Guest Editorial: Special Section on Enabling Technologies and Methodologies for Knowledge Discovery and Data Mining in Smart Grids

The advance in the research of Smart Grid methodologies opens the doors toward the conceptualization of new tools aimed at effectively addressing most challenging issues of modern power distribution systems, including the massive pervasion of renewable power generators, the strictest power quality limits, the complex interactions with the energy markets, the raising levels of security and reliability constraints, the need for maximizing the exploitation of existing electrical infrastructures [1].

In particular, it is well note that the large-scale integration of distributed and dispersed generators into running electrical grids perturbs the power system operation, inducing a number of complex side-effects mainly related to the stochastic nature of the generated power profiles, and the limited generation hosting capacity of power distribution systems, which have been traditionally designed according to the so called "passivity hypothesis", namely without assuming any generation on the load buses. Hence, the research for advanced tools for properly coordinating the operation of distributed renewable power generators in order to mitigate their negative impacts on power system operation and control, represent a strategic issue to address.

To address this complex issue, paper [2] explores the potential role of microgrids and energy storage systems, which have been considered as the most promising enabling technologies for dealing with an increased penetration of intermittent, and non-programmable generators in electrical distribution systems. In particular, this paper proposes a novel methodology based on particle swarm optimization for storage systems sizing in wind power integrated microgrids. The main idea is to integrate a cost-benefit analysis and here-and- now approach for minimizing the operation costs, maximizing the total system benefit, and considering the wind power uncertainty, for both stand- alone and grid-connected microgrid operation mode. Detailed simulation results on several case studies demonstrated the effectiveness of the proposed methodology, showing that the optimal size of the storage systems and the solution of the unit commitment problem are drastically influenced by the effects of the wind power uncertainty, which requires the deployment of reliable and proactive control frameworks.

The backbone of these new control frameworks is the capability of distributed entities, such as software modules, remote processing units, and pervasive sensor networks, to acquire, process and share data according to fixed time constraints determined by the specific application domain [3]. In this context, the enhancement of the energy management systems, which are traditionally based on low scalable architectures, mixed communication technologies, and legacy proprietary platforms, is one of the main technological challenges to face [4]. In addressing this issue, data heterogeneity, a not relevant issue in traditional power systems measurements, represents a major problem, since the deployment of the metering infrastructures is unlikely to grow over time with the same hardware and software architectures. Pervasive storing and processing of massive data-sets represent further complex issues to address, since the number of grid sensors is expected to increase over several orders of magnitude, and the corresponding data streaming should be promptly processed in order to extract actionable information in useful times [5]. In solving these complex issues, the power system operators must properly represent and discovery the intrinsic semantic of the measured data in order to have a full understanding of the information context, which allows assessing the degree of confidence of the corresponding content [6].

In this context, paper [7] proposes a methodology for feature extraction from massive power quality data, which tries to properly balance the computational efforts and the satisfactory performance of the algorithm in detecting and classifying the electrical disturbances. In particular, to deal with the intrinsic complexities of the disturbances classification problem, this paper conceptualizes a step of feature extraction that may be calculated and analyzed off-line using synthetic waveforms/signals, which are subsequently validated using field measurements.

The idea of converting massive data acquired by pervasive field sensors into high-level information and eventually into actionable intelligence at different application domain could represent a strategic tool in solving further smart grids operation problems. This asks for conceptualizing knowledge discovery frameworks aimed at processing the measured data to provide storage and inference functionalities specifically designed for supporting the smart grid operation [8]. In this context big data analysis for electromechanical dynamics monitoring represents a relevant issue to address. To solve this problem, paper [9] proposes the mathematical derivation, implementation, parameter tuning, and application of a novel data processing algorithm, which aims at identifying instantaneous relationship of system oscillation modes with respect to operating conditions from measured data streams. The proposed algorithm is based on a parallel processed on-line supervised learning algorithm, which integrates two advanced machine-learning algorithms, namely the "K Nearest Neighbors" and the "Locally Weighted Linear Regression" paradigm, and it has been validated on an 8-generator 36-node system with real operations data.

The advance in research on big data generated from pervasive grid sensors is expected to support the evolution of traditional measurement networks toward Wide-Area Monitoring Protection and Control Systems (WAMPACs), which employ a network of time-synchronized sensors, namely the Phasor Measurement Units (PMUs), to implement advance smart grid functions including optimal distributed resource management, smart restoration techniques, and proactive warning services [10]. Field experiences have shown that the pervasive adoption of WAMPACs in smart grids could sensibly reduce the occurrence of large-scale disturbances, by supporting the smart grid operator in implementing advanced protection schemes and adaptive control strategies.

Moreover, the stream of data generated by the PMUs allows simplifying the analysis of the generator dynamics, overcoming the need for identifying an aggregate model of all generators, and allowing the design of load frequency control schemes considering the entire network topology. This feature has been analyzed in paper [11], which proposes a quasi-decentralized unscented transform based scheme to control frequency and tie-line power of a multi-area interconnected power system on the basis of dynamic system state estimation based on real-time PMUs measurements. The results presented in this paper demonstrate as the application of this advanced signal-processing algorithm can provide an accurate picture of the actual state of the power system including the dynamic states of generators, which can be utilized in control algorithms to device methods to improve reliable power distribution.

Despite these potential benefits, the development of WAMPACs in power distribution systems is still in its infancy and many open issues are yet to be fixed. A particular challenge is to design holistic and highly flexible WAMPACs architectures, resilient to internal and external disturbances that might compromise their operation. In particular, many papers evidenced that the traditional hierarchical computing architecture is characterized by several shortcomings, which could compromise its deployment in the context of future smart grids.

To fix these issues, many papers emphasized the crucial role played by multi-agent and cooperative paradigms in solving critical smart grid optimization problems, such as optimal management of distributed energy resources, economic dispatch, and demand side management [12-14]. These papers demonstrated that decentralized and self-organizing computing frameworks could sensibly improve the smart grid performances, by mitigating the effect of contingencies, and enhancing the smart grid ability to remain in operation after external disturbances and/or component failures. These benefits have been confirmed in paper [15], where an adaptation of the open shortest path first routing protocol is proposed for on-line optimal network reconfiguration. The proposed algorithm, which has been deployed in secondary substation nodes according to a multi agent-based distributed architecture, has been tested on IEEE 123 modified node test feeder and on a real power distribution system. The obtained results demonstrated the benefits of distributed and decentralized computing paradigms, compared to traditional centralized algorithms in solving complex optimization problems, in terms of scalability and robustness.

On-line smart grids security assessment represents another relevant application domain that would benefit from the development of fast and reliable data-driven optimization techniques [16]. The results of this complex computing process should be obtained according to strictly time constraints, in order to allow the smart grid operator to properly plan preventive and corrective actions aimed at removing or mitigating the effect of critical contingencies. This time-constrained requirement has stimulated the research for advanced methodologies aimed at proper selecting the list of the most credible contingencies, and at reducing the computational times of the contingency analysis process [17,18].

To address smart girds security analysis, paper [19] conceptualizes a new and efficient security analysis paradigm, which integrates cascading failure simulation module for post-contingency analysis and risk evaluation module based on a decorrelated neural network ensembles algorithm. The proposed algorithm allows to drastically reduce the computational complexities of traditional N-k induced cascading contingency analysis, as demonstrated by the simulation results obtained on several realistic case studies.

From the analyzed paper it could be argued that the conceptualization of decentralized, self-organizing, proactive, and holistic computing paradigms aimed at supporting fast decision making in a massive-data, but information-sparse environment represents a very promising research activity. This could stimulate the development of a new generation of computational paradigms aimed at enhancing the smart grid operation procedures with a set of information services for knowledge discovery and data mining. Many important smart grid applications could be benefited from the deployment of these information services, including on-line grid optimization, voltage control, security analysis, synchronized wide-area measurement, pervasive grid monitoring, real-time information sharing, energy price forecasting, and renewable power forecasting.

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