Power system restoration based on intentional islanding of microgrids in disaster management using Artificial Neural Networks (ANN)

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Abstract: *The Power outages that last for weeks at a time are a result of natural disasters with an extensive influence on electrical networks. To regain power, it is difficult to suppress these effects. Researchers presented an assortment of methods for power restoration using distributed energy resources (DERs). DERs can be produced by using power devices, batteries, diesel generators as well as different sources of renewable energy. The valued distribution system requires DC voltage with low voltage, direct current which also can be delivered by DERs. In proposed research, an effort is taken to restore electricity in the wake of disasters based on deliberate islanding in intelligent architecture, called Artificial Neural Networks (ANN). Traditional power system restoration methods encounter stability issues because renewable DERs operate in an unanticipated manner. Our study highlights the value of intentionally isolating microgrids as a strategy to speed up and stabilize the restoration process. Segmenting the grid allows for the systematic identification and repair of distressed areas while preserving intact portions. This technique reduces the likelihood of further system failures while streamlining the restoration procedure. In the final analysis, compared to an islanding algorithm, the use of ANNs significantly reduced model execution times throughout the restoration process and improved stability. The output of a MATLAB simulation shows the effectiveness of the DER and its control strategy to improve dynamical stability.*

Keywords: *Artificial Neural Networks (ANNs), Disaster management and intentional islanding, DERs, Solar PV (Photovoltaic), RES, LVDC (Low Voltage DC).*

1. Introduction

Disasters caused by nature are unplanned occurrences that disrupt numerous crucial services, including energy, communication and the movement of people and goods [1]. The availability of the power system, which is becoming increasingly important, is the main issue in restoring these services to their prior states [2], [3], [4] and [5]. The alternative electricity provided by DERs, which create microgrids at the distribution level, offers a remedy for this. There are two major obstacles in using DERs for power. The first is the requirement to identify the network's healthy and disaster-affected portions and the balance of power should be obtained between load power requirements, power stored in battery and power generated by DERs. If there is typical outage or faults DERs are preferred for power resilience, as can be seen from the literature. However, compared to usual failures, the damage caused by natural catastrophes to electricity networks is distinct.

From Table 1, it can be shown that each natural disaster has a different impact on the networks that support it. For instance, during a storm, trees may fall in various places, causing the wires to break or even the utility poles to topple over, which would result in several faults [6] and [7]. Comparably, a normal outage is caused by just one random issue. Depending on how they are seen as an example, floods, for instance, distribution system is getting impacted due to this. Distribution networks comparatively, the available thing at distribution substations is disrupted by floods. Weeks or months are needed to restore flooded substations. This demonstrates that traditional power system restoration techniques intended for regular outages may encounter significant difficulties when attempting to repair outages caused by natural catastrophes [8] and [9].

In the previous study, an intentional islanding-based smart resilient power system for post-disaster conditions was attempted. A novel deliberate islanding technique for LVDC distribution systems is presented since many researchers have already dependability can be used to increase by distribution system with LVDC [10] [11].

Table1.Comparison of regular outages with natural disasters [9].

Regular outages	Natural disasters
One failure is caused by a single problem in one component.	Catastrophic damage was caused by several faults.
General analysis does not include any stochastic features.	Natural catastrophes have stochastic processes that are subject to uncertainty.
There is no spatiotemporal association with the defect, it occurs randomly.	Correlation between space and time for the faults caused by natural catastrophes.
Most electricity generation facilities are operational and remain linked.	There might be unreliable power-producing equipment.
The transmission and distribution network remain unharmed.	The transmission and distribution networks are faulty and insufficient.
Use only infrastructure for electricity grids.	Interconnectedness with other infrastructures.
Repair and restore with haste.	Repair and restoration challenges, such as debris left over from a disaster.

In order to locate the island that the DER has generated, extensive research is also done on islanding detection approaches [12], [13]. These methods merely identify the island that has been formed and have no influence on the loads connecting to the DER [14]. To provide load control and mitigate the effects of natural catastrophes, the suggested algorithm connects loads in a priority-ordered sequence to construct islands and sub-islands [15].It has been tested on a variety of case studies, but more time is taken to prevent fault and post-disaster conditions so that the stability is lost.

2. DISTRIBUTION MECHANISM FOR INTEGRATING DERS SUGGESTED BY IEEE

In 1920-year, reliable electricity is provided to networks with secondary distribution, load centers. Different networks with operating grid are composed to get load center which forms EPS (Electric Power System) in an area. Intermediary transformers are avoided for use by customers by using secondary voltage of network. In generation, the EPS secondary network is not included in general consideration. Many worries are accompanied for secondary network generation and DERs inclusion. Network criteria is violated by power flow because grids opposite direction should power flow for network and DER integration. To reduce this impact IEEE provided procedure and references which provide links between secondary distribution network and DERs.

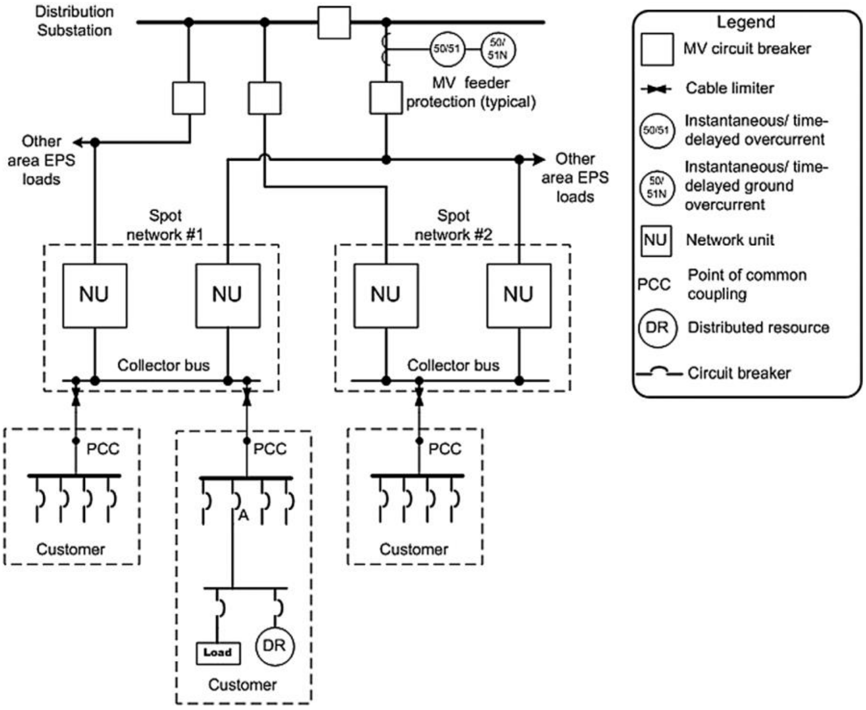

Fig.1IEEE reference number :(IEEE Std. 1547.6-2011) given for electric power system, secondary distribution network and secondary resources [16].

In Figure1, the block diagram of the IEEE-suggested practice system is displayed. For the implementation of the suggested algorithm, this system was created using MATLAB/Simulink.

3. LOW-VOLTAGE DC (LVDC) DISTRIBUTION SYSTEM

The growth of LVDC distribution systems is a result of the increased use of renewable energy sources such as solar power production, wind energy conversion systems and electric cars in the form of DC. As a continuation of the development of the 1kV intermediate LVDC distribution system, the development was initiated in Finland in 2005. When using DERs, using LVDC in the distribution system drastically minimizes losses by cutting down on the number of power conversion steps. As a result, the total system losses are decreased; the system reliability and efficiency are raised. In order to evaluate the performance of DC residential loads with standalone PV systems with AC loads technically and economically, more realistic implementations are made. An LVDC distribution system is implemented because it is more advantageous than an AC system, according to the published results [17], [18] and literature. Figure 2 shows how the LVDC system differs from a standard AC system in that power electronic equipment must be installed. The main DC system must also be connected to the DER and the various types of loads via power electronic converters.

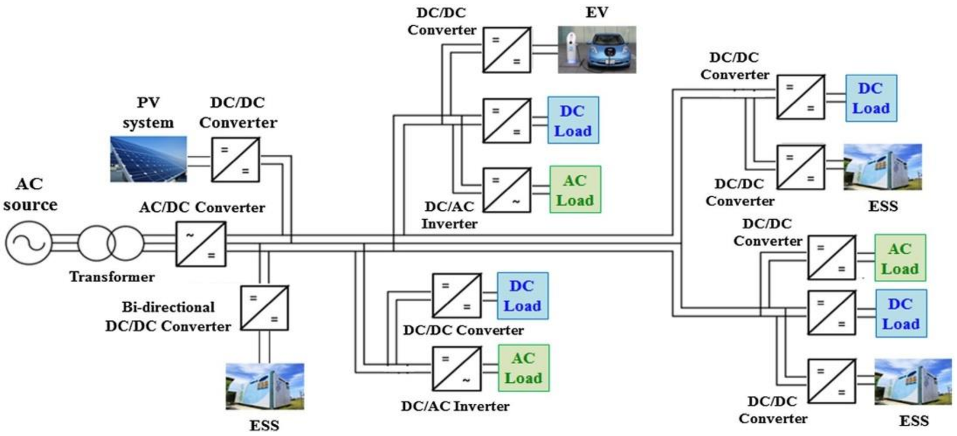

Fig.2 LVDC distribution system.

4. MODIFIED SECONDARY DISTRIBUTION SYSTEM APPROVED BY IEEE

Given IEEE reference and recommended practices are based on a conventional AC distribution system. The notion of an LVDC system is added to it, in order to improve system reliability. These modifications are shown in below Fig. 3.

The previous system is modified based on IEEE references at the customer end, as shown in Figure 3. Three DC distributors are used in the system, each with three DC loads, totaling nine DC loads that are connected by separate programmable switches.

When main grid electricity is received, the rectified AC power conversion to DC and provided for load tank with the addition of power electronic converters on each distributor (depicted by the letter R). It may be easily found in DC if it is taken from DERs or batteries. Additionally, it is observed that the DER's position is changed from the distributor end to the load end without violating any of the IEEE requirements for connection.

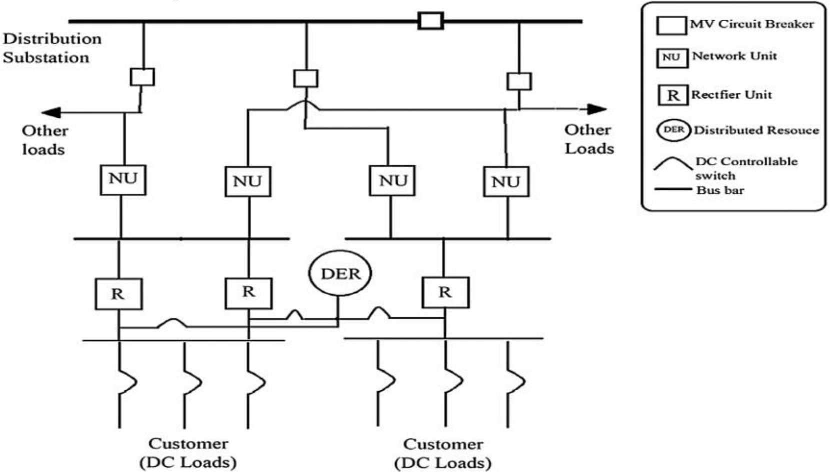

Fig3.Modified IEEE suggested practice system for connecting scattered resources to the secondary network.

The system's architecture considers the possibility that a disaster's main grid would be down during it or in its aftermath. As per DER's nature, the affected loads need to be considered for island creation when there is load powering begins by the tragedy, it will trip. Islands and sub-islands are created purposefully to isolate disaster-affected loads from distributed energy resources (DER) and each load is given control in order to prevent these kinds of disasters. The DER utilized in this study is a combination of freestanding PV systems and wind energy conversion systems(WECS)by employing an ANN controller for different advantages such as in case of accessible grid loss in the electricity is observed, energy with lowest cost, availability of regular power.

5. PHOTOVOLTAIC MODULE CHARACTERISTICS

1. Modeling Equivalent circuit for PV

Among the DERs in the present research, a freestanding PV system is used since it is environmentally beneficial and non- exhaustive. Electrical energy is obtained from solar energy by using photovoltaic module. Modeling PV may require parallel resistance, series resistance and current source with ideal conditions. Maximum current produced DC current is compared with solar cell light consumed. Leakage current and drop voltage is obtained from parallel resistance and series resistance. Using single diode PV equivalent circuit is shown below in figure 4.

model, characteristic equations for the current and voltage of photovoltaic modules are formulated [20].

$$I_{pv} = I_{ph} - I_s\left(e^{\frac{V_{pv}+I_{pv}R_s}{\eta N_s V_t}} - 1\right) - \frac{V_{pv} + I_{pv}R_S}{R_{sh}} \qquad (1)$$

The solar module's electrical settings when utilized under ideal circumstances (when the radiation is set to1000 W/m2 and 25°C is the ambient temperature).

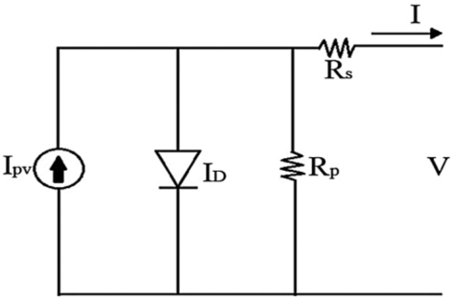

Fig.4.PV equivalent circuit.

PV equivalent circuit is designed with different properties and using mathematical formulation using simulink model Properties using the Equivalent models

Consideration the ND-1240Q2 solar panel model [12].Table 2 lists the specifications for this panel.

Table2.PVEquivalent circuit specifications are as below

PV panel parameters	Rated value
Voc Voltage at Open Circuit	37.5V
Isc, current obtained at short ckt	8.61 A
Power maximum	240W
Maximum power Voltage	30.2V
Maximum power Current	7.95 A

6. WIND ENERGY CONVERSION SYSTEM (WECS)

In this study, the Conversion System for Wind Energy was taken into consideration as an alternative DER. The development of this technology involved the usage of many electrical generator types. By considering advantages such as superior controllability, lower cost, less losses, less maintenance cost, higher efficiency, gearless construction with PMSG multi pole and variable speed is used [21].

The design is shown below which designed using Matlab-Simulink software in Figure5 is.

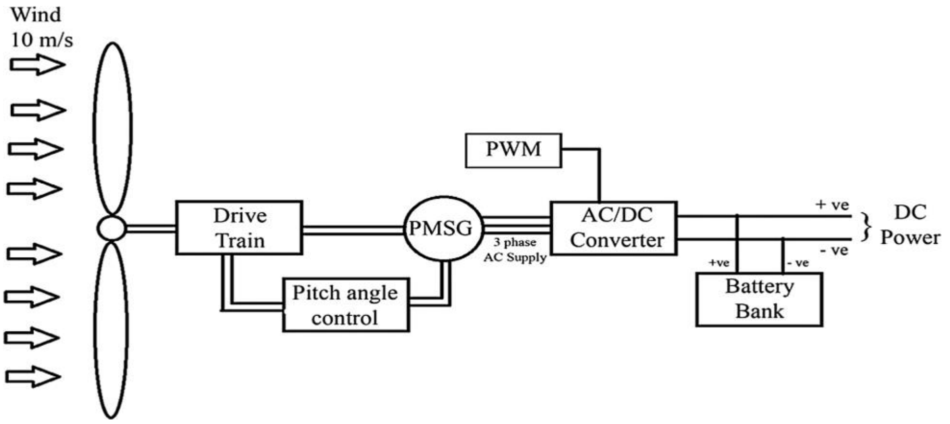

Fig.5.Block diagram of a wind power production system using PMSG.

1. Using WECS design of PMSG

Mechanical and electrical components combine with the WECS. In general, the wind turbine's power output is

$$P_m = {}_{2}\pi R \rho V C_p \qquad \textbf{(2)}$$

V is the speed of wind, ρ is the density of air, R is the radius of turbine. Coefficient of turbine is Cp which is function with nonlinearity of pitch angle β, speed of wind, rotation speed of turbine is typically used to illustrate the dynamics of the WECS drive train because it is adaptable. The PMSG does not have an damper inherent; hence, the generator shaft damping factor is ignored. The WECS subsystem in mechanical way is represented below

$$J_h \dot{\omega_h} = T_{wt} - K\theta \qquad \textbf{(3)}$$

$$J_g \, \dot{\omega_m} = K\theta - T_e \qquad \textbf{(4)}$$

$$\theta = \omega_h - \omega_m$$

Where ωh and ωm are the rotational speeds of the wind turbine and the generator; J_h and J_g are the turbine and generator inertias; θ is the electrical angle of the rotational shaft; K is the shaft stiffness; and Twt and Te are the mechanical and generator torques, respectively.

In the rotor flux vector-oriented rotating reference frame, the PMSG model can be described as

$$V_{sd} = R_s i_{sd} + L_s \frac{di_{sd}}{dt} - L_q P_n \omega_m i_{sd} \qquad (5)$$

$$V_{sq} = R_s i_{sq} + L_d \frac{di_{sq}}{dt} + L_d P_n \omega_m i_{sd} + \Psi_r P_n \omega_m \qquad (6)$$

$$T_e = \frac{3}{2} P_n \left[\left(L_d - L_q \right) i_{sd} i_{sq} + \Psi_r i_{sq} \right] \quad (7)$$

where, rotor flux is given by ψ_r, pole-pair number is given by p_n , stator winding resistance is given by Rs, Lq and Ld are the inductances dq-axes, isq, isd and vsq, vsd are the current and voltages for stator.

The input torque signal controls the machine's operation. When negative input torque functions as a generator, positive input torque operates as a motor. Block parameters given in Table3 for synchronous machine with the permanent magnet a 10kW power output.

Table3. Block parameters of wind turbine and permanent magnet synchronous machine.

Parameters	Rated value
Base power	10KW
Base wind speed	12 m/s
Max power at base wind speed in p.u	0.85
Base rotational speed in p.u	1.2
Line to line rated voltage	48V
Rated power	10KW
Supply frequency	50HZ
D-axis inductance	0.41mH

Q-axis inductance	3.971 mH
Stator leakage inductance	0.308 mH
Stator resistance	2.90mΩ

The topology of the converters on the grid and at the generator is the same. Consequently, as an illustration the grid-side converter model in the rotating reference frame with grid voltage orientation is shown here.

$$L_c \dot{i_{gd}} = v_{cd} - v_{td} + \omega_g L_c i_{gq} \quad (8)$$

$$L_c \dot{i_{gq}} = v_{cq} - v_{tq} + \omega_g L_c i_{gd} \quad (9)$$

$$C_{dc} \dot{V_{dc}} = \frac{3}{2V_{dc}} \left(v_{cd} i_{gd} + v_{cq} i_{gq} \right) + i_{dc_{rc}} (10)$$

Where v_{td}, v_{tq} are the dq-axis grid voltages and igd, igq are the dq-axis current outputs from the converter; vcd, vcq are the dq-axis converter output voltages; idc_rc is the dc current injected into the generator-side converter; and C_{dc}, Vdc indicates capacitance and voltage for dc-link. Using below equation grid side converters, active power at output is shown.

$$P_g = \frac{3}{2} (v_{td} i_{gd} + v_{tq} i_{gq}) \qquad (11)$$

7. PROPOSED ANN CONTROLLER

Artificial neurons, often known as neurons or nodes, are the core processing components of neural networks. In a simplified mathematical model of the neuron, the effects of synapses are represented by connection weights that alter the effect of associated input signals and the nonlinear behavior of neurons is represented by a transfer function. The neuron impulse is calculated from the weighted sum of the input signals, which is converted by the transfer function.

The learning ability of an artificial neuron is achieved by adjusting the weights according to the learning algorithm. In the basic design, input, hidden and output layers are the three types of neuron layers. In feed-forward networks, signal flow from input to output units is strictly feed-forward. There are no feedback linkages in data processing, which can span several layers of units. When a collection of inputs is applied to a neural network, it must create the desired set of outputs. The strength of a link can be determined in a variety of ways. To establish the weights explicitly, one technique is to employ a priori knowledge. This paper proposes power restoration based on intentional islanding of microgrids in disaster management using an artificial neural network (ANN) controller for better overall system performance, Transient reduction, faster response and settling to normal operation conditions.

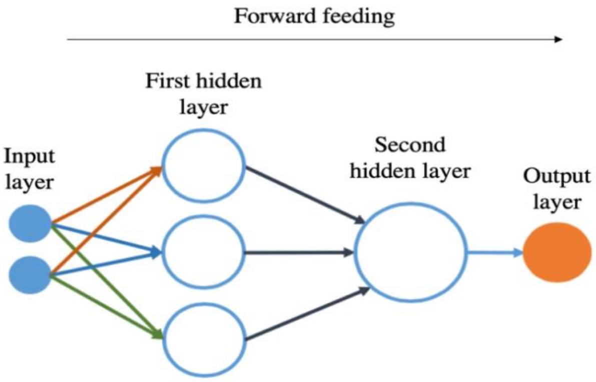

Fig.6.Feed-forward Neural Network Model.

Performance of a neural network integrated DER in- power restoration:

1. The architecture of an artificial neural network (ANN) is the input, output and hidden layers all have an impact on DER (D1, D2 and D3).
2. In a neural network, pre-defined data for grid stabilization is in the form of duty cycle.

3. The necessary data is finally identified by a neural network classifier in order to correct the DER at the receiver end.
4. In these data-driven systems, duty cycle generation is dependent on transmitting to the grid.
5. The neural network has now provided suitable impedance matching from the transmitted to the receiver.

8. SIMULATION RESULTS

For loads, power supply is supplied via main grid with advance of the arrival of faults or natural calamities. In this instance, the ANN controller determines whether the grid- side switch is on or off by examining its state. If the grid is on, it decides to turn on each switch for specific loads and distributors. Figure 7 depicts the switching pulses for the distributors.

Figure 7 demonstrates that all the distributors switching pulses are '1' or ON. The primary grid is connected to each and every distributor. Figure 8 displays the switching pulses for every load switch. The switching pulses produced for specific loads are'1'or ON, as shown in Figure 8.Thismakes it possible main grid is connected with all loads. Voltage (V), current (A) and power (W) are the variables considered for the loads. Figure 9 depicts these characteristics for one load of Distributor 1 (D1).

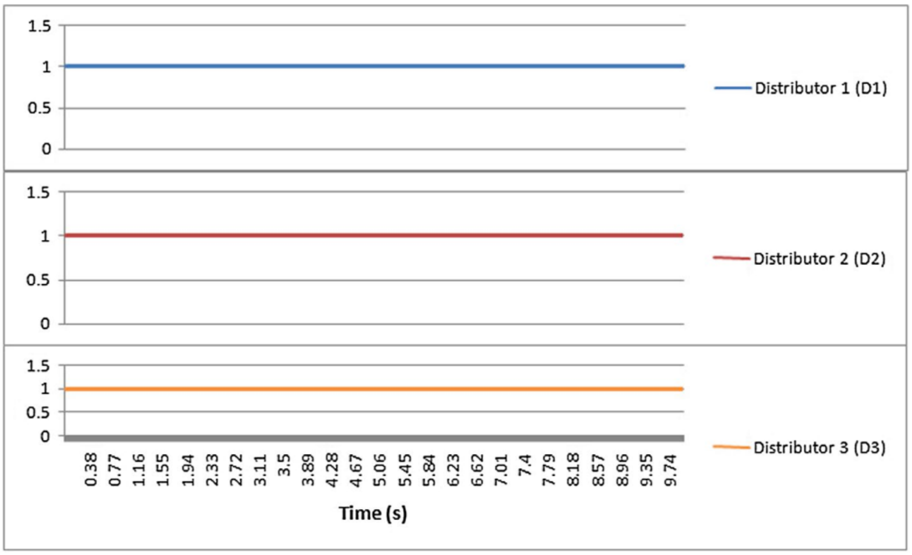

Figure7.For three distributors as D1, D2 and D3 switching pulses are shown

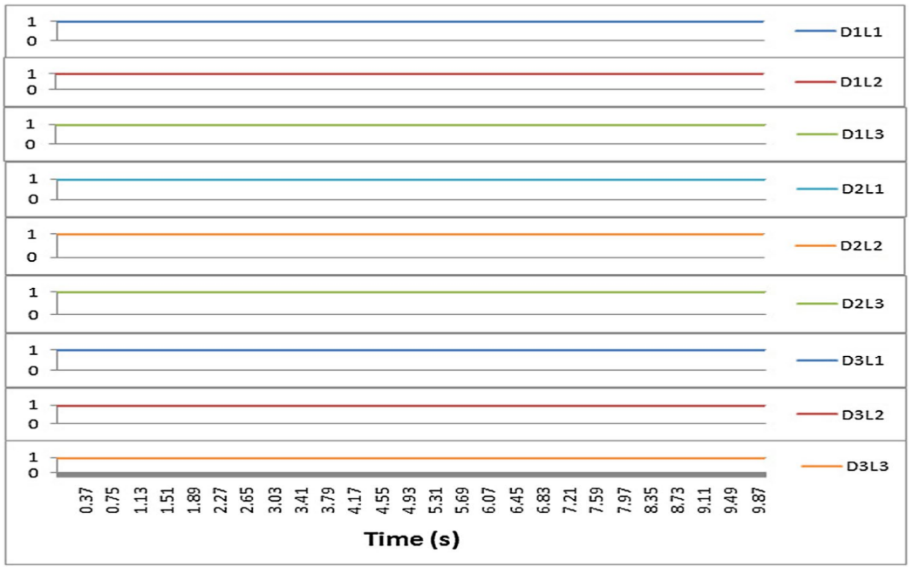

Figure8.For three distributor individual load switching pulses are shown

The voltage, current, and power waveforms of the first distributor load are shown in Figure 9. 48

V of voltage is supplied across the load, 22 A of current flows through the load and 1100 W of power is used. For all the remaining loads, these characteristics remain unaltered.

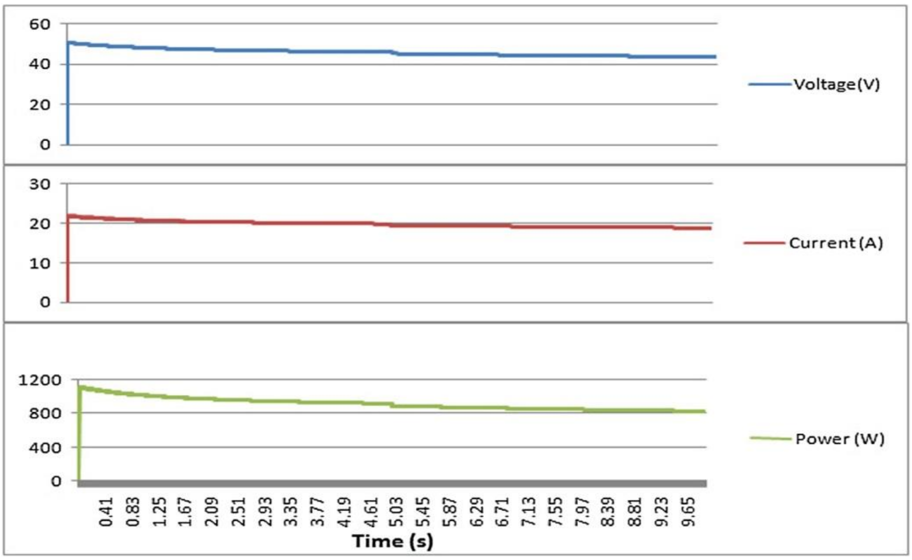

Figure9. Load at first distributor (D1 L3), Power (in Watts), Current (In amps) and Voltage (in Volts).

Single fault on single line

It is anticipated that the main grid breakers will be open due to the effects of natural calamities. When the ANN is performed under these circumstances, it recognizes the first and third distributors as healthy but the second distributor as defective. Two sub-Islands are created for two healthy distributors. As can be seen, the distributors1and3are having switching pulses as'1'orON, but distributor2generates '0' or OFF when a fault is imposed owing to a parameter violation. Distributor, or ON switching pulses are used for distributors 1 and 3's individual load switches.

The malfunctioning feeder is disconnected from the DER.

For relevant loads, power waveforms, current waveform, voltage waveform at 0W, 0A and 0V are displayed in fig. 10.

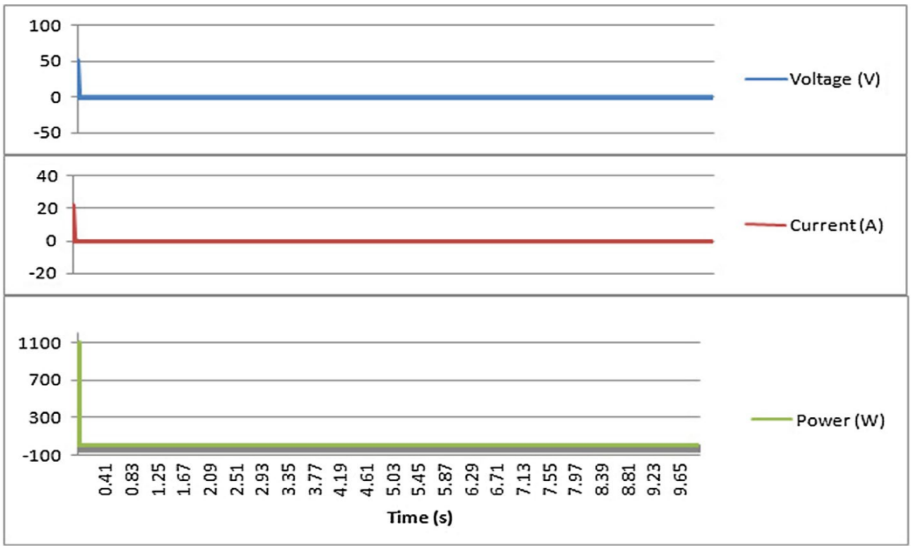

Figure 10. D2L3 (Load at Faulty distributor): and power (P in Watts), current (I in amps), voltage (V in volts).

Bad distributor won’t give any disruption when loads are healthy with sub-islands. ANN helps to shut distributor which is affected by disaster without making trouble to sub-island with healthy in case of DER powered for distributor which facing catastrophe. Fault is 0 s opposed at 3 s based on distributor fault with tracking performance purpose. In fig. 11, for distributor, ANN performance is plotted using switching pulses. Fig. 11 shows that as fault is applied for 0 s at 3 s for D2, while switching pulses for D3 and D1 is observed at 1.TheANN switches off the distributor as quickly as the fault is applied. Figure 12 displays the power sent to one of the defective distributors loads.Figure12 shows that power is provided to the load during the first three seconds.

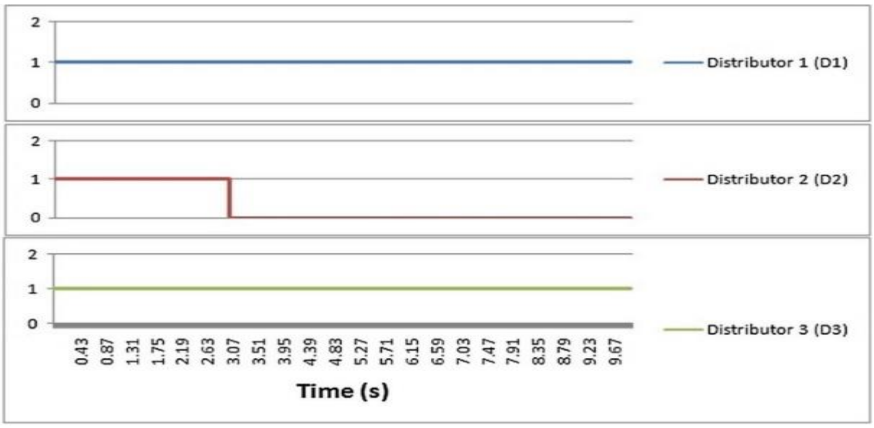

Figure11.Applied Fault at 3 s and plotted distributors switching pulses.

The load is being DER detached after 3seconds. In this instance, it is shown that load receives healthy distributor uninterrupted power delivery, as indicated in Figure 9.

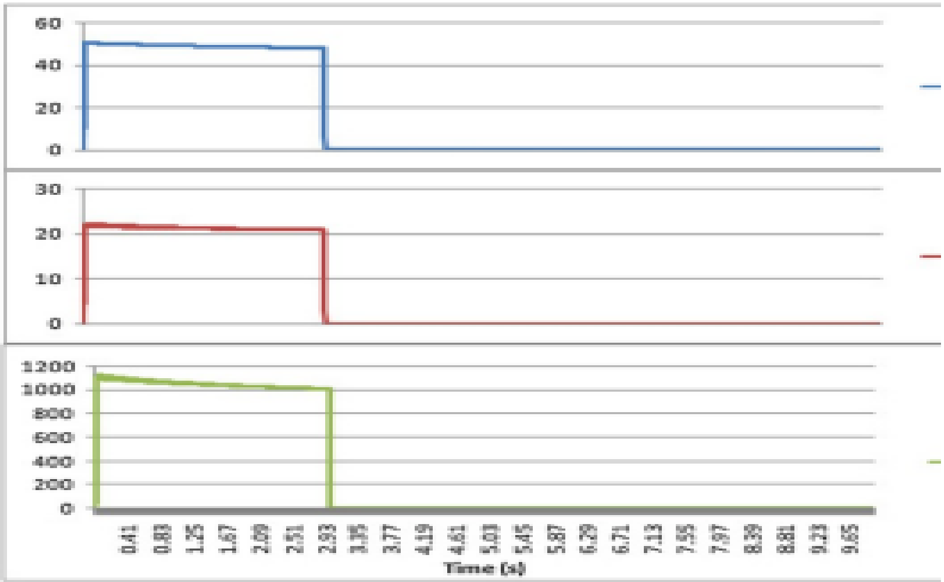

Figure12.Parameters of Load and Faulty Distributor: power, current and voltage

COMPARATIVE RESULTS:

In this study, ANN integration drastically reduced model execution durations in the restoration process when compared to an islanding algorithm and it also improved stability. The MATLAB simulation results show that the DERs and the proposed control technique effectively increase dynamic stability.

Island Algorithm:

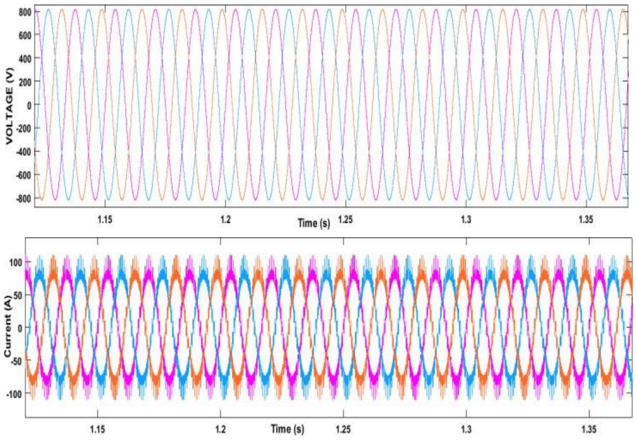

Figure13.Voltage and current of the Island algorithm for the load at distributor (D1 L3).

ANN controller:

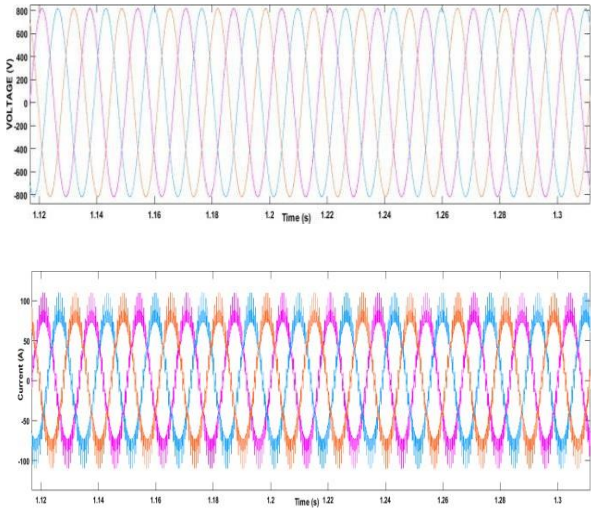

Figure14.Current and voltage of the ANN controller for the distributor load (D1 L3).

Disaster management research is also done on power restoration based on the intentional islanding of microgrids using an ANN controller for improved overall system performance, transient reduction, and faster response and settling to normal operation conditions.

9. Conclusion

This study introduces the use of DERs for a robust and efficient low voltage DC distribution system and this system is designed with the help of MATLAB software to verify the effects of natural catastrophes. It is proposed that an ANN is used in smart LVDC networks when loads are intentionally islanded. In several case studies, the ANN's effectiveness is assessed. Disaster effects can be mitigated using strategy of single-fault single-line, can result in the development of healthy distributor loads islands during a natural disaster. An additional benefit of this ANN is that it detects parameter violations and takes decisions quickly to prevent problems on lines from occurring again. By identifying a problem in a relatively short period of time, an ANN demonstrates its accuracy. The use of ANNs has considerably improved the efficiency of the restoration process. The use of ANN has significantly shortened simulation run durations, which is essential for quick decision-making in crucial restoration scenarios. For the IEEE-recommended distribution strategy of integrating DERs, the incorporation of ANNs is proven essential in improving the restoration process performance.

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