementing signal processing techniques.
- The applications and limitations of the important signal processing tools in power system analysis are reviewed.
- Future research directions regarding the signal processing applications in smart grid are proposed.

Remaining paper is organized into five sections. "The smart grids" section gives an overview of the smart grid concepts. Review of the signal processing applications in smart grid is given in "Signal processing applications in smart grids" section. The challenges and limitations of the signal processing techniques in smart grid are analyzed in "Role of signal processing in overcoming the challenges andlimitations of smart grids" section. Future research directions are discussed in "Discussion" section and, finally a conclusion is given in "Conclusion" section. Moreover, the list of abbreviations used in this article is illustrated in the end of the article.

The smart grids

The main characteristics of the existing electric grid are one way energy flow to consumers, mostly centralized energy production, few communication nodes, limited automation and utilities usually, only have monthly contact with customers. The smart grid is quite a new concept introduced in the late 1990 with the first basic practical system introduced in the early 2000. The smart grid is an electric power grid that employs information technology and signal processing techniques to constantly optimize electrical power generation, delivery and consumption [23]. The smart grid is a power grid equipped with numerous sensors that are connected through advance communication and data acquisition systems. The functionalities of theses sensors become possible with the latest information technologies and signal processing techniques [24] as shown in Fig. 2.

Smart grid saves fuel, optimises electricity consumption and transmission cost. Smart grid aslo improves reliability and enhances customer service and satisfaction. It is climate friendly as reduces emissions from power generation and transmission lines and

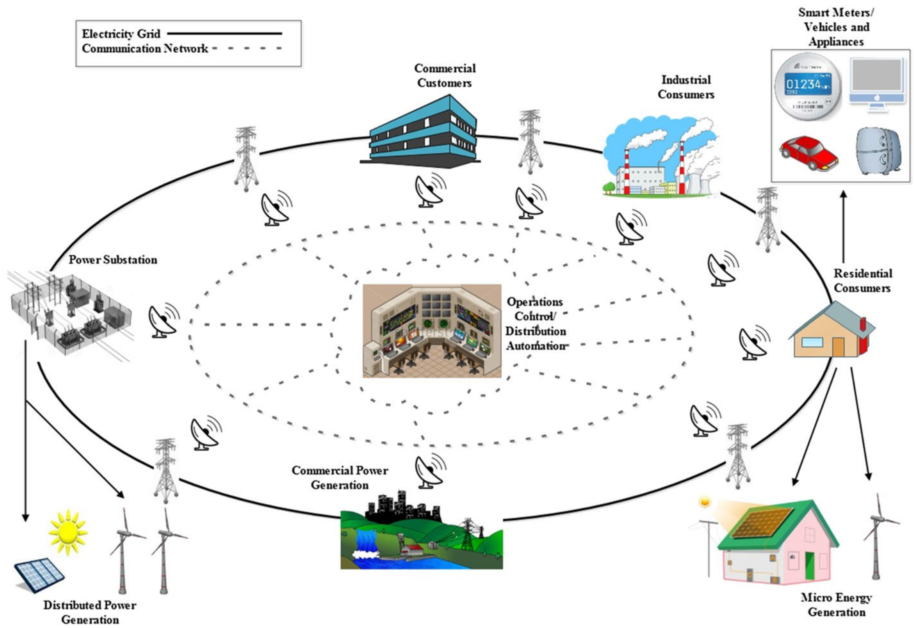

Fig. 2 Smart grid architecture highlighting communication, control and signal processing

has enabled operators of industrial, commercial, municipal buildings as well as home-owners to take part in greening the grid. All these factors together positively affects the economy [25]. Although in the existing grid, power is generated and distributed by the utility companies with very less interaction with the consumers. However, the modern grid is still largely based on the existing grid [26, 27]. Some of the other benefits of the smart grid are summarized in Fig. 3.

A smart grid is not a single upgrade to the electric transmission and distribution but a complete overhaul with twenty-first century infrastructure, metering and communication technologies. Each part of the smart grid brings its own system and societal benefits with the goal of improving electricity delivery and utility [28].

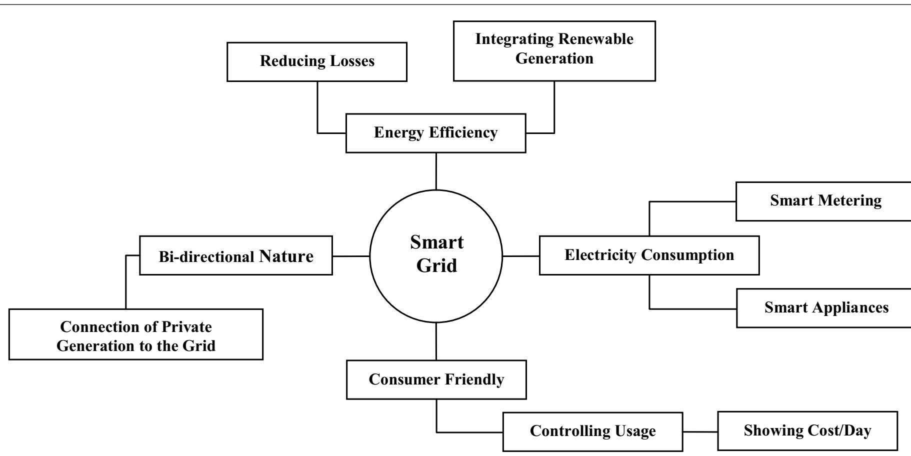

Fig. 3 Benefits of the smart grids

Signal processing applications in smart grids

In power systems signal processing provides the best characterization and analysis of the signals to be investigated. Secondly, it determines which parameters should be measured and to what level of accuracy. In addition to this, the time invariant analysis of the smart grid requires signal processing techniques comprises of digital filters, moving average, trapezoidal integration and special digital systems such as the estimation of the differentiator, time-domain harmonic distortions and the notch filters. Although the smart grid context will introduce many time varying variables in the behavior of the electric power network, the utilization of classical linear and time invariant systems will continue to be the main tool to analyze and design signal processing algorithms for the future smart grid. Current smart grids demand more signal processing techniques for electrical parameters to keep the network under control and operating at the desired quality. Furthermore, analytical tools are required for the state estimation of system parameters due to the uncertainty and non-feasibility of monitoring system parameters at various locations. This makes the estimation and further processing of electrical power system parameters an essential feature of the power system analysis [29].

Power frequency is an important parameter in a power system that is determined using spectrum estimation or spectral analysis. The applications of spectral analysis in power systems can be found in power quality analysis, protection and control. Previously, spectral analysis was used to estimate the harmonic component of a stationary signal. However, spectrum analysis of non-stationary signals with a time-varying frequency and inter-harmonics is the current focus of researchers [12].

Signals in electrical power system are time and frequency dependent. Frequency domain analysis is used to extract features and information for possible transient conditions. These transient conditions are associated with the presence of high frequency harmonics and other disturbances. As the electric smart grid of the future becomes more complex in terms of the variability of loads and generation, growth in response to market incentives and utilization of power electronics for energy processing is required. Therefore, electrical signals will require a broader set of tools and methods for signal processing. The basic bridge between time and frequency domains is the Fourier transform (FT). The FT is not the best tool to analyze power system signals because power system signals are non-stationary signals but FT assumes that the signals under analysis are stationary. In order to overcome this limitation, alternative methods have been proposed such as the short-time Fourier transform (STFT), wavelets and filter banks. These techniques are commonly known as joint time-frequency analysis [13].

The complexity of the future smart grid requires not only advanced signal processing that can identify specific parameters, but also intelligent methods for identifying particular patterns of behavior. Pattern recognition applications received a boost in the last four decades due to the increasing demand for automation, both commericially and domestically. This demand has been met by the evolution of computers, digital signal processing and processors. Examples of the applications of pattern recognition in power systems include fault identification, power quality, consumer profile identification and protection. The pattern recognition will be very useful in future power systems due to the variability of electrical signals from diverse generators and loads, to aid the system operator to properly identify problems and to control the grid's power delivery process.

All of these are creating the complex smart grid of the future where pattern recognition is an important enabling tool for operation and control [14].

Recent advances of the signal processing techniques in smart grids

A smart grid is the combination of various advanced sensing nodes, control devices and modern communication systems that make the smart grid a very complex system. Due to the increased complexity fault localization is necessary. In [30], a fault detection technique is developed utilizing the change in bus susceptance parameters of the smart grids. This technique is based on least square and generalized likelihood ratio. In [31], the fault localization problem is analyzed in the power networks by using the electromagnetic time reversal technique. In addition to this, a sensor network based algorithm is proposed for fault localization in smart grids [32]. This technique is based on the minimum measurement error criteria. Moreover, ensemble empirical mode decomposition (EMD) and Hilbert Huang transform are used for noise reduction and fault identification in the smart grid scenario [33]. Applications of the signal processing techniques in smart grids are illustrated in Fig. 4.

Smart metering is one of the important component of the future smart grid. In [34], the authors discussed the smart meter privacy issues by suing mutual information rate and the Bahl Cocke Jelinek Raviv algorithm. In [35], the independent component analysis technique in combination with principle component analysis technique is used for data recovery from various smart meters in the presence of wide band noise. Using the concept of enhanced event driven metering, the collection of information in low voltage systems for the smart metering is addressed in [36]. In addition, the smart grid safety and security issues are discussed in [37] and [38] by using various signal processing techniques. In [37], image processing techniques are introduced for the safety of dams and smart grids. The cyber security issues of the bad data injection are discussed in [38], where the authors proposed the independent component analysis technique to handle

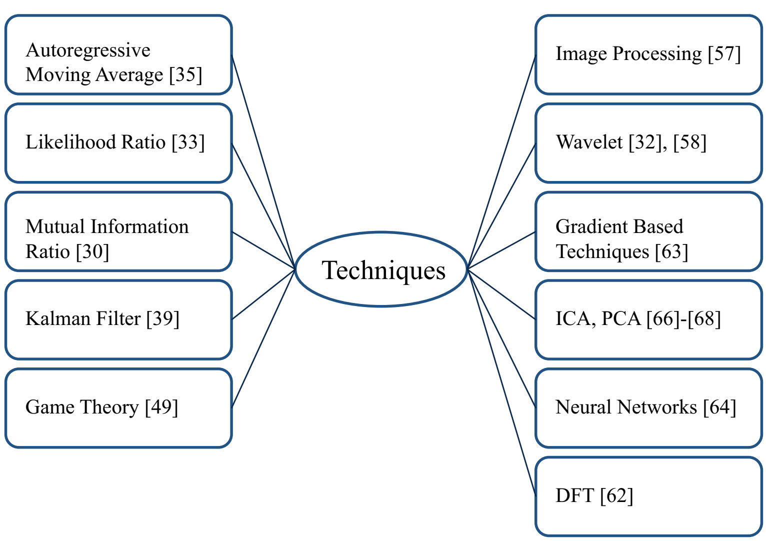

Fig. 4 Applications of signal processing techniques in smart grids

the situation. Furthermore, the state estimation of smart grid is discussed in [39]. The authors used Kalman filter based approach to resolve the synchronization problem in phase measurement units while using large scale deployment. The authors of [40] proposed a system that can generate any arbitrary pricing signal. The proposed system is able to detect the correct pricing signal and protect any attack against pricing. In [41], a method based on short term state forecasting is proposed that is able to detect false data injection in smart grids. A new routing protocol is presented in [42] for smart grid applications. In [43], instruction detection system is developed for smart grids. The proposed system fulfills real time communication requirements with the available limited resources in the smart grid scenario. Moreover, the authors in [44] suggested big data computing architecture for the smart grid. The proposed technique consists of communication architecture for enabling big data aware communication for smart grid. Furthermore, in [45] some security issues are discussed related to distributed demand management protocols and proposed a protocol that is able to share information among users providing privacy and confidentiality. In [45], the authors also proposed a protocol that can identify untruthful users in the network. Singular value decomposition (SVD) based method is developed in [46] for lossy data compression in smart distribution systems. The developed method reduces computational burden over communication networks. In [47], a Bayesian network is introduced for obtaining quantitative loss event frequency results of high granularity using traceable and repeatable process. This proposed technique differentiates the most effective part of a certain threat that is useful for plan countermeasures in a better way. Moreover, the false data injection issues are discussed in [41]. Short term state forecasting in combination with temporal correlation is used to detect such attacks.

The authors introduced auto regressive moving average technique for controlled charging of electrical vehicles [48]. Moreover, [49] utilizes wavelet transform for islanding detection and improving islanding delay. The islanding detection problem is also addressed in [50], where authors used fuzzy neural networks for islanding detection. Optimization of mobile networks in smart grids is discussed in [51]. The proposed system generate green energy in individual base stations and the base stations can share these energies to reduce the power consumption from the grid. A technique is developed in [52] for efficient energy storage systems in the smart grid scenario. The developed technique is probabilistic that is able to determine the optimal operation at each load state. A load side frequency control mechanism is developed in [53] which is able to keep the grid within operational limits. The proposed technique re-adjust the supply and demand after disturbances and also restore the frequency to its desired value. In [54], the developed technique can self repair the smart grid. This technique builds coordination for smart transformer that runs in three healing modes and performs collective decision making of the phase angles in the lines of a transmission system to improve reliability under disruptive events.

Due to the severe complexity of smart grid, the quality of electrical power is an important concern. The authors in [55] presented a signal processing based approach for power quality detection and classification in smart grids. Power quality detection and classification is performed employing the wavelet transform in combination with neural networks for the smart grids. In [56], the authors highlighted the importance of signal processing for power quality improvements in smart grids. This article addressed the demand response management and load forecasting for better power quality of smart grid. Moreover, the downlink throughput maximization of the smart meters in smart grid is discussed in [57] by using the stochastic sub-gradient approach for quality improvement of the smart grid. In [58], the independent component analysis (ICA) technique is utilized to overcome the coherency problem in different power systems connected together to improve the power quality of the smart grid. Figure 5 contains information regarding the signal processing in smart grid technologies. A transformerless active filter based technique is developed in [59] to improve the power quality of a single phase household. In [60], the effects of some advance technologies on power quality are discussed in the smart grid scenario. The technologies considered are microgrids, voltage controllers, feeder configurations, and demand side management. Study regarding investment in renewable energy by a household is performed in [61]. The possibility of providing electric power to grid is analyzed that can be performed by net metering. Secondly, the authors discussed the issues regarding the smart meters installation.

Modern smart grid requires intelligent instrumentation techniques to overcome its various challenges. Smart grid also need efficient and smart algorithms for communication and information sharing. In [62], a new signal processing technique is proposed for intelligent monitoring of smart grid. A compression technique which is an essential part of all types of data storage and communications is developed for the smart grid waveforms [63]. Furthermore, game theory based approach is presented for home power demand management in [64]. In [65], a signal processing based energy management in coordinated multipoint system is proposed for the smart grids. A newly developed signal processing based method of load disaggregation is proposed in [66]. Moreover, a

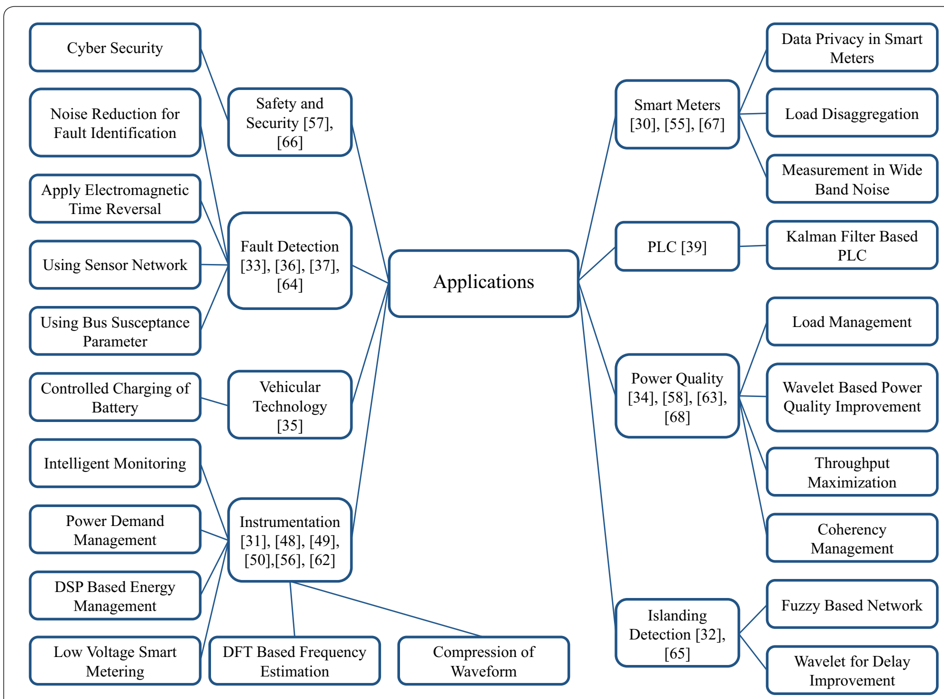

Fig. 5 Signal processing in smart grid technologies

recursive discrete Fourier transform (RDFT) algorithm is developed to estimate instantaneous frequencies in smart grids. In references [69, 70], the authors presented the concept of a modern smart home and the inclusion of renewable energy with the smart grid scenario to reduce the electric bills accordingly. A global overview of the applications of signal processing techniques in smart grids is given in Table 1.

Role of signal processing in overcoming the challenges and limitations of smart grids

A smart grid is not a single technology but an integration of important technologies like instrumentation, control, signal processing, and wireless communication, etc. Advance signal processing techniques are required for secure and efficient communication in future smart grid. In this regard, the challenges and limitations of the signal processing techniques are summarized as follows:

- Efficient processing: Efficient signal processing is a major issue in the development of the future grid due to the interconnection of various technologies and diverse nature of the smart grid.
- Secure communication: Security is a major challenge in the next generation power grid. Advance signal processing techniques should be developed to ensure security of information.
- Large number of sensor nodes: Sensor networks are suggested to be used in future smart grids. Due to the presence of large number of sensor nodes in smart grid, the existing signal processing techniques are unable to produce quality results.
- Fast and accurate processing: Diverse nature of the future power grid limits the speed and accuracy of the existing signal processing techniques that is why more accurate and fast signal processing techniques should be developed.
- Time varying scenario: One of the most challenging aspects of the future grid is its varying nature due to varying loads and the wireless channel condition.
- In case of fault alternative techniques: In case of failure some alternate signal processing techniques should be developed to overcome the situation in case of occurrence of failure of the existing algorithm.
- Signal processing in noisy area: Due to the presence of large amplitude noise, it is difficult for existing signal processing techniques to process the noisy data in smart power grid with acceptable signal quality.

Discussion

In the literature various surveys are published regarding signal processing techniques in smart grids. Limited applications of the signal processing techniques in smart grid are addressed in [12–14]. That is why we concentrated on the detailed review of the signal processing techniques in smart grids. In this paper, we concentrated on different areas of the smart grid where various signal processing techniques are used. These areas mainly include the smart metering, vehicular transportation, power quality, fault diagnosis, and modern instrumentation and control. This paper mainly highlights the importance of signal processing techniques in smart grids due to their large number of applications. Secondly, the smart grid technologies and implementation issues are discussed while

Table 1 A global overview of the signal processing techniques in smart grids

Reference no.	Year of publication	Short description
[34]	2011	Mutual information of BCJR algorithm is used for data privacy in smart meters
[62]	2011	A new algorithm is developed for intelligent monitoring in smart grids
[35]	2011	ICA based smart metering in the presence of wide band noise is developed
[49]	2012	A signal processing technique is developed to improve the islanding detection
[30]	2012	Least square based generalized likelihood ratio method is developed for fault detection in smart grids
[56]	2012	Introduces signal processing for price load forecasting in smart grids
[48]	2012	Auto-regressive moving average technique is developed for charging of electric vehicles in smart grids
[31]	2012	Electromagnetic time reversal technique is used for fault localization in a power network
[32]	2012	Sensor network based algorithm is proposed for fault localization
[67]	2013	A modified incremental bit allocation algorithm is developed for power line communication
[39]	2013	Kalman filter based state estimation technique is developed for smart grids
[38]	2013	ICA based cyber security technique is proposed for smart grid
[58]	2013	ICA based technique is proposed for coherency management in smart grids
[63]	2014	Compression technique is proposed for smart grid waveform
[64]	2015	Game theory based home power demand management technique is proposed
[36]	2015	A signal processing technique is developed for smart grid meters in low voltage systems
[37]	2015	Safety method is developed for smart grids
[55]	2015	Wavelet based power quality improvement technique is developed
[68]	2015	DFT based frequency estimation technique is proposed for smart grids
[57]	2016	Throughput maximization technique is developed for smart grids
[33]	2016	Signal processing based fault identification technique is proposed
[50]	2016	DSP based algorithm is proposed for islanding detection is smart grid environment
[65]	2016	DSP based energy management technique is proposed
[66]	2016	Load dis-aggregation method is proposed
[59]	2017	A transformer-less active filter based technique is developed for power quality improvement of a single phase household
[60]	2017	Effects of some advance technologies on power quality in the smart grid are discussed
[61]	2017	A study is performed regarding investment in renewable energy by a household
[51]	2014	The optimization of mobile networks in smart grids is discussed
[52]	2017	A technique is developed for efficient energy storage systems in smart grid
[53]	2017	A load side frequency control mechanism is developed
[54]	2016	A technique is developed that can self repair the smart grid
[40]	2016	The authors proposed a system that can generate and detect any pricing signal
[41]	2015	Proposed a system that is able detect false data injection in smart grids
[42]	2015	A new routing protocol is presented for smart grid applications
[43]	2017	A system is proposed that can fulfills real time communication requirements with the available limited resources

Table 1 continued

Reference no.	Year of publication	Short description
[44]	2017	Big data computing architecture is developed for smart grid
[45]	2015	Security issues are discussed related to distributed demand management protocols
[46]	2017	Singular value decomposition is used for lossy data compression in smart distribution systems
[47]	2017	Bayesian network is introduced for obtaining quantitative loss event frequencies
[66]	2016	Load dis-aggregation method is proposed

implementing signal processing techniques. Thirdly, the applications and limitations of the important signal processing tools in power system analysis are reviewed. Finally, future research directions regarding the signal processing applications in smart grid are proposed which are given below:

- Independent component analysis (ICA) is used in smart grid [48, 55] but, the performance of the existing ICA algorithms is not reliable in case of highly time varying scenarios. One can develop algorithms to efficiently handle large variations in the wireless channel. Secondly, most of the current employed ICA algorithms assumed a noise free environment while processing the mixed signals for un-mixing. Due to the presence of large amplitude noise in smart grid, the existing ICA algorithms should be modified to perform well in noisy scenarios.
- For efficient communication in smart grid, [55] proposed wireless sensor networks and cognitive radio networks. One can combine the two techniques in a single framework called the cognitive radio sensor networks (CRSN) to improve the performance of smart grid.
- Large amount of sensor nodes are required in smart grid while utilizing the wireless sensor networks. New algorithms are demanded to handle the resultant large amount of information in smart grid.
- Due to the existence of large amplitude noise in the power grid, the existing algorithms are unable to produce better results. Sophisticated signal processing algorithms must be developed to handle the noise intense environment of smart grid.

Conclusion

Smart grid is one of the important technological advancement for the efficient utilization of electrical energy. This efficient utilization not only conserves electrical energy but also reduces the tariff enabling smart grid friendly towards the utility companies as well as consumers. In this research work a thorough review of signal processing techniques in smart grids is presented. Recent advances of the smart grids are also reviewed followed by suggestions for further improvement and future research direction. It is hoped that this paper would provide a solid base for research in the field of applications of signal processing techniques in smart grids.

Abbreviations

FFT: fast Fourier transform; EMD: empirical mode decomposition; SNR: signal-to-noise ratios; FT: Fourier transform; STFT: short-time Fourier transform; CRN: cognitive radio network; ICA: independent component analysis; GERI: Gachon Energy Research Institute; DR: demand response; OFDM: orthogonal frequency division multiplexing; TQOS: trustworthiness-based quality of service; CPT: conservative power theory; PEVs: plug-in electric vehicles; SFCL: super-conducting fault current limiters; TCI: thyristor controlled impedance; CNSPG: cooperative network of smart power grids; PQ: power quality; CPES: cyber physical energy systems; SCADA: supervisory control and data acquisition; WSN: wireless sensor network; RTDS: real time digital simulator; AGC: automatic generation control; DMS: distribution management system; OPF: optimal power flow; IEDs: intelligent electronic devices; ICT: information and telecommunication technologies; DSM: demand side management; PEA: provincial electricity authority; FCC: fault current controller; DOE: Department of Energy; US: United States; CRSN: cognitive radio sensor networks.

Authors' contributions

ZU collected, reviewed and classified main literature for the paper. AA identified the challenges of signal processing techniques in smart grid. AQ drafted the smart grid related part of the manuscript. MA identified future research directions. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Ethics approval and consent to participate

Not applicable.

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Received: 7 September 2017 Accepted: 2 January 2018
Published online: 16 January 2018

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