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Research Article

Moving towards Reliable and Fault-Tolerant Smart Grid Systems

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Abstract **–** Smart Grid is significantly being initiated in all fields due to their extensive use of IT, monitoring, protection, and automation control. Safety, integrity, privacy and dependability of data with long-term sustainability using green sources of energy. Ensuring perfection in their implementation is a herculean task amidst varying environments. This paper sketches and highlights about the scope of implementing reliable, secure, error-controlled fault-tolerant techniques in Electric Grid-systems. Thus, the paper talks about the sub-units of Smart Grid systems. The discussions on opportunities due to nanotechnology and incorporation of FPGAs are part of this paper. Hence, the design of this paper is well thought-out as the critical focal junction in enhancing the future in design of Smart Grid systems.

Keywords –Reliable, Fault-tolerant, Testable, Smart Grids, Dependability of Smart Grids, FPGA

I. Introduction

The world at large is witnessing a major boom in the power transmission grid sector. Human society as a whole, economic needs and innovative technologies has catalyzed the grid revolution. The power grid stands as the autonomous backbone for delivering electricity to consumers that include centralized and distributed power generating infrastructure with varied storage systems ([1], [2]). Information Technologies (ITs) are working on par with traditional energy systems to provide a more reliable quality power from aging infrastructure with lower rates. Ever since fifty-five years ago, electrical power grids were managed and operated in a disconnected manner due to the unavailability of sophisticated software tools. Decisions were being implemented only after manual calculations and findings.

The lack of an appropriate system to enhance better cooperation and communication amongst plant operators in making the right decisions had a significant impact. Advances in IT sector, science and engineering in the recent decades can be utilized to bring in a new infrastructure using optimized tools, algorithms, and controllers. It facilitates the decisions to be carried out in short real-time scales to manage the uncertainty and erratic nature of renewable energy, quick fault diagnose to prevent cascading catastrophic effect ([3], [4]). A highly

Charging Electric Vehicles (CEV) in the vicinity with demand response-involving consumers as the core aspect. The smart grid brain will be capable of deciding on millions of constraints few seconds

Power losses today have a devastating effect, so the worldwide focus on "green" energy to incorporate distributed renewable energy resources is on demand. The consumer's willingness to actively participate in energy management and conservation brought about a revolution from an unidirectional, centralized power grid to a distributed, networked, and automated Smart Grid. Smart Meters and analytics tools facilitate a two-way energy flow between vendors and customers. Health of the grid, power disruption detection, identification of damage to grid assets and isolation of the fault to utilize the power dynamically from both renewable and non-renewable sources is the primary motive that has to sustain.

Integration of technology, materials science and engineering is guaranteed to improve the security, reliability of the Smart Grid. To satisfy the consumers by continuous delivery of power to the world in the future bringing about optimum economic growth is the prime goal. Strong support from Government, private sectors and educational institutions in delivering optimum Energy policies, technologies and innovation accelerates the process of achieving this long-term objective to bring about better innovation, technology in the same field [5]. Taking into consideration, the economic, societal issues spurted from the ever increasing population's demand for electricity; a self-healing Smart Grid is essential.

In above section (Section I), a brief overview of the Smart Grid has been presented. Section II, gives the infrastructure and working and issues of Traditional Power Grid; reasons for high demand for Smart Grid. In section III, the various technologies implemented to enhance its fault-tolerant features for a reliable Smart Grid, are explained in detail. Whereas, Section IV acknowledges the underlying challenges of Smart Grid. Finally, Section V, concludes as summary of the research carried out through this paper.

II. Literature Review

A power grid can be better understood as a vertical system with three layers. The top generation layer consisting of generators (power plants) produces power. The middle transmission system is used to transfer electrical power in bulk.

The bottom distribution network distributes the power received from the middle transmission layer amongst consumers in commercial, industrial and residential sectors. A utility company takes sole charge of a local distribution network, buys electricity from suppliers and delivers it to the users in their vicinity ([6], [7]). The present architecture of the power grid systems gives great emphasis to the transmission aspect of preference to the distribution phase. Power is distributed from the source to the consumers in the power distribution grid format. Electrical power generated at the power plant due to the spinning electrical generator is mostly a gas turbine by burning coal, oil or natural gas. The 3-phase AC power is produced in the plant as it has even power output at any given moment. Power is sent out over four wires with 3-phase power and ground. A typical power grid is depicted in Fig.1.

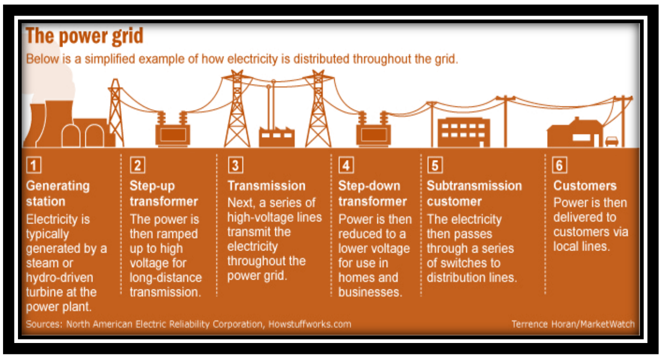

Fig 1.A brief description of power distribution

As the output of the generator, the power leaves the generator and enters the transmission substation. Here the voltage gets step-up to about 155,000 to 765,000 volts for long distance lossless transmission of for about 300 miles. A series of high voltage lines transmit the electricity throughout the power transmission grid. When the power lines reach the various sectors of consumers like industries, residential, commercial, voltage is step-down to the distribution grid at a substation in one or more phases [8]. A power substation consists of step down transformers, "bus" to split the distribution power in varied directions and circuit breakers and switches to disconnect it from the transmission grid when necessary. The power goes from the transformer to the distribution bus to produce different voltages.

Power is converted from three-phase to two-phase or single phase accordingly. At the consumer' premises, there is the main distribution box consisting of Fuses and circuit breakers which distributes power to all sections of the premises The power then enters a section through a typical circuit breaker panel.

The power industry has always witnessed a slow growth because the transformation of a large-scale power grid requires a massive capital investment and it does not happen overnight. The switch to Smart Grid has been taken seriously by the electric power industry, government bodies, and academics. Firstly, the growing power demand and the need to upgrade or replace existing equipment. Secondly, the location of power plants far from users and at the vicinity of sources of energy have greatly resulted in transmission losses up to 7.5% mostly that is dissipated as heat [9]. Thirdly, the world is taking a giant leap towards the Eco-friendly move to incorporate both renewables and non-renewable sources of energy. Certainly it is a daunting task to bring in both stable and varying power generation to provide a safe, continuous, cheap power to the consumers.

It is inevitable that an electrical grid built worldwide in a patchwork manner over 100 years will have reliability issues resulting in recurring failures. The need to solve these problems is a heated debate. Mechanical failures may lead to unstable power load supply, phase or voltage fluctuations. Even a drop of 2 Hz below 50 Hz is being sufficient to destroy the bearings due to intense development of heat leading to the circuit trip. Thirdly, two-thirds of electric power is lost in its conversion and the end only 84% of electricity generated is received by the consumers according to the facts obtained. Fourthly, the need to enhance security measures is the need of the hour due to the heavy dependence of power in the human sustenance. Fifthly, drastic climatic changes are suggesting a move towards eco-friendly power generation. Lastly, the need to shift our dependence from non-renewable to renewable sources of power.

III. Control of Smart Grid

In Smart Grid System (SGM), the control unit is used to manage the energy in real-time. Data should be converted to information fast enough to promptly diagnose the situation in order to take corrective actions dynamically with the aid of feedback loops [10]. Hence, work is verified to produce yields appropriately with the following characteristics.

- Self-healing to spontaneous repair potentially hazardous equipment from the site before failure, and reconfigure the system to deliver power to the customers.
- Flexibility to rapidly and safely interconnect generation and storage of energy in the system.
- Predictive use of statistics, models, adaptive algorithms to estimate the next most likely events so that appropriate possible events before worst events occur.
- Instructiveness in appropriating information transparently concerning the status of the system or subsystem in real time,

• Optimality in both vendor and customer point of view to most efficiently and economically manage actions.

• Security on a two-way basis to protect all critical assets of the Smart Grid.

IV. Various Sub-units in Smart Grid

Control of Smart Grid at all critical stages of transmission, distribution, and consumption points is essential. In literature, the following technologies proposed are below. To make it more readable we present Figures 2 and 3 [11].

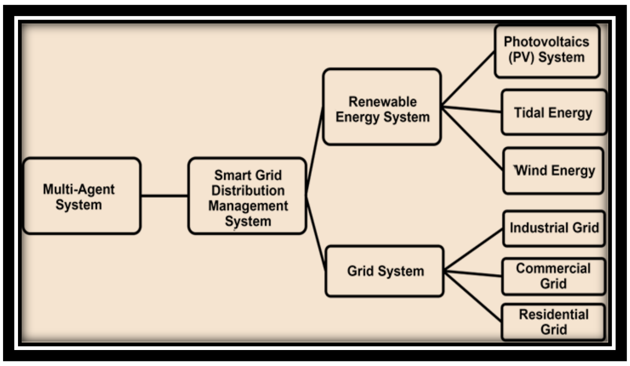

Fig. 2 Grid distribution management system

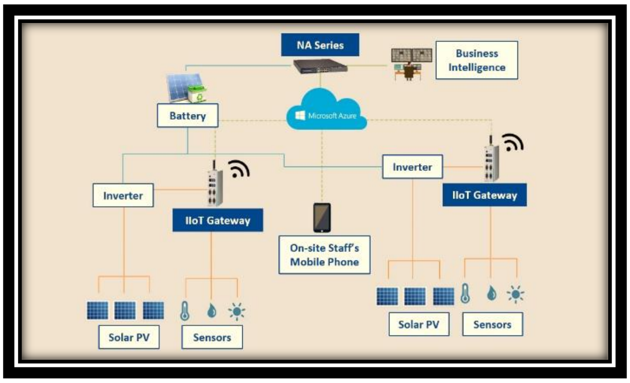

Fig. 3 A Smart grid distribution management system [11]

A. *AMI's, Demand Response and Load Management*

Advanced Metering Infrastructure (AMI) provides dual distributed consumption control and load management at both the consumer and vendor sites. Home Area Network provides automated control of home appliances through subscription services. [12] When controlled by Approximate Dynamic Programming (ADP) algorithms, self-healing capabilities that can be built in to the automated reconfiguration regimes.

B. *Flexible Power Integrated Technology*

Smart Grid devices must include power flow routers such as fault current limiters, sectionalizing switches, Flexible AC Transmission Systems (FACTS) devices, and Smart Wires meant to diffuse dynamically the power around load congestion and to intimate the officer for necessary remedial action.

C. *Photovoltaics and Solar Heating*

Photovoltaics provides local load relief for the Smart Grid when distributed coupled in a two-way flow manner from homes and offices to the Grid. However, it delivers unpredictable power but sufficient to relieve the load in a local area.

D. *Recharging of Electric Vehicles*

Recharging of Electric Vehicles and Plug-in Hybrid Electric Vehicles is needed in primary during the day prior to the journey for work that also includes a public transportation system such as subways. A part of power load is transferred to EV storage facilities and charging stations. Vehicle-to-Grid technologies (V2G) are a vital mobile source of power in emergency case of crises such as blackouts [13].

Fig. 4 Working of V2G and G2V technology [13]

E. *Micro Grid*

Micro grids are small scale, mostly independent grids that remain connected to the Smart Grid. They contain distributed generation sources, storage and EV recharging stations as a self-sustaining stand-alone grid. They can operate independently when detached from the main grid in an emergency. Building Management Systems and Heating Ventilation and Air Conditioning Systems installed in large groups of buildings are also to be included in Micro grid. They stand as potential sources of load relief in periods of peak demand. Benefits of having a strong micro-grid is the first place of reliable Smart Grid. A typical integrated micro grid management system and micro grid's elements are depicted in Figs. 5 and 6 respectively [14].

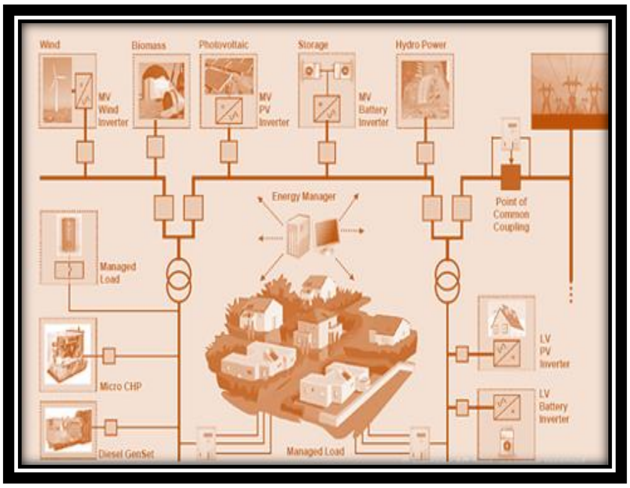

Fig. 5 Integrated micro grid management system

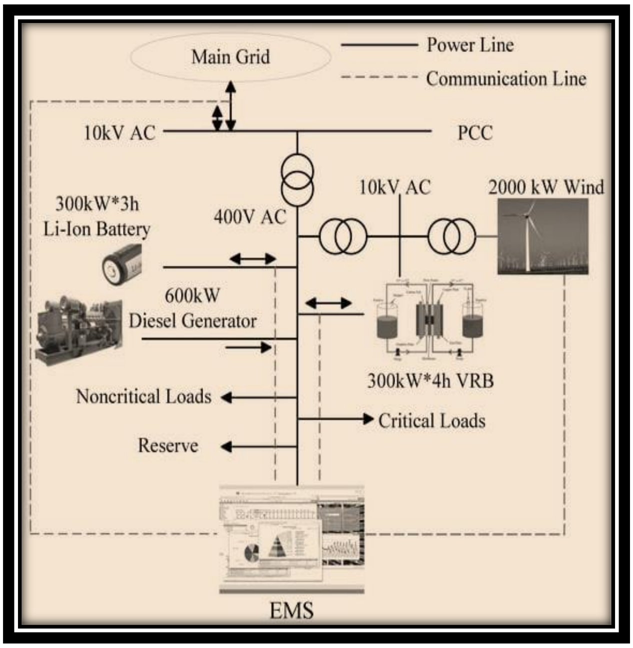

Fig. 6 Elements of micro grid

F. *Storage of Energy*

The deployment of significant energy storage facilities mitigates Smart Grid control issues. Power generated by renewable energies like PV, Solar Thermal, and Wind is stored and utilized in times of cloudy and/or windless weather. The Electricity Storage Organization tracks the cost of large and small scale energy storage systems and large scale battery storage devices. All the storage technologies are viable, if affordable and controllable.

G. *Distributed Generation*

The Smart Grid also must be able to control small-scale production owned by customers. Facilities such as Combined Heat and Power (CHP) cogeneration and emergency diesel generators will be managed along with PV, EV and micro grid sources and storage facilities in order to preserve adequate power margins at all times.

H. *Environment Alertness*

The key exogenous variable is the weather, and its corollary is accurate storm forecasting. Weather must be continuously monitored in all Smart Grid control systems. New methods linking these erratic sources of storage is necessary if we are to treat these renewable sources and sinks as dispatch table loads.

İ. *Massive Solar Thermal and Wind Generation Facilities*

Solar thermal power generation and wind turbine facilities can be used to power steam generators to produce electricity. Smart Grid must adequately predict cloud cover and weather changes in the areas of solar and wind generation plants.

J. *Opportunities due to Nanotechnology*

Smart Grid must tap the potential opportunities due to developments nanotechnology in applications in the fields of distributed energy sources and storage media. Enumerated below are benefits of nanotechnology.

- PV costs get dropped down by 100 fold or more.
- Reduction in CO2 emissions.
- Nano thermochemical catalysts that directly convert light and water to hydrogen to work efficiently at temperatures lower than 900 degrees Celsius.
- Cells get cheaper by 10 - 100 folds and they work even at low temperature with a starting reversible capacity.
- Nano-batteries, super-capacitors, and little friction nano flywheels improve efficiency by a fold of 10 - 100 in transportation and distributed generation.
- Nano- computers and Nano-sensors results in better SCADA systems,
- Nano-lighting serves as a better incandescent, fluorescent light source.
- Nano paints for the exterior of buildings that generate electricity, and ultimately.
- Quantum wires (QW) enable worldwide transmission of electricity.

V. Fault Tolerance

Various fault-tolerant techniques, which can be exploited for reducing the failure rates of the sub-units of smart grid systems independently. More complex model of fault-tolerant techniques could be exploited to reduce the down time by reducing the control of the Mean Time To Failure (MTTF) and Mean Time To Repair (MTTR). Adding the testability techniques, secure data transmission and error control with authenticated procedures ([14] - [19]) will be better options for making enhanced fault-tolerant techniques for the smart grids. That will be our future goal of investigations.

VI. Conclusion

Smart grid greatly helps in managing the growing demand for power, conserve energy, improve asset utilization, optimize grid security and reliability and reduce carbon footprint. It emerges because of the merger between the existing and emerging standards-based on interoperable technologies. In this article, a detailed explanation of basic working of traditional grid, the challenges incurred leading to the strong reasons for the emergence of Smart grids [20]. The various fault-tolerant technologies and their implementation in creating a reliable Smart Grid is envisioned.

In addition, Field Programmable Gate Arrays (FPGAs) have emerged as a reconfigurable technology, which maintains an optimal balance between processing power, energy requirements, flexibility and its high-level parallelism makes FPGAs a promising candidate for implementing composite fast fault tolerant operation based system.

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References

[1] S. Enrique, R. Gary, L Tang and X. Feng, "Getting smart," *IEEE Power and Energy Magazine*, vol. 8, no. 2, pp. 26-30, 2009.

[2] A. Ahmad, "Testing of complex integrated circuits (ICs) - the bottlenecks and solutions," *Asian Journal of Information Technology*, vol. 4, no. 9, pp. 816-822, 2005.

[3] F. Zhong, P. Kulkarni, S. Gormus, C. Efthymiou, G. Kalogridis, M. Sooriyabandara, Z. Zhu, S. Lambotharan, and W. H. Chin, "Smart grid communications: overview of research challenges, solutions, and standardization activities," *IEEE Communication Surveys & Tutorials*, vol. 5, no. 1, pp. 21-38, 2011.

[4] A. Ahmad, N. K. Nanda, "Effectiveness of multiple compressions of multiple signatures," International Journal of Electronics, vol. 66, no. 5, pp. 775-787, 1989. (6 April 2007) Available: Taylor & Francis website [Online].

[5] M. Saed, K. Daimi, N. Al-Hollow. "Smart grid security concepts and issues," *in Proc. of the World Congress on Eng., London, UK,* vol. II, pp1258-1263 July 3-5, 2013.

[6] V. C. Gungor, D. Sahin, T. Kocak, S Ergut, C. Buccella, C. Cecati and G. P. Hancke, "Smart grid technologies: communication technologies and standards," *IEEE industrial electronics magazine*, vol. 6, no. 4, pp. 529-539, 2011.

[7] V. C. Gungor, D. Sahin, T. Kocak, S Ergut, C. Buccella, C. Cecati and G. P. Hancke," Smart grid and Smart homes: key players and pilot projects, *IEEE industrial electronics magazine*, vol. 6, no. 4, pp. 18-34, 2012.

[8] A. A. Irfan, E. K Mike and T. M. Hussein, "A reliable IEEE 802.15.4 model for cyber physical power grid monitoring systems," *IEEE Trans. on Emerging Topics in Comp.* vol. 1, no. 2, pp. 258-27218-34, 2013.

[9] Y. S. Ahmed. K. V. Ganesh. "Potentials and promises of computational intelligence for smart grids," *IEEE Systems Journal*, vol. 4, no. 3, pp. 285-294, 2010.

[10] M. Sabita, Q. Zhu, Y. Zhang, S. Gjessing, and T. Basar, "Dependable Demand Response Management in the Smart grid: A stackelberg game approach," *IEEE Trans. on Smart Grid*, vol. 4, no. 1, pp. 120-132, 2013.

[11] (20 April 2023) Available: website [Online]. https://www.axiomtek.com/Default.aspx?MenuId=Solutions&FunctionId=SolutionView&ItemId=2381&Title=Smart+Grid+Management

[12] A. Hahn, A. Shock, S. Sridhar and M. Govinda Raju, "Cyber physical security testbeds: architecture, application, and evaluation for smart grid," *IEEE Trans. on Smart Grid*, vol. 4, no. 2, pp. 847-855, 2013.

[13] T. Jay, K. Randy and C. David, "Defining CPS challenges in a sustainable electricity grid," in Proc. 3rd IEEE Int'l Conf. on Cyber-Physical Systems, Beijing, China, pp.119-128,17-19 April 2012.

[14] A. Ahmad, "A Simulation experiment on a built-in self-test equipped with pseudorandom test pattern generator and multi-input shift register (MISR)," *International Journal of VLSI Design & Communication Systems(VLSICS)*, vol. 1, no. 4, pp. 1-12, December 2010.
(8 Apr 2021) The SSRN website. [Online]. Available: https://ssrn.com/abstract=3811385.

[15] A. Ahmad, M. J. Al-Mushrafi and S. Al-Busaidi, "Design and study of a strong crypto-system model for e-commerce," in Proc. 15th Int'l Conference on Computer Communication, pp. 619–630, Dec. 2002. (ISBN 10: 1-8913-6508-8).

[16] A. Ahmad, "Critical role of polynomial seeds on the effectiveness of an LFSR-based testing technique," *Int'l Journal of Electronics*, vol.77, no.2, pp.127-137, 1994. (ISSN: 0020-721 7).
(6 April 2007) Available: Taylor & Francis website [Online].

[17] A. Ahmad, N. K. Nanda, K. Garg, "The use of irreducible characteristic polynomials in an LFSR based testing of digital circuits," in Proc. *Fourth IEEE Region 10 International Conference TENCON*, pp. 494-496. 1989.
(August 2002) Available: IEEE Xplore website [Online].

[18] N. K. Nanda, A. Ahmad and V. C. Gaindhar, "Brief Communication Shift Register Modification for Multipurpose use in Combinational Circuit Testing," International Journal of Electronics, vol. 66, no. 6, pp. 875-878, 1989.
(26 April 2007) Available: Taylor & Francis website [Online].

[19] A. Ahmad, D Al-Abri, S. S. Al-Busaidi, “Adding pseudo-random test sequence generator in the test simulator for DFT approach,” *Computer Technology and Application*, vol. 3, no. 7, pp. 463-470, July 2012.

[20] N. Abosata, S. Al-Rubaye and G. Inalhan, “Lightweight payload encryption-based authentication scheme for advanced metering infrastructure sensor networks sensors, *[PMC free article]*, 2022, 22:534. doi: 10.3390/s22020534.