Simulation and Classification of Islanding Condition Detection for an IEEE 9 bus system using PMUs and A3C based deep reinforcement learning algorithm respectively

A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In Electrical Engineering

By

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Certificate

This is to certify that the thesis entitled "**Simulation and Classification of Islanding Condition Detection for an IEEE 9 bus system using PMUs and A3C based deep reinforcement learning algorithm respectively**" submitted by Millend Roy (Adm. No. 17JE003018), in the fulfilment of the requirements for the honor of Bachelor of Technology degree in Electrical Designing at Indian Institute Of Technology (Indian School Of Mines), Dhanbad is a credible work completed by him under my watch and direction. Apparently, the matter typified in the proposal has not been submitted to some other College/Foundation for the award of any Degree or Certificate.

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ABSTRACT

The assimilation of distributed generation networks from centralized traditional networks was implemented in response to rising energy demands around the world and the threat of depleting conventional fossil fuels. Distributed generation (DG) is the generation of electricity close to the point of consumption using renewable energy sources such as wind, solar, tides, biomass, geothermal heat, and so on.

The various problems and issues encountered in the trending DG networks have been an important subject for researchers where many flaws need to be focused on, channeling the field of analysis.

Islanding detection in DG systems is one of the challenging problems that leads to a slew of security and safety issues. A micro-grid operates in grid connected mode or standalone mode. The main utility network takes care of easy operation in coordination with the safety and control units in grid linked mode, while in standalone mode, the micro-grid acts as a self-reliant and self-sufficient power island that is electrically isolated from the main utility network. Furthermore, without strict frequency regulation, the islanded circuit's equity and equilibrium between load and generation would be broken, resulting in abnormal frequencies and voltages. As a result, various anti-islanding detection methods are investigated, which report to the control system about the next set of steps that need to be taken in the event of any islanding.

Essentially, an attempt is made to create a real-time power system with multiple trending distributed generation systems mounted at the load end, followed by monitoring the action of all electrical parameters in the event of any faults or disturbances. Even cases of islanding are considered, and subsequent power system safety is incorporated by designing different relays and circuit breakers wherever required.

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CHAPTER 1

INTRODUCTION

1.1 Background

Since previous decades, power grid architectonics has emerged remarkably from a unidirectional centralized management approach to a rational and decentralized doctrine that allocates autonomous solutions in administering today's amplifying demand complications. The idea of decarbonizing while increasing electrification has stymied the ability of DG technologies to disrupt existing power grids, allowing for more convenient power generation for customers. As a result, DG is a concept that refers to the output of electricity close to the point of consumption. Solar power generators, wind turbines, gas turbines, and micro-generators are all examples of renewable energy sources that can be set up near the load side end. As a result, it can be said that traditional power distribution systems are passive networks, in which electrical energy is invariably supplied to consumers at the distribution level from power resources associated with the bulk transmission scheme.

Significant environmental benefits, increased adaptability, restriction of transmission and distribution (T&D) capacity promotion, reduced T&D line losses, remodeling power quality, and providing better voltage support are just a few of the benefits of incorporating DG services. Before the DG units are applied to the networks, however, a variety of issues must be addressed. Voltage stabilization, frequency ballast, renewable resource intermittency, and power quality debates are among these issues. Professional engineers and researchers use innovative technology and power economics to overcome certain technological challenges.

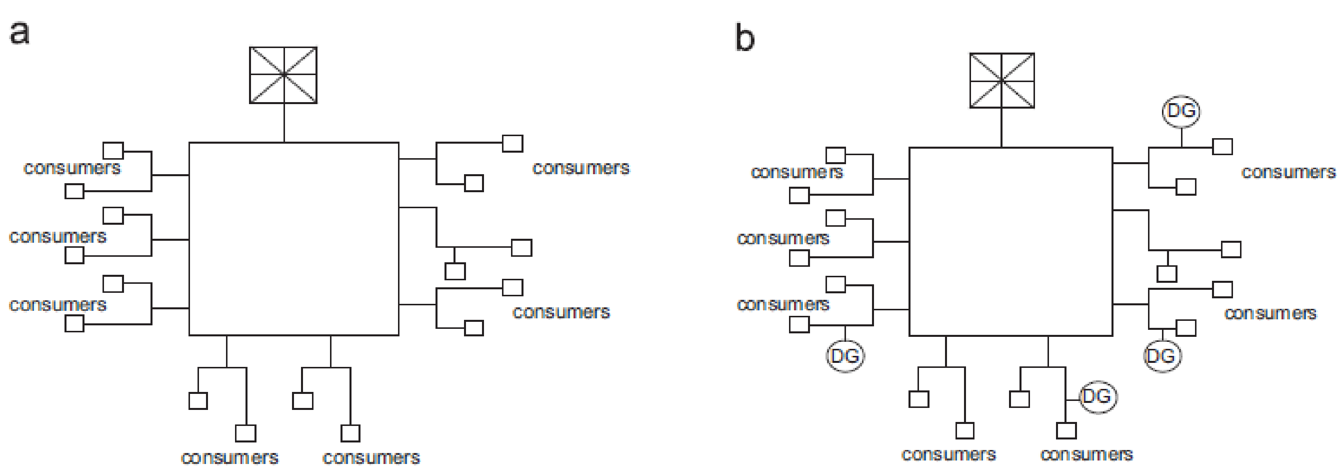


Fig1 Shifting of Technology from Centralized to Decentralized
a) Conventional centralized power distribution system
b) Microgrid network consisting of DG sources at load end

1.2 Definition

According to IEEE standards, **islanding** is a state in which a portion of an ELECTRIC POWER SYSTEMS (EPS) region is energized solely by one or more local EPS through the associated point of common coupling (PCC), while the rest of the area EPS is electrically isolated.

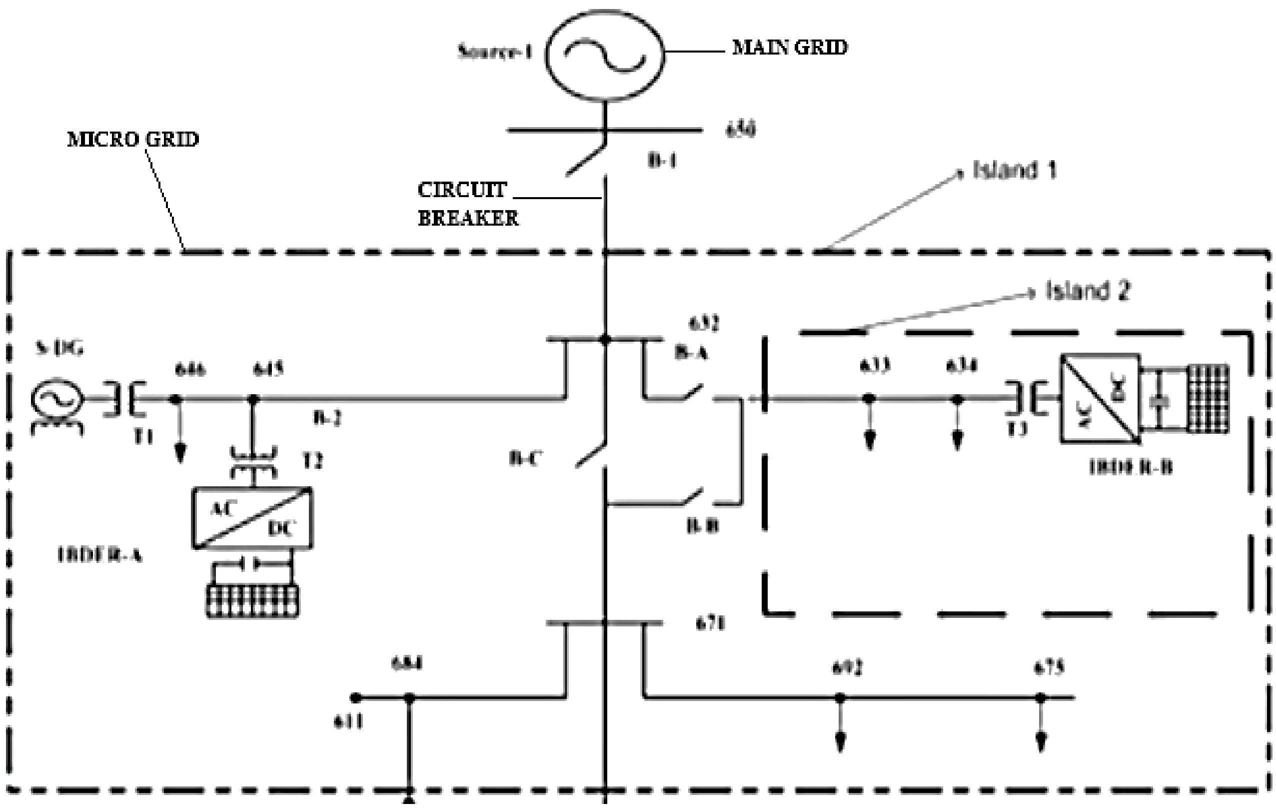


Fig2 Islanded mode operation

It's possible that an islanding situation is either intentional or unintentional. Intentional islanding is done as part of the leading utility's required maintenance, while unintentional islanding can occur at any moment due to the set of common faults or other power system uncertainties.

The security of power systems is jeopardised by unintentional islanding. It is exacerbated by all of the issues discussed below.

- **SAFETY CONCERN**: - Due to electricity supplied by distributed generators, the grid may still be powered in the event of a power outage. As a result, utility employees can be exposed to life-threatening dangers such as shocks and burns if they believe there is no electricity until the utility power is turned off.

- **DAMAGE TO CUSTOMER’S APPLIANCES**: - There may be a bi-directional flow of electricity due to islanding and distributed generation. This may cause severe damage to electrical equipment and devices. Some devices which are more sensitive to voltage fluctuations should be equipped with surge protectors. What exactly are surge protectors, then? - Device that protects electronic devices from voltage spikes, which are transient events that last 1 to 30 microseconds and can reach over 1,000 volts. A transient surge protector attempts to keep the voltage supplied to an electric system under control by blocking or shorting the current to keep it below a safe level. Blocking is accomplished by the use of inductors, which trigger a sudden shift in current. Shorting can be accomplished with spark gaps, discharge tubes, Zener-type semiconductors, and MOVs (Metal Oxide Varistors), all of which begin to conduct current after a certain voltage threshold is reached, or capacitors that do not cause a sudden voltage shift. Surge protectors with multiple elements are available.

- **INVERTER CONTROL MODE SWITCHING: -** With distributed generators such as solar and wind, many inverters are installed. The inverters have a control strategy, and if the microgrid is disconnected from the main grid, the PCC voltage and frequency will shift. The voltage and frequency input from the inverters of various types of renewable resources are fed into the control strategy through the point of common coupling (PCC). As the frequency and voltage of the PCC change, so does the input to the inverter controller. As a result, the controller can switch to a different mode of operation. Islanding disrupts the inverters' ability to act properly.

- **GRID PROTECTION INTERFERENCE: -**During the islanded mode of operation, various types of relays, reclosures, and fuses used in the grid for protection can malfunction.

As a result, protection engineers face a significant challenge when it comes to islanding in power networks. Unintentional islanding detection will become more important and challenging as DG integration grows. As a result, a slew of new islanding detection methods (IdMs) have been created to address these issues. Furthermore, if properly applied, the guidelines for deliberate and accidental islanding have safe operating solutions and mitigate the effects of DG islanding. Many IdMs have been introduced over the years, revealing the fact that islanding is still a research issue.

1.3 Analogy with physical Islands

A conglomerate of islands linked together by a bridge-like chain, as shown besides, is an analogy. The bridges reflect the grid's intertwining power lines. Each island would become isolated, both physically and electrically, if the bridges were fragmented. In order for the grid to continue to function on the island, it must be able to produce enough power to meet load demands. Each island will have a different frequency. And, once the acquaintances have been repaired, the two connecting islands must synchronize their frequencies before connecting, or both will fail.

Fig3 Interlinking of ideas between physical islands and electrical islands

CHAPTER 2

LITERATURE REVIEW

2.1 Existing Islanding Detection Methods

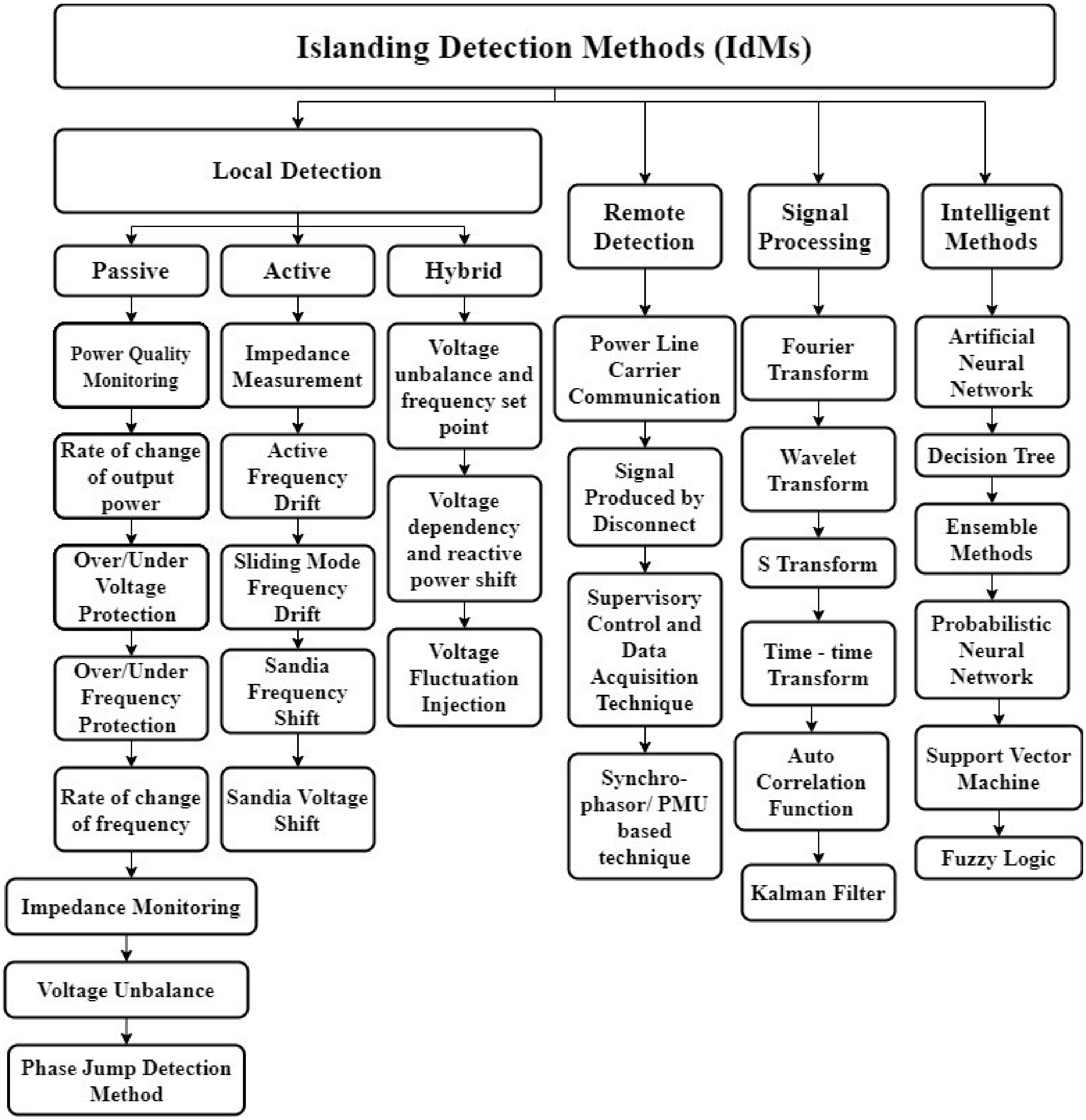


Fig4 Chart showing the different existing Islanding Detection Methods

2.2 Concept of Non-Detection Zone (NDZ)

The main grid is disconnected from the micro grid while operating in islanded mode. This does not imply that the load's POWER OUTPUT = the DG sources' POWER Produced. This is referred to as a power mismatch state. It is entirely dependent on the micro grid system's mode of operation, i.e., how many loads are turned on or off, how many DGs are operational, and so on.

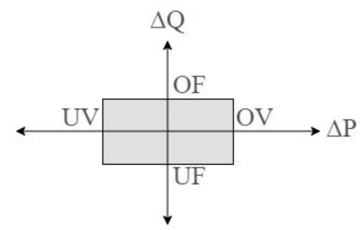


Fig5 Non-Detection Zone

From Fig5,
OV = Over Voltage reach
UV = Under Voltage reach
OF = Over Frequency reach
UF = Under Frequency reach

- ΔP (active power mismatch) = P (active load power) – P (DG active power generation) = P (active power taken or given to grid).
- ΔQ (reactive power mismatch) = Q (reactive load power) – Q (DG reactive power generation) = Q (reactive power taken or given to grid).
- 0% ΔP indicates **P(load) =P(DG)**
- +10% ΔP indicates **P (load) > P (DG)**; the system is loaded and the voltage is going to reduce. Hence under voltage relay is going to experience some tripsing. And if ΔQ is +ve **Q (load) > Q (DG)**, then under frequency relay is going to be actuated.
- -10% ΔP indicates **P (load) < P (DG)**, then over voltage relay is going to be actuated. Similarly, if ΔQ is -ve **Q (load) < Q (DG)**, then over frequency relay is going to be actuated.

The **NON-DETECTION ZONE (NDZ)** specifies the percentage of power mismatch for which the islanding relay fails to detect the islanding state. To detect whether the changed voltage and frequency are within the limits or not, all DERs must be fitted with under voltage and over voltage relays, as well as under frequency and over frequency relays**.** According to IEEE standards OVR=1.11 per unit and UVR= 0.88 per unit; OFR=60.5per unit, UFR=59.3 per unit and the islanding detection should be within 1-2 seconds.

The relation between the thresholds of power mismatch and voltage/frequency limits can be derived using the following equations.

- $\{(\frac{V}{Vmax})^2 - 1\} \leq \frac{\Delta P}{P} \leq \{(\frac{V}{Vmin})^2 - 1\}$
- $[Q_f\{1 - (\frac{f}{fmin})^2\}] \leq \frac{\Delta Q}{P} \leq [Q_f\{1 - (\frac{f}{fmax})^2\}]$

Where V_{max}, V_{min}, f_{max}, and f_{min} are the maximum and minimum voltage/frequency threshold limits of the relays in the DG system; ΔP and ΔQ represent the power mismatches prior to the main grid disconnection; Q_f is the load quality factor usually considered to define parallel RLC load.

2.3 Comparison between the islanding detecting methods (IdMs)

Each IdMs has certain advantages and disadvantages.

- Passive approaches are easy to use and can diagnose the islanding state using standard security techniques. However, when the DG and load power are balanced, these methods fail to detect the islanding state, resulting in a large NDZ.
- While active methods have a quick detection speed and a small NDZ, their effect on power quality can degrade the power system's efficiency.
- Remote methods are quick to detect, have high reliability, and can work with a variety of device configurations. The key limitations associated with remote IdMs are computational performance, implementation expense, and malfunctioning due to communication connection failure.
- Owing to the implementation of signal processing, pattern recognition, and artificial intelligence techniques, signal processing IdMs are becoming more accurate and effective.
- Intelligent methods suffer from a significant computational burden due to the existence of multiple training and testing procedures, making them less favorable in comparison to the other signal processing IdMs.

As a result of the foregoing discussions, it is clear that signal processing methods are favored due to their simplicity, low cost, low computational burden, precision, and real-time industrial applications.

CHAPTER 3

PHASOR MEASUREMENT UNITS

3.1 Introduction

Phasor Measurement Units (PMUs) are devices that generate synchro-phasors, frequency, and rate of frequency estimates from voltage or current signals received from PTs and CTs, as well as a time synchronized signal obtained from GPS satellites via GPS clock.

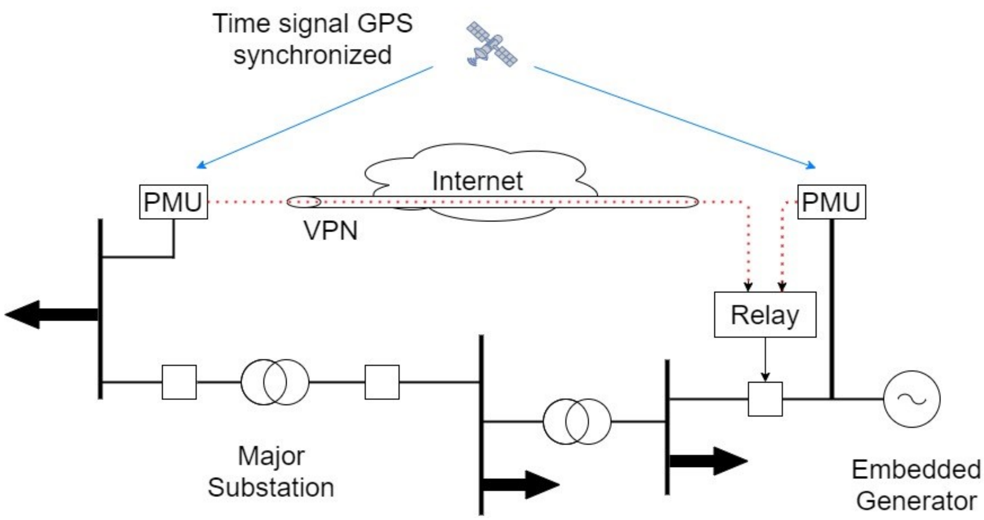


Fig6 Working of PMUs

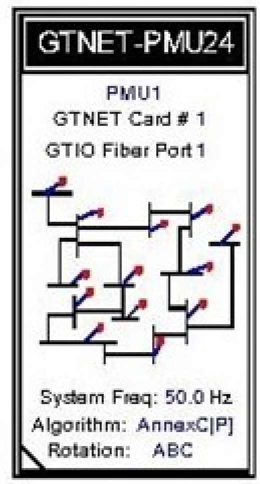


Fig7 PMU block in RSCAD

Fig 6 shows one PMU is located on the grid side, and the other is installed on the DG side. The data obtained from the PMUs' voltage and current signals is now sent to the relay, which detects some form of islanding. A circuit breaker is attached, which causes the relay to make a decision.

Assume the main substation is turned off and the breaker on the left is left open. The PMU 1 detects the grid-connected voltage phasor, which includes both magnitude and angle. Similarly, the PMU 2 detects the DG connected voltage phasor. These data are sent to the relay, where they are compared either by magnitude or by phasor angle or frequency. Disconnection means that the voltage and frequency have shifted unpredictably, causing the circuit breaker to trip.

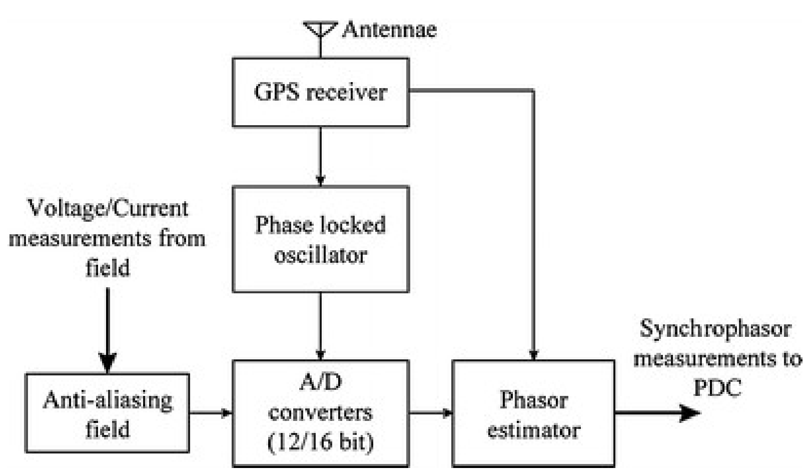


Fig8 Block diagram showing the inside functionalities of a PMU

PMUs are thus expected to research and track the real-time data obtained from the simulation. The PMU block in RSCAD (Fig 7) is used to collect data and feed it to the PMU Connection TESTER, which checks whether all of the PMUs in the simulation are exporting data. The collected data is then fed into the OpenPDC Manager, where it is translated to an excel file, from where they can be assessed and analysed.

3.2 Comparison with SCADA

1. The **speed at which data is transferred** from SCADA to the EMS is the most important factor. SCADA's output data rate has typically been once every 4-6 seconds, i.e., data fed to the algorithm receives data once every 4-6 seconds.

   If a disturbance occurs, and it is necessary to analyze such disturbances or how the system acts after the disturbance (post disturbance analysis), then the performance rate of once every 4-6 seconds is likely insufficient. Since the power system is a complex system that changes rapidly, we would be unable to capture the values of the power system in a timely manner. Therefore, we are not able to view the exact behavior of the power system and if the exact behavior is not extracted, then there might be a chance of ending up with wrong control actions.

   As a consequence, data is required at a much faster rate, which aids in the stagnation and application of all numerical data values. A new technology known as synchro-phasor emerges so that this disadvantage can be eradicated.

2. In SCADA, attempts are made to gather data from various parts of the power grid, although the data may have some timing lag or delay, the issue is sending data to a control center and some other substation located very far away and is also attempting to send data to the same control center; however, due to the **geographical distance**, the substation which is closer would be able to receive the data faster. As a result, local clocks are used to time the data coming from local substations, allowing us to determine what time those data belong to. To provide an accurate view of the entire power system, time synchronized wide area system data is needed.

3. SCADA technology **only provides magnitudes** of various electrical quantities such as voltages, currents, frequency, and so on. Since AC networks are examined which have both magnitude and angle phasors, therefore, focusing solely on magnitude results in knowledge loss and incorrect system monitoring.

Because of all the above reasons, PMUs are gaining much popularity nowadays.

CHAPTER 4

MODEL BUILDING METHODOLOGY

4.1 Overview of the Research Procedure

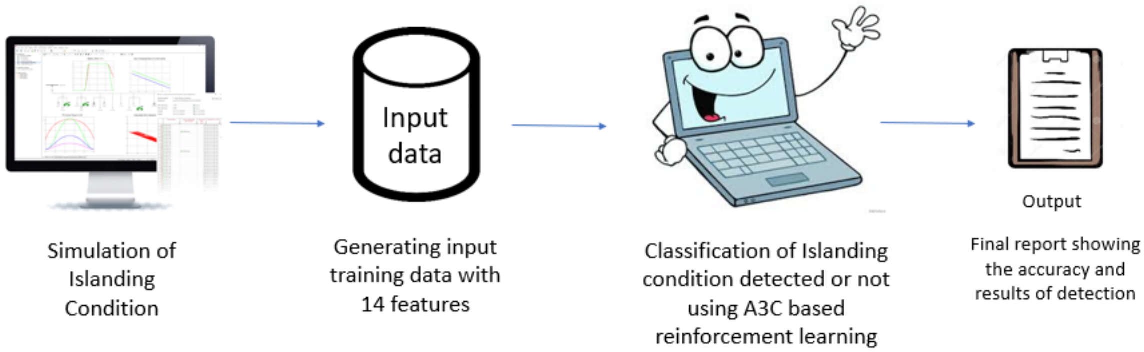


Fig9 Diagram representing the workflow of the research procedure

Firstly, the islanding condition is simulated in RSCAD software which acts as an interface for Real-Time Digital based Power System Simulator (RTDS) using PMUs which help to capture the essential electrical quantities.

Next, this data is retrieved in excel format so as to perform data analysis on it.

A classification model is built using Asynchronous Advantage Actor Critic (A3C) based deep reinforcement learning algorithm which gets trained on the generated data from the simulation model.

Finally, a report is prepared showing the accuracy and results of detection.

4.2 Knowing about RTDS and RSCAD Software Handling

RTDS is a real-time power system simulator with a sophisticated yet user-friendly graphical user interface. The RTDS enables users to reliably design and effectively simulate their models. RSCAD involving a library of power and control system modules, is used to architect the power system model in RTDS. In order to construct the required circuit, RSCAD allows the developer to choose a pictorial representation of the power system or control system components from the library. Once the system has been drawn and the necessary parameters have been entered, the RTDS compiler generates the low-level code required for simulation on the RTDS simulator. RTDS is capable of producing real-time signals, which allow the user to simulate circumstances that commonly occur in the power system.

RSCAD is software that allows the user to create a test case by using the various components available in the RSCAD library. To plan and run a new simulation scenario, complete the steps below.

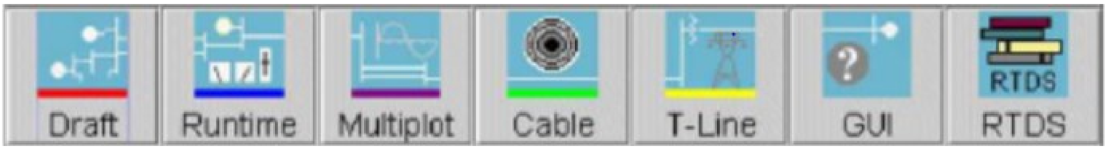


Fig10 Options available on opening RSCAD

- Launch the RSCAD/Draft program module.
- In the 'File Manager' module, a new 'Project' and 'Case' directory is developed.
- The circuit is then compiled after a new circuit diagram is generated for simulation.
- Finally, the simulation case is launched via RSCAD/RunTime.

The RSCAD/Draft software module is used to build the circuit that will be simulated with the RTDS simulator.

Fig11 Options available on draft window

After the successful compilation of the system, the user simulates the system by using the RSCAD/ RunTime software module.

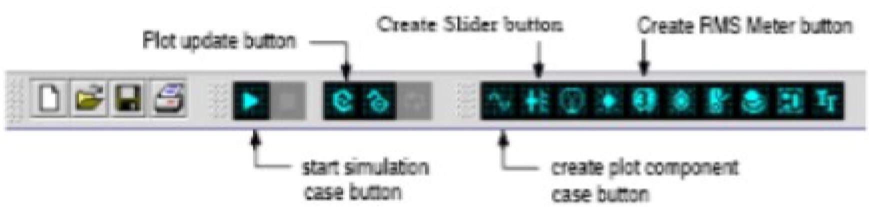


Fig12 Options available on runtime window

In RunTime mode, the user may add switches, buttons, meters, and sliders for fault application, plot graphs for voltage, current, power, fault, and frequency, among other things, and increase or decrease various physical quantities. After completing the plot selection in the RunTime, the user can simulate the device by pressing the "Start Simulation" button in the RSCAD/RunTime module.

4.3 Fault Control Logic

Various types of faults can occur in electrical systems on occasion. These flaws endanger both the safety of the machinery and the safety of the citizens. Unsymmetrical faults in a three-phase system include single-line-to-ground, double-line-to-ground, line-to-line, and three-phase symmetrical faults. The function of the power system during each of these faults can be examined using sequence components discovered by Charles L. Fortescue.

- **Symmetrical Faults: -** Prior to the fault, voltage and current were 120o phase displaced and balanced, which means that the magnitudes of both phases were the same. Even after the fault, the magnitudes and phases of voltage and current remain balanced. As a result, this type of fault is referred to as symmetrical faults. Faults can now be either short circuit (L-L-L) or ground (L-L-L-G).
- **Unsymmetrical Faults:** - The system is balanced prior to the fault, but after the fault, it becomes unbalanced. Line to ground (L-G), line to line (L-L), and double line to ground (L-L-G) faults are particularly common.

According to the Fortescue Theorem, if there are n unsymmetrical phasors, these phasors can be resolved into n-1 symmetrical phasors and one co-phasal quantity. Since this debate is about current and voltage vectors, there are only three unsymmetrical vectors, which can be split into two symmetrical vectors and one co-vector.

Since faults may be permanent or temporary, i.e., transient for a limited period of time, both types of faults have been considered for simulation purposes.

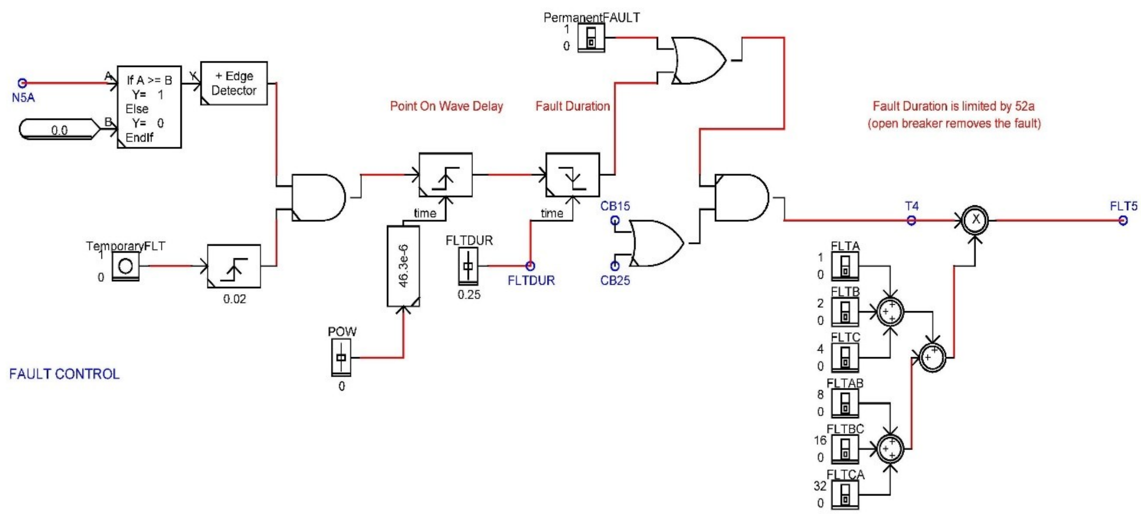


Fig13 Fault Control Logic

4.4 Protection Relay Blocks and Logics

The main goal of this article was to secure transmission and distribution lines from faults, so some types of relays came into play to help us achieve that. Distance relays with directional features, specifically MHO relays, are mostly used in transmission lines, whereas overcurrent directional relays and differential relays are mostly used in distribution lines. RSCAD allows you to use their built-in models of distance protection components.

a. **Distance Protection: -** It is determined by the distance between the feeding point and the fault. The time it takes for such a safety to operate is determined by the ratio of current and voltage, i.e., admittance, or voltage and current, i.e., impedance. Since the MHO relay is an admittance relay, the discussions about it are more detailed in this article. MHO relay, also known as angle impedance relay, is a high-speed relay. The volt ampere element purchases the administering torque in this relay, and the voltage element refines the restraining torque. As a result, an MHO relay is a voltage-controlled directional relay. The torque equation can be written as: -

$T = K1VI \cos(\theta-\tau) - K2V2 - K3$ where K3 is the control spring effect and θ and τ are defined as positive when I lag behind V. At balance point: -

i. $0 = K1VI \cos(\theta-\tau) - K2V2$ (considering spring effect as 0)
ii. $K1VI \cos(\theta-\tau) = K2V2$
iii. Therefore, $Z = K1/K2\cos(\theta-\tau)$ which reflects an equation of a circle passing through origin whose diameter is K1/K2 =ZR (ohmic setting).

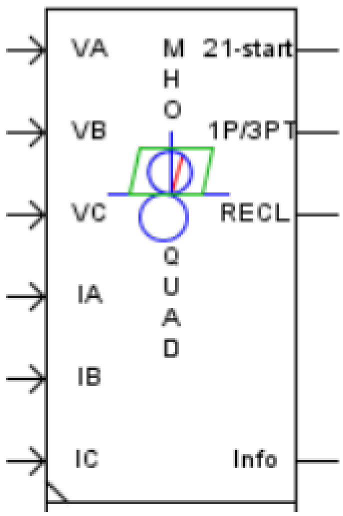


Fig14 MHO Relay block in RSCAD

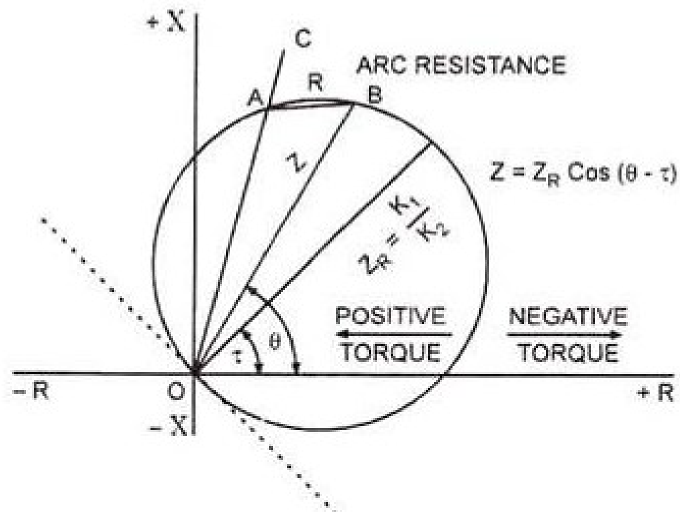


Fig15 Operating characteristics of MHO Relay

The voltages and currents of different phases detected by the secondary of CTs and PTs linked in the main transmission lines will be the component's inputs in Fig 14. The performance, on the other hand, would be in the form of a WORD that must be translated to BITs before it can be accessed by other logic.

As a result, the reasoning employed here compares admittance or even impedance to the threshold zone impedance already set inside the relay. If the impedance is less than the fixed impedance, it is safe to assume that a fault has occurred in that zone due to an increase in current flow.

b. **Overcurrent Relay Protection Logic:** In the same way as distance safety is used, a distinction is made between the rms current flowing through the transmission lines and the threshold values. If the values rise above the threshold, over protectional relays assist in tripping the corresponding circuit breakers by transmitting the trip signal. The rationale employed is depicted below.

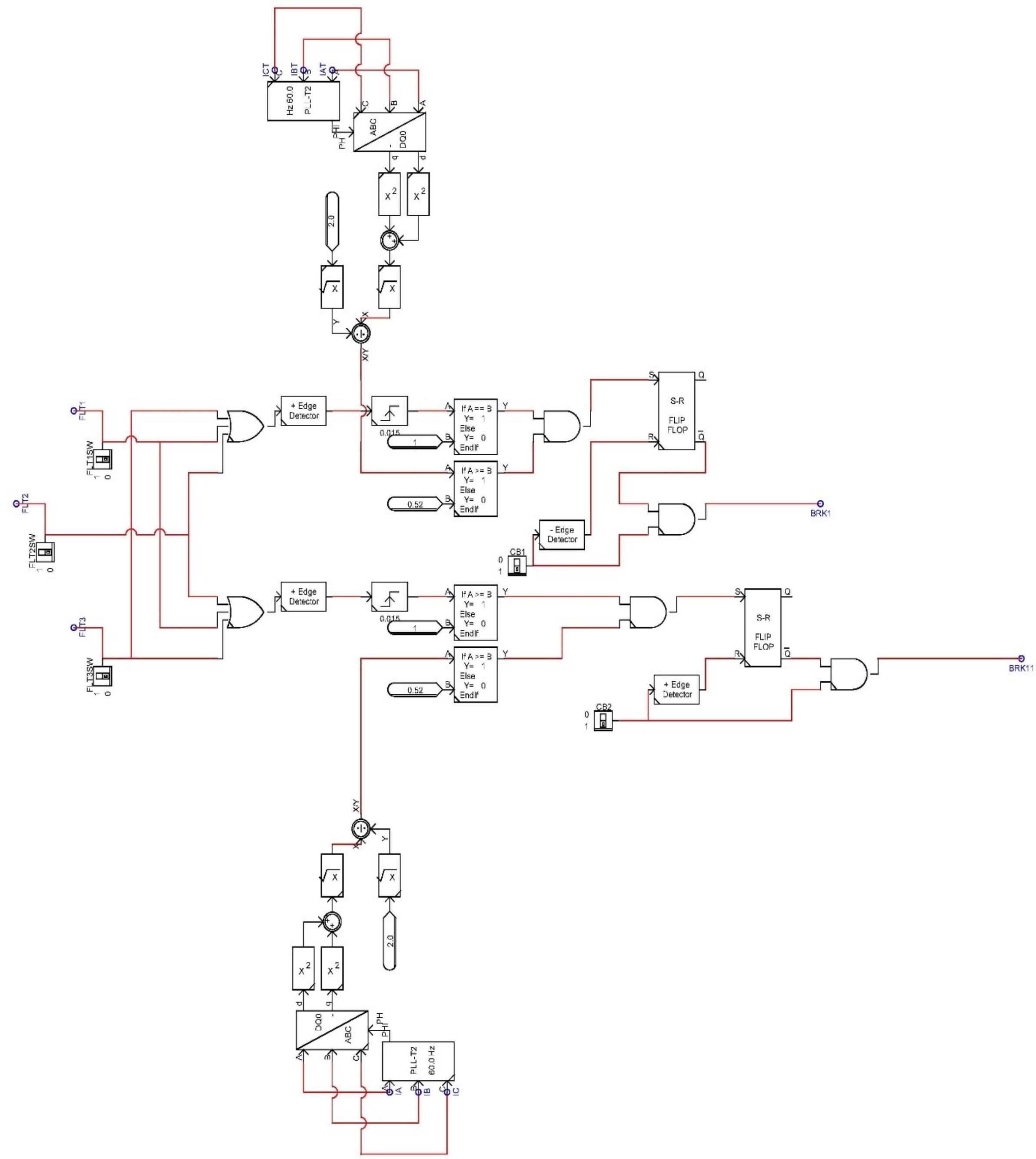


Fig16 Overcurrent Relay Protection Logic

4.5 Load Variation

Since the simulation is performed in real time, it is preferable if the load is varied and the synchronisation of the power generators is observed. Voltage and current magnitudes and phasors, as well as frequency, are all involved in synchronisation.

The generator receives mechanical energy as input and produces electrical energy equal to the load requirement as output. If the load is unexpectedly increased by 10%, the electrical energy available is now greater than the mechanical energy produced. As a result, the accumulated rotational kinetic energy in the generator's rotor is transformed to provide excess electrical energy.

N_s=120*f/P where N_s is the speed of the rotor, f is the frequency and P is the no. of poles of the Machine.

Assume that electrical generation exceeds load requirement, indicating that Ns is greater and therefore frequency produced is greater, which must be reduced by slowing down the rotor speed and retained at reference. Similarly, when electrical generation is less than the load specifications, the reverse occurs. This is how frequency synchronisation is accomplished.

Next, Load data is obtained from an official NYISO, which has an excel sheet with varying loads every 5 minutes in 11 different regions. Load data (https://www.nyiso.com/load-data) This excel data must be fed into the RSCAD model, where simulation can take place. Data can now only be fed via the port. As a result, data are sent to the appropriate ports using the User Datagram protocol (UDP) and Python code.

4.6 Final Model

1. To begin, the model is created by connecting the utility grid and microgrid in RSCAD's draft window, and the transmission lines data is fed into the T Line window by specifying the length and positive and zero sequence impedances as required.
2. The faults are then made to appear in the transmission lines, depending on the type of fault the consumer wants to monitor in the simulation's runtime window. A switch may provide a permanent fault, or a push button may provide a temporary fault.
3. The voltage and current signals are then sampled using signals from CTs and PTs, which are then fed into DFTs to collect samples of the 60 Hz portion.
4. PMUs detect these data, and the extracted data is sent to relays, which decide what action to take next and send it to the circuit breakers accordingly.
5. When the power grid's circuit breakers open, the microgrid becomes islanded, as it would be during a fault; frequency, current, and voltage magnitudes, as well as phasors, are not synchronized. Circuit breakers transmit the trip signal from relays and are disconnected due to a lack of synchronization.
6. If a temporary fault occurs, the time span for disconnection can be brief. If permanent faults occur, the circuit breakers are tripped first, then the circuit breakers are reconnected after a certain time period in the hope that the fault has cleared. When they discover that the fault has not been resolved, they open the CB once more, and this process continues for a total of four times until they are certain that the fault occurred is permanent and locks the CB in the open position for the rest period of time. Maintenance workers must come and clear the fault and close the breakers in order to maintain power flow.

Now, when islanding, a quick search is performed, which proves to be very useful in the end. The load requirement is compared to the power provided by the DG resources. If the load requirement is less than the power produced, quickly, a contact signal is sent to the inverter to shut down the DG, as this can cause damage to other household electrical equipment and even track back to the defective transmission line position where the maintenance workers are working, posing a danger to their lives. If the load exceeds the DG's capacity, take the necessary steps to synchronize and switch on other DGs if they are available; otherwise, keep the DG running on low voltage until power from the grid is restored.

The 9-bus model used in the simulation is shown below: -

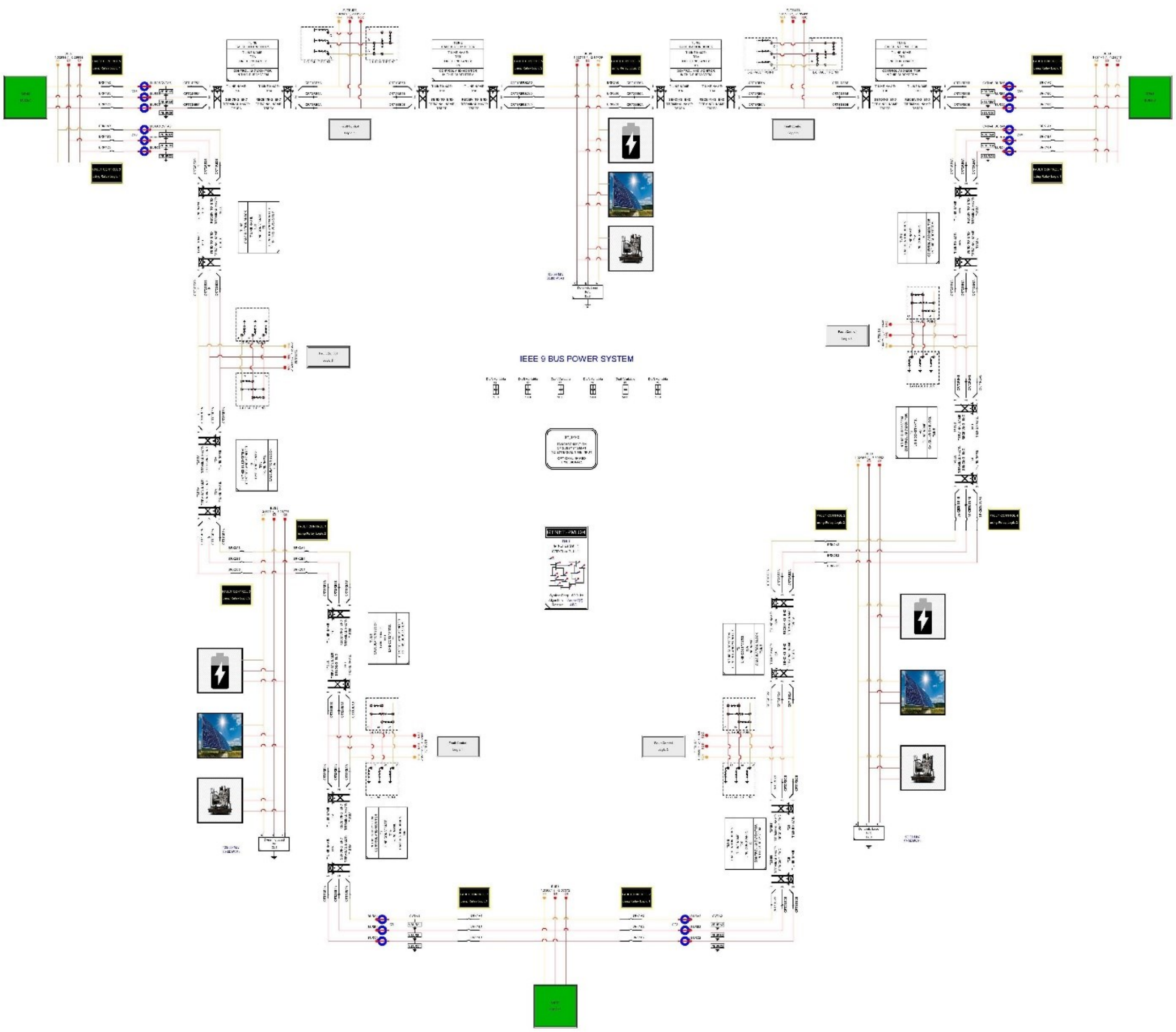


Fig17 Final 9 bus power system model with DG Sources installed

4.7 Data Generation Procedure

Methodology of time series data generation:

1. Fault resistances varied across all the faults and data was collected. Fault Resistances = {0.1, 10, 20, 30, 40, 50, 60}
2. Faults made to occur at different bus positions. Fault loc: {7-8, 8-9, 7-5, 5-4, 9-6, 6-4}
3. Types of faults: {AN, BN, CN, AB, BC, CA, ABN, BCN, CAN, ABC}

Total time captured = 0.7 seconds
Fault duration =10 cycles =10/50 = 0.2 seconds.

Data Produced for each case = 7,00,000
Total data = 7 (fault resistances) x 6 (fault locations) x 10 (types of faults) x 7,00,000 (time series data per case) = 29,40,00,000

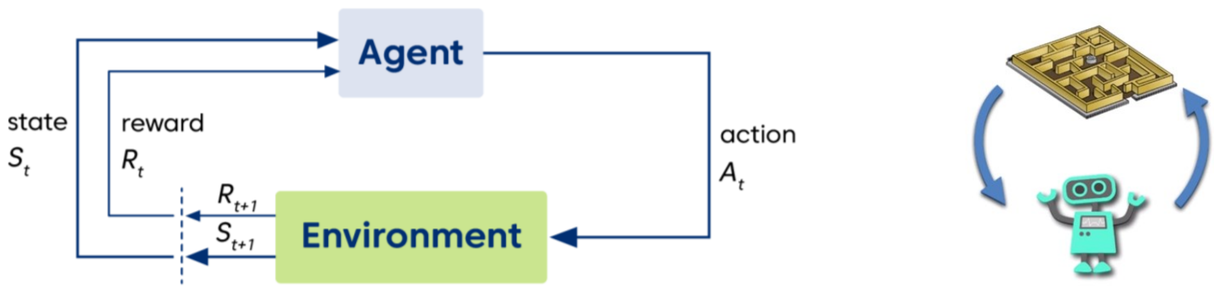
Features:

1. Current in phase A= IA,
2. Current in phase B= IB,
3. Current in phase C= IC,
4. Voltage in phase A= VA,
5. Voltage in phase B= VB,
6. Voltage in phase C= VC,
7. Frequency= f,
8. Rate of change of frequency= ROCOF,
9. Phasors of IA,
10. Phasors of IB,
11. Phasors of IC,
12. Phasors of VA,
13. Phasors of VB,
14. Phasors of VC

CHAPTER 5

OVERVIEW OF ASYNCHRONOUS ADVANTAGE ACTOR CRITIC (A3C) ALGORITHM

5.1 Introduction of Deep Reinforcement Learning



(a) (b)

Fig18 (a) Block diagram of a Reinforcement Learning Algorithm, (b) Example of a Maze Runner Bot

Here, for Fig 18 (b), let's consider a Maze Runner bot who has to travel through the maze starting from the initial point and has to come out of the maze from the end point. So, here, the Maze runner bot acts as the agent. The maze is actually the environment. The agent here can take 4 actions i.e., can move straight, can move backwards, can move left and right. Using these actions, it has to traverse through the maze. By taking an action, each position it ends up inside the maze can be called as state. Therefore, based on the actions the agent takes, environment feedbacks a reward which helps it to learn how to proceed next and quantify the action it has taken as bad or good. The main aim of the agent is to maximize the reward, and hence by taking it as the objective it can learn how to navigate through the maze.

So, a reinforcement learning always has these 5 parameters which helps in training of the model. Therefore, in our case, these parameters are as follows:

1. Agent: Here, the AI algorithm- Asynchronous Advantage Actor Critic (A3C) Algorithm.
2. Environment: The Excel file generated from OpenPDC Manager containing the time series data.
3. Action (a): Only 2 things either islanding detected or not, since a binary classification problem. [0,1]
4. State (s): Each row sample in the dataset.
5. Reward: While choosing the values of the rewards, the ratio of the number of majority class elements to minority class elements is used, which is referred as ***ρ***.

$$r = \begin{cases} \frac{1}{\rho}, & \text{if correct classification of majority class} \\ \frac{-1}{\rho}, & \text{if false classification of majority class} \\ 1, & \text{if correct classification of minority class} \\ -1, & \text{if false classification of minority class} \end{cases}$$

Here majority class is the non-islanded class, and minority class is the islanded values.

5.2 Actor Critic

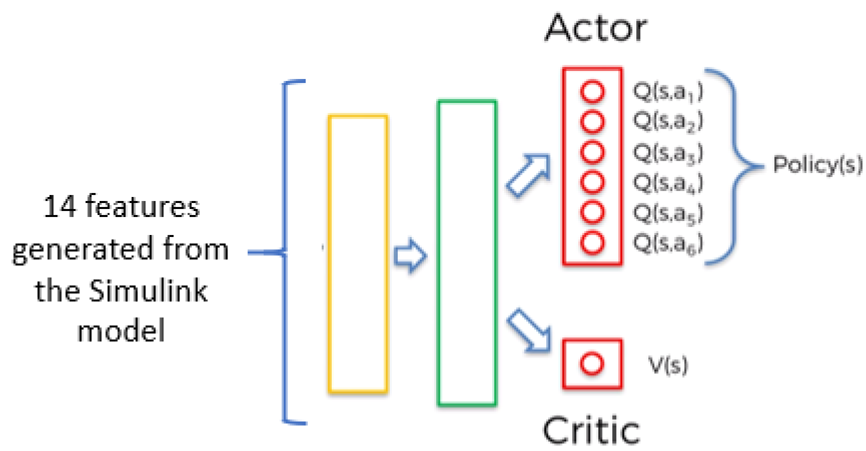


Fig19 Neural Network model representing Actor and Critic

Here, the 14 features describe the input nodes of the neural network. After which the hidden layers and no. of input nodes can be decided using keras-tuner or GridSearchCV. Here, there are 2 types of outputs – Actor and Critic.

Actor denotes the actions, Q(s,a) quantifies the action a taken by the agent in the state s. Here only 2 output nodes will be there denoting Q(s,a1) and Q(s,a2) since in our case, the agent can take only 2 actions i.e. detecting either the case is islanded one or not.

Critic V(s) signifies the value of the state, in which the agent is present currently. Since each row is a state, so every iteration, it takes in one state (which is represented by the 14 features) and outputs the value of the corresponding state.

5.3 Asynchronous

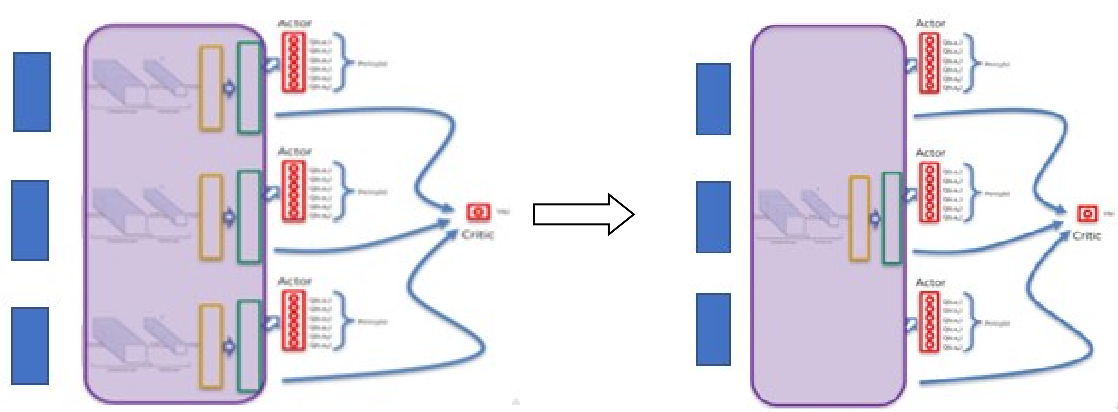


Fig20 Neural Network models representing parallel asynchronous agents

The samples we collect during an agent's run have a strong degree of correlation. We easily run into problems with online learning if we use them as they come.

As a result, there should be a method for breaking this connection while still using online learning. We can run several agents in parallel, each with their own copy of the environment, and use their samples as they come in. Different agents are likely to have different experiences, thus avoiding the correlation. Another advantage is that we don't need to store the samples, so this method uses much less memory.

This is called asynchronous since the multiple agents used have different initialization points in the environment (i.e., in our case different starting positions within the excel sheet).

5.4 Advantage

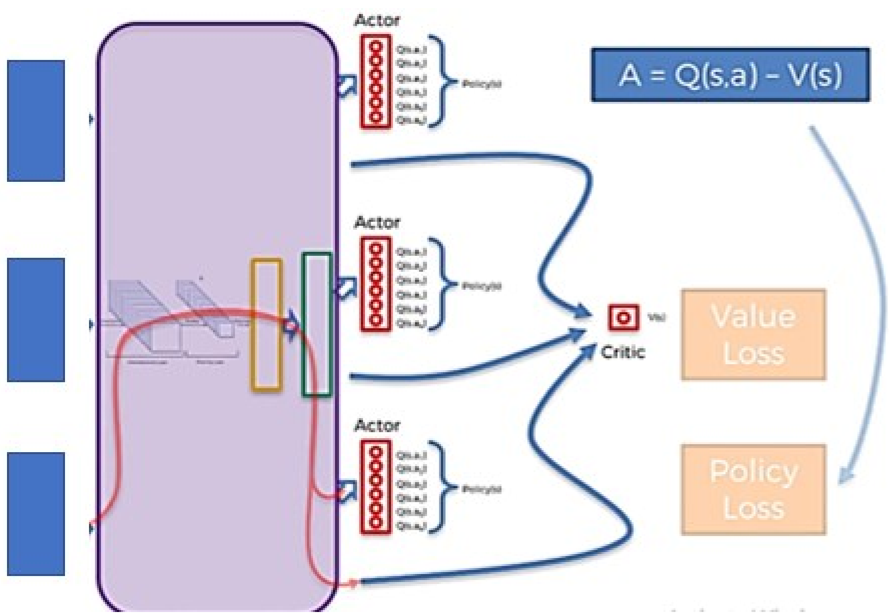


Fig21 Neural Network model representing how losses are backpropagated to update weights

The value of Discounted Returns is typically used in the implementation of Policy Gradient to tell the agent which of its actions are rewarding and which are penalized. The agent also discovers how much better the rewards were than it anticipated by using the importance of Advantage instead. The agent gains new insight into the world as a result, and the learning process improves. The advantage metric is given by the following expression: -
Advantage: A = Q(s, a) – V(s)

5.5 Final Model with addition of LSTM layer

Following is the final model described which has Long short-term memory (LSTM) cells of Recurrent Neural Networks (RNN) present inside it. LSTM cells take care of the time series analysis because of the presence of the memory lane in its structure. The disadvantage of vanishing gradient in RNNs is also eradicated with the addition of LSTM cells.

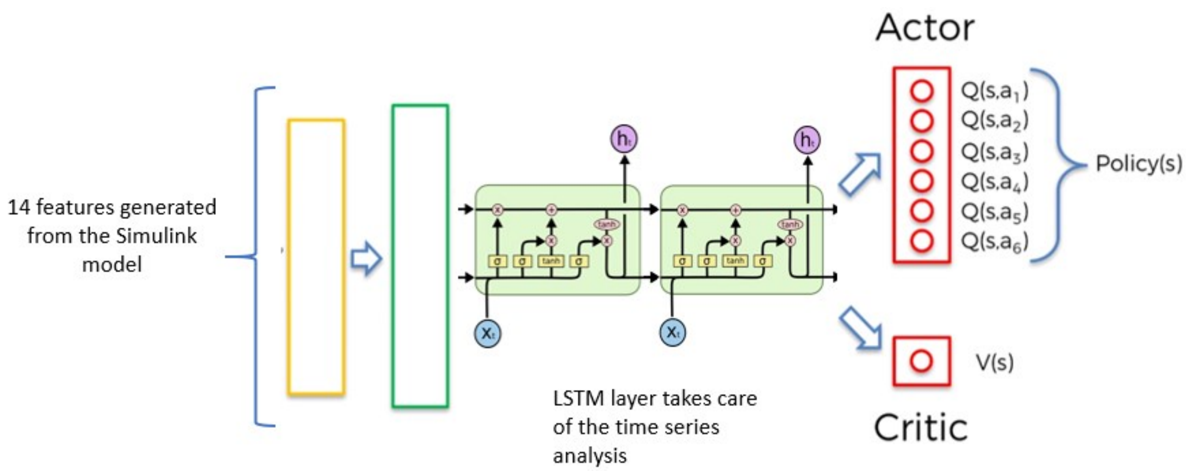


Fig22 Final Asynchronous Advantage Actor-Critic Model

5.6 Pseudo Code of the A3C Algorithm

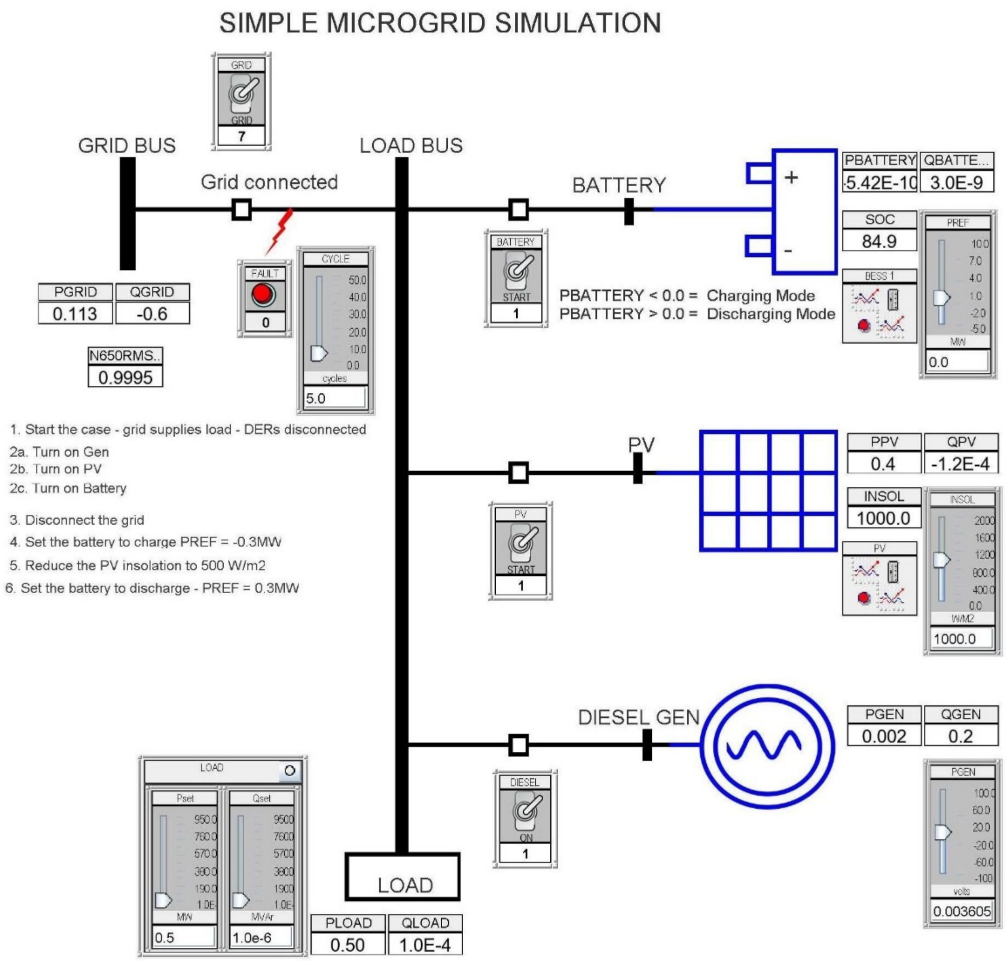
Algorithm 1 Asynchronous one-step Q-learning - pseudocode for each actor-learner thread.

// Assume global shared θ, θ^-, and counter $T = 0$.
Initialize thread step counter $t \leftarrow 0$
Initialize target network weights $\theta^- \leftarrow \theta$
Initialize network gradients $d\theta \leftarrow 0$
Get initial state s
repeat
    Take action a with ϵ-greedy policy based on $Q(s, a; \theta)$
    Receive new state s' and reward r
    $$y = \begin{cases} r & \text{for terminal } s' \\ r + \gamma \max_{a'} Q(s', a'; \theta^-) & \text{for non-terminal } s' \end{cases}$$
    Accumulate gradients wrt θ: $d\theta \leftarrow d\theta + \frac{\partial (y - Q(s,a;\theta))^2}{\partial \theta}$
    $s = s'$
    $T \leftarrow T + 1$ and $t \leftarrow t + 1$
    if $T \mod I_{target} == 0$ **then**
        Update the target network $\theta^- \leftarrow \theta$
    end if
    if $t \mod I_{AsyncUpdate} == 0$ or s is terminal **then**
        Perform asynchronous update of θ using $d\theta$.
        Clear gradients $d\theta \leftarrow 0$.
    end if
until $T > T_{max}$

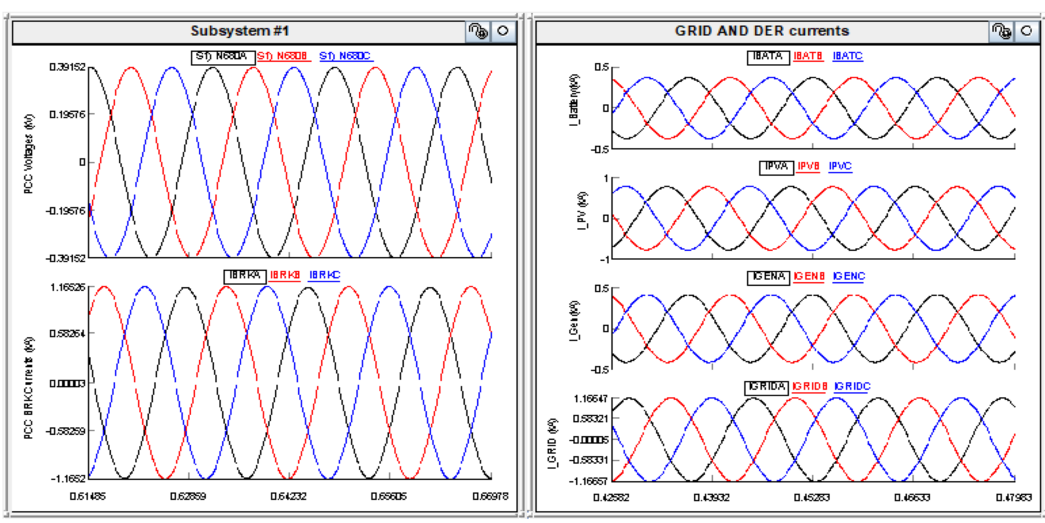
CHAPTER 6

OBSERVATION AND CONCLUSION

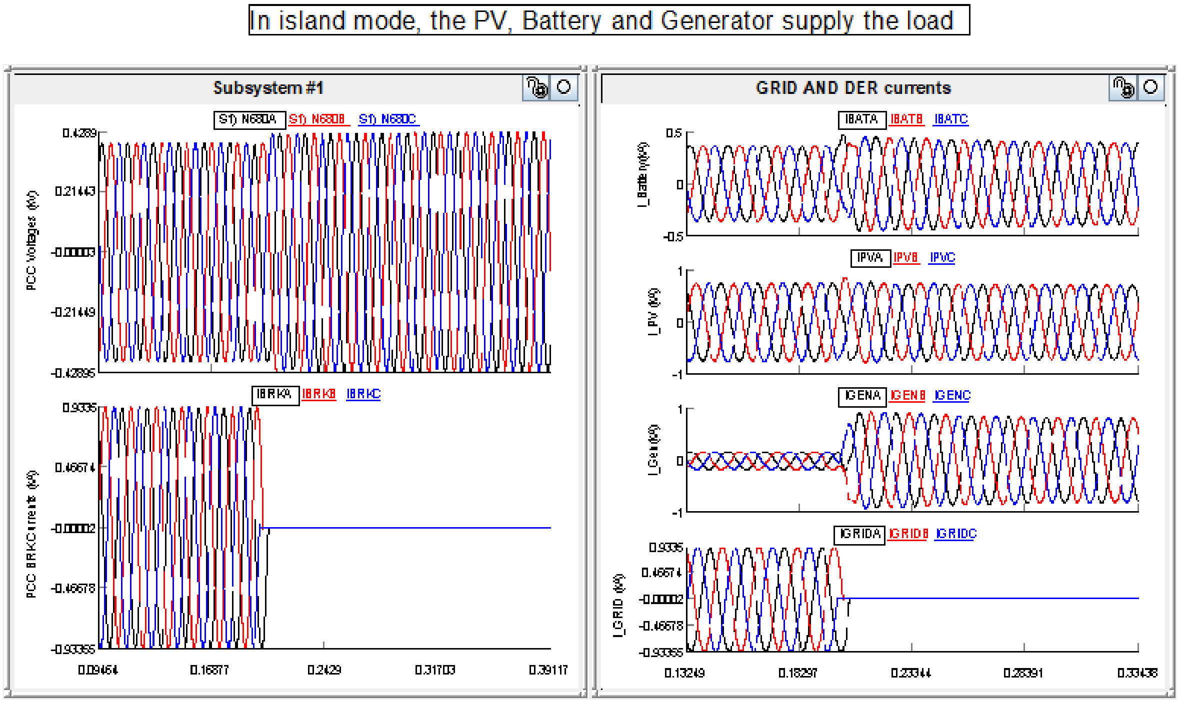
6.1 Simulation Results



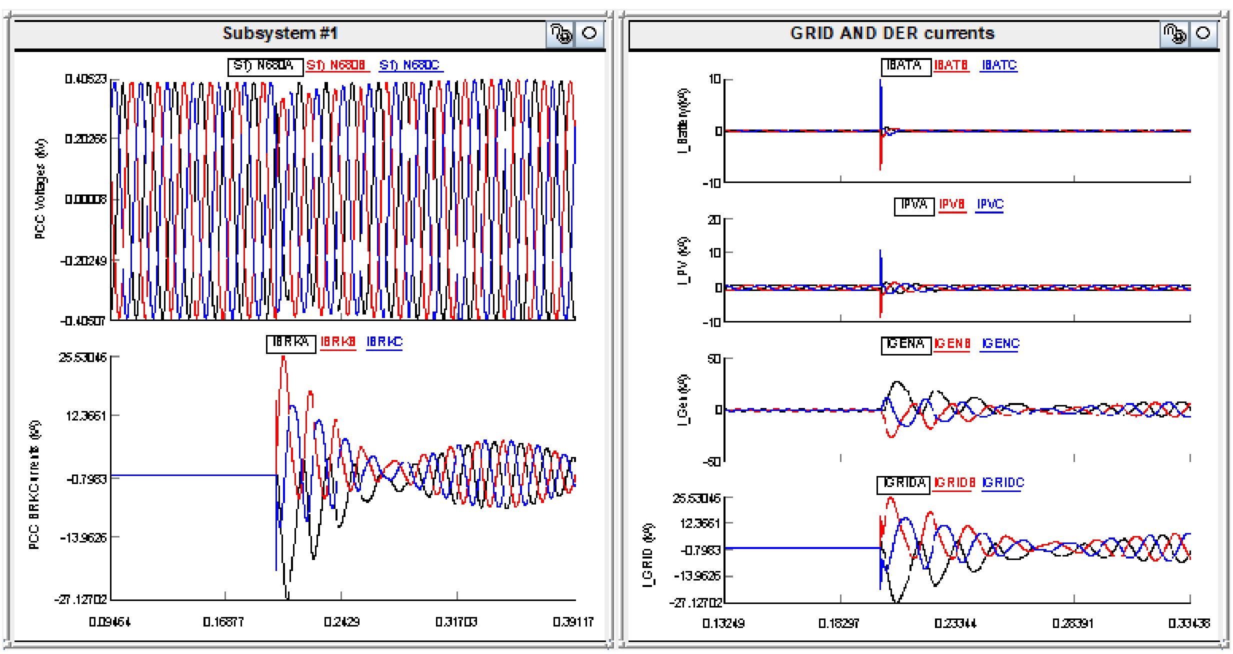
(a)



(b)



(c)



(d)

Fig23 (a) Runtime model of a portion of the 9 bus model, (b) Electrical Signals in normal condition before islanding/ fault injection, (c) Signals during islanded mode of operation, (d) after fault clearance, signals trying to resynchronize with the main utility grid

6.2 Reinforcement Learning Accuracy

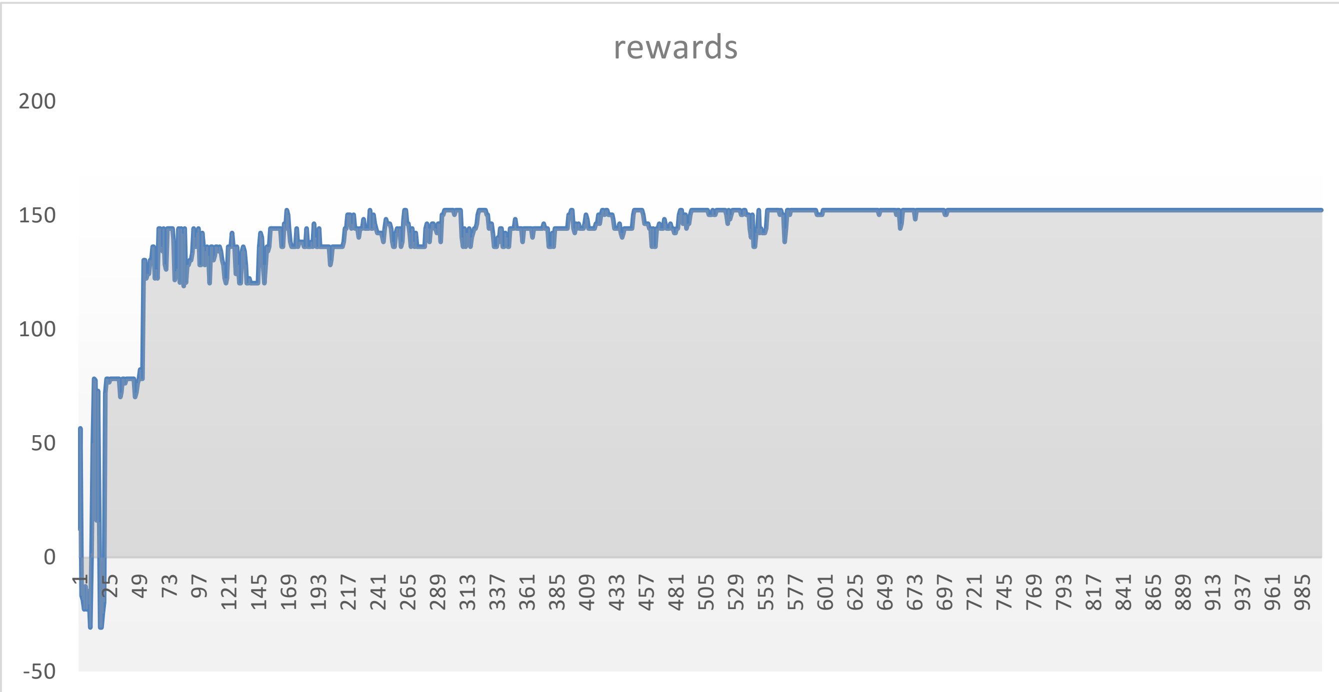


Fig24 Rewards achieved during training of Advantage Actor-Critic Model over time

	precision	recall	f1-score
0	0.97	1.00	0.99
1	1.00	0.93	0.96
accuracy			0.98
macro avg	0.99	0.96	0.97
weighted avg	0.98	0.98	0.98

	precision	recall	f1-score
0	0.97	1.00	0.99
1	1.00	0.93	0.96
accuracy			0.98
macro avg	0.99	0.96	0.97
weighted avg	0.98	0.98	0.98

Fig25 Training and Test Results

6.3 Discussion

1. First and foremost, the runtime model is designed to run. The DERs are initially paired, and the load is supplied by the micro grid as well as the utility grid. The battery is discharged (Pref = +0.5) in Fig 23. b), and the excess power is sent to the grid. A minus sign indicates that power is being received from some source, while a positive sign indicates that power is being sent. The battery's state of charge (SOC) is then examined. If it drops below 50%, the PREF value is set to -0.5, which forces it into charging mode. However, as long as synchronized activity is carried out, there will be no such signal interference.

2. Then, by pressing the push button key, trigger a fault to occur. (This is shown by the shift in colour of the spark sign.) It will be noted that the Square representing CB will also turn red, indicating the disconnection of the main utility grid. This can be seen in Fig 23. c), which shows the main circuit breaker's current as well as the grid turning to zero. Simultaneously, the diesel generator on site attempts to compensate and feed the load with the ample power provided by the main grid. As a result, the circuit breaker's total current signal increases.

3. Now, since a temporary fault was forced to occur, it is cleared after a period of time, and the relay's reclose signal is sent to the circuit breaker. The circuit breaker reopens and checks to see if the fault is still there. When it sees a fault that needs to be repaired, it attempts to synchronize the signals with the other generators that are running and assists in maintaining a constant flow of power to the load. In Fig 23 d), how the signals try to resynchronize is shown, after which it returns to the state shown by Fig 23 b).

6.4 Future Scope

Coming to the future reach of the research, which is the main goal, there is a much broader factor behind researching all of these findings and observations.

There are two ways that a relay's signals can be disrupted. One is when a genuine error has arisen, while the other is when cyber criminals feed incorrect data to CTs and PTs, thus tampering with the initial data and sending erroneous data to the relay. Now, if the relay operates solely in accordance with the CT and PT adjacent to the relay and sends a trip signal to the circuit breaker, the result obtained may not be entirely satisfying, resulting in the implementation of an incorrect decision that may thwart the smooth operation of a particular EPS. As a result, the primary goal of analyzing the PMU data obtained is to create a pattern that can be fed to the relay and used to make decisions. This is because if an invader can manipulate a single PMU's data, the other PMUs acting when a fault occurs can ideally have the correct result. The main area of research now is determining the pattern that the PMUs pursue when a fault arises, as cyber security goes hand in hand with the need to make the grid smarter across various communication channels.

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