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An instrumentation engineer's review on smart grid: Critical applications and parameters

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ABSTRACT

Conventional electrical grid is transforming into smart grid—an evolutionary solution to satisfy rapidly emerging and vibrantly changing requirements of utilities and customers by intelligently leveraging telemetry concepts of instrumentation and control engineering in form of communication technology network infrastructure. The paper presents analogy of 'smart grid' to 'industrial process' and 'communication technology infrastructure' to 'instrumentation telemetry'. Automated Metering Infrastructure (AMI), monitoring and automation of substations, power network monitoring, Home Automation Network (HAN), Demand Response (DR) and integration of solar PV—have been identified as 'Critical Applications' and Reliability, Scalability, Interoperability, Congestion, Energy Efficiency, Latency and

Abbreviations: ABDP, Accumulated Bandwidth Distance Product; AEPS, Area Electric Power System; AIHC, Average Interruption Hours of Customer; AM, Amplitude Modulation; AMI, Advanced Metering Infrastructure; AMR, Automated Meter Reading; ARQ, Automatic Repeat Query or Automatic Repeat reQuest; CIM, Common Information Model; CM, Condition Monitoring or Congestion Management; CoHEM, Coordinated Home Energy Management; CoSMoNet, Cost-aware Smart Microgrid Network; CSMA/CA, Carrier Sense Multiple Access with Collision Avoidance; CT, Current Transformer; DAU, Data Aggregator Unit; DBMS, DataBase Management System; DBPC, DataBase Processing Center; DCU, Data Concentrator Unit; DDU, Dharmsinh Desai University; DER, Distributed Energy Resource; DES, Distributed Energy Storage or Distributed Energy Systems; DRES, Distributed Renewable Energy Sources; DG, Director General or Distributed Generation or Decentralized Generation; DG&S, Distributed Generation and Storage; DoS, Denial-of-Service; DR, Demand Response; DREGs, Distributed Renewable Energy Generators; DRX, Delay-aware cross layer; DSEM, Demand Side Energy Management; DSM, Demand Side Management; DSP, Digital Signal Processor; DT, Delaunay Triangulation; EMS, Energy Management System; EMU, Energy Management Unit; EPS, Electric Power System; EV, Electric Vehicles; FDR, Frequency Disturbance Recorder; FDRX, Fair and Delay-aware cross layer; FLC, Fuzzy Logic Control; FM, Frequency Modulation; FNET, Frequency monitoring NETwork; FRA, Frequency Response Analysis; FRL, Find Reliable Link; GERMI, Gujarat Energy Research and Management Institute; GFN, Ground Fault Neutralizer; GIS, Geographic Information System; GPRS, General Packet Radio Service; GPS, Global Positioning System; GWAC, GridWise®® Architecture Council; HAN, Home Automation Network or Home Area Network; HASG, High Assurance Smart Grid; HEMS, Home Energy Management System; HES, Head End System; HMI, Human Machine Interface; HWMP, Hybrid Wireless Mesh Protocol; IC, Instrumentation and Control or Integrated Circuit; ICMP, Internet Control Message Protocol; ICT, Information and Communication Technology; IEC, International Electrotechnical Commission; IED, Intelligent Electronic Device; IEEE, Institute of Electrical and Electronics Engineers; IET, Institution of Engineering and Technology; iHEM, in-Home Energy Management; ILP, Integer Linear Programming; IoT or IOT, Internet of Things; IP, Internet Protocol; ISA, International Society of Automation; ISO, Independent System Operators or International Standards Organization; IT, Information Technology; ITP, Interoperability Test Platform; ITU, International Telecommunication Union; LAN, Local Area Network; LCIM, Levels of Conceptual Interoperability Model; LOLP, Loss Of Load Probability; M2M, Machine to Machine; MAC, Medium Access Control; MAS, Multi-Agent System; MATLAB, MATrix LABoratory; MCEM, Monte Carlo Expectation Maximization; MCS, Monte Carlo Simulation; MDMS, Meter Data Management System; MPC, Model Predictive Control; MTBF, Mean Time Between Failure; MTTR, Mean Time To Repair; MV/LV, Medium Voltage/Low Voltage; NAN, Neighborhood Area Network; NCAP, Network Capable Application Processor; NCC, Network Control Center; NIST, National Institute of Standards and Technology; NN, Neural Network; ODSRAS, On-line Distribution System Risk Assessment System; OLTC, On-Load Tap-Changer; OREM, Optimization-based Residential Energy Management; PD, Partial Discharge (PDA: Partial Discharge Analysis); PERSON, PERvasive Service-Oriented Networks; PDPU, Pandit Deendayal Petroleum University; PHEV, Plug-in Hybrid Electric Vehicle; PHIL, Power-Hardware-In the-Loop; PHY, PHYsical; PKI, Public Key Infrastructure; PLC, Power Line Communication; PLCC, Power Line Carrier Communication; PMU, Phasor Measurement Unit; PPCOM, PLC Power Controlled Outlet Module; PPS, Photovoltaic Power System; PV, Photo Voltaic; QoS, Quality of Service; RBD, Reliability Block Diagram; RBTS, Roy Billinton Test System; RDAU, Remote Data Acquisition Unit; RMCPS, Remote Monitoring and Controlling Power Socket; RSS, Remote Sensor System; RTO, Regional Transmission Organization; RTP, Real Time Pricing; RTU, Remote Terminal Unit; SAS, Single Agent System; SCADA, Supervisory Control And Data Acquisition; SCSN, Spectrum-aware Cognitive Sensor Network; SCUC, Security Constraint Unit Commitment; SDG, Smart Distribution Grid; SEDAX, SEcure Data-centric Application eXtensible; SEP, Smart Energy Profile; SG, Smart Grid; SGIMM, Smart Grid Interoperability Maturity Model; SHEMS, Smart Home Energy Management System; SMGN, Smart Micro Grid Network; SMS, Short Message Service; SoS, System of Systems; SPS, Special Protection System; SSTP, Scalable and Secure Transport Protocol; TDMA, Time Division Multiple Access; TCP, Transmission Control Protocol; ToU, Time of Use; TVWS, Tele Vision White Space; UGVCL, Uttar Gujarat Vij Company Limited; UK, United Kingdom; USA (or US), United States of America; UTC, Coordinated Universal Time; VAR, Volt-Ampere Reactive; V2G, Vehicle-to-Grid; WAMS, Wide-Area Measurement System; WAN, Wide Area Network; WCRN, Wireless Cognitive Radio Network; WDM, Wavelength Division Multiplexing; WECC, Western Electricity Coordinating Counci; Wi-Fi or WiFi, Wireless Fidelity; WiMAX, Worldwide interoperability for Microwave Access; WLAN, Wireless Local Area Network; WMN, Wireless Mesh Network; WSN, Wireless Sensor Network; WSHAN, Wireless Sensor Home Area Network; WTIM, Wireless Transducer Interface Module; XMPP, eXtensible Messaging and Presence Protocol

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Communication technology
Instrumentation and control
Measurement and monitoring
Telemetry
Automation

Security – have been identified as 'Critical Parameters'. Review of recent works has been presented for each segment.

Contents

1. Introduction [1–6]

The smart grid (SG) has started attracting attention of global research community and demonstrating rapid growth potential. SG is transformation of the legacy stand-alone unidirectional non-intelligent electric grid into automatic-intelligent-adaptive system of systems for bidirectional exchange of electric power and information. Reliability of critical power infrastructures has been the area of major focus today, wherein smart grids are expected to play game changing role. SG, the modernization of conventional power grid using technological advancements, is digital automation of electric power system from power generation to customer appliance for improvements of quality, reliability, efficiency and environmental friendliness. SG facilitates for active participation of consumers with timely access and control to their energy usage. Consumers can bid their energy resources at the electric market. SG supports real-time power quality monitoring and active diagnostics to respond power quality deficiencies and reduces loss to customers due to insufficient quality of power. SG possesses the capability to anticipate and respond to system disturbances by continuous self assessment to take corrective action.

Constantly changing customer choices-behavior, increased integration of renewables, varieties of DR programs, etc. all are likely to increase the fluctuations in the ratio of produced and consumed power. Hence, utilities must make strong efforts to deal with the increasing volatility and vibrancy in classification, affordability, feasibility and final choices of power production, demand, distribution and consumption. Important features, such as Real Time Pricing (RTP), require intensive monitoring of the consumers' power consumption patterns along with close real-time asset monitoring and timely provision of control actions. This necessitates data prioritization and delay-responsiveness using communication links with sufficient reliability, data rates and latency.

Communication is expected to play quite significant role in overall SG evolution by facilitating services such as self-healing, real-time demand response and efficient use of energy. Due to the large number, distributed and intermittent nature of energy resources (e.g. wind and solar plants), SG will rely heavily on communication for super-fast balance between demand and supply of electricity. A quick and accurate match between electricity supply and demand has financial and technical benefits. This helps avoid running extra costly plants (e.g. gas turbines) on peak hours and enhances power grid stability. In order to realize the SG vision, it is necessary to have guaranteed QoS for the reliable communication and networking technology used in various SG subsystems, ranging from power generation, transmission, distribution, to the customer service applications. Rapidly growing Communication Technologies have also been proved as vital development forces deciding present and future evolutionary designs of smart grids. Recent developments in software-networking technologies and cost-effective hardware availability are supporting increasing penetration of SGs not only at large scale installations, but also at private-residential applications as well in forms of Microgrids via islanding techniques. Overall, Smart Grid promises good opportunities for future work in research and novel application developments for the growing residential as well as industrial-commercial domains in the interest of the nation.