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Enhancement of Frequency Stability of the Nigerian 330kv Transmission Network Using Ultra Capacitor Technique

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ABSTRACT
Frequency stability is concerned with the ability of generators to supply the loads at an acceptable frequency after a disturbance. Frequency stability is governed by the kinetic energy stored in the generator-prime mover rotating masses and the prime mover frequency primary regulation. If frequency excursions are not within +/−2.5Hz range, cascade tripping of the remaining generators can occur because of generator over/under frequency protections tripping. Energy storage systems can contribute to frequency stability enhancement if their discharging is governed by a frequency controller.If frequency excursions are not within +/-1.5 Hz range, cascade tripping of the remaining generators can occur because of generator over/under frequency tripping. Energy storage systems can contribute to frequency stability enhancement if their discharging is governed by a frequency controller. This paper reports the dynamic model developed for a time domain simulation and controller design of frequency stability, and field tests undertaken to validate models and the controller settings. A simple but still accurate moderl is presented. The proposed model takes into account the UC's state of charge (SoC) and it represents the dynamics of the power electronics by means of a non-linear first model. The frequency control consists of droop control and inertia emulation. Ramp rate limits, power limits, power limits and SoC are also taken into account in the frequency control. In comparison with the recorded field tests, the proposed model is able to accurately represent the response of the UC for the purpose of frequency stability analysis

Keyword: Enhanced, Frequency, Stability, Nigerian 330KV, Transmission, Ultra Capacitor Technique

I. INTRODUCTION

There are two basic factors that cause power system instability some of them are when the per unit volt does not fall within the range of 0.95 through 1.05 and power /rotor angle delta if it falls above 90^0 it will fall out of step or lose of synchronism but if the angle is within 70^0 though 85^0 range the system will be stable. The above two factors are the cause of power instability. This instability in power system is overcome by enhancement of frequency stability using Ultra capacitor technique.

II. METHODOLOGY

To characterize 330kv transmission network by running load flow on the network

Table 1 330KVtransmission network characterized data collected from Newhaven Enugu transmission

Bus No	Bus code	P.U	Ang Deg	Load MW	Load Mvar	Gen MW	Gen Mvar	Inject Min	Inject Max	Inject Mvar
1	1	0.92	0	00.0	0.0	0.0	0.0	0	0	0
2	0	1.0	0	00.0	0.0	0.0	0.0	0	0	0

3	0	1.0	0	150.0	120	0.0	0.0	0	0	0
4	0	1.0	0	0.0	0.0	0.0	0.0	0	0	0
5	0	1.0	0	120.0	60	0.0	0.0	0	0	0
6	0	1.0	0	140.0	90	0.0	0.0	0	0	0
7	0	1.0	0	0.0	0.0	0.0	0.0	0	0	0
8	0	1.0	0	110.0	90.0	0.0	0.0	0	0	0
9	0	1.0	0	80.0	50.0	0.0	0.0	0	0	0
10	2	1.035	0	0.0	0.0	200	0.0	0	180	0
11	2	1.03	0	0.0	0.0	160	0.0	0	120	0

To run the load flow of the characterized data to find the faulty buses that their p.u volts did not fall within the range of 0.95 through 1.05 thereby making the frequency unstable

```
disp(9.9')
basemva = 1000;  accuracy = 0.0001;  maxiter = 10;
%330KV transmission network characterized data collected from Newhaven
%Enugu transmission load flow
% The impedances are expressed on a 1000 MVA base.
% In the base is mistakenly stated as 100 MVA.
%      Bus  Bus   |V|  Ang   ---Load---      ---Gen---   Gen Mvar Injected
%      No.  code p.u.  Deg   MW     Mvar   MW   Mvar   Min   Max    Mvar
busdata=[1   1   0.92   0    00.0    0.0     0.0   0.0    0    0    0
        2    0   1.0    0    00.0    0.0     0.0   0.0    0    0    0
        3    0   0.81   0   150.0  120.0     0.0   0.0    0    0    0
        4    0   1.0    0     0.0    0.0     0.0   0.0    0    0    0
        5    0   1.0    0   120.0   60.0     0.0   0.0    0    0    0
        6    0   0.6    0   140.0   90.0     0.0   0.0    0    0    0
        7    0   1.0    0     0.0    0.0     0.0   0.0    0    0    0
        8    0   1.0    0   110.0   90.0     0.0   0.0    0    0    0
        9    0   1.0    0    80.0   50.0     0.0   0.0    0    0    0
        10   2   1.035  0     0.0    0.0   200.0   0.0    0   180   0
        11   2   1.03   0     0.0    0.0   160.0   0.0    0   120   0];


%       Bus   Bus     R       X       1/2B
%       No.   No.    p.u.    p.u.     p.u.
linedata=[1    2    0.00    0.06    0.0000   1
         2    3    0.08    0.30    0.0004   1
         2    6    0.12    0.45    0.0005   1
         3    4    0.10    0.40    0.0005   1
         3    6    0.04    0.40    0.0005   1
         4    6    0.15    0.60    0.0008   1
         4    9    0.18    0.70    0.0009   1
         4   10    0.00    0.08    0.0000   1
         5    7    0.05    0.43    0.0003   1
         6    8    0.06    0.48    0.0000   1
         7    8    0.06    0.35    0.0004   1
         7   11    0.00    0.10    0.0000   1
         8    9    0.052   0.48    0.0000   1];
%        Gen.  Ra     Xd'
gendata=[ 1     0     0.20
         10     0     0.15
         11     0     0.25];
lfybus        % Forms the bus admittance matrix
lfnewton      % Power flow solution by Newton-Raphson method
```

```
busout       % Prints the power flow solution on the screen
Zbus=zbuildpi(linedata, gendata, yload)%Forms Zbus including the load
symfault(linedata, Zbus, V)    % 3-phase fault including load current

>> disp(9.9')
basemva = 1000;  accuracy = 0.0001;  maxiter = 10;
%330KV transmission network characterized data collected from Newhaven
%Enugu transmission load flow
% The impedances are expressed on a 1000 MVA base.
% In the base is mistakenly stated as 100 MVA.

%     Bus  Bus  |V|  Ang   ---Load---     ---Gen---   Gen Mvar Injected
%     No.  code p.u.  Deg   MW      Mvar   MW   Mvar   Min   Max    Mvar
busdata=[1    1   0.92   0    00.0    0.0     0.0   0.0    0     0    0
        2    0   1.0    0    00.0    0.0     0.0   0.0    0     0    0
        3    0   0.81   0    150.0  120.0    0.0   0.0    0     0    0
        4    0   1.0    0    0.0     0.0     0.0   0.0    0     0    0
        5    0   1.0    0    120.0   60.0    0.0   0.0    0     0    0
        6    0   0.6    0    140.0   90.0    0.0   0.0    0     0    0
        7    0   1.0    0    0.0     0.0     0.0   0.0    0     0    0
        8    0   1.0    0    110.0   90.0    0.0   0.0    0     0    0
        9    0   1.0    0    80.0    50.0    0.0   0.0    0     0    0
        10   2   1.035  0    0.0     0.0     200.0 0.0    0     180  0
        11   2   1.03   0    0.0     0.0     160.0 0.0    0     120  0];


%      Bus   Bus     R       X       1/2B
%      No.   No.    p.u.    p.u.     p.u.
linedata=[1    2    0.00    0.06    0.0000    1
        2    3    0.08    0.30    0.0004    1
        2    6    0.12    0.45    0.0005    1
        3    4    0.10    0.40    0.0005    1
        3    6    0.04    0.40    0.0005    1
        4    6    0.15    0.60    0.0008    1
        4    9    0.18    0.70    0.0009    1
        4    10   0.00    0.08    0.0000    1
        5    7    0.05    0.43    0.0003    1
        6    8    0.06    0.48    0.0000    1
        7    8    0.06    0.35    0.0004    1
        7    11   0.00    0.10    0.0000    1
        8    9    0.052   0.48    0.0000    1];
%      Gen.  Ra     Xd'
gendata=[ 1    0     0.20
        10   0     0.15
        11   0     0.25];
    lfybus              % Forms the bus admittance matrix
    lfnewton            % Power flow solution by Newton-Raphson method
    busout              % Prints the power flow solution on the screen
    Zbus=zbuildpi(linedata, gendata, yload)%Forms Zbus including the load
    symfault(linedata, Zbus, V)    % 3-phase fault including load current
   9.9000

  Power Flow Solution by Newton-Raphson Method
  Maximum Power Mismatch = 7.62339e-008
  No. of Iterations = 10
```

Bus No.	Voltage Mag.	Angle Degree	------Load------ MW	Mvar	---Generation--- MW	Mvar	Injected Mvar
2.0							
1	0.920	0.000	0.000	0.000	253.440	-51.227	0.000
2	0.923	-1.026	0.000	0.000	0.000	0.000	0.000
3	0.922	-3.903	150.000	120.000	0.000	0.000	0.000
4	0.991	-3.556	0.000	0.000	0.000	0.000	0.000
5	0.964	-9.692	120.000	60.000	0.000	0.000	0.000
6	0.924	-4.828	140.000	90.000	0.000	0.000	0.000
7	0.998	-6.795	0.000	0.000	0.000	0.000	0.000
8	0.943	-7.075	110.000	90.000	0.000	0.000	0.000
9	0.940	-6.833	80.000	50.000	0.000	0.000	0.000
10	1.015	-2.644	0.000	0.000	200.000	312.281	0.000
11	1.020	-5.895	0.000	0.000	160.000	225.770	0.000
Total			600.000	410.000	613.440	486.824	0.000

The faulty buses are buses are buses 1, 2, 3, 6, 8 and 9 that their P.U. volts are 0.920,, 0.923 , 0.922, 0.924 , 0.943 and 0.940 . These are the buses their frequency is below 50Hz

To model 330kv transmission network in Simulink/MATLAB

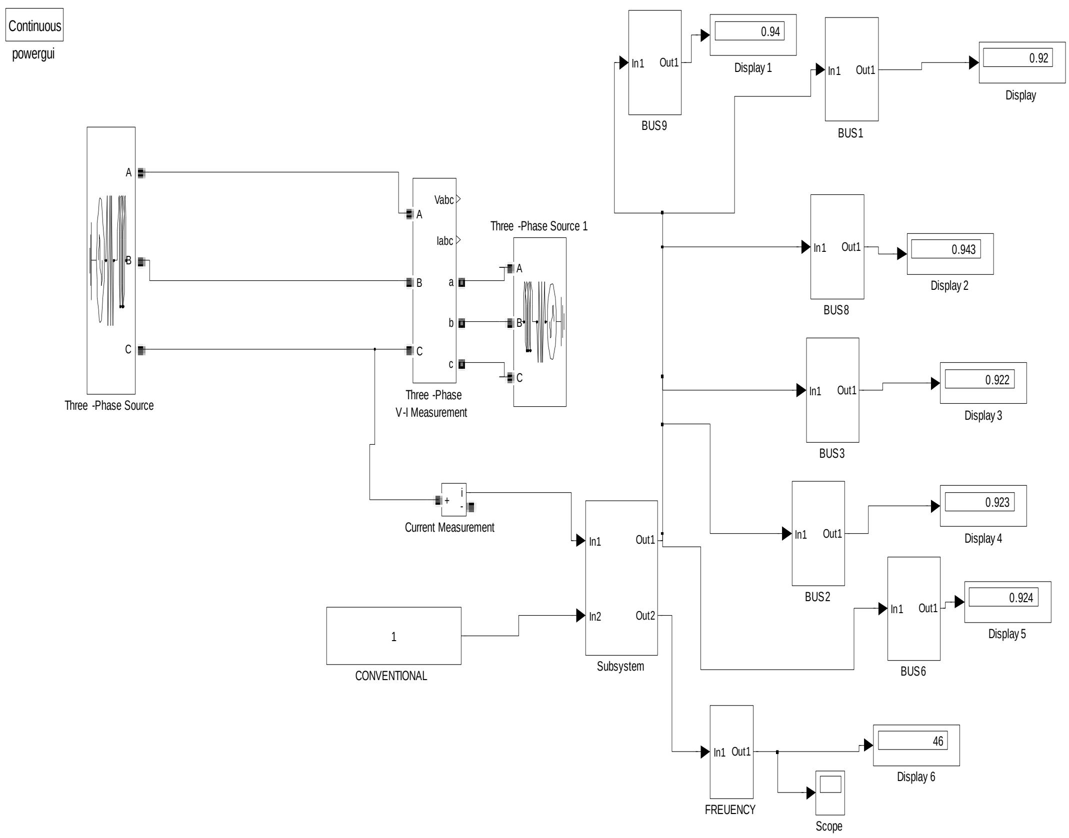

Fig 1 Conventional modeled 330kv transmission network in Simulink/MATLAB

Fig 1 shows Conventional modeled 330kv transmission network inSimulink/MATLAB.
The results obtained after simulation are as shown in figures 4.1, 4.2, 4.3, 4.4, 4.5, 4.6 and 4.7.

To develop a Simulink model of the Ultra-capacitor for enhancing frequency stability of the network.

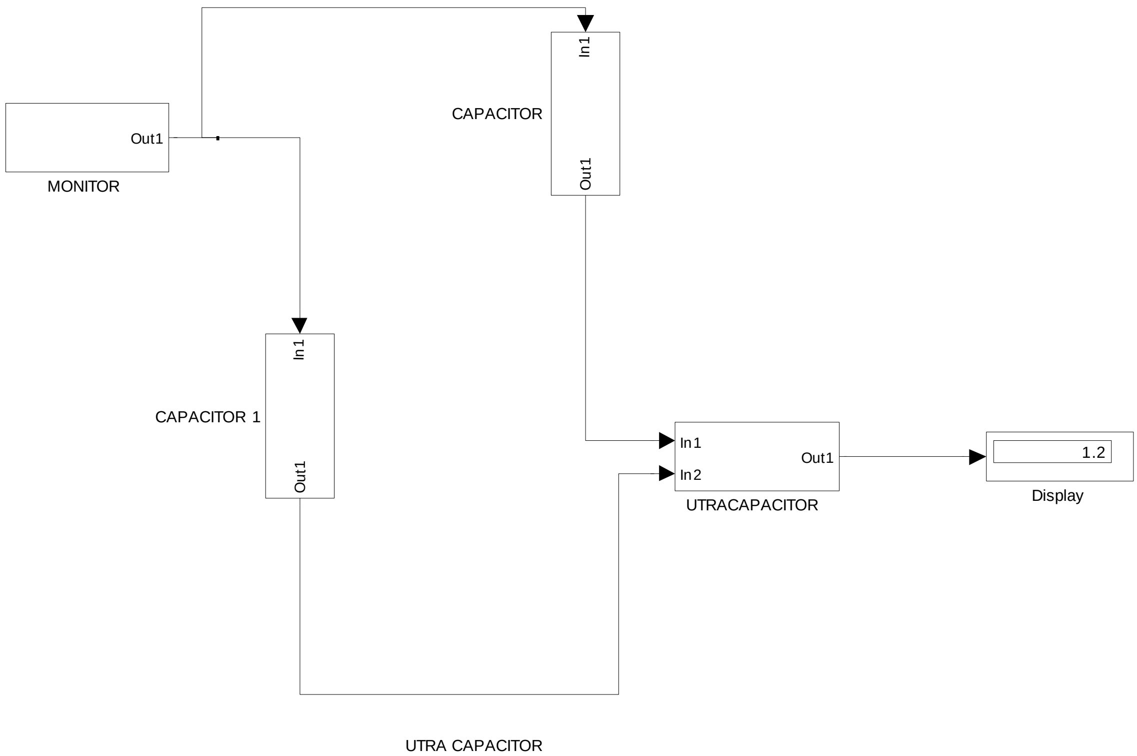

Fig 2 developed Simulink model of the Ultra-capacitor for enhancing frequency stability of the network.

Fig 2 shows developed Simulink model of the Ultra-capacitor for enhancing frequency stability of the network. Fig 2 is a highly sophisticated software that detects frequency instability as a result of the per unit volts not falling within the range of frequency stability of 0.95P.U. Volts through 1.05 P.U. volts.

To develop a neural network controller for the Ultra-capacitor in Simulink/MATLAB

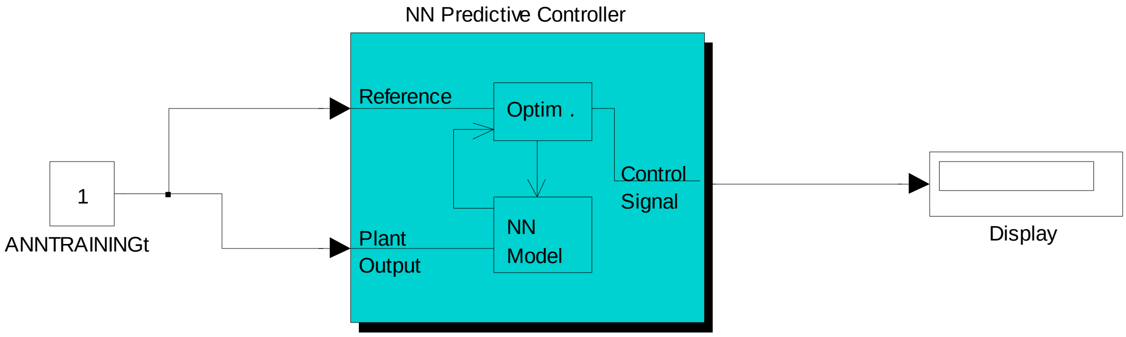

Fig 3 developed neural network controller for the Ultra-capacitor in Simulink/MATLAB.

Fig 3 shows developed neural network controller for the Ultra-capacitor in Simulink/MATLAB. This enhances the efficacy of the Ultra capacitor in terms of detecting and enhancing the frequency stability of 330KV transmission network.

To integrate the developed Ultra-capacitor and its ANN controller into the 330kv model.

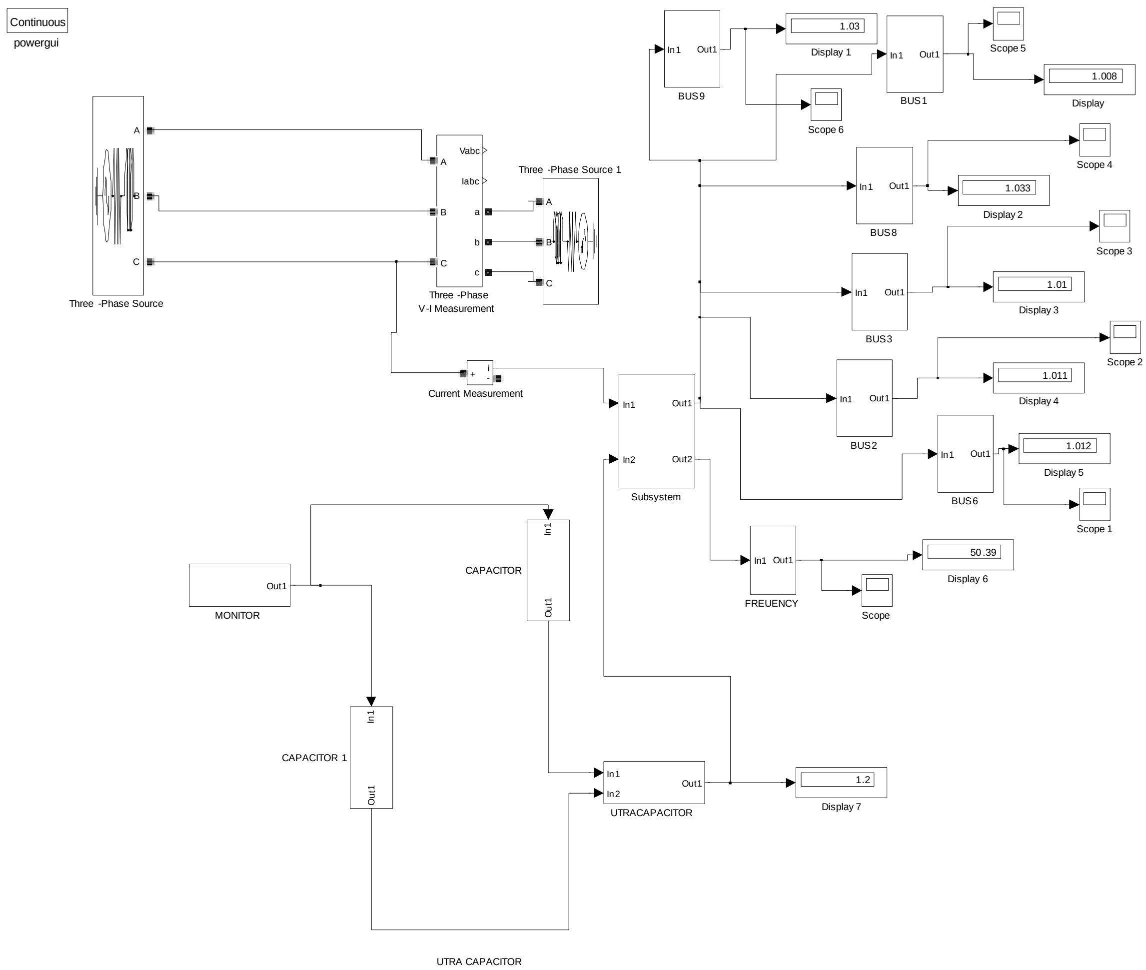

Fig 4 integrated developed Ultra-capacitor and its ANN controller into the 330kv model.

Fig 4 shows integrated developed Ultra-capacitor and its ANN controller into the 330kv model. The results obtained after simulation are comprehensively analyzed in figures 5 through 9. In this case, there will be stable power supply devoid of low power factor, high voltage, over current that is characterized by frequency instability.

III. DISCUSSION OF RESULT

Table 2 Comparing conventional and ultra capacitor P.U. volts of bus1

Time(s)	Conventional bus1 P.U. volts	Ultra capacitor P.U. volts bus1
0	0	0
2	0.8	0.82
4	0.92	1.008
10	0.92	1.008

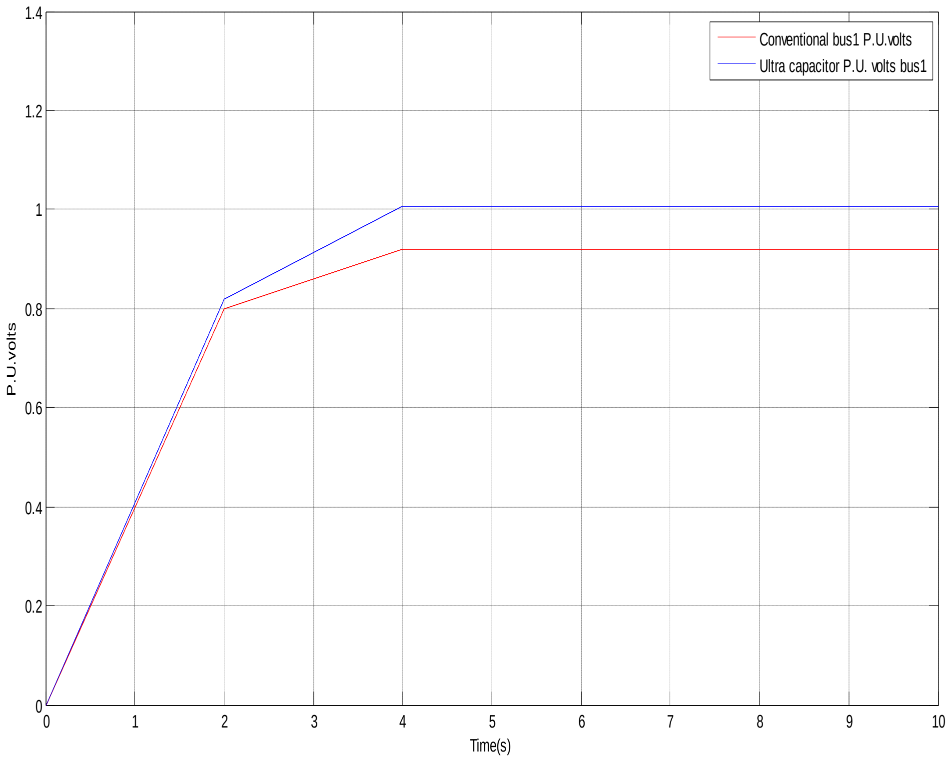

Fig 5 Comparing conventional and ultra capacitor P.U. volts of bus1

Fig 5 shows Comparing conventional and ultra capacitor P.U. volts of bus 1. In fig .5 the conventional 330KV transmission line per unit volts at 4s through 10s is **0.92** P.U. volts thereby making the frequency on stable or less than 50Hz. This will equally attribute to high current, low voltage and high voltage. On the other hand, when ultra capacitor is incorporated in the system, the per unit volts attain stability of 1.008 P.U. volts with a stable frequency of 50Hz that enhanced 330KV transmission network performance enhancement that is devoid of low power factor, intermittent power supply, low and high voltage. The bus 1 that was faulty was rectified when ultra capacitor is incorporated in the system.

Table 3 Comparing conventional and ultra capacitor P.U. volts of bus2

Time(s)	**Conventional bus2 P.U.Volts**	**Ultra capacitor P.U. Volts bus2**
0	**0**	**0**
2	**0.8**	**0.81**
4	**0.923**	**1.011**
10	**0.923**	**1.011**

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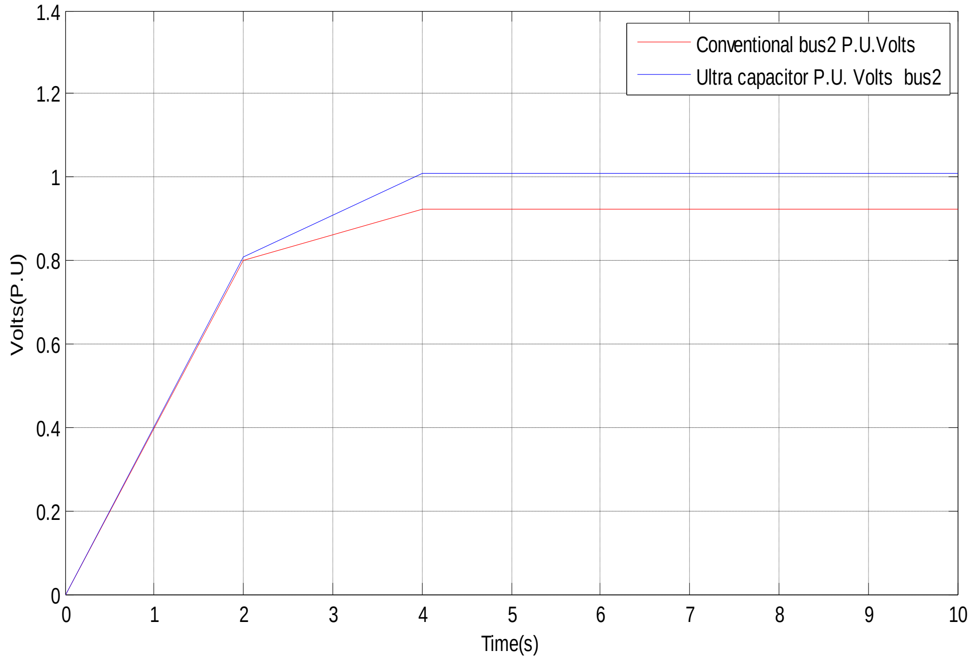

Fig 6 Comparing conventional and ultra capacitor P.U. volts of bus2

Fig 6 shows Comparing conventional and ultra capacitor P.U. volts of bus 2. The conventional per unit volts of bus 2 at 4 through 10 seconds are 0.923P.U. volts thereby making the frequency of the transmission network unstable. Meanwhile when ultra capacitor is imbibed in the system it enhanced the per unit volts to 1.011 P.U. volts hence forth making the transmission network frequency stable.

Table 4 Comparing conventional and ultra capacitor P.U. volts of bus3

Time(s)	**Conventional bus3 P.U. volts**	**Ultra capacitor P.U. volts bus3**
0	0	0
1	0.58	0.6
2	0.8	0.81
3	0.88	0.9
4	0.922	1.01
10	0.922	1.01

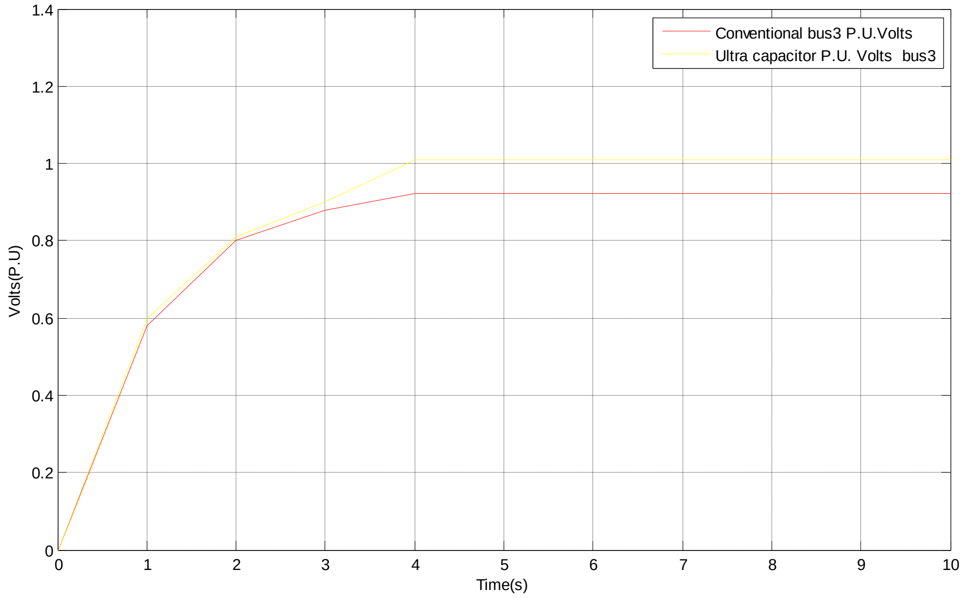

Fig 7 Comparing conventional and ultra capacitor P.U. volts of bus3

Fig 7 shows Comparing conventional and ultra capacitor P.U. volts of bus 3. In fig 7 the conventional per unit volts was stable from 4s through 10s at out of range per unit volts of 0.922 P.U. volts. However, when Ultra capacitor is integrated in the system it enhanced the transmission network performance with a per unit volts of 1.01 P.U. volts. Meanwhile, ultra capacitor equally, enhanced the frequency stability of 50Hz.

Table 5 Comparing conventional and ultra capacitor P.U. volts of bus6

Time(s)	Conventional bus6 P.U. volts	Ultra capacitor P.U. volts bus6
0	0	0
1	0.6	0.8
2	0.8	0.83
3	0.84	0.9
4	0.924	1.012
10	0.924	1.012

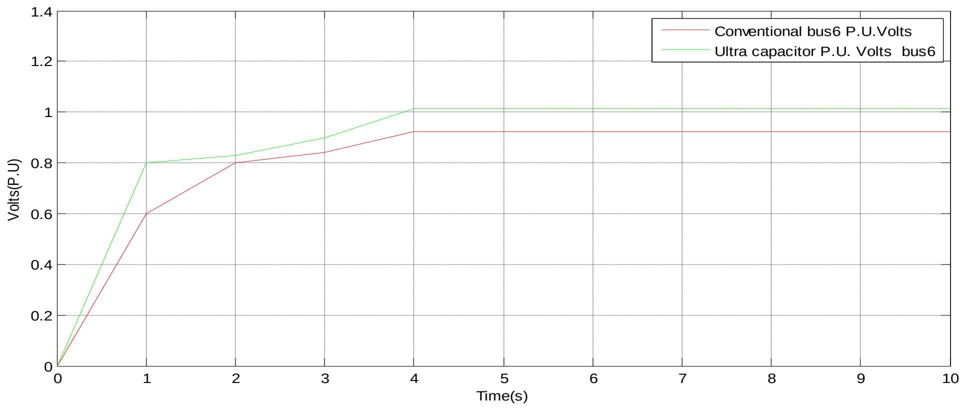

Fig 8 Comparing conventional and ultra capacitor P.U. volts of bus 6

Fig 8 shows Comparing conventional and ultra capacitor P.U. volts of bus 6. In fig 8 the conventional per unit volts in faulty bus 6 is 0.924P.U.volts. While that when ultra capacitor is inculcated in the system is 1.012P.U.volts signifying an improvement in bus 6.

Table 6 Comparing conventional and ultra capacitor P.U. volts of bus8

Time(s)	**Conventional bus8 P.U. volts**	**Ultra capacitor P.U. volts bus8**
0	0	0
1	0.6	0.62
2	0.82	0.85
3	0.9	0.93
4	0.943	1.033
10	0.943	1.033

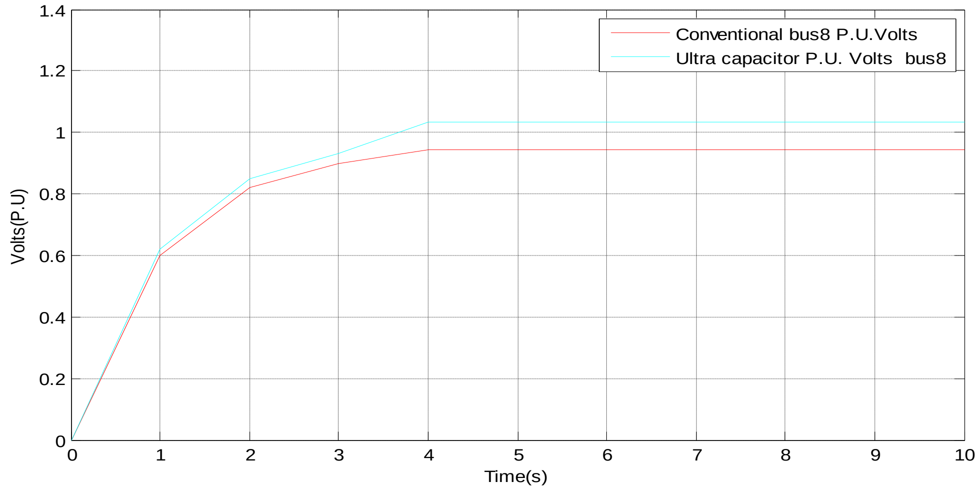

Fig 9 Comparing conventional and ultra capacitor P.U. volts of bus 8

Fig 9 shows Comparing conventional and ultra capacitor P.U. volts of bus 8. The conventional faulty bus 8 that has per unit volts that did not fall within the range of 0.95 through 1.05 P.U. volts was enhanced when ultra capacitor was imbibed in the system.

Table 7 Comparing conventional and ultra capacitor P.U. volts of bus9

Time(s)	**Conventional bus9 P.U. volts**	**Ultra capacitor P.U. volts bus9**
0	0	0
1	0.6	0.63
2	0.8	0.83
3	0.9	0.92
4	0.94	1.03
10	0.94	1.03

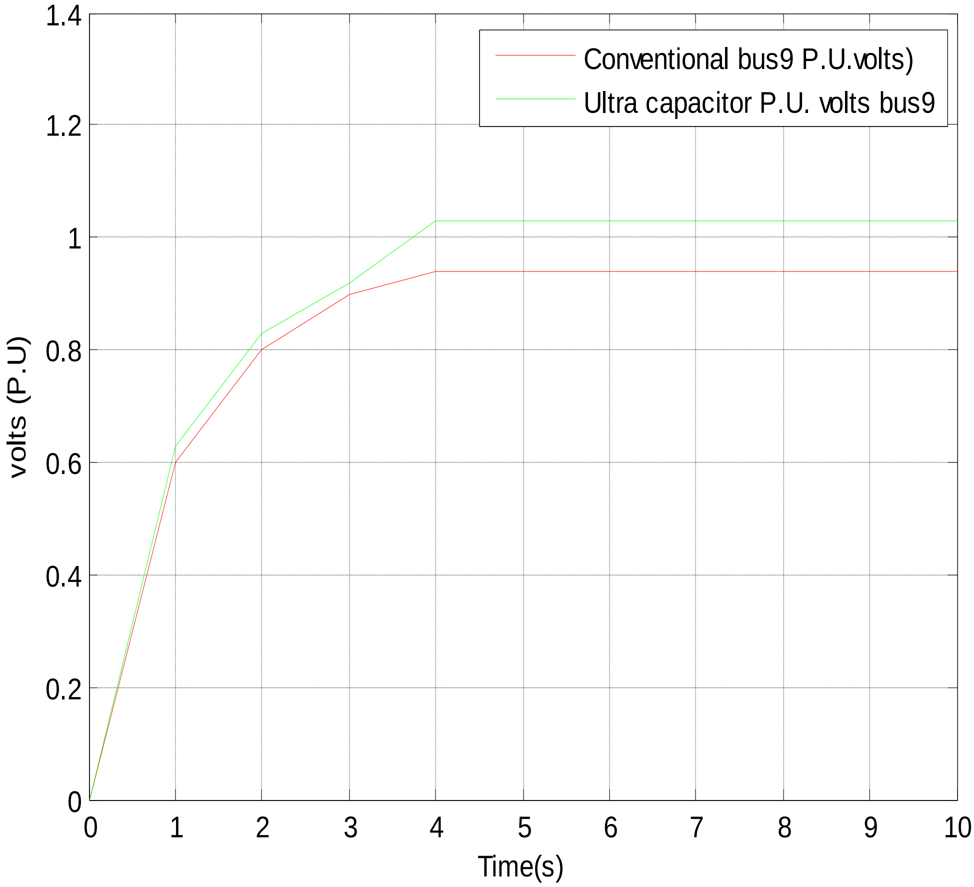

Fig 10 Comparing conventional and ultra capacitor P.U. volts of bus9

Fig 10 shows Comparing conventional and ultra capacitor P.U. volts of bus9. In fig 10 the conventional per unit volts is 0.94P.U. volts while that when ultra capacitor is inculcated in the system is 1.03P.U. volts thereby improving the transmission network performance to the peak.

Table 8 Comparing conventional and ultra capacitor frequency of buses1, 2, 3, 4, 6, 8 and 9

Time(s)	**Conventional frequency(Hz)**	**Ultra capacity frequency(Hz)**
0	0	0
1	28	30
2	40	42
3	44	48
4	46	50
10	46	50

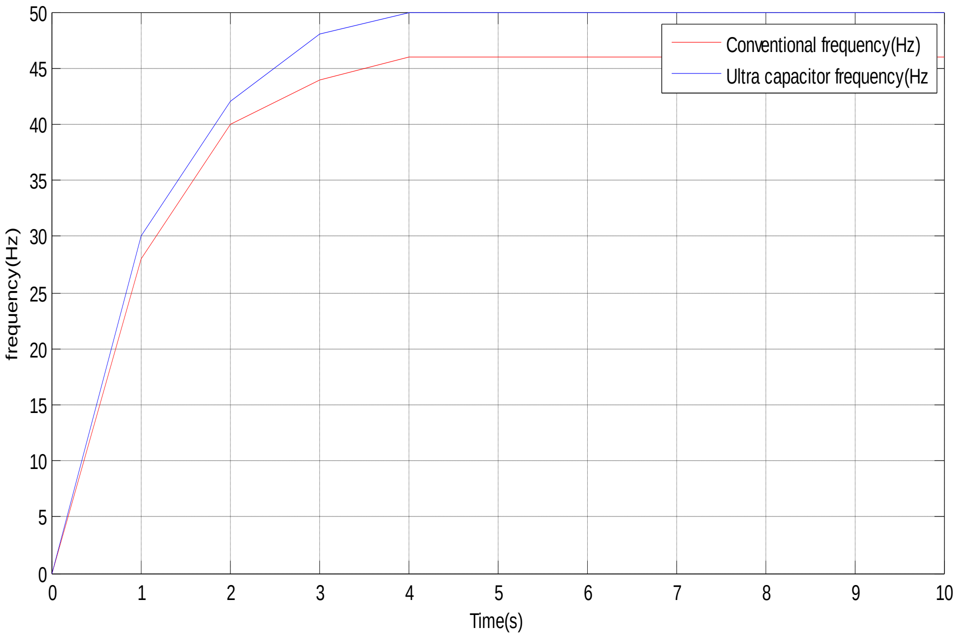

Fig 11 Comparing conventional and ultra capacitor frequency of buses1, 2, 3, 4, 6, 8 and 9

Fig11 shows Comparing conventional and ultra capacitor frequency of buses 1, 2, 3, 4, 6, 8 and 9. The conventional faulty buses of 1, 2, 3, 4, 6, 8 and 9 have frequency of 46Hz which is below the thresh hood frequency of 50Hz. This under frequency makes the transmission network to reduce its performance because it is characterized with over voltage, low voltage, over current, low power factor to mention a few. On the other hand, when ultra capacitor is incorporated in the system it stabilized the frequency to 50 Hz thereby enhancing the transmission network performance to the peak with steady power supply devoid of any sort of power failure. Conventional and ultra capacitor P.U. volts of bus 2. The conventional per unit volts of bus 2 at 4 through 10 seconds are 0.923P.U. volts thereby making the frequency of the transmission network unstable. Meanwhile when ultra capacitor is imbibed in the system it enhanced the per unit volts to 1.011 P.U. volts hence forth making the transmission network frequency stable. conventional and ultra capacitor P.U. volts of bus 6. In fig 4.4 the conventional per unit volts in faulty bus 6 is 0.924P.U.volts. While that when ultra capacitor is inculcated in the system is 1.012P.U.volts signifying an improvement in bus 6. conventional and ultra capacitor P.U. volts of bus9. In fig 4.6 the conventional per unit volts is 0.94P.U. volts while that when ultra capacitor is inculcated in the system is 1.03P.U. volts thereby improving the transmission network performance to the peak.

IV. CONCLUSION

The instability power supply in the transmission network that is caused by frequency instability is over come by enhancement of frequency stability of the Nigerian 330KV transmission network using ultra capacitor. It is done in this manner, characterizing 330kv transmission network by running load flow on the network modeling 330kv transmission network in Simulink/MATLAB. determining the frequency stability of the network, developing a Simulink model of the Ultra-capacitor for enhancing frequency stability of the network, developing a neural network controller for the Ultra-capacitor in Simulink/MATLAB, integrating the developed Ultra-capacitor and its ANN controller into the 330kv model and simulating the entire system and evaluating the performance of the technique. The results obtained are conventional and ultra capacitor P.U. volts of bus 1. In fig .4.1 the conventional 330KV transmission line per unit volts at 4s through 10s is 0.92 P.U. volts thereby making the frequency on stable or less than 50Hz. This will equally attribute to high current, low voltage and high voltage. On the other hand, when ultra capacitor is incorporated in the system, the per unit volts attain stability of 1.008 P.U. volts with a stable frequency of 50Hz that enhanced 330KV transmission network performance enhancement that is devoid of low power factor, intermittent power supply, low and high voltage. The bus 1 that was faulty was rectified when ultra capacitor is incorporated in the system. Conventional and ultra capacitor P.U. volts of bus 3. In fig 4.3 the conventional per unit volts was stable from 4s through 10s at out of range per unit volts of 0.922 P.U. volts. However, when Ultra capacitor is integrated in the system it enhanced the transmission network performance with a per unit volts of 1.01 P.U. volts. Meanwhile, ultra capacitor equally, enhanced the frequency stability of 50Hz. conventional and ultra capacitor P.U. volts of bus 8. The conventional faulty bus 8 that has per unit volts that did not fall within the range of 0.95 through 1.05 P.U. volts was enhanced when ultra capacitor was imbibed in the system. Conventional and ultra capacitor frequency of buses 1, 2, 3, 4, 6, 8 and 9. The conventional faulty buses of 1, 2, 3, 4, 6, 8 and 9 have frequency of 46Hz which is below the thresh hood frequency of 50Hz. This under frequency makes the transmission network to reduce its performance because it is characterized with over voltage, low voltage, over current, low power factor to mention a few. On the other hand, when ultra capacitor is incorporated in the system it stabilized the frequency to 50 Hz thereby enhancing the transmission network performance to the peak with steady power supply devoid of any sort of power failure. Conventional and ultra capacitor P.U. volts of bus 2. The conventional per unit volts of bus 2 at 4 through 10 seconds are 0.923P.U. volts thereby making the frequency of the transmission network unstable. Meanwhile when ultra capacitor is imbibed in the system it enhanced the per unit volts to 1.011 P.U. volts hence forth making the transmission network frequency stable. Conventional and ultra capacitor P.U. volts of bus 6. In fig 4.4 the conventional per unit volts in faulty bus 6 is 0.924P.U.volts. While that when ultra capacitor is inculcated in the system is 1.012P.U.volts signifying an improvement in bus 6. conventional and ultra capacitor P.U. volts of bus9. In fig 4.6 the conventional per unit volts is 0.94P.U. volts while that when ultra capacitor is inculcated in the system is 1.03P.U. volts thereby improving the transmission network performance to the peak.

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