Literature Review

Utsav Sharma

May 2021

1 Microgrids

1.1 What is a Microgrid

A Microgrid is a localized group of electricity sources that under normal circumstances connect to a traditional electrical grid or main grid. Microgrids are smaller versions of a centralized electricity system. They are constructed to achieve local goals of the community being served. Local goals can include reliability and carbon emission reduction.

Microgrids generate energy with the help pf Renewable Energy Sources (RES) such as Solar Energy Wind Energy and many more. Renewable energy has is very beneficial as it provides clean and non-pollutant energy but has a major shortcoming i.e. its intermittent nature. Microgrid has the ability to disconnect itself from the main grid and to operate in islanded mode and function autonomously. This comes in handy in multiple situations as it can function properly in power outages.

Microgrids generate power, distribute, and regulate the flow of electricity on a local scale. Smart microgrids are a good way of integrating renewable resources at the community level and also let customers participate in the electricity business. Microgrids are one of the building blocks of the perfect power system. [11]

1.2 Importance of a Microgrid

Microgrids are a great, reliable backup source of power in times of need. They should be considered because they cut costs and give communities access to clean energy which is environmentally friendly. They can connect to local resources which would be too small and unreliable for an entire grid system, resources like a local waterfall or unused fields which would otherwise remain unused are great resources to power a microgrid.

Power cuts annoy everyone and microgrids could be the solution to ensure an uninterrupted flow of power which would be particularly useful in hospitals and research centers. Microgrids indirectly allow for the development of undeveloped places because of the reliability of energy consumption that comes with them. [11]

1.3 Microgrid Shortcomings

Although microgrids offer a spectrum of advantages, its implementation and various features are still associated with multiple difficulties. They can be listed as-

- **Bidirectional power flow-** Microgrid includes distributed generators of low capacity, which cause power to flow in both direction which can lead to complexity in protection coordination and undesirable power flow pattern.
- **Power quality issues in ac/dc microgrid**
- **Low Inertia-** Microgrids have low inertia in order to maintain its power electronic interfaced DG's, which improve the systems dynamic performance. But when in isolated mode, the low inertia causes high rate of frequency deviations.
- **Islanded mode of operation-** Microgrid shifts from grid connected to islanded mode due to faults or voltage drops. In this situation, the power flow, voltage and frequency control become a major challenge for reliable and efficient operation.
- **Coordinated control of Multiple DG's-** Microgrid consists of multiple distributed generators and proper coordination control of these DG's is a matter of great concern.
- **Energy Storage Options-** The Renewable Energy Sources are very intermittent in nature and which leads difficulties in continuation of power supply. Energy storage systems not only stabilise load and generation imbalance but, also help in safe and reliable operation of microgrid.
- **Economical and Reliable Operation**
- **Technology and Cybersecurity-** Availability of low cost technology for safe, reliable operation along with need of proper control and technology for integration of renewable sources is a key challenge. [14]

2 Scenarios for Microgrid Simulations

The aim of my project is to create a virtual environment for a microgrid with the help of a Microgrid Simulation tool and then run simulations on different scenarios of a microgrid. These scenarios are-

- Temperature above a certain value i.e. a very humid day- With more energy being generated, the microgrid can store that extra energy in Energy Storage Facilities also known as Batteries.
- Rain affected or a Cloudy day- With more rain during the day, the microgrid won't be able to generate minimum required electricity for the day. In such cases, the microgrid usually uses stored energy.

- System failure- System failures usually occur in the main grid and the microgrid disconnects itself form the main grid in order to run in island mode.
- Addition of new buildings- With the addition of new buildings, more electricity will be required to run those buildings efficiently.
- More solar panels being used for energy generation- With more solar panels being used, more energy will be generated.
- More appliances requiring energy in several buildings- The energy requirements of these buildings will go up and they will require more energy to operate successfully.

These scenarios are further discussed in the Summary of Key Artefact Literature Section.

3 Relevant Literature Artefacts

- A. Bani-Ahmed, M. Rashidi and A. Nasiri, "Coordinated failure response and recovery in a decentralized microgrid architecture," 2017 IEEE Energy Conversion Congress and Exposition (ECCE), Cincinnati, OH, 2017.
- M. D. Phung, M. De La Villefromoy and Q. Ha, "Management of solar energy in microgrids using IoT-based dependable control," 2017 20th International Conference on Electrical Machines and Systems (ICEMS), Sydney, NSW, Australia, 2017.
- S. Aslam, H. Herodotou, N. Ayub and S. M. Mohsin, "Deep Learning Based Techniques to Enhance the Performance of Microgrids: A Review," 2019 International Conference on Frontiers of Information Technology (FIT), Islamabad, Pakistan, 2019.
- A. Khodaei, "Resiliency-Oriented Microgrid Optimal Scheduling," in IEEE Transactions on Smart Grid, vol. 5, no. 4, pp. 1584-1591, July 2014, doi: 10.1109/TSG.2014.2311465.
- Abhishek Pokhrel, Vikash Katta, and Ricardo Colomo-Palacios. 2020. Digital Twin for Cybersecurity Incident Prediction: A Multivocal Literature Review. In ¡i¿Proceedings of the IEEE/ACM 42nd International Conference on Software Engineering Workshops¡/i¿ (¡i¿ICSEW'20¡/i¿). Association for Computing Machinery, New York, NY, USA, 671–678. DOI:https://doi.org/10.1145/3387940.3392199
- K. Josifovska, E. Yigitbas and G. Engels, "Reference Framework for Digital Twins within Cyber-Physical Systems," 2019 IEEE/ACM 5th International Workshop on Software Engineering for Smart Cyber-Physical Systems (SEsCPS), 2019, pp. 25-31, doi: 10.1109/SEsCPS.2019.00012.

- Sushrut Thakar, Vijay A.S., Suryanarayana Doolla,System reconfiguration in microgrids, Sustainable Energy, Grids and Networks, Volume 17, 2019, 100191, ISSN 2352-4677, doi.org/10.1016/j.segan.2019.100191.
- B. Yu, J. Guo, C. Zhou, Z. Gan, J. Yu and F. Lu, "A Review on Microgrid Technology with Distributed Energy," 2017 International Conference on Smart Grid and Electrical Automation (ICSGEA), 2017, pp. 143-146, doi: 10.1109/ICSGEA.2017.152.
- W. Danilczyk, Y. Sun and H. He, "ANGEL: An Intelligent Digital Twin Framework for Microgrid Security," 2019 North American Power Symposium (NAPS), 2019, pp. 1-6, doi: 10.1109/NAPS46351.2019.9000371.
- A. Canedo, "Industrial IoT lifecycle via digital twins," 2016 International Conference on Hardware/Software Codesign and System Synthesis (CODES+ISSS), 2016, pp. 1-1.
- Esther Mengelkamp, Johannes Gärttner, Kerstin Rock, Scott Kessler, Lawrence Orsini, Christof Weinhardt, Designing microgrid energy markets: A case study: The Brooklyn Microgrid, Applied Energy, Volume 210, 2018, Pages 870-880,
- Alexis Lagrange, Miguel de Simón-Martín, Alberto González-Martínez, Stefano Bracco, Enrique Rosales-Asensio, Sustainable microgrids with energy storage as a means to increase power resilience in critical facilities: An application to a hospital, International Journal of Electrical Power Energy Systems, Volume 119, 2020, 105865,
- Di Zhang, Nilay Shah, Lazaros G. Papageorgiou, Efficient energy consumption and operation management in a smart building with microgrid, Energy Conversion and Management, Volume 74, 2013, Pages 209-222,
- Shreya Dutta, Yanling Li, Aditya Venkataraman, Luis M. Costa, Tianxiang Jiang, Robert Plana, Philippe Tordjman, Fook Hoong Choo, Chek Fok Foo, Hans B. Puttgen, Load and Renewable Energy Forecasting for a Microgrid using Persistence Technique, Energy Procedia, Volume 143, 2017, Pages 617-622
- D. E. Olivares et al., "Trends in Microgrid Control," in IEEE Transactions on Smart Grid, vol. 5, no. 4, pp. 1905-1919, July 2014, doi: 10.1109/TSG.2013.2295514.
- M. R. Dadash Zadeh, A. Mazloomzadeh, H. Ghaffarzadeh and H. Castro, "Model-Driven Microgrid Controller," 2019 FISE-IEEE/CIGRE Conference - Living the energy Transition (FISE/CIGRE), 2019, pp. 1-6, doi: 10.1109/FISECIGRE48012.2019.8984972.
- Ran Wang, Ping Wang, Gaoxi Xiao, Shimin Gong, Power demand and supply management in microgrids with uncertainties of renewable energies, International Journal of Electrical Power Energy Systems, Volume 63, 2014, Pages 260-269, ISSN 0142-0615, https://doi.org/10.1016/j.ijepes.2014.05.067.

4 Summary of Key Literature Artefacts

4.1 Coordinated failure response and recovery in a decentralized microgrid architecture

4.1.1 Aim

There are several failures that occur in a microgrid system. The challenge of failure management emerges at different control layers within the microgrid. This paper proposes a Failure Management Unit which aims to detect failures and build reliable microgrids. The Failure Management Unit will work as an essential function in the microgrid energy management system.

4.1.2 Solution

For a fault tolerant system, each component must have its own failure model, that addresses the aspects related to systems reliability. In Failure Management Unit (FMU), the microgrids Energy Management System ensures taking actions to minimise frequency and voltage deviations and helps in restoring the microgrid to its desired set points.

The FMU receives data from the control environment through four different detection methods- (i) Local Sensing- The operational control of the microgrid can sense local parameters. This data can be collected and analysed to predict possible system failures, (ii) Communications- Decentralised Architecture is beneficial for as it ensures reliable communication network connecting all peer controllers in the microgrid. Intelligent controllers can then interpret delays and time stamping mismatch, (iii) Peer Reports- Some controllers can detect failures which cannot be detected by sensing and communications.

This technique speeds up the system fault handling as all controllers inform about occurring failures, (iv) Self Reports- The local controller performs a sanity check which can detect or predict any failure that may occur. This allows the decentralized controllers to respond faster to failures. Thus, the FMU receives data from the control environment and runs a failure detection algorithm.

4.1.3 Evaluation

The microgrid system is considered to be normal if-

The equations are not violated, where the voltage and frequency are within limits.

Sanity check performed locally results a valid condition.

Peer reports are valid, stating all controllers are working properly and the system is stable. [2]

4.2 Resiliency Oriented Microgrid Optimal Scheduling

4.2.1 Aim

During system failures, the microgrid goes through curtailment reduction, which means that Microgrids don't receive any energy for the main grids. This paper proposes a model that aims to minimize these curtailment loads by efficiently scheduling available resources to the microgrid when the energy supply from the main grid is halted during this system failure.

4.2.2 Solution

There a few uncertainties which can influence the scheduling decisions. These uncertainties cannot be controlled by the microgrid and are identified as Weather Forecast errors and main grid supply interruption. The microgrid optimal scheduling is decomposed into 2 problems, The Normal Operation Problem- this determines the optimal scheduling of dispatchable units, energy storage, adjustable loads and power transfer from the main grid. The second problem, The Resilient Operation Model- this minimises the power mismatches between microgrid generation and load.

The model comes up with an optimization method consisting of algorithms, for capturing the uncertainties. Weather forecast uncertainties can be determined by the worst-case solution of the resilient problem, which is the highest mismatch that can be resulted when uncertain parameters fluctuate. The main grid supply interruption can be captured by defining a set of islanding scenarios with different start times and duration's.

4.2.3 Evaluation

A mathematical modelling of the microgrid optimal scheduling problem based on resiliency considerations delivered expected benefits. Those benefits were Least cost normal operation- it determined the operations of dispatchable units, energy storage, adjustable loads and power transfer from the main grid minimises the cost of supplying local loads in normal operation.

- Resiliency Considerations- Sufficient DER's were provided for a seamless islanding.
- Uncertainty Considerations- These scenarios were determined and solved by an optimization model and worst-case analysis.
- Operational Flexibility- This model provides an efficient method for the microgrid on employing the available resources for addressing resiliency needs.

[8]

4.3 Management of Solar Energy in Microgrids Using IoT-Based Dependable Control

4.3.1 Aim

Solar energy generation requires efficient monitoring and management in order to achieve technologies for net zero energy buildings. This paper presents a dependable control system based on IoT, that aims to control and manage energy flow of renewable energy collected by solar panels within the microgrid.

4.3.2 Solution

IoT Technology has been utilised to provide ubiquitous computing and control within the microgrid. The solution proposes a solar tracking module and discusses the reliability and resilience of the system for solar energy management. Firstly, An Energy Management System is designed. The tracking modules include photovoltaic panels, used for collecting solar radiations. The motion can be controlled either by a built-in function or a remote controller. The data is aggregated by algorithms implemented in an application server to analyse the power usage, evaluate the harvested energy and detect abnormal events. At the core of the system are IoT based controllers. They provide reliable control for solar trackers under situations of hardware failures and communication techniques.

The setup includes a solar tracker and photovoltaic array located at the rooftop of a building. Different inverters and isolators are used to regulate the harvested energy and feed it to the microgrid.

4.3.3 Evaluation

Reliability and self-recovery capability of the system is subjected to a hardware failure by intentionally unplugging the power supply of the duty controller. This action causes interruption in data communication and led to a timeout event. Without dependable control, it's impossible to recover the operation, as a regular backup controller cannot compute the dissipation to maintain system stability. A standby controller in the dependable system detected the timeout and switch the duty mode to take control of the system. The solar tracker eventually reaches the expected operating angles. The whole operation is viable, using IoT network and dependable control. [12]

4.4 Digital Twin for Cybersecurity Incident Prediction: A Multivocal Literature Review

4.4.1 Aim

This research paper summarised on what exactly a Digital Twin is and discussed about Digital Twins various usability's in cybersecurity. The researcher has performed a Multivocal Literature Review to understand Digital Twins various uses.

4.4.2 Solution

The MLR process consists of 6 steps which helps in obtaining results. The first step is of determining Research Questions and strategizing of search process. The research questions obtained were "What are the uses of Digital Twin" and the second question was "What are the uses of Digital Twin in cybersecurity for Fault Detection and Incident Prediction". The researcher concluded this step by discussing his search process. The search process includes 4 phases, which were The Initial Phase- Selecting studies related to the topic; Remove Duplicates; First Selection Process; Second Selection Process- Evaluating each paper with careful and rigorous reading.

The second step consisted of the Inclusion Criteria and the Exclusion criteria. The First Selection process mentioned in the first step is based on this. During Inclusion Criteria, we must check whether the literature is related to and discusses the research questions, it discusses the application of Digital Twins in cybersecurity and finally discusses its implementations. The Exclusion Criteria contain simple steps such as excluding papers which aren't written in English, paper's which don't contain any abstract and text, duplicated literature and non-relevant literature. The third step is the Search execution from trusted sources. The fourth step is the selection procedure of papers. It's pretty much similar to the Inclusion Exclusion criterions. The fifth step consists of reviewing each selected paper meticulously. The final step consists of summarising the results.

Moving back to the first research question, the researcher mentions that he collected data from various sources and concludes that Digital Twins can represent Manufacturing assets in cyberspace. Digital Twin can represent people which would include their data to better understand their well-being and their conditions. Digital Twins can represent each aspect of a business. The researcher concluded this question by stating that the Digital Twins main aim is to remain present at all times and is accessible at any given place and time by cloud monitoring.

Now moving to the second research question. The researcher discussed various use cases and examples to prove that Digital Twins can detect faults in a system and can predict fault failures as well. These use cases included Intrusion detection- this uses CPS Twinning framework. It compares real-time Digital Twin signals and device signals

Another use case discussed was Anomaly Detection- this use case proves that Digital Twins can detect anomalies through malicious cybersecurity intrusions. It compares real-time signals to historical data and in some cases checks whether the signals are violated.

The Virtual Commissioning use case discussed about detecting manipulations done by cyber attackers when the physical isn't consistent. It performs various system tests on virtual models. Other use cases used to prove fault detection and predicting incidents were Predictive Analytics, Autonomy, Monitoring.

4.4.3 Evaluation

Digital Twin has increased productivity, reliability, efficiency and quality. It has reduced cybersecurity threats and consists of a predictive maintenance and scheduling. It has resulted in time and cost savings. It's helped reducing complexity and risks. It has led to real time better documentation and communication, consists of an efficient and informed support system and has enabled real time monitoring and control. [13]

4.5 Reference Framework for Digital Twins within Cyber-Physical Systems

4.5.1 Aim

There's no framework about the main building blocks of a Digital Twin, which discuss its properties and interrelations. This framework focuses on the development of Digital Twins and its applications withing a Cyber Physical System.

4.5.2 Solution

The research questions for this framework are-

- What are the main building blocks of a Digital Twin, used with relation to various CPS application fields?
- What are the properties of a Digital Twin in terms of its structure and interrelation among the building blocks?

To answer these questions, the researcher defines a research methodology which starts by applying a Search strategy. He performs a Systematic Literature Review and identifies the relevant sources he'll go through.

Then he applies the Inclusion and Exclusion criteria. For Inclusion Criteria, he accepts sources which describe a Digital Twin Framework on mirroring properties of a physical device. Sources that discuss Digital Twins building blocks, functionality and properties, sources that discuss about Digital Twins architecture and sources that introduce application scenarios. For Exclusion scenario, he excludes sources which were published before 2002 and sources that don't represent Digital Twin frameworks. The researcher then proceeds to perform a qualitative data analysis and synthesis. This process leads to data extracting and analysis. Again, similar literature sources are read.

Digital Twin Framework- After completing each step, the researcher identifies 4 main building blocks of Digital Twin. Physical Entity Platform- It's a physical entity, persisting in the real-world and has to be mirrored in the virtual world. Its divided into 3 different parts

- Physical Object, it does not have the ability to communicate and perform actions in a physical environment. Its simply an observable object, which can be observed by sensors. Physical Node, it can communicate with different nodes and can perform actions in the physical world. Human, it is an entity found in the physical environment. It can be observed by Physical node and is classified as an individual entity.

- Virtual Entity Platform- The goal of this platform is the generation and maintenance of semantics models of a physical activity. It consists a variety of semantic models such as Geometric Model, Physical Model, Behavioural Model, Rule Model and Process Model, which fulfills a concrete goal.

- Data Management Platform- Its responsible for data acquisition and storage. It includes various Data Models which integrate Physical, Service, Virtual and fused data. It also includes Data Management Methods, which are used for data collection, transmission, storage, processing, cleaning and data mining.

- Service Platform- It's the core part for ensuring optimization. It consists of various service models and service management layers.

- Service Model- It indicates concrete services and sub-services which combine to complete targeted goals. Service Management Layers- It controls and manages the concrete services and ensures service provisioning to specific entities. [7]

4.6 A Review on Microgrid Technology with Distributed Energy

4.6.1 Aim

This paper discusses the characteristics and key technologies used in a Microgrid and the key challenges existing during its development.

4.6.2 Solution

Microgrid has risen as an effective component for tackling the issue of energy shortage globally. A microgrid has different characteristics such as- Flexibility, it runs on grid-connected and Isolated mode. Interactivity, when operating in isolated mode, a microgrid can not only shortage the power outage, but can also help in rebooting the grid. Compatibility, Microgrid is the most effective way to achieve the connection of Distributed Energy. It integrates distributed energy and stabilises power supply. It balances between supply and demand through energy storage and controls protection, which overcomes randomness and intermittence of Distributed Energy. Economy, Microgrid has access to large amounts of Renewable energy. Microgrids can combine with medium sized heat supplies which reduce the conversion of different energy forms and improves energy efficiency.

The key technologies in a Microgrid are- Operation, when a microgrid is connected to the main grid, the microgrid provides excess power generated by Distributed Energy. When detecting failures in the main grid, the Microgrid checks the power quality and if the quality isn't up to standards, it disconnects itself from the main grid. Additionally, the isolated mode of the Microgrid provides a higher power supply reliability. Control, a microgrid provides power to its customer and can achieve this through good management and control within its system. In case there's a failure in the main grid, the microgrid disconnects itself and provides power in isolated mode. Energy Storage, the applications of energy storage plays an important role in stabilising the fluctuation of renewable energy and maintaining the systems stable operation. There are different storage technologies in a microgrid being, Mechanical, Electromagnetic and Electrochemical Energy Storage but, Batteries are the best option for renewable energy grid because of its easy instalment and manufacture. Lithium batteries and Liquid batteries are the most effective in large scale fields. Economics, its an important foundation for promotion and development of microgrid technology. The economic optimization of microgrid is different from the traditional grid as its unique design provides higher reliability.

The challenges in the development of a Microgrid are- Reliability and Stability, Microgrid is distributed in the Distribution Grid as a special power source, which can both import and export energy. The further interaction of Microgrid will affect the Distribution grids reliability. Programming and Designing, it is necessary to consider problems such as distributed power supply, microgrid structure, location and integrated optimization of distribution grid. Controlling, the distributed power supply connects the grid through an electronic inverter since there's no self-synchronization. The load fluctuation in Microgrid has a great impact on the power output. Intermittence and randomness also increase the difficulty of voltage and frequency control in distributed power supply. Protection, it is essential to ensure the safety and stability of the entire system when there's a system failure. Failure in a microgrid can occur when there's something wrong with the distribution network or when the grid operates under abnormal conditions. Scheduling, the effective scheduling and management of a microgrid can be achieved by using auxiliary tools such as modelling and simulating the microgrid to achieve protection for isolated network, overcome unfavourable factors of intermittence and randomness. [17]

4.7 ANGEL: An Intelligent Digital Twin Framework for Microgrid Security

4.7.1 Aim

The ANGEL Digital Twin for Cyber-Physical System Security is a novel approach for improving the security of critical and non-critical infrastructure. This paper presents a framework for adapting the Digital Twin to the application of

Microgrid Security.

4.7.2 Solution

The ANGEL digital twin has the ability to monitor the power system in real-time and provides insights into the inner working of grid dynamics. The digital also has the ability to access real-time data about the physical system. The ANGEL DT is being developed to secure modern cyber physical grid against cyber-attacks and exploits. It uses real-time, physics- based modelling and simulation techniques along with stochastic methods. The ANGEL system has the ability to identify a breach and can also evaluate the potential damage before it occurs.

The ANGEL system has the ability to gather system data and present anomalies to the operator. The first step is to gather anomaly data, which is then implemented by a Machine Learning algorithm, to make intelligent decisions. Once the ANGEL system is equipped with AI, it will create a learning and self-healing system, which will make it the fully developed Digital Twin, that's needed to defend the microgrid. The ANGEL DT for CPS security of microgrids can be a major game changer in the defence of Distributed Energy Resources. The applications of Digital Twins for cyber defence are- False Data Injection, this is the most common and potential attack to a microgrid.

Once equipped with the ANGEL system, the physics-based simulation will make it more difficult for attackers to inject data, that aligns with a probable real-world solution. To conclude, signal data that doesn't align with simulation-based system will be flagged and evaluated. Denial of Service, Digital Twin relies on a constant stream of data to keep the simulation model in a lockstep with physical twin. If the stream is cut-off, the digital twin would not be effective in directing the physical system, since no control will be present. In these cases, the system defaults back to its traditional SCADA system. Topology Attack, also known as the 'Man in the Middle Attack'. The attacker usually intercepts the network and meter data, and further modifies the data and forwards the modified data to the control system. In this case, the Digital Twin is able to detect any unnatural changes in the data it receives form the physical data and successfully tackles the attack. Vulnerability to Attack, addition of more elements in a system creates a potential vulnerability for attacks. The ANGEL system mitigates this risk by designing the Digital Twin to fall back on SCADA system. [5]

4.8 Designing microgrid energy markets A case study: The Brooklyn Microgrid

4.8.1 Aim

This paper aims to ensure a reliable balance of energy generation and consumption. It presents a state-of-the-art literature review of microgrid energy markets, blockchain technology and their combined energy markets.

4.8.2 Solution

Microgrid Energy Markets allow small-scale participants like consumers and prosumers to actively trade energy within their community in real-time. This facilitates a sustainable, reliable and balance of generation and consumption. This ensures a viable option for integrating distributed RES's to the current energy system in an economical way. Blockchain is an emerging information technology, which offers new opportunities for decentralized market designs and provides transparent and user-friendly applications that allow consumers to participate in the decision of who produces their energy and through which technology its generated. The conceptualization and implementation of blockchain-based microgrid energy markets have gained attention in recent times. This paper discusses a case study on the Brooklyn Microgrid and doesn't show any actual implementation.

The Brooklyn Microgrid consists of a microgrid Energy Market based in Brooklyn and the participants are located across three distribution grid networks. Due to severe weather events like hurricanes and heat waves, troubled the already outdated electrical grids. A physical microgrid can be used to reduce the impact of grid issues through decoupling and control the energy supply within the community. Furthermore, the previously used electrical grids struggled with the growing amount of renewable generation and the characteristics of new appliances. The Brooklyn Microgrid addresses these challenges and provides a local energy market which allows the participants to trade.

The research derives seven components for the efficient operation of blockchain-based microgrid energy markets named C1-C7, Microgrid Setup, Grid Connection, Information System, Market Mechanism, Pricing Mechanism, Energy Management Trading System and Regulation. Except for Regulation, each other component is implemented in the Brooklyn Microgrid. The Brooklyn Microgrid is the among the first projects to actually facilitate a block-chain based electricity transaction and have turned out to be suitable information systems that facilitate localized energy markets. There are several advantages of microgrid energy markets like the active local integration of RES into the energy system.

Still further researches regarding economic and socio-economic impact of Microgrid Energy Markets is required. The requirements and structures of blockchain-based energy markets are still being analysed. Finally, this paper proposes to focus on the scalability and robustness of blockchains as microgrid energy markets and evaluate electrical energy resources and transactions. [10]

4.9 Sustainable microgrids with energy storage as a means to increase power resilience in critical facilities: An application to a hospital

4.9.1 Aim

This paper presents the benefits provided by an improvement of the energy resilience, that can be achieved by installing a Microgrid in a Hospital fed by renewable energy sources.

4.9.2 Solution

A simulation has been carried out in this paper, using ReOpt software. The microgrid uses a scheme based on Solar Photovoltaic in addition to diesel generators and an energy storage system based on electrochemical batteries. According to the simulation in ReOpt, the microgrid saves 440K AUD while also increasing the minimum resilience of the installation for more than 34 hours.

Microgrids have the ability to isolate themselves from the main grid, when a power outage occurs. They have the ability to supply their critical loads without interruption, which is useful in critical facilities. Energy resiliency has become critical in recent years as a result of many natural disasters. One solution to power cuts might be to set up Renewable Energy Hybrid System Microgrid, which comprises of PV panels, batteries, and Diesel Generators. In some cases, the use of diesel generators is not appropriate, since they don't work during natural disasters.

Most of the energy used by the loads of the hospital are obtained by solar PV. Batteries are used when the sun is about to set or when the demand for electricity is high. But batteries aren't used during power outages, due to the valorisation of the stored energy. This whole process has made it possible to establish the schedules when electricity is cost less. When the demand for electricity is high, all PV energy is used up to power the loads. Thus, with high solar resources can, the addition of solar photovoltaic makes it possible to increases the resilience of a microgrid in the event of power outages.

With the help of microgrids, the dependence on the use of diesel generators in hospitals will reduce. Moving onto the ReOpt software results. The results are relevant and provide a number of scenarios giving a resilience capability, which is used as an input and also provides financial insights. By installing Photovoltaic panels, Li-Ion batteries and diesel generators, the microgrid can save approximately 440K AUD over a 20-year life cycle (as discussed above). [9]

4.10 Efficient energy consumption and operation management in a smart building with microgrid

4.10.1 Aim

This paper studies the optimal scheduling of smart homes energy consumption using a Mixed Integer Linear Programming.

4.10.2 Solution

A MILP model has been proposed for energy consumption and operation management in a smart building with smart homes and it has its own microgrid, to provide energy locally which includes some DER's such as, wind generator, thermal storage, CHP generator, boiler and electrical storage. The microgrid is in grid connected mode when obtaining electricity during demand peak hours and sells electricity to the grid when there's surplus electricity. The building has its own energy management system, local controllers for DER's and communication system to distribute energy consumption scheme. Two examples have been considered, one with 30 homes and another with 90 homes with the same living habits, on a winter day have been studied.

The power generated from the wind generator varies according to the weather conditions. With the help of the proposed MILP scheduling model, the power generated by wind generators can be used when available, which provides further savings for the customers. The CHP generator is used more efficiently and provides heat more steadily in this optimised scheduling scenario. When the peak demand price scheme is applied, the highest peak demand from the grid and total peak demand over the threshold can be reduced. This power demand reduction can release the burden off the main grid and reduces the expense of upgrading the main grid infrastructure to fulfill increasing energy demands.

Both examples have similar cost savings, while under the peak demand scheme. Example 1 demonstrates more savings, while Example 2 has different starting times for flexible tasks. Example 2's average power peak is lower than that of Example 1 since, the tasks are scattered without scheduling. In both examples, when the microgrid is utilized, the lowest cost saving is 13 percent and the lowest peak demand saving is 18 percent. Microgrids application is an important alternative solution for cost and peak demand reductions. In smart grids, it is considered that there's a two-way communication between power supplier and customers. The power is distributed according to demand and supply. Traditional methods provide the customers with a flat electricity pricing, while smart grids provide real time electricity pricing. This model considers the problem from the customers point of view.

To conclude, twelve domestic electrical tasks and equipment operations are scheduled based on given time slots, real-time half hourly grid electricity prices and peak demand extra charge to obtain minimum cost and energy demand. Significant cost savings and peak demand savings have been achieved in both examples. [18]

4.11 Deep Learning based Techniques to Enhance the Performance of Microgrids: A Review

4.11.1 Aim

The aim of this paper is to summarise the state-of-the-art deep learning and machine learning methods in implementing energy forecasting.

4.11.2 Solution

Solar energy plays an important role in green energy among all Renewable Energy Sources and is also available at most parts of the world. Solar panel converts the direct sunlight to electrical energy. Solar Panels generate maximum electricity when the sun has high radiations and the lowest when its dark at nights or when its cloudy. Such fluctuations can cause problems and is considered the main problem in power distribution and may lead to instability in a Microgrid. To ensure safe operation, accurate forecasting of the Microgrid is required as it enables the power utility to manage supply efficiently. This paper discusses Deep Learning and Machine Learning based tools for energy forecasting on the basis of historical data.

The most commonly used Deep Learning Based Methods for energy management and Power forecasting are- Artificial Neural Networks, it is based on a collection of nodes or units called neurons. These are basic components of a network, through which communication takes place. It receives input and produces output. Deep Neural Networks, these consist of multiple hidden layers between the input and output layers. The DNN processes the input with mathematical manipulation to produce the output. Convolutional Neural Networks, these are used for visual image processing, energy management in smart grids and pattern recognition. It contains an input, an output and hidden layers i.e. convolutional layer, flatten layer and etc.. The input and output layers in the hidden layers are hidden by an activation function. This activation function produces a more accurate product. The convolutional layer in CNN is used to downscale the input data in such a way that it becomes easy to process. Recurrent Neural Networks, these are developed to process sequential data. These contain feedback connections in the units of the hidden layer. RNN is used to make a prediction based on the sequence of the last 6 data inputs, then the data would be unfolded into a 6-layer neural network.

The rest of the paper discusses real-life examples used for Energy Forecasting. [1]

4.12 Load and Renewable Energy Forecasting for a Microgrid using Persistence Technique

4.12.1 Aim

This paper illustrates an approach to use historical power data instead of numerical weather predictions to produce short-term forecast results.

4.12.2 Solution

A microgrid system usually consists a mix of renewable and non-renewable generation, controllable and non-controllable loads and Energy Storage Systems such as batteries. Its important to determine the demand of how much RES generation is required and that can be accomplished through forecasting techniques. Due to the intermittent nature of RES, its difficult to forecast wind or solar power accurately. The concept of Persistence Method is presented to tackle this problem.

The main function of a forecasting algorithm in a microgrid is to predict the demand of loads in microgrid network. This also determines how much power is utilized from controllable resources. Any forecast performed in order of hours or days are called Short Term forecasting. Short Term forecasting is required for microgrid applications. Some popular short-term forecasting techniques are, ARIMA, ANN, Kalman Filter method and Multiple Linear Regression. The Persistence Algorithm is chosen as the preferred forecast algorithm since, it is simple to implement and unlike other forecasting algorithms, it doesn't rely on weather forecast data or any in-built software tool. This results in more straightforward results. The Persistence Algorithm has adopted for short term wind forecasts since, the wind power varies frequently and there's no fixed pattern for its generation. Thus, it uses immediate past data for forecast to yield more accurate results. It has been said to have higher accuracy compared to other complex algorithms.

The forecast results observed the accuracy of forecast depends on the look-back time and the extent of change of the data over time. For instance, the PV generation suddenly drops if there' s a cloud cover. Additionally, the load and PV forecasts, the existing persistence algorithm may be improved by using previous day patterns along with more recent historical data. [6]

4.13 Trends in Microgrid Control

4.13.1 Aim

This paper discusses the major issues and challenges in Microgrid grid control and reviews the state-of-the-art control strategies and trends.

4.13.2 Solution

There's been an increasing interest in integrating intermittent Renewable Energy Sources into microgrids reliable operation and control mechanism need to be designed. Microgrids and the integration of DER units introduces many operational challenges which need to be addressed in designing control and protection systems in order to ensure the reliability of Microgrids is not affected and the benefits of DG are fully harnessed. Some of these challenges arise from invalid assumptions typically applied to conventional distribution systems and others are resulted from stability issues observed at transmission system level.

The most relevant challenges in Microgrid Control and Reliability are- Bidirectional Power Flows, integration of DG units at low voltage levels can cause reverse power flows and lead to complications in fault current distribution and voltage control, undesirable power flow patterns. Stability Issues, local oscillations emerge from the interaction of the control systems of DG units, which further requires a thorough small-disturbance stability analysis. Low Inertia, due to the significant share of electronic-interfaced DG units, microgrids show low inertia. This can lead to severe frequency deviations in isolated operation if a proper control mechanism isn't implemented. Uncertainty, the economical and reliable operation of microgrids require a certain level of coordination among different DER's. This becomes more challenging in isolated microgrids, where the critical demand-supply balance has higher component failure rates.

The microgrids control system must ensure reliable and economical operation of the microgrid, while overcoming the above-mentioned challenges. The desirable feature a microgrid must include are- Output Control, the output voltages and currents of DER units must track their reference values and ensure oscillations are properly damped. Power Balance, DER units in the microgrid must accommodate sudden active power imbalances, keeping frequency and voltage deviations within acceptable ranges. DSM, proper DSM mechanisms must be designed in order to incorporate the ability to control a portion of the load. Economic dispatch, DER units participating in the operation of a microgrid can significantly reduce the operating costs or increase the profit. Transition between modes of operation, this is a desirable feature of microgrids, to work in both grid-connected and stand-alone modes of operation, including a smooth transition between them. Reliability considerations must also be taken into account in the dispatch of units, especially in stand-alone operation.

The Microgrid Control Strategies can be classified into- The Primary Control, also called the local control is the first level in the control hierarchy and features the fastest response. Its control is based on exclusive local measurements and it requires no communication. The state-of-the-art techniques in Primary Control are Droop Based Methods, Non-Droop Based Methods, and the Inverter Output Control. The Secondary Control, its also known as the Energy Management System (EMS) of a microgrid. Its responsible for reliable, secure, and economical operation of microgrids in both grid-connected and isolated modes. The state-of-the-art techniques in Secondary Control are the Centralized and Decentralized Approach. The Tertiary Control, is the highest level of control and sets points depending on the requirements of the host power system. Its responsible for coordinating the operation of multiple microgrids interacting with one another in the system.

The Energy Storage System is an important technology for integrating renewable energy with microgrids. ESS can decrease losses and increase reliability. It enables large scale integration of intermittent RES. RES's are the main pillar of microgrids but without storage, their generation can't improve system reliability and has to duplicated by other means of generation. A storage unit can provide a functionality similar to the inertia of a synchronous generator by absorbing temporary mismatches between power generation and demand. [**?**]

4.14 Model-Driven Microgrid Controller

4.14.1 Aim

This paper presents a model-driven microgrid control approach that significantly simplifies the process of development and testing microgrid control functions.

4.14.2 Solution

A microgrid control system is required to manage and control a microgrid's dispatchable quantities. This control system can be physically implemented in a centralized or distributed manner. This control system communicates with local controllers with the microgrid both directly and indirectly. The Microgrid Control Strategy heavily depends on the type of microgrid, its assets, sources, loads, network topology and reliability requirements. It is difficult to optimally fit a generic microgrid controller that's designed to support certain features for each application. Additionally, programming a controller for each microgrid application is costly and requires extensive expert engineering. A true Model-Driven microgrid controller approach can be used, where control logic can be programmed, customized and enhanced with minimum effort.

The model-driven approach is an approach for developing a product where the system and product can interact together in a software environment through simulations. With the help of this approach, the users can first develop new functional blocks and modify existing ones within the simulation. The performance and impact of these functional blocks on the system can be evaluated. Control functions developed within the controller can be tested in the simulation and can be transferred to a hardware to realize the microgrid controller. The second aspect of model-driven approach is, the control functions modelled in the simulation, which are supposed to be deployed in the hardware are aware of the properties and connectivity of the system and their assets as it can be utilized to minimize the complexity of settings required to describe system data. The third aspect of model-driven approach allows the use of predictive simulation to enhance and achieve certain required control functionality. In context of microgrid controller, the power system simulating microgrid can perform predictive analysis, such as dynamic stability for different load shedding strategies requested by the microgrid controller.

The digital twin of the microgrid controller is the true model of the model-driven approach. A case study is demonstrated where the proposed controller was applied in- control power at the microgrid point of common coupling, dispatch energy storage to minimize the cost of importing power, smoothen the intermittent profile of renewable resource from the main grid and continuously derive a load shedding strategy to cope with intermittent nature of microgrid resources. [4]

4.15 Power demand and supply management in microgrids with uncertainties of renewable energies

4.15.1 Aim

The aim of this paper is to present an optimisation scheme to tackle the problem of fluctuating Power Demand and Supply Management in microgrids.

4.15.2 Solution

Power Demand and Supply Management in a microgrid are used to maintain a good match between power generation and consumption at a minimum cost. Renewable Energies constitute a significant portion of the power resources in

Microgrids. But since the renewable energies are highly fluctuant, it becomes difficult for the Microgrid Central Controller (MGCC) to fulfill the customers requirement. Microgrids are expected to be more robust and cost-effective than the traditional centralized grids. They may adopt hierarchical or decentralised demand control schemes. The decentralised control scheme allows distributed energy and management of large complex systems. The hierarchical control scheme is managed by a master controller and is responsible for matching the power generation and demand load. A three-step scheme has been proposed to tackle this problem.

Firstly, to tackle the randomness nature of Renewable Energy i.e. Wind and Solar Energy, a reference distribution is introduced, and a distribution uncertainty set is defined according to past observations to confine the uncertainty. This model allows convenient handling of fluctuating renewable generation as long as the generation isn't drastically different from the past observations and empirical knowledge. Secondly, an optimization problem is formulated to determine the optimal power consumption and generation scheduling for minimizing the fuel cost. A robust approach for handling the load balance is proposed. Then the main problem is decomposed into a subproblems for an easier solution. The power demand and supply management framework discussed so far is an offline approach for planning energy consumption and generation well ahead of time. This proposed algorithm can be used in cases where the real-time adjustment is of big concern. The numerical results of the proposed algorithms indicated that the energy management scheme can significantly cut down energy expenses. Factors such as reference distribution, fault tolerant limit, types and number of uninterruptible loads and user elasticity are each carefully evaluated. These evaluations help in providing useful insights in the development of more effective policies for MGCC. [16]

4.16 Load Frequency Controller Design for Microgrid using Internal Model Control Approach

4.16.1 Aim

This paper presents a design procedure of Internal Model Control tuned with PI controllers to enhance the frequency regulations in Microgrids.

4.16.2 Solution

The intermittent nature of RES used in microgrids results in frequency fluctuations. The frequency must be maintained properly to ensure better quality of electricity delivery. This paper presents a microgrid formed by combining Wind Energy produced by wind turbines, Fuel Cells, Diesel Generators, Aqua Electrolytes and Batteries as energy storage systems. For instance, Wind Energy is very inconsistent and intermittent in nature which cause frequency deviations, but once coordinated with batteries, it can control those deviations. The batteries play a major role in load frequency control, when the system frequency is less than the nominal value, the batteries discharge and charge the system until its greater than the nominal value. PI controllers minimize battery usage and control the microgrid frequency effectively when tuned optimally.

The Hybrid Microgrid system proposed in this paper has a unique configuration comprising of Diesel Generators, these provide quick start up and high efficiency. Power deficits in the microgrid are balanced using the electrical output from Diesel generators system. This compensates for the intermittent nature of wind energy. Fuel Cell, electrical power is generated by electrochemical reaction of hydrogen gas produced by aqua electrolyzer. Aqua Electrolyzer System, is formed up of hydrogen gas and is used in this model because of its cleanliness. The AE system absorbs electrical energy from renewable resources and produces hydrogen gas for the Fuel Cell. Battery Energy Storage Systems, it consists of a DC battery. It is capable of being both a load and a generator. When the frequency drops, it can discharge power into the network or when the frequency rises, it can charge the power. Lastly, Wind Turbine generators are also used in this system.

For the load frequency controller design, this paper has introduced IMC method. The Internal model control simulates a system in order to estimate the systems disturbance. A transfer function is designed and simulated to obtain results of the whole system. During the load variations, all the energy sources coordinated well in order to maintain the frequency over the nominal value. The method of utilizing PI controllers tuning with IMC approach has given overwhelming results. The Battery Energy Storage System improves the frequency control by delivering power constantly. [15]

5 Summary of Aspects That Require Further Work

The aim of my project is to discuss about different scenarios occurring in a microgrid. Most of these scenarios are related to a concern that may arise within a microgrid and halt the progress. A simulation is created for each scenario, and running them is very beneficial as it solves real-world problems safely and efficiently. It provides an important method of analysis which is easily verified, communicated, and understood. Across industries and disciplines, simulation modeling provides valuable solutions by giving clear insights into complex systems. There are still aspects of a microgrid which need to be investigated and can also be observed by modeling simulations for those components.

More research is needed on relevant technologies to highlight the best applicable communication system for microgrids, targeting overall microgrid operations, including transient response of its distributed resources. Improving reliability and minimizing delay when it comes to sensitive data transmission, such as protective relays, switches, and fault detectors is required. Machine Learning is a vast topic. It has its various advantages which can be used in optimising microgrids to their highest potential. the scenarios discussed in the paper can potentially be solved with Machine Learning and AI methods and require more research in it. [3]

References

[1] Sheraz Aslam, Herodotos Herodotou, Nasir Ayub, and Syed Muhammad Mohsin. Deep learning based techniques to enhance the performance of microgrids: A review. In *2019 International Conference on Frontiers of Information Technology (FIT)*, pages 116–1165, 2019.

[2] Abedalsalam Bani-Ahmed, Mohammad Rashidi, and Adel Nasiri. Coordinated failure response and recovery in a decentralized microgrid architecture. In *2017 IEEE Energy Conversion Congress and Exposition (ECCE)*, pages 4821–4825, 2017.

[3] Abedalsalam Bani-Ahmed, Luke Weber, Adel Nasiri, and Hossein Hosseini. Microgrid communications: State of the art and future trends. In *2014 International Conference on Renewable Energy Research and Application (ICRERA)*, pages 780–785, 2014.

[4] Mohammad R. Dadash Zadeh, Ali Mazloomzadeh, Hooman Ghaffarzadeh, and Hugo Castro. Model-driven microgrid controller. In *2019 FISE-IEEE/CIGRE Conference - Living the energy Transition (FISE/CIGRE)*, pages 1–6, 2019.

[5] William Danilczyk, Yan Sun, and Haibo He. Angel: An intelligent digital twin framework for microgrid security. In *2019 North American Power Symposium (NAPS)*, pages 1–6, 2019.

[6] S. Dutta, Yanling Li, A. Venkataraman, L. Costa, T. Jiang, R. Plana, P. Tordjman, F. Choo, C. F. Foo, and H. Puttgen. Load and renewable energy forecasting for a microgrid using persistence technique. *Energy Procedia*, 143:617–622, 2017.

[7] Klementina Josifovska, Enes Yigitbas, and Gregor Engels. Reference framework for digital twins within cyber-physical systems. In *2019 IEEE/ACM 5th International Workshop on Software Engineering for Smart Cyber-Physical Systems (SEsCPS)*, pages 25–31, 2019.

[8] Amin Khodaei. Resiliency-oriented microgrid optimal scheduling. *IEEE Transactions on Smart Grid*, 5(4):1584–1591, 2014.

[9] Alexis Lagrange, M. D. Simón-Martín, Alberto González-Martínez, S. Bracco, and Enrique Rosales-Asensio. Sustainable microgrids with energy storage as a means to increase power resilience in critical facilities: An application to a hospital. *International Journal of Electrical Power Energy Systems*, 119:105865, 2020.

[10] Esther Mengelkamp, Johannes Gärttner, Kerstin S. Rock, S. Kessler, L. Orsini, and Christof Weinhardt. Designing microgrid energy markets : A case study : The brooklyn. 2018.

[11] Sina Parhizi, Hossein Lotfi, Amin Khodaei, and Shay Bahramirad. State of the art in research on microgrids: A review. *IEEE Access*, 3:890–925, 2015.

[12] Manh Duong Phung, Michel De La Villefromoy, and Quang Ha. Management of solar energy in microgrids using iot-based dependable control. In *2017 20th International Conference on Electrical Machines and Systems (ICEMS)*, pages 1–6, 2017.

[13] Abhishek Pokhrel, Vikash Katta, and Ricardo Colomo-Palacios. Digital twin for cybersecurity incident prediction: A multivocal literature review. New York, NY, USA, 2020. Association for Computing Machinery.

[14] P. Singh, P. Paliwal, and A. Arya. A review on challenges and techniques for secondary control of microgrid. 2019.

[15] A. J. Veronica and Dr. N. Senthil Kumar. Load frequency controller design for microgrid using internal model control approach. 2017.

[16] R. Wang, P. Wang, Gaoxi Xiao, and Shimin Gong. Power demand and supply management in microgrids with uncertainties of renewable energies. *International Journal of Electrical Power Energy Systems*, 63:260–269, 2014.

[17] Ben Yu, Junke Guo, Changxin Zhou, Zhiyong Gan, Jinshan Yu, and Fei Lu. A review on microgrid technology with distributed energy. In *2017 International Conference on Smart Grid and Electrical Automation (ICSGEA)*, pages 143–146, 2017.

[18] D. Zhang, N. Shah, and L. Papageorgiou. Efficient energy consumption and operation management in a smart building with microgrid. *Energy Conversion and Management*, 74:209–222, 2013.