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Research Article

Improving Voltage Stability in Transmission Network using Facts Devices and Artificial Intelligence

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Abstract

The constant power failure in our transmission network that has crippled business activities for those that solely depend on power for their daily routine businesses is caused by voltage instability. This is squarely overcome by introducing improving voltage stability in transmission network using facts devices and artificial intelligence. To achieve this perfectly well, it was done in this manner, characterizing voltage stability in transmission network, running a load flow analysis of the characterized 330kV transmission network to identify the faulty buses that causes voltage instability, training ANN in the fault buses for stabilization, designing a SIMULINK model for facts devices, developing an algorithm that will implement the process, designing a SIMULINK model for improving voltage stability in transmission network using facts devices and artificial intelligence and validating and justifying percentage improvement in voltage stability of the transmission network with and without using facts devices and artificial intelligence. The results obtained were, the conventional voltage of faulty bus 25 that caused intermittent power supply in the transmission network was 0.947P.U.V. meanwhile, when FACTS DEVICES and artificial intelligence were inculcated in the system, it instantaneously improved the voltage to1.042P.U.Vthereby improving consistent power transmitted and the conventional voltage of faulty bus 30 was 0.919 P.U.V. on the other hand, when FACTS DEVICES and artificial intelligence was imbibed in the system, it automatically stabilized the voltage of the faulty bus30 to1.011P.U.V. Finally, with these results obtained, it definitely shown that percentage in improvement of voltage stability in transmission network when FACTS DEVICES and artificial intelligence were integrated in the system was 10.01%.

Keywords: Voltage Stability; Transmission Network; Artificial Intelligence; Facts Devices

Introduction

Voltage stability is a critical aspect of power systems, as it ensures the steady and reliable supply of electricity within transmission networks. When voltage instability occurs, it can lead to voltage collapse and, in severe cases, widespread blackouts. Maintaining voltage stability is particularly challenging in modern power systems due to the increasing complexity of the grid and the growing demand for electricity. The concern of every Consumer of electricity in Nigeria is the unreliable power supply in the country, Emphasis is now on renewable energy power sources (Ugwu and Ngang,2021). Traditionally, voltage stability is maintained by adjusting reactive power sources, but this approach may not be sufficient in today's dynamic power environment (Kundur, 1994). For over a decade, transmission networks had been overloaded and are subjected closer to their stability limits (Ngang,2021). In recent years, Flexible AC Transmission Systems (FACTS) devices have been deployed to improve voltage stability. FACTS devices, such as the Static Synchronous Compensator (STATCOM) and Static Var Compensator (SVC), help manage reactive power flow and improve voltage stability by enabling flexible control over power system parameters (Hingorani & Gyugyi, 2000). These devices have proven effective in controlling transmission line flows, reducing losses, and enhancing system stability. However, to achieve optimal performance, integrating Artificial Intelligence (AI) with FACTS devices has become increasingly relevant.

Artificial Intelligence, specifically techniques such as machine learning and fuzzy logic, offers significant potential for enhancing the effectiveness of FACTS devices in maintaining voltage stability. AI can provide real-time analysis and control of system parameters, which are essential for handling the complex, nonlinear nature of voltage stability problems (Sharma, 2018). AI-based systems can predict potential instability by monitoring various factors and can autonomously adjust FACTS devices to prevent disruptions (Verma et al., 2021). This synergy between AI and FACTS not only improves the efficiency of power networks but also ensures that voltage stability is maintained in real-time, even under varying load conditions.

As power systems integrate more renewable energy sources, the challenges associated with maintaining voltage stability are likely to increase, as renewable energy sources introduce variability and intermittency to power generation. Thus, combining FACTS devices with AI-driven solutions could be an effective approach to stabilize transmission networks while accommodating higher levels of renewable integration (Chakrabarti & Sadhu, 2020). The study aims to explore how intelligent control mechanisms, powered by AI, can enhance the voltage stability capabilities of FACTS devices, creating a robust framework for modern power system stability

Extent of Past Related Works

Voltage stability is a critical concern in modern power systems due to the increasing demand for electricity and the integration of renewable energy sources. The combination of Flexible AC Transmission Systems (FACTS) and artificial intelligence (AI) has emerged as a promising solution for enhancing voltage stability in transmission networks. This literature review synthesizes research on the application of FACTS devices and AI in improving voltage stability.

Voltage Stability Challenges in Transmission Networks

Voltage stability refers to the ability of a power system to maintain acceptable voltage levels under normal and post-disturbance conditions. Voltage instability can lead to power outages, system collapse, and inefficient operation. Kundur et al. (1994) explained that voltage instability arises from heavily loaded systems and reactive power deficiencies. This challenge is exacerbated by the growing complexity of transmission systems and the integration of renewable energy sources, as highlighted by Kothari and Nagrath (2019).

Role of FACTS Devices in Voltage Stability

FACTS devices are power electronic systems designed to enhance the controllability and power transfer capabilities of transmission networks. These include Static VAR Compensators (SVCs), Static Synchronous Compensators (STATCOMs), and Unified Power Flow Controllers (UPFCs). Hingorani and Gyugyi (2000) emphasized that FACTS devices dynamically regulate voltage, reactive power, and line impedance, contributing to improved stability. Singh et al. (2017) demonstrated that STATCOMs, in particular, stabilize voltage by providing fast and flexible reactive power compensation.

Padiyar and Kulkarni (2002) observed that integrating FACTS devices could mitigate voltage sag and enhance power quality. Similarly, Ramachandran et al. (2020) investigated the strategic placement of FACTS devices and found significant improvements in voltage profiles and system reliability.

Artificial Intelligence in Voltage Stability Enhancement

AI technologies, including machine learning (ML) and artificial neural networks (ANNs), offer advanced solutions for predicting and managing voltage stability issues. El-Hawary (2014) noted that AI can develop predictive models for assessing and controlling voltage stability. Reinforcement learning has shown particular promise in optimizing FACTS device operations (Sivaramakrishna et al., 2019).

ANNs have been widely applied to fault detection and voltage stabilization. Tiwari et al. (2021) demonstrated that ANNs trained on historical data could predict voltage instability and recommend corrective actions. Moreover, hybrid models combining ANN and fuzzy logic enhance the robustness of voltage stability solutions (Chaturvedi et al., 2010).

Synergistic Application of FACTS Devices and AI

The integration of FACTS devices with AI creates a powerful framework for improving voltage stability. AI can optimize the placement, sizing, and operation of FACTS devices to maximize their effectiveness. Anbazhagan and Kothari (2013) reported that AI-optimized FACTS devices achieved better voltage profiles and reduced system losses compared to conventional methods.

Jain and Kumar (2020) proposed a model where AI algorithms coordinated multiple FACTS devices, achieving a balanced distribution of reactive power in the network. Salim et al. (2022) highlighted that combining AI with FACTS devices stabilized voltages and improved network resilience against contingencies.

Recent Advances and Future Directions

Recent research focuses on leveraging deep learning and advanced optimization algorithms for voltage stability. Xu et al. (2021) demonstrated that deep neural networks (DNNs) effectively manage high-dimensional data from complex networks, enabling rapid stabilization. Emerging trends also include swarm intelligence and genetic algorithms to optimize FACTS device parameters and placement. Singh et al. (2023) found these methods significantly improved the performance of AI-enhanced FACTS systems.

The integration of AI with Internet of Things (IoT) technology has also been proposed for remote monitoring and control of voltage stability (Kumar et al., 2023).

Research Objectives

The general objective is the improvement of voltage stability in transmission network using facts devices and artificial intelligence

The Specific Objectives of this work are:

1. Characterizing voltage stability in transmission network,
2. Running a load flow analysis of the characterized 330kV transmission network to identify the faulty buses that causes voltage instability,
3. Training ANN in the fault buses for stabilization,
4. Designing a SIMULINK model for facts devices,
5. Developing an algorithm that will implement the process,
6. Designing a SIMULINK model for improving voltage stability in transmission network using facts devices and artificial intelligence
7. Validating and justifying percentage improvement in voltage stability of the transmission network with and without using facts devices and artificial intelligence

Methodology

Step 1: To characterize voltage stability in transmission network

The table below shows the values of the parameters under investigation.

Table 1 characterized voltage stability in transmission network

Bus No	*Bus code*	*P.U*	*Ang Deg*	*Load MW*	*Load Mvar*	*Gen MW*	*Gen Mvar*	*Inject Min*	*Inject Max*	*Inject Mvar*
1	1	0.93	0	00.0	0.0	0.0	0.0	0	0	0
2	2	0.81	0	21.70	12.7	40.0	0.0	-40	50	0
3	0	1.0	0.0	2.4	1.2	0.0	0.0	0	0	0
4	0	1.27	0.0	7.6	1.6	0.0	0.0	0	0	0
5	2	1.01	0.0	94.2	19.0	0.0	0.0	-40	40	0
6	0	1.0	0.0	0.0	0.0	0.0	0.0	0	0	0
7	0	0.92	0.0	22.8	0.0	10.9	0.0	0	0	0
8	2	1.01	0.0	30.0	30.0	0.0	0.0	-30	40	0
9	0	0.83	0	0	0	0.0	0.0	0	0	0
10	0	1.0	0.0	5.8	2.0	0.0	0.0	-6	24	19
11	2	1.082	0	0.0	0.0	0.0	0.0	0	0.0	0
12	0	1.0	0	11.2	7.5	0	0.0	0	0	0
13	2	1.071	0	0.0	0	0.0	-6	24	0	0
14	0	1.0	0	6.2	1.6	0.0	0.0	0	0	0
15	0	1	0	8.2	2.5	0.0	0.0	0	0	0
16	0	1	0	3.0	1.8	0.0	0.0	0	0	0
17	0	1	0	9.0	5.8	0.0	0.0	0	0	0
18	0	1	0	3.2	0.9	0.0	0.0	0	0	0
19	0	1	0	9.5	3.4	0.0	0.0	0	0	0
20	0	0.92	0	2.2	0.7	0.0	0.0	0	0	0
21	0	1.	0	17.5	11.2	0.0	0.0	0	0	0
22	0	1	0	0	0.0	0.0	0.0	0	0	0
23	0	1	0	3.2	1.6	0	0.0	0	0	0
24	0	1	0	8.7	6.7	0	0	0	0	4.3
25	0	1	0	0	0.0	0	0.0	0	0	0
26	0	1	0	3.5	2.3	0	0.0	0	0	0
27	0	0.82	0	0	0.0	0	0.0	0	0	0
28	0	1	0	0	0.0	0.0	0.0	0	0	0
29	0	0.62	0	2.4	0.9	0.0	0.0	0	0	0
30	0	0.86	0	10.6	1.9	0.0	0.0	0	0	0

Step 2: To run a load flow analysis of the characterized 330kV transmission network to identify the faulty buses that cause voltage instability

```
>> basemva = 100; accuracy = 0.001; accel = 1.8; maxiter = 100;
```

```
%       IEEE 30-BUS TEST SYSTEM (American Electric Power)
```

Bus No	Bus Code	Voltage Mag.	Angle (°)	Load MW	Load Mvar	Gen MW	Gen Mvar	Qmin	Qmax	Static Mvar (+Qc/-Ql)
1	1	0.93	0.0	0.0	0.0	0.0	0.0	0	0	0
2	2	0.81	0.0	21.7	12.7	40.0	0.0	-40	50	0
3	0	1.0	0.0	2.4	1.2	0.0	0.0	0	0	0
4	0	1.27	0.0	7.6	1.6	0.0	0.0	0	0	0
5	2	1.01	0.0	94.2	19.0	0.0	0.0	-40	40	0
6	0	1.0	0.0	0.0	0.0	0.0	0.0	0	0	0
7	0	0.92	0.0	22.8	10.9	0.0	0.0	0	0	0
8	2	1.01	0.0	30.0	30.0	0.0	0.0	-30	40	0
9	0	0.83	0.0	0.0	0.0	0.0	0.0	0	0	0
10	0	1.0	0.0	5.8	2.0	0.0	0.0	-6	24	19
11	2	1.082	0.0	0.0	0.0	0.0	0.0	0	0	0
12	0	1.0	0.0	11.2	7.5	0.0	0.0	0	0	0
13	2	1.071	0.0	0.0	0.0	0.0	0.0	-6	24	0
14	0	1.0	0.0	6.2	1.6	0.0	0.0	0	0	0
15	0	1.0	0.0	8.2	2.5	0.0	0.0	0	0	0
16	0	1.0	0.0	3.5	1.8	0.0	0.0	0	0	0
17	0	1.0	0.0	9.0	5.8	0.0	0.0	0	0	0
18	0	1.0	0.0	3.2	0.9	0.0	0.0	0	0	0
19	0	1.0	0.0	9.5	3.4	0.0	0.0	0	0	0
20	0	0.92	0.0	2.2	0.7	0.0	0.0	0	0	0
21	0	1.0	0.0	17.5	11.2	0.0	0.0	0	0	0
22	0	1.0	0.0	0.0	0.0	0.0	0.0	0	0	0
23	0	1.0	0.0	3.2	1.6	0.0	0.0	0	0	0
24	0	1.0	0.0	8.7	6.7	0.0	0.0	0	0	4.3
25	0	1.0	0.0	0.0	0.0	0.0	0.0	0	0	0
26	0	1.0	0.0	3.5	2.3	0.0	0.0	0	0	0
27	0	0.82	0.0	0.0	0.0	0.0	0.0	0	0	0
28	0	1.0	0.0	0.0	0.0	0.0	0.0	0	0	0
29	0	0.62	0.0	2.4	0.9	0.0	0.0	0	0	0
30	0	0.86	0.0	10.6	1.9	0.0	0.0	0	0	0

```
% Line code
% Bus bus   R     X     1/2 B    = 1 for lines
% nl  nr  p.u.  p.u.  p.u.    > 1 or < 1 tr. tap at bus nl
linedata= [1   2   0.0192   0.0575   0.02640    1
        1   3   0.0452   0.1852   0.02040    1
        2   4   0.0570   0.1737   0.01840    1
        3   4   0.0132   0.0379   0.00420    1
        2   5   0.0472   0.1983   0.02090    1
        2   6   0.0581   0.1763   0.01870    1
```

```
         4  6   0.0119   0.0414   0.00450    1
         5  7   0.0460   0.1160   0.01020    1
         6  7   0.0267   0.0820   0.00850    1
         6  8   0.0120   0.0420   0.00450    1
         6  9   0.0      0.2080   0.0     0.978
         6 10   0        .5560    0       0.969
         9 11   0        .2080    0          1
         9 10   0        .1100    0          1
         4 12   0        .2560    0       0.932
        12 13   0        .1400    0          1
        12 14    .1231    .2559   0          1
        12 15    .0662    .1304   0          1
        12 16    .0945    .1987   0          1
        14 15    .2210    .1997   0          1
        16 17    .0824    .1923   0          1
        15 18    .1073    .2185   0          1
        18 19    .0639    .1292   0          1
        19 20    .0340    .0680   0          1
        10 20    .0936    .2090   0          1
        10 17    .0324    .0845   0          1
        10 21    .0348    .0749   0          1
        10 22    .0727    .1499   0          1
        21 22    .0116    .0236   0          1
        15 23    .1000    .2020   0          1
        22 24    .1150    .1790   0          1
        23 24    .1320    .2700   0          1
        24 25    .1885    .3292   0          1
        25 26    .2544    .3800   0          1
        25 27    .1093    .2087   0          1
        28 27    0        .3960   0       0.968
        27 29    .2198    .4153   0          1
        27 30    .3202    .6027   0          1
        29 30    .2399    .4533   0          1
         8 28    .0636    .2000   0.0214     1
         6 28    .0169    .0599   0.065      1];

lfybus                  % form the bus admittance matrix
lfgauss           % Load flow solution by Gauss-Seidel method
busout            % Prints the power flow solution on the screen
lineflow        % Computes and displays the line flow and losses
Press Enter to terminate the iterations and print the results
```

```
Iterative Solution did not Converge
Maximum Power Mismatch = 0.192989
No. of Iterations = 101
  Bus  Voltage  Angle    ------Load------    ---Generation---   Injected
  No.  Mag.     Degree     MW       Mvar       MW       Mvar      Mvar
   1   0.930    0.000    0.000     0.000   285.335    89.617     0.000
   2   0.832   -6.938   21.700    12.700    40.000  -233.134     0.000
   3   0.913  -11.992    2.400     1.200     0.000     0.000     0.000
   4   0.909  -14.650    7.600     1.600     0.000     0.000     0.000
   5   1.000  -22.162   94.200    19.000     0.000   182.421     0.000
   6   0.934  -17.242    0.000     0.000     0.000     0.000     0.000
   7   0.956  -19.938   22.800    10.900     0.000     0.000     0.000
   8   0.963  -18.875   30.000    30.000     0.000   126.571     0.000
   9   1.000  -20.874    0.000     0.000     0.000     0.000     0.000
  10   0.983  -22.666    5.800     2.000     0.000     0.000    19.000
```

11	1.082	-20.816	0.000	0.000	0.000	42.576	0.000
12	0.988	-21.519	11.200	7.500	0.000	0.000	0.000
13	1.021	-21.519	0.000	0.000	0.000	24.110	0.000
14	0.973	-22.566	6.200	1.600	0.000	0.000	0.000
15	0.969	-22.738	8.200	2.500	0.000	0.000	0.000
16	0.977	-22.366	3.500	1.800	0.000	0.000	0.000
17	0.976	-22.805	9.000	5.800	0.000	0.000	0.000
18	0.961	-23.507	3.200	0.900	0.000	0.000	0.000
19	0.959	-23.761	9.500	3.400	0.000	0.000	0.000
20	0.965	-23.549	2.200	0.700	0.000	0.000	0.000
21	0.969	-23.186	17.500	11.200	0.000	0.000	0.000
22	0.969	-23.158	0.000	0.000	0.000	0.000	0.000
23	0.959	-23.252	3.200	1.600	0.000	0.000	0.000
24	0.954	-23.557	8.700	6.700	0.000	0.000	4.300
25	0.947	-23.150	0.000	0.000	0.000	0.000	0.000
26	0.930	-23.559	3.500	2.300	0.000	0.000	0.000
27	0.951	-22.678	0.000	0.000	0.000	0.000	0.000
28	0.939	-18.009	0.000	0.000	0.000	0.000	0.000
29	0.932	-24.038	2.400	0.900	0.000	0.000	0.000
30	0.919	-25.158	10.600	1.900	0.000	0.000	0.000
Total			283.400	126.200	325.335	232.160	23.300

The faulty buses in Nigerian 330KV 30 bus transmission networks are buses 1, 2, 3, 4,6,25, 26, 28, 29 and 30. These buses cause instability in power supply in Nigeria because their per unit volts do not fall within 0.95 through 1.05. The per unit volts of these faulty buses are 0.930, 0.832, 0.913, 0.909, 0.934, 0.947, 0.930, 0.939, 0.932 and 0.919

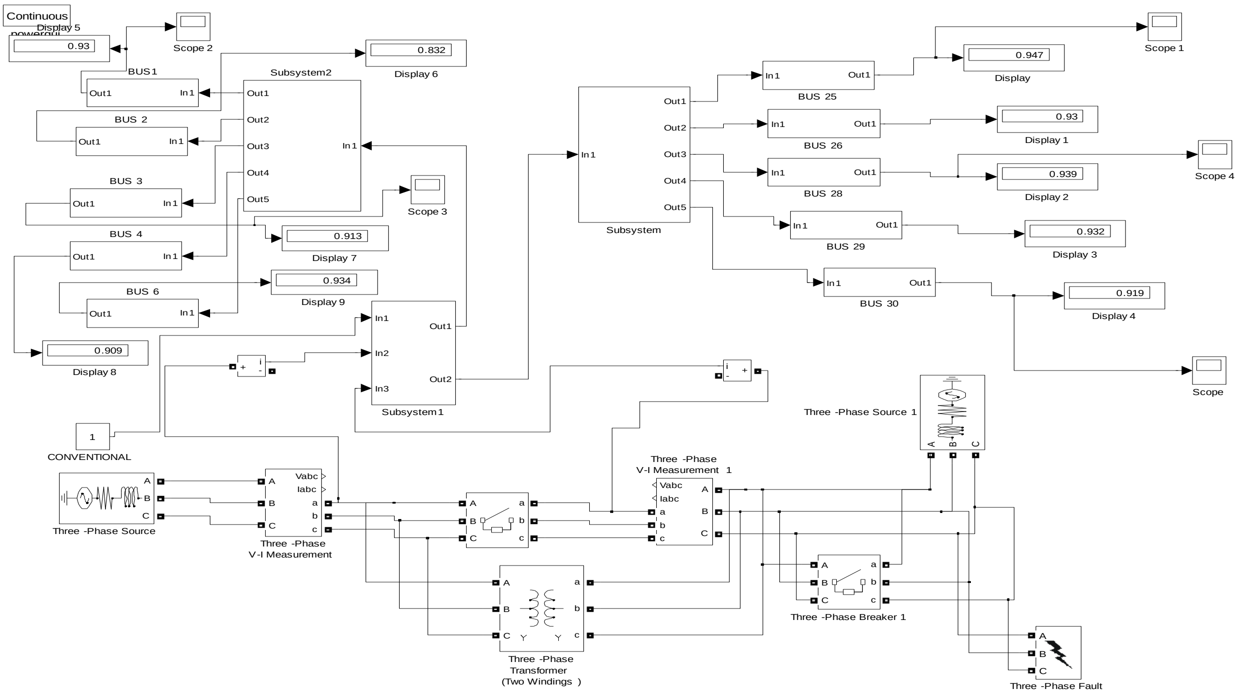

Fig. 1: Conventional SIMULINK model for voltage stability in transmission network

The results obtained in the load flow for the faulty buses were imbibed in the model and simulated and it gave the exact faulty buses that their per unit volts could not attain stable voltages of 0.95 through 1.05 per unit volts. The comprehensive results obtained after simulation are as shown in figures 6 through 8

Step 3: To train ANN in the fault buses for stabilization

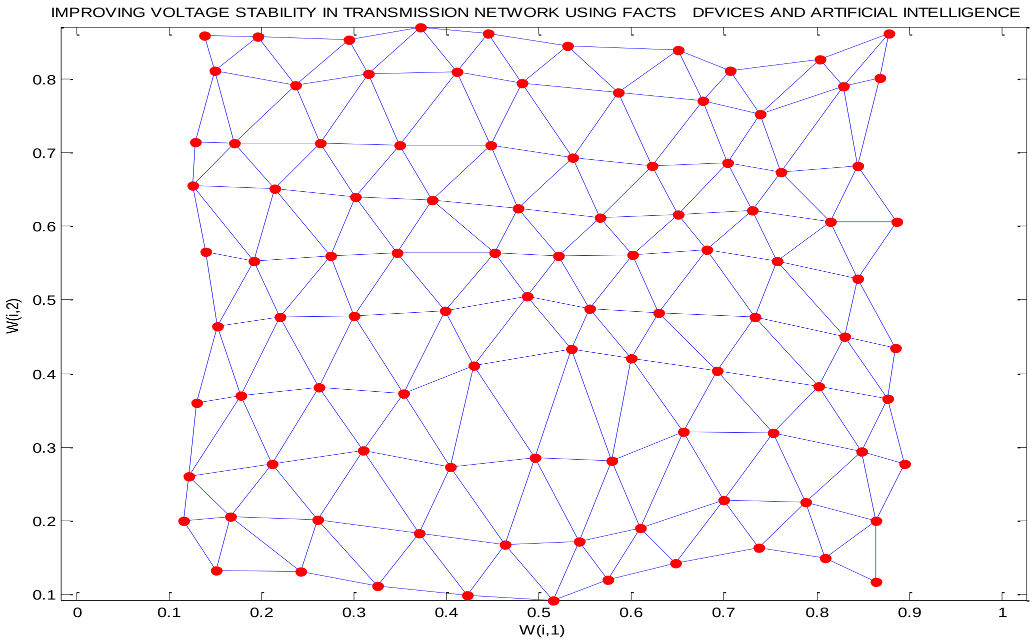

Fig. 2: Trained ANN in the fault buses for stabilization

ANN was trained ten times in the ten faulty buses 10 x10 = 100 hundred neurons that look identical to human brain. This simultaneously stabilize the faulty buses to attain voltage stability thresh hold of 0.95 through 1.05 P.U.V.

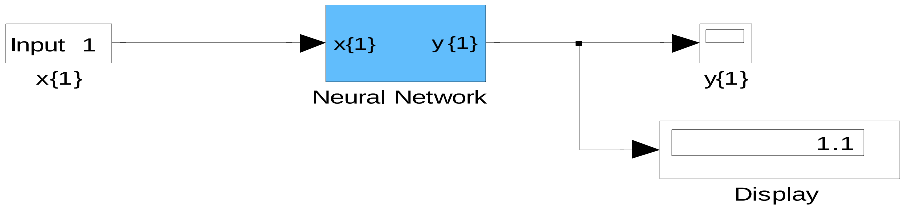

Fig. 3: Result obtained during the training

Step 4: To design a SIMULINK model for facts devices

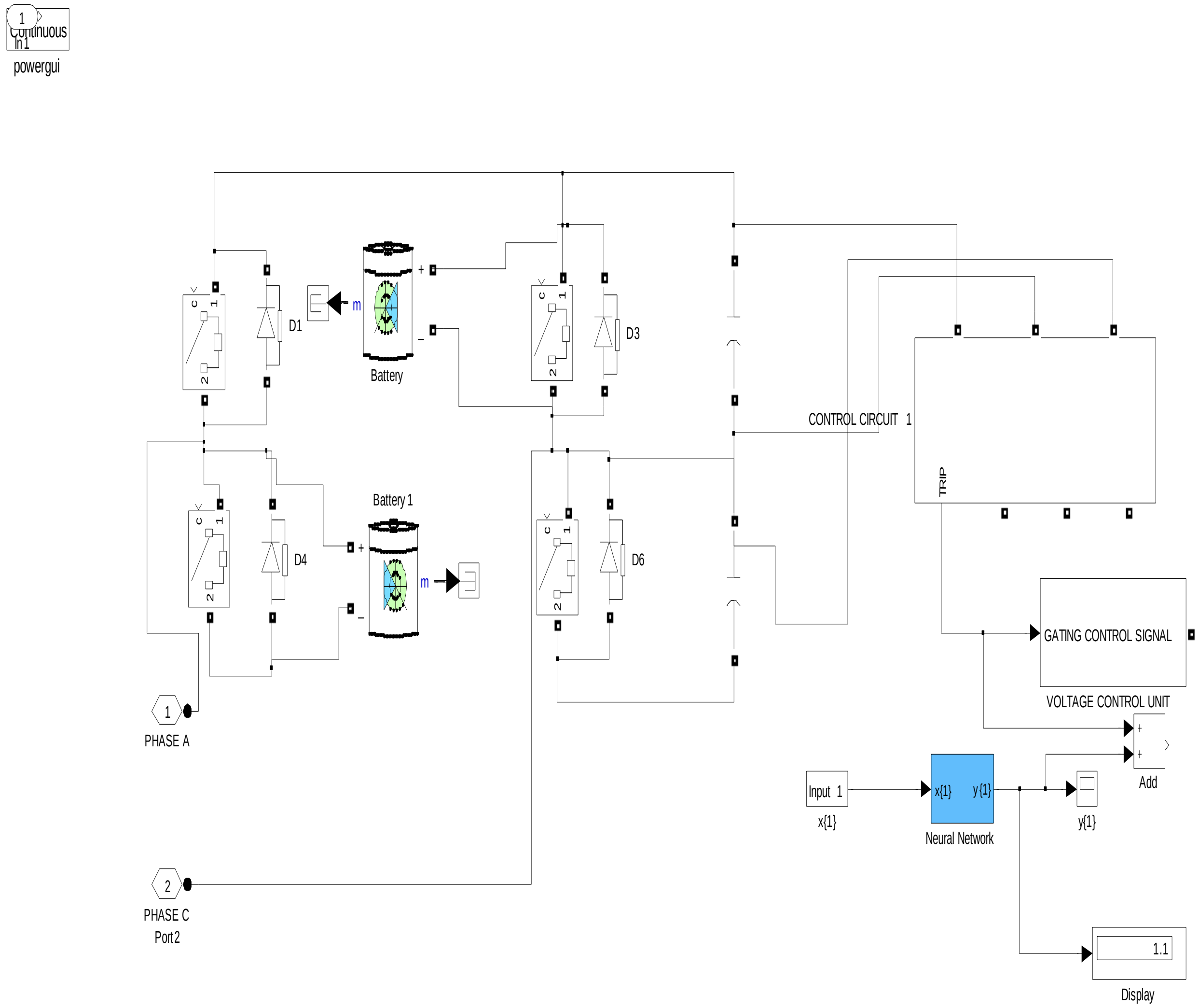

Fig. 4: Designed SIMULINK model for facts devices

This would be integrated in fig 1 to obtain the results shown in figures 6 through 8

Step 5: To develop an algorithm that will implement the process

characterize voltage stability in transmission network

Run a load flow analysis of the characterized 330kV transmission network to identify the faulty buses that causes voltage instability

Identified buses were buses 1, 2, 3, 4,6,25, 26, 28, 29 and 30

Design a conventional SIMULINK model for voltage stability in transmission network and integrate 3

Train ANN in the fault buses for stabilization

Design a SIMULINK model for facts devices

Integrate 5 and 6.

Integrate 7 in 4

Did the per unit voltage of the faulty buses attain voltage stability of 0.95 through 1.05 when 7 was integrated in 4?

IF NO go to 8

IF YES go to 12

Improved voltage stability in transmission network

Stop

End

Step 6: To design a SIMULINK model for improving voltage stability in transmission network using facts devices and artificial intelligence

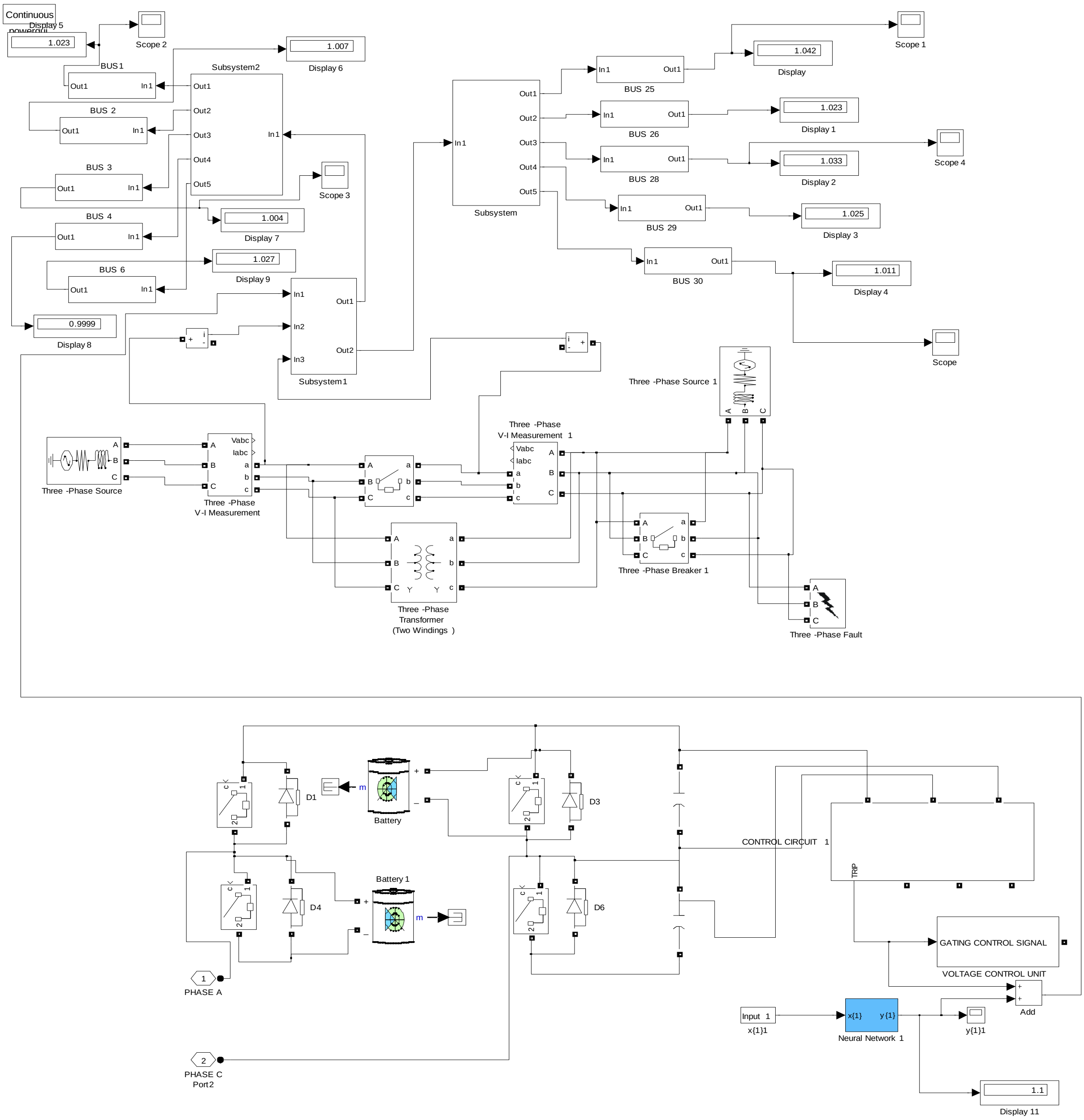

Fig. 5: Designed SIMULINK model for improving voltage stability in transmission network using facts devices and artificial intelligence

The results obtained were as shown in figures 6 through 8

Step 7: To validate and justify percentage improvement in voltage stability of the transmission network with and without using FACTS DEVICES and artificial intelligence

To find percentage improvement in the voltage stability of faulty bus1 when FACTS DEVICES and artificial intelligence were integrated in transmission network

Conventional faulty bus 1 voltage =0.947 P.U

FACTS DEVICES and artificial intelligence bus 1 voltage =1.023P.U.V

%improvement in the voltage stability of faulty bus1 when FACTS DEVICES and artificial intelligence were integrated in transmission network =

$$\frac{\text{FACTS DEVICES and A.I bus1 voltage - Conventional faulty bus1 voltage}}{\text{Conventional faulty bus1 voltage}} \times \frac{100\%}{1}$$

%improvement in the voltage stability of faulty bus1 when FACTS DEVICES and artificial intelligence were integrated in transmission network = $\frac{1.023\text{P.U.V} - 0.930\text{ P.U}}{0.930\text{ P.U}} \times \frac{100\%}{1}$

%improvement in the voltage stability of faulty bus1 when FACTS DEVICES and artificial intelligence were integrated in transmission network = 10%

To find percentage improvement in the voltage stability of faulty bus25 when FACTS DEVICES and artificial intelligence were integrated in transmission network

Conventional faulty bus25 voltage = 0.947 P.U

FACTS DEVICES and artificial intelligence bus25 voltage =1.042P.U.V

%improvement in the voltage stability of faulty bus25 when FACTS DEVICES and artificial intelligence were integrated in transmission network =

$$\frac{\text{FACT DEVICES and A.I bus25 voltage - Conventional faulty bus25 voltage x 100\%}}{\text{Conventional faulty bus25 voltage}}$$

1%improvement in the voltage stability of faulty bus25 when FACTS DEVICES and artificial intelligence were integrated in transmission network =

$$\frac{1042\text{P.U.V} - 0.947\text{ P.U x }100\%}{0.947\text{ P.U}}$$

%improvement in the voltage stability of faulty bus25 when FACTS DEVICES and artificial intelligence were integrated in transmission network = 10.03%

To find percentage improvement in the voltage stability of faulty bus30 when FACTS DEVICES and artificial intelligence were integrated in transmission network

Conventional faulty bus30 voltage = 0.919 P.U

FACTS DEVICES and artificial intelligence bus30 voltage =1.011P.U.V

%improvement in the voltage stability of faulty bus30 when FACTS DEVICES and artificial intelligence were integrated in transmission network =

$$\frac{\text{FACT DEVICES and A.I bus30 voltage - Conventional faulty bus30 voltage}}{\text{Conventional faulty bus30 voltage}} \times \frac{100\%}{1}$$

%improvement in the voltage stability of faulty bus30 when FACTS DEVICES and artificial intelligence were integrated in transmission network = $\frac{1.011.\text{U.V} - 0.919\text{P.U}}{0.919\text{ P.U}} \times \frac{100\%}{1}$

%improvement in the voltage stability of faulty bus30 when FACTS DEVICES and artificial intelligence were integrated in transmission network = 10.01%

Table 3: Comparison of voltage stability of conventional and FACTS DEVICES and artificial intelligence faulty bus1 voltage in transmission network

Time (s)	*Conventional faulty bus1 voltage in transmission network (P.U.V)*	*FACTS DEVICES and artificial intelligence faulty bus1 voltage in transmission network (P.U.V)*
1	0.934	1.023
2	0.934	1.023
3	0.934	1.023
4	0.934	1.023
10	0.934	1.023

Table 4: Comparison of Voltage Stability of Conventional and FACTS DEVICES and Artificial Intelligence Faulty bus25 Voltage in Transmission Network

Time (s)	*Conventional faulty bus25 voltage in transmission network (P.U.V)*	*FACTS DEVICES and artificial intelligence faulty bus25 voltage in transmission network (P.U.V)*
1	0.947	1.042
2	0.947	1.042
3	0.947	1.042
4	0.947	1.042
10	0.947	1.042

Table 5: Comparison of Voltage Stability of Conventional and FACTS DEVICES and Artificial Intelligence Faulty bus30 Voltage in Transmission Network

Time (s)	*Conventional faulty bus30 voltage in transmission network(P.U.V)*	*FACTS DEVICES and artificial intelligence faulty bus30 voltage in transmission network(P.U.V)*
1	0.919	1.011
2	0.919	1.011
3	0.919	1.011
4	0.919	1.011
10	0.919	1.011

Results and Discussion

The integration of FACTS devices and ANN demonstrated a highly effective strategy for improving voltage stability in transmission networks. The ANN's ability to learn and adapt to complex fault patterns complemented the dynamic control capabilities of FACTS devices. This synergy resulted in rapid and precise voltage stabilization, outperforming conventional methods. The comparative analysis in Figures 6 through 8 underscores the superiority of this hybrid approach, highlighting its potential for real-world applications in modern power systems.

The results validate the hypothesis that combining artificial intelligence with advanced hardware can significantly enhance the resilience of power transmission networks. Future work may explore optimizing the ANN architecture further and integrating additional FACTS device configurations for even greater performance.

Figure 1 presents the conventional SIMULINK model employed for analyzing voltage stability in a transmission network. The load flow results for faulty buses were integrated into this model. The simulation results accurately identified buses whose per unit voltages could not maintain stability within the standard range of 0.95 to 1.05 p.u. These unstable buses were further analyzed for corrective measures. The detailed simulation results are depicted in Figures 6 through 8, showcasing the effectiveness of the model in diagnosing voltage instability.

Figure 2 illustrates the implementation of an Artificial Neural Network (ANN) model designed for stabilizing voltages in faulty buses. The ANN was trained ten times, covering ten faulty buses, leading to a total of 100 neurons configured to mimic the computational efficiency of the human brain. This architecture demonstrated high adaptability and accuracy in learning patterns associated with voltage instability, as shown in Figure 3.

To further enhance voltage stability, Flexible AC Transmission Systems (FACTS) devices were incorporated into the SIMULINK model, as shown in Figure 4. This integration aimed to regulate voltage levels dynamically and mitigate instability issues identified during the initial simulations.

Figure 5 demonstrates a hybrid SIMULINK model combining ANN and FACTS devices. This model was tested to improve voltage stability in the transmission network. By leveraging artificial intelligence and advanced control strategies, this approach provided a robust solution for real-time voltage correction.

Figure 6: Comparison of voltage stability for Bus 1 using conventional, FACTS devices, and ANN methods. The results indicate a significant enhancement in voltage stability when FACTS devices and ANN are applied.

Figure 7: Evaluation of Bus 25 voltage stability. FACTS devices and ANN achieved better stabilization than the conventional method, maintaining voltages closer to the desired range of 0.95 to 1.05 p.u.

Figure 8: Analysis of Bus 30 voltage stability. The hybrid model demonstrated superior performance, effectively restoring voltage levels within acceptable limits.

Conventional Approach: Limited effectiveness in maintaining stable voltage levels under fault conditions.

ANN Model: Successfully identified patterns in fault data and improved stabilization efficiency.

FACTS Devices: Provided dynamic control, effectively mitigating voltage instability.

Hybrid Approach: Combining ANN and FACTS devices proved to be the most effective, ensuring stability across multiple faulty buses.

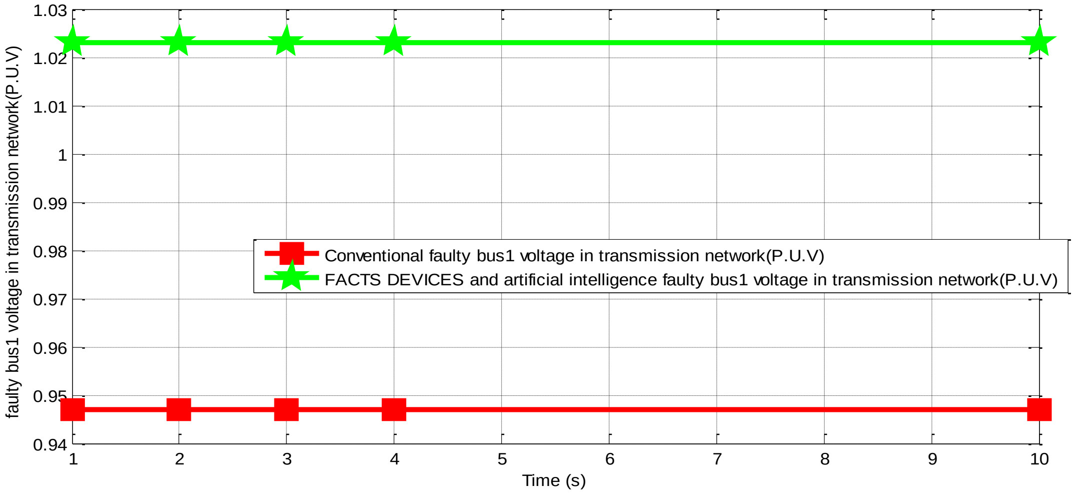

Fig 6: Comparison of voltage stability of conventional and FACTS DEVICES and artificial intelligence faulty bus1 voltage in transmission network

The conventional voltage of faulty bus 1 was0.934 P.U.V thereby constituting instability in power supply in the transmission network because the voltage could not attain voltage stability thresh hold of 0.95 through 1.05. On the other hand, when FACTS DEVICES and artificial intelligence were incorporated in the network, it automatically boosted the per unit volts of the faulty bus1 to 1.023P.U.V thereby enhanced constant power supply in the transmission network.

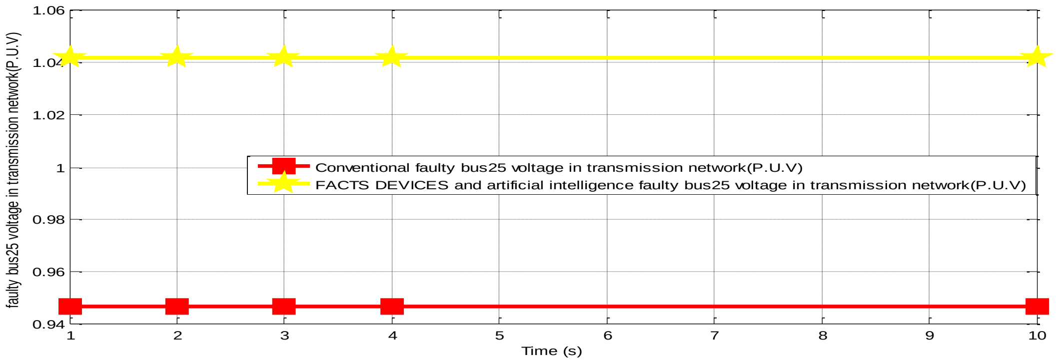

Fig 7: Comparison of voltage stability of conventional and FACTS DEVICES and artificial intelligence faulty bus25 voltage in transmission network

The conventional voltage of faulty bus 25 that caused intermittent power supply in the transmission network was 0.947P.U.V. meanwhile, when FACTS DEVICES and artificial intelligence were inculcated in the system, it instantaneously improved the voltage to 1.042P.U.Vthereby improving consistent power transmitted.

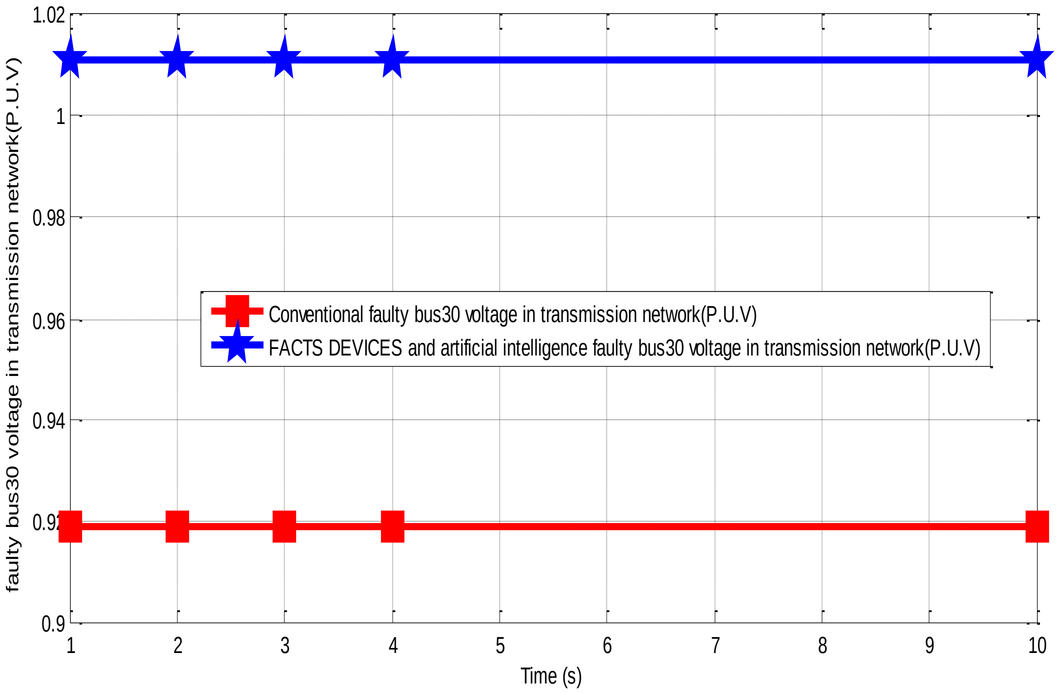

Fig 8: Comparison of voltage stability of conventional and FACTS DEVICES and artificial intelligence faulty bus30 voltage in transmission network.

The conventional voltage of faulty bus 30 was 0.919 P.U.V. on the other hand, when FACTS DEVICES and artificial intelligence was imbibed in the system, it automatically stabilized the voltage of the faulty bus30 to1.011P.U.V. Finally, with these results obtained, it definitely shown that percentage in improvement of voltage stability in transmission network when FACTS DEVICES and artificial intelligence were integrated in the system was10.01%.

Conclusion

The persistent power failures in the transmission network were attributed to voltage instability. To address this issue, the study focused on enhancing voltage stability through the integration of FACTS devices and artificial intelligence. The approach involved several key steps: characterizing voltage stability in the transmission network, conducting load flow analysis on the 330kV network to identify faulty buses causing instability, training an Artificial Neural Network (ANN) to stabilize these faulted buses, designing a SIMULINK model for FACTS devices, developing an implementation algorithm, and validating the percentage improvement in voltage stability with and without the proposed enhancements.

The results demonstrated significant improvements. Specifically, the initial voltage at faulty bus 25, which was 0.947 P.U., increased to 1.042 P.U. after incorporating FACTS devices and artificial intelligence, ensuring consistent power transmission. Similarly, the voltage at faulty bus 30 improved from 0.919 P.U. to 1.011 P.U. following stabilization. These findings indicate a measurable enhancement of 10.01% in voltage stability across the transmission network.

Finally, the integration of FACTS devices and artificial intelligence proved to be highly effective in mitigating voltage instability and improving power transmission reliability in the network.

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