Smart Grid Resilience Issues & Enhancements

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Abstract - *This paper talks about generation information about the progress of smart grids, and the concepts of resilience. Then it highlights resilience issues in smart grids, in addition to solutions and enhancement techniques. The paper highlights issues like cyber threats such as FDI and DoS attacks. Natural disasters like earthquakes Typhoons, floods, wildfires, and hurricanes. Then goes to talk about some enhancement techniques such as using Energy Storage Systems, Distributed Energy reousces, Electric Vehicles ,Microgrids, mobiles devices. The paper also include application of Blockchain in smart grid.*

Key Words: Smart Grid, Resilience, Cyber-Physical Protection, Islanding, Microgrids, Natural Disaster, Blockchain

1.INTRODUCTION

With the rapid increase of demand for high quality, reliable, efficient, environmentally friendly, and affordable electricity, the movement toward the adoption and the implementation of smart grid technologies and concepts become a priority for utilities, regulators, governments, and researchers [1]. EPRI defines smart grid as a network that uses sensors, communication, and processing computers to control and enhance the functionality and the grid's ability to deliver electricity. It also is optimized to use it infrastructure like generation plants, transmission, distribution, distributed energy resources (DER) and storage methods such as batteries and electric vehicles (EV) to improve operation, decrease environmental impact, and efficiently manage the grid assets [2], as well as features like self-healing, self-monitoring, two-way communications, and two-way power flow supported by advanced metering infrastructure (AMI) [3]. With such an dramatic change in the design, behaviour and components of the grid, several challenges raised such as renewable energy integration, which due to their unpredictable nature, advanced and expensive technologies need to be integrated to an already old grid. Another issue related to cyber security. The increased penetration of components such as smart meters, Internet-of-Things (IoT), phasor measurement unit (PMU) will require safe internet connection to be reliably used to monitor and take actions that will affect the operation of the grid [4]. Natural disasters or Low-Frequency High Impact (LFHI) such as earthquakes and tornados have always impacted the reliability of the grid. With integration of DERs such as solar forms, or grid close to the sea or exposed to the environment that are easily affected by typhoons and heavy rainfall [5]. the complexity and the interconnectedness of the grid makes it interdependent on other auxiliary services such as supply chains, fuel sources, and communication infrastructure. Other challenges include physical attacks such as sabotage and vandalism, social acceptance and public participation, lack of standardization and protocols, aging grid and equipment failure, interoperability, and interdependencies [6].

The concept of smart grid resiliency was the outcome of different bodies in the industry attempting to resolve those issues and challenges. While there is lack of consensus on the definition of power system resilience due to its recent adoption, there is an agreement on its key aspects such as, robustness, resourcefulness, rapid recovery, and adaptability. The National Infrastructure Advisory Council (NIAC) defines resilience as the system's ability to anticipate, prepare for and adopt to changes in the system conditions, and can withstand and recover from events such as attacks, accidents and natural disaster in a timely manner [7][8]. The concept of resilience can be observed clearly in the resilience curve, shown in Figure-1, that is widely used to assess and quantify infrastructure resiliency [9].

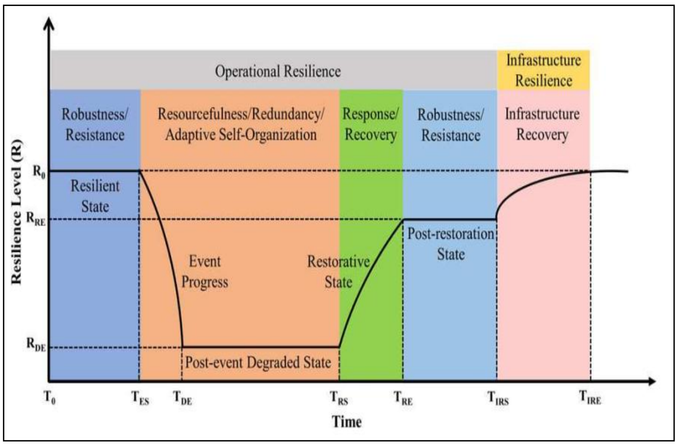


Fig -1: Curve for infrastructure resilience [9].

There are a lot of research that is being conducted to tackle resiliency issues in smart grid, and with continuous growth and new technology penetration to the grid, more issues will continue to appear. Hence, this paper will highlight some of significant published research in the field of smart electric grid resilience enhancement and impact reduction or elimination methods, especially in the field of cyber-security, micro-grid islanding, equipment failure and grid performance degradation, natural disasters, and extreme weather events.

2. Cyber Security issues

There are many components of the smart grid that are connected through the internet such as the smart meters, IoTs, home appliances and CCTV. Other are connected through private communication methods such as PMU and SCADA systems and even substations. Attacks like False Data Injected (FDI), or Distributed Denial of Service (DDosS), Man in The Middle (MITM) can impact how those component operation, and can cause severe consequences such as blackouts and restoration impacting resilience , and might affect personal such as increase in monthly bills due to lack of communication with utility. [11].

2.1 False Data Injection

The cyber security aspect of smart grid resilience focuses on performing risk assessment, prevention, detection, and mitigation of various cyber threats such as false data injection (FDI) against wide-area monitoring, protection, and control application (WAMPAC) [10]. FDI allows users to manipulate data going to the grid's data centers to facilitate energy theft, load shedding and even blocking the data from being obtained by the control centers [12].

In [13], it is proposed that an optimized coding scheme be used to detect FDIs more precisely and allow sufficient resources to be allocated to mitigate its impact. Another strategy is proposed by [14] to reduce the to detect and isolate the source of corrupted data source without impacting the operation of the grid using distributed communication schemes that can act as a secondary control system. Another scheme is suggested by [15] aimed at increasing the cyber- resilience of microgrids (MG) under FDI attacks against the grid's sensors, actuators, and communication links, by introducing a hidden control layer in addition to the standard three layers of control associated with MGs as shown in Figure-2. The hidden layer will be responsible for the timely restoration of the MG in addition to mitigating the impact of the attack to the primary control layers.

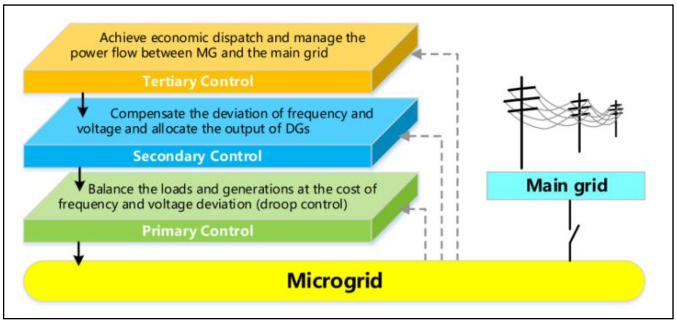


Fig -2: Standard control layers of MG [14].

The authors of [16] created a multi-sensor based temporal prediction algorithm that enhances cyber-resilience of WAMPAC by detecting bad system parameters data injected to the system such as wrong voltages that might cause grid instability or blackouts. Another scheme is designed by the authors of [17] that enables them to detect sophisticated FDI, also called CFDI, aimed the PMUs used by smart grid. Their paper introduces the concept of Secure CFDI Detection and Mitigation scheme (SeCDM) that uses decentralized computation schemes along side knowledge sharing algorithms to calculate measurement residuals and allow a centralized FDI detection scheme to analyze the data and detect any CFDI in progress. A control based defensive strategy is proposed by [18] where a sliding mode adaptive controller will ensure the reliable operation of the smart grid during an FDI by automatically updating the parameters of the control system in a way it will eliminate the effect of the FDI aimed at the actuators of the generators, or any other external disturbances such as load shedding. In [19], a lag compensation is introduced between the primary and secondary control loops of the MGs in order to create a timescale separation between them. This allows better detection and mitigation timing against multiplicative FDI attacks, in addition to increasing the frequency and voltage stability margins without the need for additional components which adds to the overall system resilience and efficiency. A fast detection algorithm is proposed by [20], using a time-varying dynamic model that reduces the worst-case delays (WDDs) of FDI attacks. This model can detect and capture the state transition changes due to attacks through a state estimation algorithm. The algorithm can differentiate between attacks and normal grid transients allowing the reduction of delays and increase grid availability and resilience. Another proposed dynamic model aimed at optimizing wide area damping controllers (WADC) to mitigate the impact of false data injection on the PMU and the shared communication methods. The strategy entitles switching the control loop from the one being attacked another one. Furthermore, a used-defined law can be programmed to detect and switch the loops if attacks were hidden [21]. A false data injection against the synchronization systems of a DER based microgrid is investigated in [22]. They proposed a mitigation strategy is to establish a system to detect rapid change in frequency of the system -which is an indication of a cyberattack- and giving signal to the governor control to react for quick system performance restoration and added resiliency. The prevention of FDI attack on Load Frequency Control system (LFC) is discussed in [23]. The work proposes training machine learning methods such as support vector machine (SVM) on the historical data of frequency, active power and load deviation in the grid to enable them to detect any anomalies. Then a proposed Kalman Filtering (KM) is used to mitigate the impact of the false data and restore the LFC to normal operation by calculating the optimal control signal. Another machine learning model is proposed by [24] in order to classify bad data and actual attempts of FDI attacks. The paper proposes back-propagation neural networks to improve the work of state estimation, in order to identify FDI. The trained model allows reduction of action time and computational power requirements. While the method of detection is getting more sophisticated, the paper in [25] suggests Remedial Action Scheme (RAS) in case detection methods have failed, and swift recovery of the grid is required. The proposed method include using deep recurrent neural network (DRNN) to optimally located FACT devices, formulate FDI attacks and combine the results to create and RAS. Another defense strategy against FDI attacks is proposed by [26]. The paper tackles FDI attacks from a network and a system wise. It aims to design a virtual hidden network connected to the physical network to overcome the structural challenges that can be exploited during an FDI attack and adds overall flexibility to the system. In [27], the threat of FDI attack toward Electric Vehicle (EV) connected to smart grid is studied to attempt timely detection. The authors use machine learning algorithms in order to distinguish between safe data and compromised data flowing through the system during peer-to-peer (P2P) transaction between EV owners, and initiate mitigation protocols with the assistance of available systems. The design of a micro–Automatic Generation Control system (uAGC) for microgrids is suggested in [28]. The proposed scheme allows microgrids (MG) to be resilient against loss of frequency control from the grid. Because of the size of the uAGC, it is able to react quickly to changes in frequency and power fluctuations during FDI attacks or normal load or renewable energy changes. Another paper focuses on the cyber resilience of AGC proposes the using of H-infinity filter to detect and mitigate transferred signals in smart grid. The H-Infinity based state estimator to detect the bad data injected into the data going to the control center and use to control the AGC [29]. A deep unsupervised machine learning algorithm is developed in order to detect false data injection into large amount of sensor across large portions of the smart grid. The proposed method by [30] uses real time and efficient algorithms to detect anomalies and causal interaction between the different subs-systems in the grid.

2.2 Denial of Service Attack

Due to the vast natural of smart grids, and interconnectedness of different components with different manufacturing and protection standard, and the grids reliance of fast and reliable internet and communication method to deliver its services, it has become a usual target for a Distributed Denial of Service attacks causing reduction in the grid resilience by increase the data loss and corruption , and therefore, the detection and correction mitigation technique is required [31]. This is done by overloading the system communication infrastructure with scam data, or wrong signals going to Remote Terminal Units (RMU) or Phasor Measurement Units (PMU) [32]. Similar to FDI, DoS is also countered using the method of Prevention, Detection, Isolation & Mitigation [33].

In smart grid, one of the forms of denial of service is denial of electric service. Smart grid allows the utility to control the flow of electricity to user through the use of Remote Connection or Disconnection (RCD) units in smart meters. Attacker might hijack the signal going to the RCD and cause service interruption to different user types like individuals or commercial as shown in Figure-3. A vast number of hijacked RCD might cause grid instability or blackouts. The paper suggested setting a time delay between the execution of signal from all RCD which allow time for detection and isolation. Also, slow changes in the load status will make it easy for the grid to stabilize. The paper also suggested methodical time delays and delay mechanisms for different cases of RCD usages and type of loads [34]. When it comes to Dos attack against micrograms, the authors of [35] discuss method to detect, location and isolate faults associated with DoS attacks. This is done by creating a discrete model that enable control centers to estimate magnitude changes in the system which is indicative of attack presence.

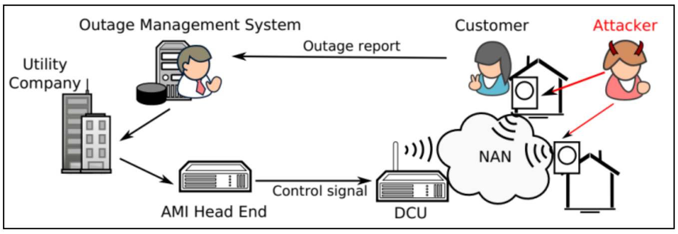


Fig -3: Typical RCD attack on customers [34]

The resilience of a load frequency system is enhanced using a predictor-based scheme in [36]. The authors study the effect of DoS attack on multi-region LFC and method of resilient restoration. Using Lyapunov theory, the authors established a set of conditions that will allow the LFC system to remain stable for longest period during different DoS attack, allowing detection and isolation time. A piecewise observer is proposed by [37] to increase the resilience of frequency regulators in microgrids through providing real-time estimate of the system's states and unknown ongoing signal. Furthermore, it provides criterion that allow the system to be stable during different cyber-attacks using H∞ controller. A machine learning based DoS detection method is proposed by [38]. The method include collecting network data and using algorithms like SVM to detect any abnormalities within this data stream. The SVM model allow distinction between normal data, bad data and data showing signs of sabotage like DoS, illegal access to remote machines (R2L), and illegal access by users (U2R). the SVM model show higher detection rate, which improve the security of the communication and the overall resilience of the grid. The uncertainty to the system caused by DoS attacks is studied by [39] to create a scheme that allows saving the communication bandwidth which help with operation continuity. Furthermore, an adaptive H∞ controller is introduced based on Lyapunov-Krasovskii to improve stability during DoS attacks as shown in Figure-4. By implementing this scheme into the LFC system, it will allow the triggering of mitigation method in early stages, while maintaining the stability of the operation.

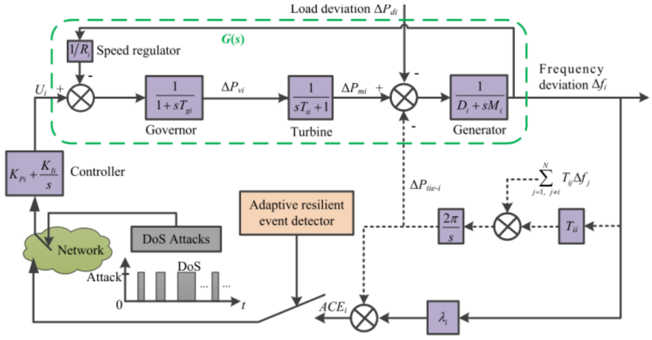


Fig -4: event-triggered LFC during DoS attack [39]

In [40], a protocol to provide resilience against DoS attacking using Flocking-Based method is proposed. The consider data packets inside the network interact similarly as flock of birds. Studied flocks behavior like centering and matching were associated with smart grid parameters like phase angles, and frequency synchronization. This similarity allowed the author to based their resilient communication protocol to be based on flocking models. In [41], the defense against load altering attacks is studied. unlike typical methods, the authors propose a model-free approach that deal with actuator faults using simplified representations of the system. The paper showed that model-free approach demonstrate great performance against data packet losses caused by DoS.

3. Natural Disasters

Natural disasters are one of the main resilience issues of smart grid, as many of the recent blackouts in the world were accredit to natural disasters. Data from the USA are shown in Table-1 [42].

Table -1: Large Blackout Causes in the USA [42]

Type	**% of events**	**Mean size in MW**	**Mean size in customers**
Earthquake	0.8	1,408	375,900
Tornado	2.8	367	115,439
Hurricane / tropical storm	4.2	1,309	782,695
Ice storm	5	1,152	343,448
Lightning	11.3	270	70,944
Wind/rain	14.8	793	185,199
Other cold weather	5.5	542	150,255
Fire	5.2	431	111,244
Other external cause	4.8	710	246,071

In [43], the authors studied the effect of earthquakes on smart grid with great DER penetration. They propose that while increasing DER improves energy availability, it does increase the chance of being impacted by localized earthquakes. The paper [44] establishes a framework for evaluating and improving the resilience of small grids or Island City Integrated Energy system (IC-IEC) by analyzing both failures on system and component wise to allow the establishment of recovery strategy in case of earthquakes and increase the resilience of the system. A dynamic restoration strategy is proposed by [45] to minimize the power outage after events like earthquakes, which helps with the grid resilience. Their algorithm will be fed with real-time data about the event happening, available DERs and grid condition, allow it to dynamically produce a grid reconfiguration plan that will provide optimal amount of power for the impacted area. The paper [46] proposes a economically practical approach to move from reliability based network investment to resilience based one. This is done by identifying the best network investment that have resilience against risks like earthquakes or other HILP events. A distribution network resilience enhancement method based on energy storage is proposed by [47]. The historical data of earthquake location and magnitude are modeled and studied to determine the location and the sizing of Battery Energy Storage Systems (BESS) are determined in order to supply critical loads during earthquakes in a resilience and timely manner as shown in Figure-5.

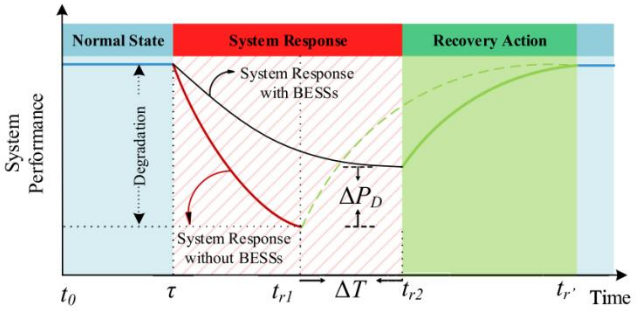


Fig -5: Response of BESS due to earthquake [47]

In [48], a quick restoration of power supply using the energy stored in local electric vehicles (EV) through the concept of vehicle-to-grid (V2G) is proposed. The paper introduced a recovery model that uses data of network faults events, EV users behavior and travel patterns to create a spatial and temporal distribution that serve as a dispatch plan for post-disaster restoration strategy. Addition enhancement strategies to the distribution network were introduced in [49] by going through the historical data of the region, and allocating distributed generation (DG) units in certain nodes that will allow power restoration to that area post-earthquake. Mobile generation units such as Mobile Emergency Generator (MEGs), Truck Mounted Energy Storage System (MESS) and electric vehicles (EV) can be used to enhance the resilience of the distribution network by offering rapid restoration of power during high impact low probability events like earthquakes [50].

Hurricanes are one of the natural disasters that had a lot of impact on the grid causing large blackouts such as the one in Texas winter blackout in 2021. By implementing the fragility curve, the authors of [51] identified the probability of line outage due to high wind speed associated with hurricanes. In addition to that, they considered risk of overloading lines, load shedding to create a risk-based assessment. Another team created a spatio-temporal hurricane impact analysis (STHIA) to quantity the damage of hurricanes on the power grid based on the historical data of the region and potential risk factors, which can be used in the design of the grid [52]. A Markov based pro-active dispatch process is proposed by [53] to prepare an optimal generation location and dispatch plan before incoming hurricane or typhoon and post-even operation which reduces curtailment and increases resilience. Another stochastic model is developed in order to predict the chance of flood caused by the hurricanes that might impact substation. Resilience is enhanced by protection important energy distribution hubs from going offline due to floods [54]. The authors of [55] took into consideration minimizing the power curtailment during hurricane in addition to considering the financial costs of creating a hurricane resilient generation dispatch plant, and considering the consequences of such strategies after system returns to normal. Increase the resilience of the distribution grid through optimal placement of switches. The paper [56] simulates the impact of the hurricanes on the availability of different components of the smart grid. Then an optimization model is used to place the switches where it is more resilient during HILP events. In [57], the resilience of the transmission line and the generation plants are simulated with the consideration of capacity lost, restoration costs and the damage to the system. The paper managed to demonstrate how increase of DER might impact the resilience negatively without proper modeling and placement. Another resilience enhancement method during hurricanes is proposed by [58]. Using Dynamic Micro Grid (DMG) to improve the resilience of a smart grid partition during hurricane is proposed. The paper also use simulation to highlight the difference in resilience improvement between Fixed MGs and Dynamic MGs. The proposed enhancement method uses optimization formulations for deploying the two types of micro grids during a hurricanes. The simulation showed the DMGs can carry more load during grid failures than FMGs as shown in Chart-6.

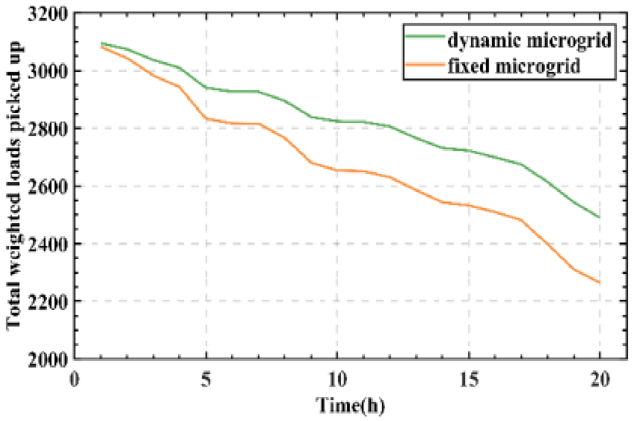


Chart -1: Picked up loads by two types of MGs during restoration from hurricane [58]

By combining the data from hurricane prediction algorithms, and the proactive prediction of grid line outages during hurricanes, a hybrid model based on component fragility curve, simulation, and scenario reduction algorithm, is established. This model enhances the planning and deployment of grid resources while considering line outages [59]. Another proactive strategy is suggested by [60] to optimally locate DERs and the optimized formulation of the microgrids that can serve optimal amount of loads during interruption. In [61], the deployment of mobile emergency resources is considered during hurricane to supply the islanded critical loads. The proposed algorithm also produces the best deployment location, path to location optimization, transportation and any constraints in terms of available infrastructure such as blocked roads or non-critical loads.

A method to enhance resilience during typhoon disasters is highlighted by [62]. The proposed scheme involved optimal preventative scheduling approaching in addition to taking actions toward optimizing the topology of the transmission line to maximize power delivery. Furthermore, the authors of [63] attempt to tackle the issue of uncertain path that typhoons takes and consider a three-stage day-ahead unit commitment for the generation unit. This will allow optimal dispatch during the disaster and during restoration. This is done by implementing stochastic model for typhoon paths. In [64], resilience would be considered during the planning stages of transmission system and components by creating a probabilistic typhoon model incorporated into fragility curve. A Regional Integrated Energy System (RIES) optimal operation through coordinated optimization considering available energy equipment and demand response is create by [65]. The paper proposes an enhancement for RIES during typhoons allowing optimal operation.

In [66], an overall review of the impact of wildfire on different parts of the smart grid is conducted. The paper highlights different actions that can be taken before, during and after the wildfire impacting the grid. This includes forecasting risks and damages, state estimation, preventive and corrective actions, and restoration and the end of the event. The authors of [67] and [68] discuss several impacts of wildfires on the smart grid system damaging transmission towards causing the collapse of the line. In addition to the particles and smoke from the fire impacting the properties of the insulation and the conductors. An increase of conductor temperature would increase resistance and cause expansion and sagging. The paper [69] discusses protective generation plan and unit dispatch strategy to allow the mitigation of the impact of the wildfire. It also utilizes Markov decision process to model the condition and provide the operator of the system to take rapid decisions that ensure the resilience and the reliability of the grid and reduce curtailment of power and costs. The fire growth, progression and trajectory is also simulated in [70] as a way to enhance understanding of required preventative response and impact to the grid as shown in Figure-6.

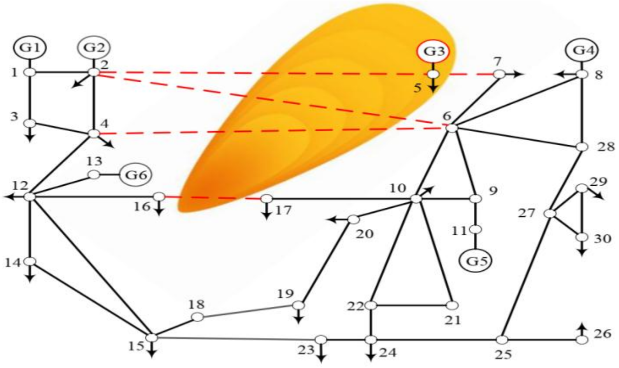
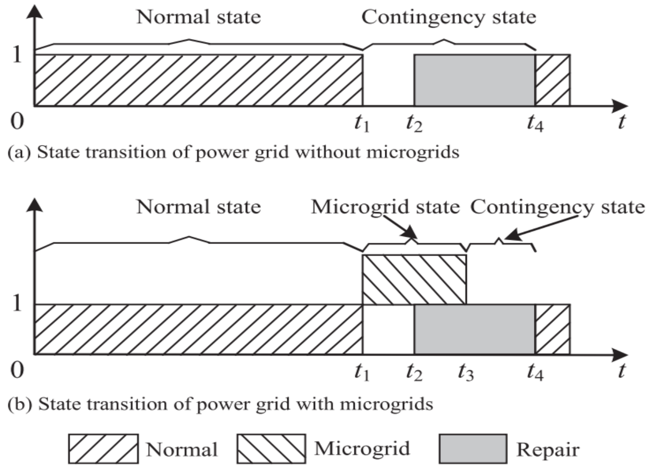


Fig -6: wildfire progression on simulated IEEE 30-Bus system

In [71], the paper attempts to simulate a wildfire event and its impact on the components of the power system. The proposed method will allow mitigation of the impact of the wildfire, in addition to identifying the behavior of the fire such as intensity, arrival time, path and ignition point. This allows better decision making, planning future strategies. The authors of [72] studied the impact of wildfires on the dynamics and performance of micro grids. The paper models the wildfire in form of heat gain and heat loss, and then uses optimization method to decrease the impact of the fire on the power delivery with restraints on DERs, ESSs and power balance. EV penetration can also impact the grid's resilience against wildfires. In [73], suggest the impact of mass EV mobilization and charging requirements during wildfires. A model is designed to simulate EV users evacuating and charging their cars during an event. In [74], the authors provide an optimal expansion strategy to the stake holders of the grid supporting their decision to add new transmission lines, or enhancing the resilience of the current infrastructure in addition to development of new Distributed Energy resources (DERs). The use of deep reinforced learning to analyze that that can be used by the operators to take decision during wildfires to improve the resilience of the grid is investigated in [75]. Wildfire propagation model, and Markov decision process is used with IEEE test system showed this approach can help reduce load by reducing power flow into damaged lines. In [76], micrograds are used to improve the resilience of the grid during wildfires. This is done by integrating several micro grids in strategically placed location to allow different operational mode to be entered easily. Similar work is done by [77] which focuses on the optimal location for micro grids to improve the resilience of the grid during extreme weather while overbudgeting. Improving the resilience of the existing grid against wildfires and other natural disasters by replacing wood transmission poles and vegetation management [78]. The authors of [79] propose a flexible scheduling strategy using EV ax auxiliary power source in case major DERs went offline due to wildfires or other disasters. The optimal scheduling and location will be determined using two-stage model considering the random behavior of EV users. A multi spatio-temporal resilience assessment strategy against extreme weather is suggested by [80] using assessment techniques incorporating the fragility curve and statistical simulation in order to build a real-time mapping of the grid components and their failure potential against events like high wind speed. A similar planning strategy for the long-term resilience of the electrical network that combats extreme weather events is proposed by [81]. The framework will consider high penetration of DERs, IRES and will include mitigation techniques based on the improved design of the grid. A simulation base don fragility curve is used to create a strategy for defensive islanding during extreme events [82]. The strategy includes dividing the system into stable and safe sections, and sections that can be at risk of cascade failure, or might impact the operation of other sections of the grid. The use of microgrids to improve resiliency is also proposed in [83]. The authors analyzed the mechanism extreme events affect he resilience of the smart grid, and used Markov and Monte Carlo simulation to output a strategy for deploying microgrids to supply power to load,. The effect of the microgrid can be seen in Figure-7. In [84], the authors attempt to tackle the issue of reactive power shortage during an extreme event because of DERs inability to produce enough. The paper proposes different optimization techniques that will optimally dispatch networked microgrids to improve reactive power magnitude and overall mitigate the impact of the extreme conditions.



(a) State transition of power grid without microgrids

(b) State transition of power grid with microgrids

Fig -7: Grid operation with and without microgrid [83]

4. Smart Grid Resilience Enhancements

A frequency control method based on distributed energy storage devices is proposed in [85] as a method to increase the resilience of the grid during abnormal grid transients enabling the grid to overcome rapid frequency changes and accelerate synchronization and stability of the system. In [86], a framework is established to use DESS to overcome frequency and voltage transient issues during cyber-attacks or natural disasters. The paper [87] reviews the method of which battery and energy storage systems (ESS) can improve the resilience of the smart grid. If the operation of the grid was hindered due to severe weather, sabotage of theft, battery systems can take over the lost loads, and supply them with power. The battery systems can be dispatch to damaged grid locations, and help create and support microgrids to compensate for lost load, speeding up restoration and increasing resilience at the same time as shown in Figure-8.

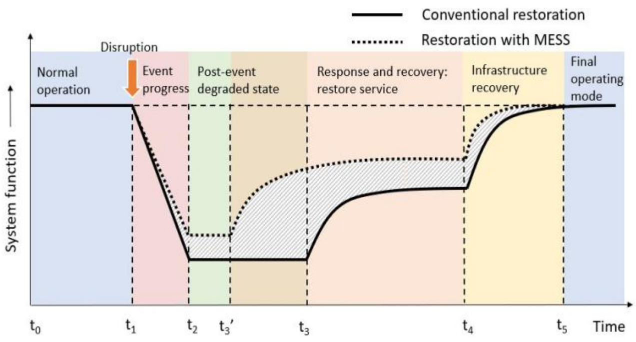


Fig -7: Grid Resilience with and without ESSs [87]

An optimization method that can optimize the economics of a new Energy Storage Systems (ESS) and the best location and routing to be considered during a crisis is proposed by [88]. The model will also provide information about the optimal dispatch to create a high resilience microgrid to support smart grid during failures. The application of mobile energy storage device to enhance the resilience of the smart grid is studied in [89]. The paper shows the advantages of mobile energy storage such as fast deployment time, better control schemes and infrastructure, and load serving capabilities. Also batteries are more environmentally friendly comparing to mobile diesel generation for example. Furthermore, the mobility of the system allow its installation in more economically and technically feasible locations as demonstrate in the Figure-8.

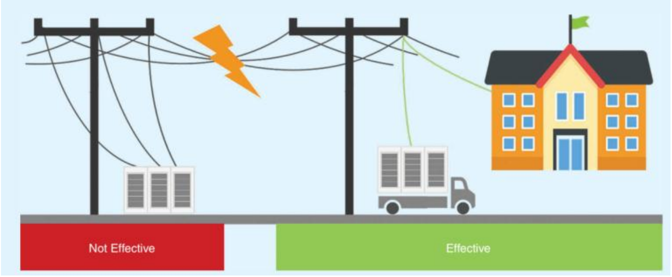


Fig -7: Effectiveness of Mobile vs. Fixed ESSs [89]

In [90], an optimization model is created to optimize the location and the capacity of the energy storage system with technical and economic restrictions such as operating costs, accessibility for power demand and non-black-start (NB-S). the work also extends to proper sizing and location of photovoltaic cells (PV). In [91], the distributed energy storage devices owned by individuals are examined to perform a resilience enhancement task during crisis. The paper creates a framework for optimizing the process of selling and buying electricity from individuals and MGO to increase microgrid availability [92].

In [93] proposes using Smart Contracts through Blockchain technology to enhance cyber security by decentralizing the energy management and data processing hubs which makes it extremely difficult to manipulate date it requires the verification of 50% of the nodes in the network and passing different consensus algorithms. Furthermore, it introduces using Smart Contracts that facilitates P2P transactions between small and commercial power producers without established trust or prior communication and encouraged more small producers to connect to the grids, which reduces interruption times, and increases the resilience of the grid. This allows rapid energy transaction during disaster and peak demand, increase the grid overall resilience. Blockchain is also used to enhance the security and improve the communication between the Distributed System Operators (DSO) and the localized AMIs during power transaction between DERs owners and the grid. The role of blockchain is to create a high security, transparent and private communication between the DSOs and smart meters that enable the exchange of real-time pricing, energy consumption data and patterns, diagnosis, billing, planning and prediction[94] . the peer-to-peer (P2P) transaction in smart grid would also be more secure and rapid allowing prosumers to inject energy from their DERs and DESSs which help with supply electricity during peak demand or loss of generation units due to crisis [95]. Taking advantage of the blockchains security features to use smart contracts to buy and sell electricity in increased speed, scale, and high security levels [96]. The authors of [97] show the blockchain security features in the energy trading between DSOs and independent energy suppliers and prosumers, and how it can improve the resilience of the grid due to available energy supplies. In [98] highlight further advantages of blockchain to counter some cyber-attacks by detecting abnormal data in the system, and due to the decentralized property of the blockchain, countering cyber attacks is facilitated through rapid detection and mitigation techniques. It also provides real-time transparent transactive environmental improving demand and supply management and allows secure participation of different parties in the grid like prosumers, EV owners, and DSOs. Enhancing the resilience of the energy market using blockchain is studied in [99]. The paper proposed blockchain technology to establish self-sovereign Identify (SSI) allowing user to control their market identity as a method of secure trading energy through the blockchain smart contract technology. By encouraging all grid participants to become SSIs, the transaction will become more secure, and faster since SSI provide trust and identify customers during the creation of the identity. The proposed framework is shown in Figure-8.

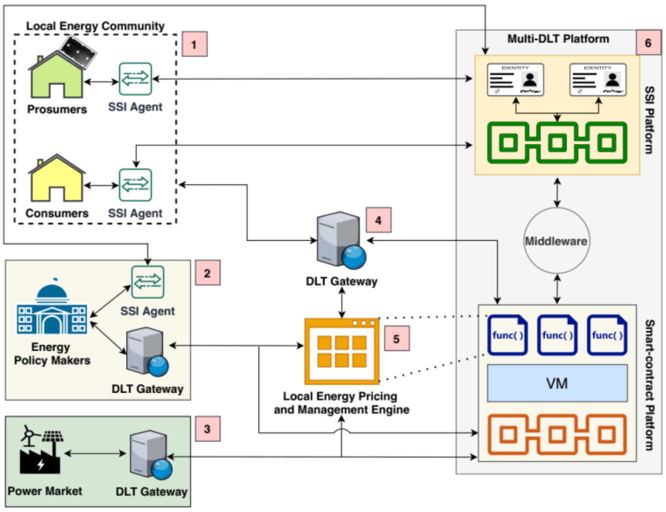


Fig -8: framework of using SSI in Blockchain as a means to enhance energy trading and therefore, increase resilience of the grid [98].

A distributed predictive control scheme using blockchain as infrastructure is proposed by [100] to provide DC microgrids with high levels of security for their two way communication protocols to prevent any sabotages or cyber-attacks. The control strategy will improve proactive resilience and the robustness of the DC microgrid. It also takes advantage of blockchain's resilience toward hacking to improve the security of the DC micro grids without compromising the systems ability to intervene during peak demand or during natural disasters or grids loss of generation units.

Reliable and autonomous Microgrid are main part of a resilient smart grid. It connects loads with DERs and allows customers to have a secure and reliable source of electricity, especially during anticipated disasters [101]. In [102], the location of microgrid location is determined using information about the critical infrastructure available along a certain geographical area, such as gas lines, water treatment facilities or hospitals. One method to improve the resiliency of microgrids is to implement FACTS devices into the design of microgrids to allow trouble-free transition between grid-connected mode to islanded or autonomous mode of MG operation [103]. This allow maintaining frequency and voltage withing acceptable range of operation, which can help loads to maintain normal operation. If the network is very large, then implementing microgrids would increase the resilience of he grid while maintaining economical feasibility. The case of the European grid [104], which require increase of capacity through penetration of DERs, DESSs and introduction of backup generation which are part of a typical scheme of microgrids. In [105] different advantages of microgrids are highlighted. During failure of certain point of the transmission or distribution network, the load connected to affected node can be fed from a different microgrid connected through different routes. Furthermore, if the microgrid was fully isolated from the grid due to disaster of man-made failure, it can operate in islanded mode to supply the local connected load reliably. Different failure scenarios can be seen from Figure-8.

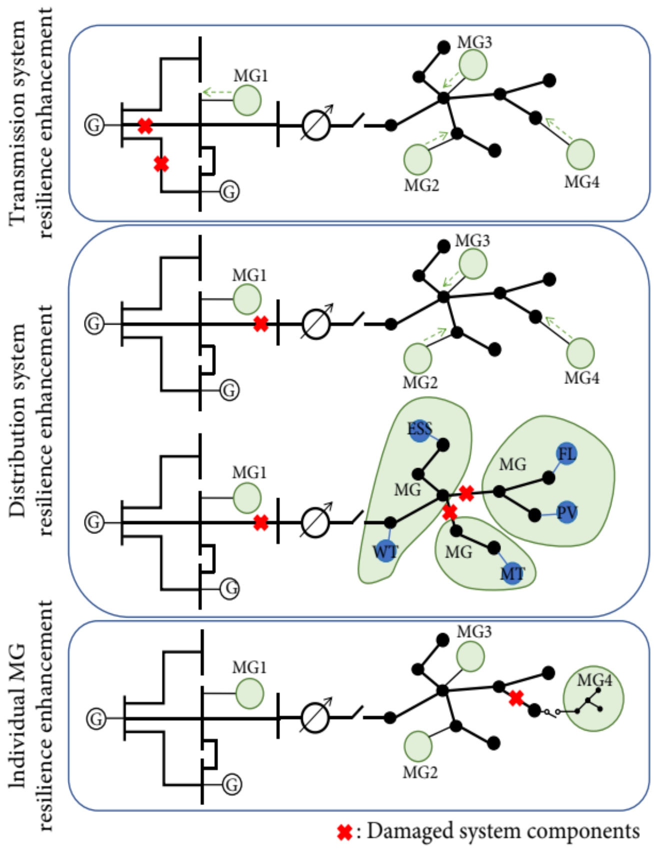


Fig -8: Resilience improvement of grids using MG during different failure events [105].

In [106], the authors suggest proper planning and deployment of microgrids in future smart grids in order to counter the impact of natural and made-made disasters on the power system. The study showed resilience against issues like islanding, cybersecurity, and natural disasters. The authors of [107] review different resilience aspects of networked microgrids (NMG). The study shows that NMGs improved grid resilience during large scale outage compared to standalone microgrids or standard outage management protocols. This is due to NMG's coordination that maximizes the utilization of the power supply available. Furthermore, NMGs can take power from regular utility network allowing more coverage of customers. In [108] the resilience oriented microgrid formation and scheduling is discussed. Formation help with determining the switching plan and the boundaries of each MG to allow maximum coverage of loads during different scenarios. The scheduling part focuses on optimal energy dispatch in terms of meeting demand and optimizing costs. Microgrids are also flexible when it comes to location, operating voltages and concepts, connected DERs and operational modes as they can be connected to other microgrids, utility gris or operated in standalone [109]. During accidents, the DSO is able to convert the operation mode of microgrids to islanded mode to serve local critical loads as studied in [110]. The autonomous microgrid can manage the DER to supply sufficient power to the connected loads. As a matter of fact, if the microgrid has enough generating units, it might become the primary source of energy while keeping the utility as a secondary source. The paper [111] highlights the role of microgrids in overall grid resilience during disasters and peak demand, and its ability to manage alternative energy sources optimally so that changes in load in the main grid will not impact the normal operation. In [112], the authors investigated the properties that makes a microgrid more resilient to different natural and man-made events. With he objective to recover and supply critical loads the moment disaster happens, the location and sizing of microgrids are important. Furthermore, interconnecting the microgrids to different and critical nodes in the grid will help increase the resilience and the effectiveness of microgrid in restoring loads. The paper [113] proposes a two-stage approach to restore power to critical loads after a HILP event. The stages include configuration of the connected microgrid to supply damaged sectors, and the next stage is to use demand response from the critical load to optimally supply them with electricity. The algorithm proposed will also plan to integrate the microgrid back to the main grids or creating new circuits with the non-effect switches and lines after the event passes. The small signal stability of the grid might cause frequency propagation and eventually blackouts if not controlled properly. In [114] microgrids are used to improve the dynamic resilience of the microgrid through the use of power-electronic interfaced energy resources. This is done by using several optimization techniques to find the optimal operational points and stability margins. The stability of the microgrids would add up to the overall resilience of the smart grid. The paper [115] also introduces the concept of electric springs that improve microgrid responses during fluctuating renewable distributed energy resources, by acting like an inertial mass like flywheel in transitional generators.

In [116], the propose an optimization technique to select the optimal location for the generators in microgrids. The paper tackles issues related to the discrete nature of selecting the location of the DG and the continuous nature of sizing the generator in addition to integrating a cost function to consider the economic factor. The authors of [117] suggest Intentional Islanding Techniques (IIT) in order to mitigate the impact of severe conditions and allow better probability to serve critical loads. A machine learning model is created to predict the chances of failure of different components of the microgrid during disaster using historical data , and suggest optimal location and deployment scheme [118]. A Decentralized decision making algorithm is proposed by [119] in order to allow optimal decision making in case control centers were impacted by HILP events through a consensus based system.

Electromagnetic Pulse (EMP) is one of the rare natural phenomena that would several damage the smart grid. EMP can disable entire electrical and electronical infrastructure in short period of time. The authors of [119] study the impact of EMP on the smart grid. The impact can vary from no effect at all, to complete destruction of the Printed Circuit Board (PCB) that is a core part of every device in the smart grid. The only method to restore service is replacement of those PCBs. Furthermore, EMP would bring a cascade damage to all connected equipment such as transformers, communication and protection devices, and generators. Table-2 shows the impact of different type of EMP on the component of typical electrical Grid. Possible mitigation techniques include installing protectors on critical equipment like communication devices, inverters, and power supplies. Protectors include Faraday cages, mesh wires, or installing them deep underground.

Table -2: Impact of HILP EMP on Smart Grid [118]

Equipment At Risk	EMP (Nuclear)	Solar Storm	Cyber	Physical Attacks
Generator Stations	DPE	DEU	DPE	DPE
SCADA / 1ndustrial Controls	DPE	DPE	DPE	DPE
Utility Control Centers	DPE	DPE	DPE	DPE
Transformers	DPE	DPE	PPE+CE	DPE
Telecommunications Including Cellphones	DPE	DPE	DPE	CE
Internet	DPE	DPE	DPE	CE
Radio Emergency Communications	DPE	TE	CE	CE
Emergency SATCOM Communications	DPE	TE	CE	CE
GPS	DPE	TE	CE	CE
Transportation	DPE	CE	CE	CE
Water	DPE	CE	PPE+CE	CE

DPE = Direct Permanent Effects
EU = Direct Effects Uncertain.
CE = Cascading Effects (if no backup power).
DPE+CE = Potential Permanent Effects plus Cascading Effects.
TE = Temporary Effect (0.5-36 hours) assuming backup power.

The restoration speed is a significant part of the resilience of the grid. In [121], the optimal strategy to restore the grid after HILP event have passed is determined using optimization algorithms that ensures that power is restored to critical loads using secondary network nodes through technical information about grid condition, available equipment, future demand for the loads and implementation of restorative computerized procedure. Another restoration strategy is suggested by [122]. It is assumed that after a major unplanned outage, the energy sources by normal utility feeders will be scarce. One method to rapidly restore electric power is the use of available mobile emergency resources such mobile energy storage system, or dynamic microgrid. A model is created to optimally determine the path to travel to critical grid nodes to be supplied by the MESs. When the best routes are determined, the critical loads nearby are scheduled to be fed. The restoration method proposed by [123] implements a restoration strategy based on Electrical Vehicles. Restoration using optimized location of DERs considering typical load flow to critical loads are suggested by [124] as a method of rapid restoration and resilience increase of the smart grid. The paper [125] suggests a Resilient Distribution Network (RDN)that consists of DERs that support the effort to restore energy to all critical loads. This is done by restoration area plans with partial load restoration such as hospitals or military camps. Then each area will have a deployed DERs that can sustain its energy needs until utility is returned to service. A mathematical optimizing problem is created to optimally create electrical boundaries for the RDNs. The authors of [126] suggest similar work utilizing dynamics microgrids and Markov decision making algorithm to support critical loads.

3. CONCLUSIONS

In this paper, resilience issues facing smart grid were surveyed and summarized. The topics ranged between cyber threats such as FDI and DoS, Natural disasters like earthquakes, typhoons, hurricanes and floods. In addition to some general enhancement techniques to improve the resilience against know issues in Smart Grid.

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