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MINIMIZATION OF THE IMPACT OF THREE PHASE FAULTS ON THE VOLTAGE PROFILE OF THE NIGERIA 330KV TRANSMISSION NETWORK USING CAPACITOR COMMUTATED CONVERTER-BASED HIGH VOLTAGE DIRECT CURRENT (CCC-HVDC)

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Abstract: *This research paper presents the minimization of the impact of three phase fault on the voltage profile of the Nigeria 330kV transmission network using Capacitor Commutated Converter-based High Voltage Direct Current (CCC-HVDC). Power system disturbances caused by loss of generation, switching actions, change in loads, and majorly faults lead to various degrees of voltage instabilities. The consequence of voltage instabilities in our Power networks can be severe. This is because it can lead to loss of loads, loss of generation and loss of generator synchronism, under-frequency, and ultimately, voltage collapse. Imbalance in the reactive power supplied and the reactive power absorbed by the system has been identified as the key cause of voltage instabilities on our networks. High Voltage Direct Current and Flexible AC Transmission System (FACTS) are new technologies that employ modern Power electronic techniques in controlling transmission system parameters. These devices are very fast, flexible, and effective in controlling active and reactive power independently. In this paper, Capacitor Commutated Converted-based High Voltage Direct Current (CCC-HVDC), was used to minimize the impact of three phase fault on the voltage profile of the 28-bus Nigerian 330kV network. The HVDC model and its neural network controller were developed in Simulink-Matlab, utilizing resources from Matlab and Simscape libraries. Transmission network data obtained from the Transmission Company of Nigerian (TCN) Osogbo and augmented with simulation data were used to train the ANN controllers. A performance training of 94% ensured that the neural network controllers produced the desired results. Result of simulations of the network models showed that CCC-HVDC minimized the impact of three phase fault on the voltage profile of the Nigerian network by enhancing the voltage profile of the network. CCC-HVDC improved the network's voltage profile by 97.5% without three phase faults. During a contingency of three phase faults, CCC-HVDC improved the network's voltage profile by 6.25%. It was concluded that CCC-HVDC controlled by neural network was effective in minimizing the impact of three phase fault when*

connected between the point of fault and the bus of interest. ANN controlled CCC-HVDC was able to achieve this by exploiting its capacity of simultaneously controlling active and reactive power in a network thereby boosting the voltage profile during fault situation.
Keywords: *Converter-based, Nigeria-330kV, Three-Phase, Transmission-network, Voltage*

1 Introduction

Disturbances are common in our power networks. These disturbances can come in different forms, ranging from switching actions, change in load loss or addition) and changing the generator excitation to fault conditions. The effects of these various forms of disturbances in a power system can be devastating especially when the disturbances occur suddenly as is usually the case It could result in loss of synchronism, progressive increase or sagging in voltage profile, severe under frequency and ultimately voltage collapse. The fragile and stressed nature of most power networks can make the system even more vulnerable to disturbances which could lead to these undesirable effects that can make our system unreliable. Faults are one of the most severe constraints experienced in our power networks. This is because of its far-reaching negative impacts on the power system infrastructure and stable power supply. Fault situations are characterized by injection of very high fault current in the network as well as highly reduced voltage profile of affected phase. Both the crashed voltage profile and shooting fault current are very dangerous to power system equipment and effective power transfer within the network. Severe fault situations if not properly managed can lead to cascaded blackouts and voltage collapse. Power system protective devices like relays and circuit breakers combine to sense and isolate faulty sections of a power network. Unfortunately, this traditional method of protecting the network is prone to inaccuracies capable of exposing the network to fault currents and voltages to some extent before other control actions are taken. By utilizing its capacity to simultaneously control active and reactive power in an AC network; High voltage direct current link (HVDC) is able to offer active and reactive power support that boosts power transfer capacity of the network during fault situation and by so doing keeps current and bus voltages at normal levels. In this regard, HVDC links acts as a fault tolerant device when connected to an AC network. One major advantage of applying HVDC in resolving fault issues is that it has the capacity to appreciably minimize the impacts of fault without isolating the faulty section of the network.

2 High Voltage Direct Current (HVDC) Technology

AC transmission has some inherent advantages in power transfer. Some of them include: ability to be transformed to different voltage levels; high capacity for long distance power transmission using transformers; Cheaper and more robust motors and the advantage provided for circuit breakers by the natural current zeros that occur twice per cycle in an AC system (Lidong, 2010). Despite these merits, dc transmissions still remain very relevant. HVDC link is one of the most attractive means of ac transmission over long distances. Some situations exist where HVDC transmission technology is either the only or the most effective means of transmitting electric power over a distance. Lidong (2010) summarizes these scenarios as follows:

i. **Electric Power Transmission through Cables**: The physical structure of cables makes it have capacitive currents created by alternating voltages. The losses involved in ac transmission via cables is so high that long distance transmission in not feasible thereby making High Voltage Direct Current (HVDC) transmission the only feasible option for long-distances via cables "eg" in the submarine cable transmission.

ii. **Long-Distance Bulk Power Transmission:** HVDC transmission has been found to be more cost effective in bulk power transmission over a long-distance of at least 400km. Also the stability limitations relating to ac long-distance transmission is largely eliminated in dc transmission

iii. **Power Transmission Involving Two Unsynchronized Interconnected System**: AC transmission is the only possible way to synchronize interconnected systems with the same nominal frequency. However, the use of HVDC removes the bottlenecks of synchronization and need for interconnected systems to have same nominal frequency. Other benefits of HVDC power transmission as highlighted by Lidong (2010) include: The ability of HVDC transmission to improve power system stability by being able to manipulate large amount of power within a short period; ability of HVDC links to offer solid protection against spreading from one system to another of cascaded ac-system outages.

Another advantage of HVDC link over ac transmission is its ability to damp oscillation two to three times better than reactive shunt compensators (Mehmet, 2009).

(Burglen and Zurich (2015) identified two categories of HVDC technologies based on their terminal voltage and current wave forms at their DC side. They are current source converter (CSC) and voltage source converter (VSC).

The CSC maintains the DC current at the same polarity and as such the power flow direction through the converter is determined by the DC voltage polarity. CSC's are designed with semi-controllable switches such as thyristors, in which current interruption is only determined by the zero-ac voltage zero crossing. The CSC produces current and voltage harmonics on the ac side needing large ac filters to remove (Burglen and Zurich, 2015). Despite its successful application, Lidong (2010) observed that the CSC technology suffers some inherent weaknesses. Some of such weaknesses include: High consumption of reactive power either in the rectifier or inverter side; commutation failure at the inverter station due to disturbances in the ac systems. Conversely voltage source converter (VSC) keeps the polarity of the DC voltage constant such that the power flow direction is determined by the DC current polarity. Fully controllable semiconductor switches such as IGBTs and GTOs, with the help of a gating command, are able to conduct and switch off current at any instant (Lidong, 2010). This is unlike the CSC where the thyristor valve can only be switched off by getting line voltages reversed. As a result of this VSC can independently generate its own sinusoidal voltage wave form using pulse-width

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modulation technique. (Burglen and Zurich, 2015). Typically, the DC side of a VSC is connected in parallel with a capacitor that is relatively large when compared with the voltage source.
Schematic diagrams of CSC and VSC are presented in figures 2.1 and 2.2 respectively.

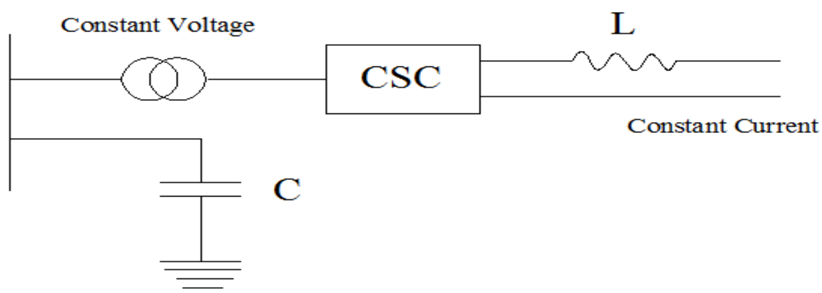

Fig 2.1: Current Source Converter
(Source: Burglen and Zurich, 2015)

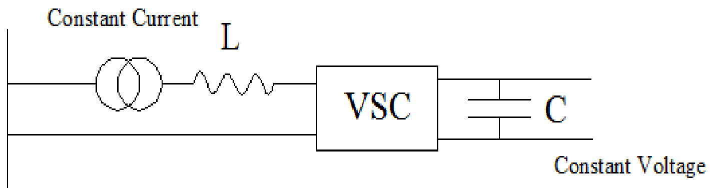

Fig 2.2: Voltage Source Converter
(Source: Burglen and Zurich, 2015)
Lidong (2010) associated three major types of VSC with HVDC applications. They are two level converters, three level converter, and modular multilevel converter (MMC). In more recent designs of MMC voltage and current harmonics on the AC side by VSC have been greatly reduced thereby eliminating entirely or reducing the size of filters needed to only small ones. This dramatically reduces the size of converter stations thereby opening up a new page on the HVDC technology like the off shore converters and urban area converters. It is now possible for VSC HVDC to use a DC of I525 KV, to link up to 2600MW and a transmission distance of more than 1500km (Lidong, 2010). In summary, the key difference between CSC and VSC is that VSC can control active and reactive power independent of the system state and independent of each other. This important characteristic makes VSC-HVDC more attractive than CSC-HVDC in terms of real time power system control added to being able to affect quicker power reversal. Other advantages that put VSC–HVDC ahead of CSC–HVDC include: ability to connect to weak networks, quicker grid restoration etc. One important advantage of VSC-HVDC

technology is its ability to link an AC grid with unsynchronized supplies from distributed generating systems like solar cell and wind turbines.

The above discussion clearly reveals the viability of a VSC based HVDC technology in effective active and reactive power control. Interestingly, this capacity to independently control active and reactive power is a key pointer to the technology's ability to improve voltage stability of an electrical network especially networks characterized by very long lines.

Despite these many advantages of VSC-HVDC over CSC-HVDC, CSC-HVDC is still dominantly applied due to low-cost bulk transmission advantage over VSC-HVDC (Arunkumar, 2010).

In an effort to improve on the power control capacity of CSC-HVDC system and reduce its inherent high risk of communication failure, while keeping bulk transmission cost low, another technology in HVDC transmission, called capacitor-commutated converter (CCC) HVDC system evolved. The CCC-HVDC is a modification of CSC-HVDC. This modification is the addition of a series capacitor between the transformer and the valves of each phase.

Balzer (2001) noted that the additional series commutation capacitors make available additional commutation voltage that makes it possible for the inverter to be operated at a small firing angle and small extinction angle respectively. As a result of this, the converters' reactive power consumption are reduced likewise the size of the fitter capacitance. This improves the overall stability of the system; the CCC-HVDC system is most suitable for networks whose short circuit ratio (SCR) is lower than that of the HVDC converters. One major challenge of the CCC-HVDC technology is the increase in high ac harmonic caused by a reduced commutation time and also reduced overlap angle. This challenge can be overcome by increasing the AC filter rating (Balzer, 2001). The advantage derived from the CCC technology lies in the fact that the converters are much less dependent on the AC network strength for the successful commutation of the valves. As a result, commutation failures due to network disturbances are highly reduced (Magne, 2000).

Literature Review on CCC-HVDC

Arunkumar (2010) worked on the "selection of Dynamic performance control of parameters of classic HVDC in PSS/E.". The main aim of the research was to define the strategy of tuning the parameters of the voltage dependent order limiter and current controller so as to achieve improved dynamic performance with different ac system using PSS/E as tool. The work mainly dealt with dynamic response of HVDC systems. It was observed that dynamic instabilities occur mainly at dc systems connected to weak ac network on the receiving side. These instabilities cause fluctuations in the ac voltage thereby making the dc system recovery difficult in the face of repetitive commutation failures. The work analyses the response of different transmission type control parameters and network strength. Analysis of the results of simulation performed showed that contingency of the system was successfully handled, and that the optimized parameters were able to manage faults in large network characterized by weak and strong ac systems.

Fischer *et al* (2012) developed a new control scheme for a CCC-HVDC with an inverter operating with constant alternating voltage. The main objective of the work was to propose a new control strategy that can be used for a CCC-HVDC. In the new arrangement, the inverter is to emulate the operation of a VSC such that both active and reactive power can be independently controlled. Their studies showed a significant reduction in the interaction between the inverter and the connected ac network. The study also proved that it is possible to operate the inverter into an almost passive ac network using the proposed new scheme. The result of the simulation showed satisfactory operation of HVDC transmission with the inverter working into a network with a short circuit ratio as down as 0.2.

Sulaiman, (2014) worked on the control of series HVDC bridges with different firing angles. The research work described an alternative application of bridge circuit using bridges connected in series with varying ratings and firing angles. It presented both the transient and steady-state operation of the system. Simulation result revealed that series bridges of the laboratory model was able to handle sudden changes of the system voltage up to + 29% by adjusting the switching angle alpha of the achieved fast time- response that effectively damped-out the oscillation on the variation of the feed-back parameters. Also, it was shown that the calculated and experimental results were in agreement and in accordance with general characteristics obtained with series bridges when compared with conventional bridge arrangement, the reactive volt-ampere absorption.

The HVDC converter topology proposed for this project is the capacitor commutated converter (CCC). Here the focus is to model the CCC-HVDC and its neural network controllers. The capacitor commutated converter (CCC) is a conventional HVDC link provided with commutation capacitors between the transformer and the inverter valve. The basic idea in this concept is that the capacitors contribute to the valve commutation voltage. This contribution makes it possible to operate the CCC with much lower reactive power consumption compared to the conventional converter (Khatir *et al*, 2007). Furthermore, in terms of voltage stability, CCC gives a more robust and stable dynamic performance of the inverter station, especially when inverters are connected to weak AC systems and/or long DC cables. Increased commutation margins can be achieved, without increasing the reactive power consumption of the converter station. This is done by reducing the capacitance of the commutating capacitors in order to increase their contribution to the commutation voltage.

3 Modeling the Capacitor-Commutated Converter Based HVDC (CCC-HVDC)

Parmiris (2009) identified three configurations of HVDC systems: the two-terminal system, the back to back system and the hybrid system. The choice of configuration depends on the functions and location of the converter stations. (Note: Figure 3.1 is derived from the CIGRE AVDC benchmark model)

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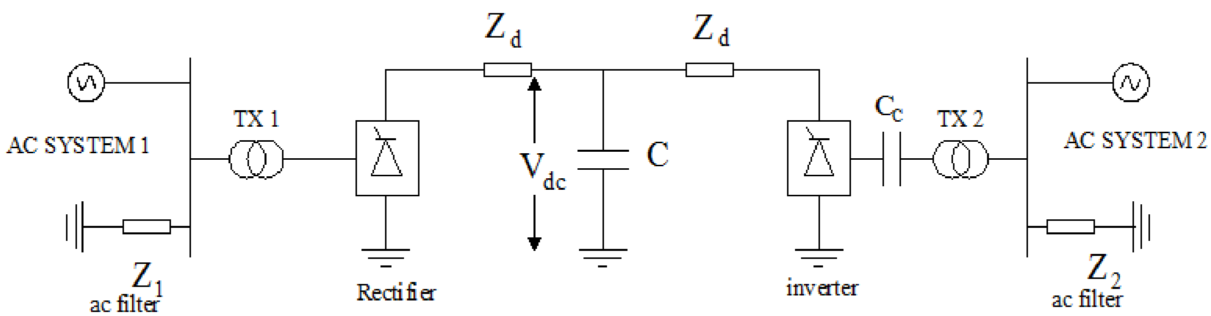

Fig 3.1: Proposed CCC-HVDC model derived from the benchmark.

HVDC converters employed in actual transmission applications are composed of a number of elementary converters such as two-level, six-pulse bridges, and multi-level topologies such as a three-phase, three-level, and twelve-pulse bridges. In this project the rectifier and inverter in the CCC-HVDC are three-phase, three-level, and 12-pulse converters using two 6-pulse thyristor bridges connected in series.

In the conventional HVDC converter, the electrical angle corresponding to the time at which the valve turns off to the positive zero crossing of the line-to-line voltage at the ac converter bus is known as the extinction angle,□. Khatir (2007) showed that the value of the extinction angle depends on the firing angle (□) and the overlap angle (□).

□ = □ - (□+□) (3.1)

Where □ is the firing, μ is the overlap angle and □ is the Extinction angle

The power factor of the rectifier is expressed as a function of the firing angle. The power factor of the rectifier is given by Alireza (2007) as:

$$Cos\Phi = {}^{1}/_{2}\left[Cos \propto + Cos[\propto + \mu]\right] \qquad (3.2)$$

The rectifier power factor increases with increase in inverter firing angle, α as seen in equation 3.2. Similarly, the inverters power factor is expressed as a function of the firing angle. The power factor of the inverter is given by Alireza (2007) as:

$$Cos\Phi = {}^{1}/_{2}\left[Cos\gamma + Cos[\gamma + \mu]\right] \qquad (3.3)$$

Also, the power factor increases with increase in inverter extinction angle (γ) as seen in equation 3.3.

Implementation of the CCC-HVDC Simulink/Matlab Model

The capacitor commutated converter based High Voltage Direct current models shown in Figure 3.1 is a modification of the CIGRE HVDC benchmark model. The implementation was done in MATLAB Simulink environment. All the component blocks including: the rectifier, inverter, DC line, AC filter, three phase transformers, capacitors, bus bars and impedance blocks where sourced from Simulink and Simscape library. After importing the component blocks in an empty model space, the blocks were

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carefully connected and configured to reflect appropriate ratings as regards voltage, frequency, phase angle, active and reactive power, current etc.
The implemented CCC-HVDC simulink model is shown in figure 3.2

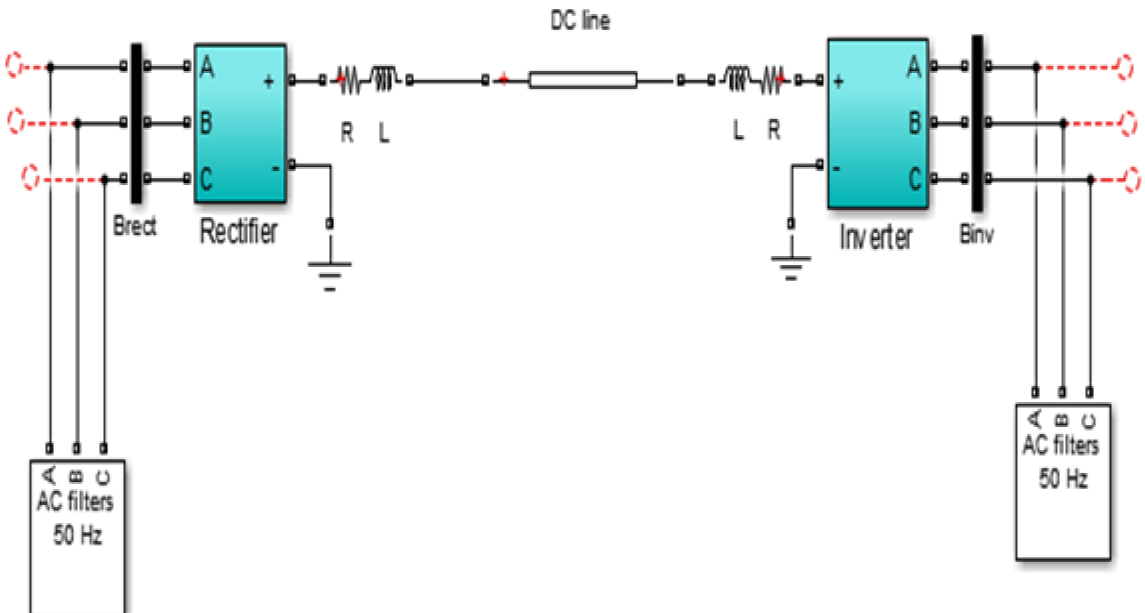

Fig. 3.2: Implemented Simulink Model of the

CCC-HVDC Control Strategy

Alireza (1997) showed that in comparison with Proportional Integral (P.I) controller ANN provided superior performance under different system conditions when used to control a simple rectifier connected to an active load. Since an HVDC link is basically made up of a rectifier, an inverter and a dc link; it is expected that ANN will offer more improved control ability when compared with P.I controllers. Studies by Gunnar (2013) confirmed this.
The reactive power demand of the rectifier has been found by Alireza (1997) to be increasing with converter firing angle, α, while the inverter reactive power demand also increases with the inverter extinction angle "γ".

$$Cos\emptyset = {}^{1}/_{2}\,[\cos\propto\ + \cos(\propto\ + \mu)] \qquad (3.4)$$

$$Cos\emptyset = {}^{1}/_{2}\,[\cos\gamma\ + \cos(\gamma\ + \mu)] \qquad (3.5)$$

Since increase in power factor ($Cos\emptyset$) implies reduction in reactive power demand, from equations 3.4 And 3.5, it is evident that to operate the system at a reasonable high-power factor ($Cos\ \emptyset$)and minimum reactive power demand, the rectifier firing angle, α and the inverter extinction angle "γ" has to be at their possible minimum values. This is the HVDC control strategy.

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Modeling the HVDC Neural Network Controllers

The neural network fitting app has the capacity to map between a data set of numeric inputs and outputs with very high degree of accuracy with proper training and adequate volume of data. For a set of input data characterizing state or states of a system and the corresponding set of output data; the neural network fitting app will learn the input-output pattern such that when presented another set of input data set for the same system, it is able to predict the output with a very high degree of accuracy. The degree of accuracy depends largely on the volume of training data and level of training. Higher volume of training data gives better accuracy.

In this project, voltage profiles of vulnerable buses were collected. This data set formed the input to the developed HVDC model. Adjustments in both the firing and extinction angles were made until the system achieved stability and acceptable voltage profiles. The corresponding measured DC voltage (V_d), measured DC current (I_d) and reference DC current (I_{ref}) that gave the stable results were recorded for both the rectifier and the inverter. The corresponding triggering pulses for the rectifier and the inverter were also recorded. The network's three phase voltages (V_{ar},V_{br},V_{cr}), measured DC voltage (V_{dr}), measured DC current (I_{dr}), and the reference DC current (I_{refr}), formed the input of the neural network while the triggering pulses formed the output or target of the neural network. The rectifier Artificial neural network (ANN) controller therefore has six inputs including V_{ar}, V_{br}, V_{cr}, V_{dr}, I_{dr} and I_{refr}. Similarly, the inverter ANN controller has six inputs including: V_{ai}, V_{bi}, V_{ci}, I_{di}, V_{di} and I_{refi}. A connection of the ANN rectifier controller (with its six inputs) and the rectifier simulink model is shown in fig. 3.3. Also, a connection of the ANN inverter controller (with its six inputs) and the inverter simulink model is shown in fig.3.4. Both the rectifier and the inverter are made of twin bridges. Each bridge is triggered by six pulses. As a result, the rectifier has 12 outputs representing 12 pulses for the two bridges. The inverter also has 12 outputs. The architecture of the Simulink model of the created rectifier ANN controller (same as the inverter ANN controller architecture) is shown in figure 3.5.

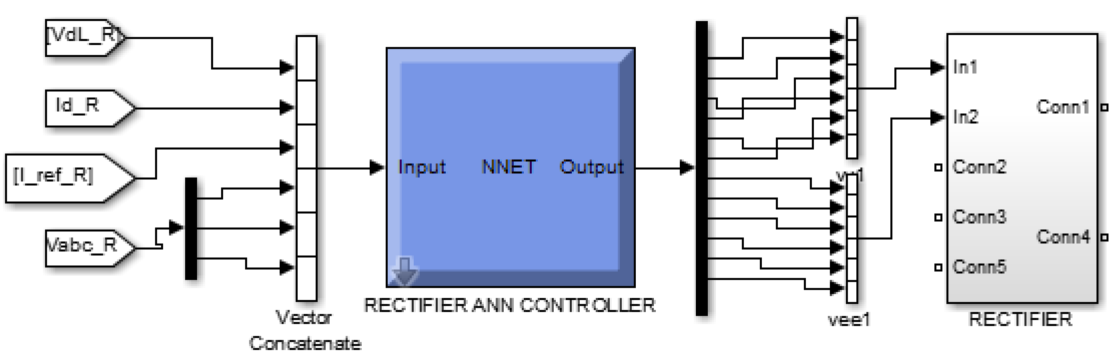

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Fig. 3.3: Connection of ANN rectifier controller with the Rectifier.

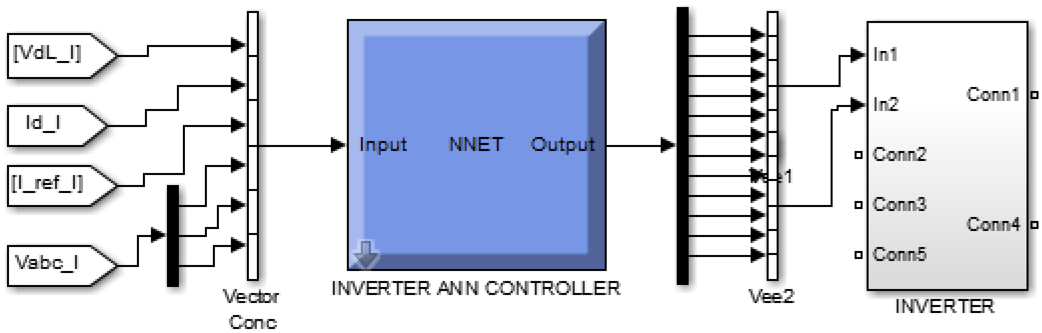

Fig. 3.4: Connection of ANN inverter controller with the inverter

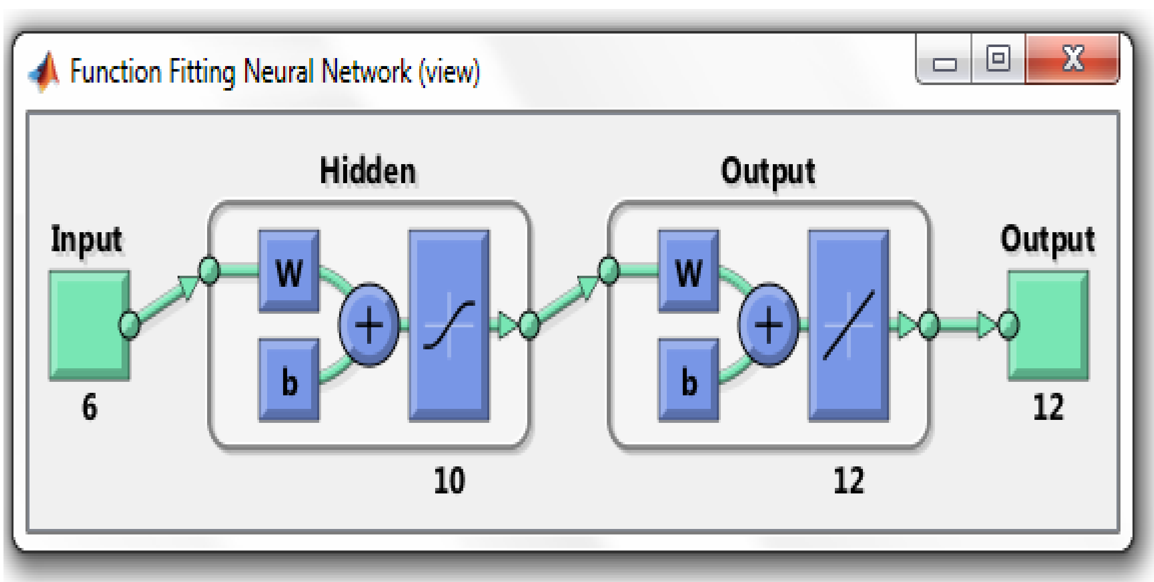

Fig.3.5: Simulink model of the Created Rectifier ANN Network

To create the above network, the data set for the input and target were first loaded through the Matlab workspace. The network was then trained with the data set. A total of five thousand rows of data for both input and target were loaded for the training. 15% of the data was used for testing; and another 15% was used for validation while the remaining 70% was used for training.

Fig 3.6 showed that the mean square errors in the training, validation and testing progressively reduced to its best value of 0.024198 in 43 epochs. This result implies that the overall mapping between the input and output in training, validation and testing were less than 6%. This shows an accuracy of about 94.4%.

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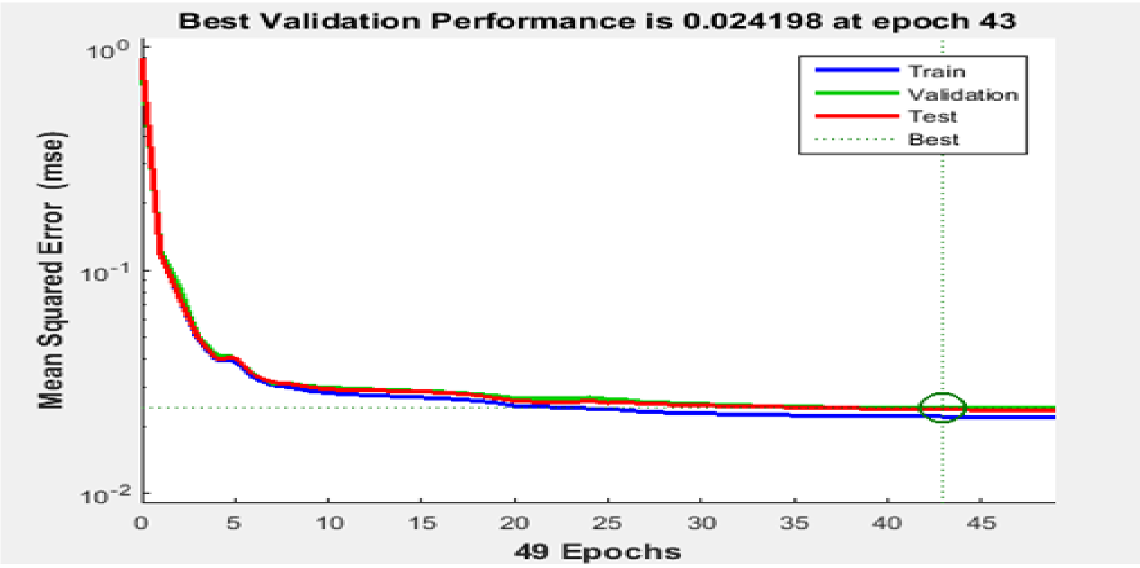

Nigerian 330kV 28-Bus Network

The Nigerian 330kV 28-bus network modeled in PSAT/Simulink MATLAB is presented in fig 3.7. The developed model was loaded in PSAT as the data file. The continuation power flow was then run in PSAT. The PSAT/Simulink blocks used to build the Nigerian 330kv network include: the real power and voltage specified (PV) generator block, slack bus, constant real and reactive power specified (PQ) load, transmission line and bus bar block. After building the network, each block was then configured with the corresponding parameter value and ratings.

A load flow study is critical in identifying the weak buses in a network. The standard is to consider all buses with voltage level lower than 0.95pu to be vulnerable. The optimum bus voltage for stable operation is 1.0pu. For a network with many vulnerable buses, it is usual to build compensation around the most vulnerable buses. We observe that the buses Jos, Makurdi, Kaduna, Gombe, and Yola are the most vulnerable buses. It is important to identify the weakest bus in the network. This is because the evaluation of the proposed voltage stability enhancement technique will be done using the weakest bus. Yola bus is selected as the weakest bus for recording the lowest voltage profile during the continuation power flow (see fig 3.8).

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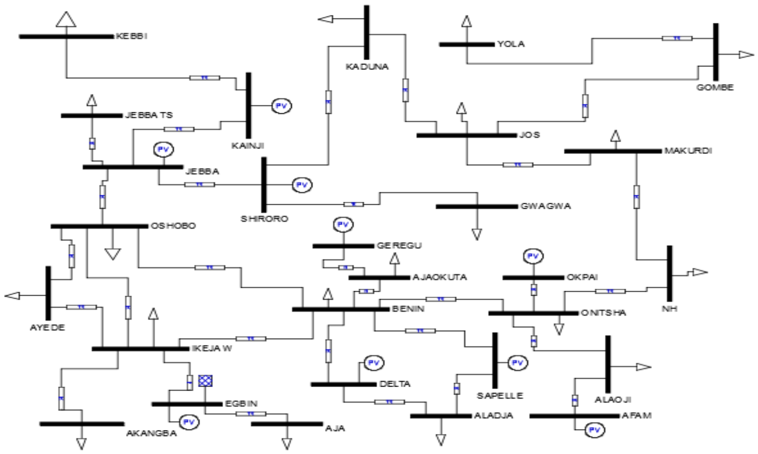

Fig 3.7: Nigerian 330kV 28-bus Network Simulink Model

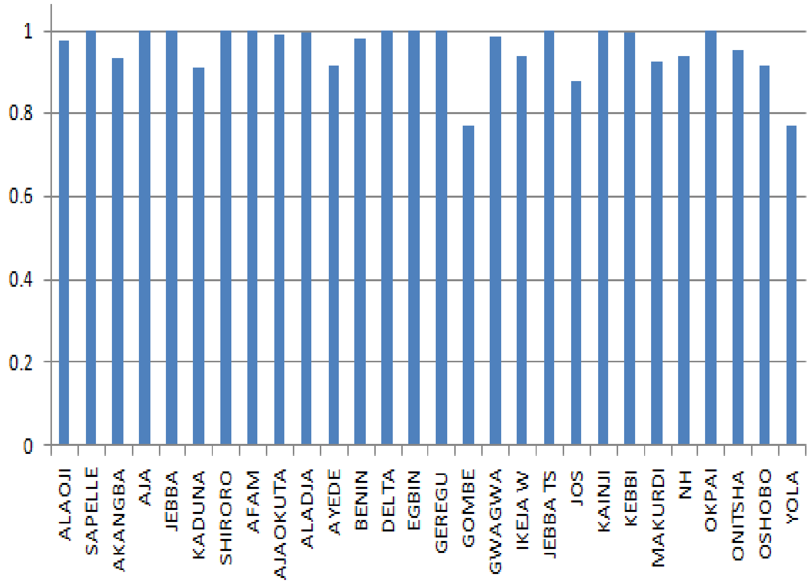

Fig 3.8: Bar chart showing Voltage magnitude profile

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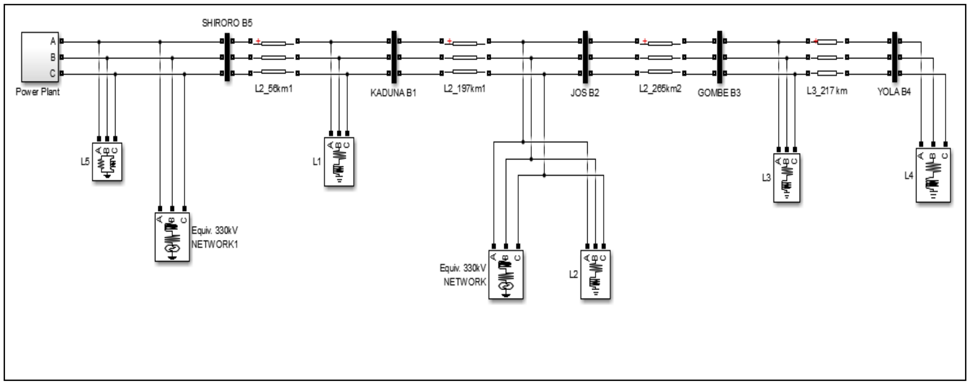

Fig 3.9: Three phase equivalent Simulink model of the Nigerian 330kV network showing Yola, Gombe, Jos and Kaduna buses

The single line simulink model of the 28-bus 330kV Nigerian Network was simple and convenient in running load flow and continuation power flow on the network in PSAT environment. However, considering that the simulink models of the HVDC and UPFC were developed in three phase, these compensating devices cannot be connected to the single line model for simulation, hence the need for developing the three-phase equivalent simulink model of the test network. Developed three phase equivalent Simulink model of the Nigerian 330kV network is shown in fig. 3.9. Using the reduced equivalent model makes the analysis and evaluation of the impact of the compensating devices simpler. To test the efficacy of CCC-HVDC in limiting the impact of three phase faults in a transmission network; the implemented CCC-HVDC model is connected between the weakest bus (Yola) and the bus closest to the point of fault. A three-phase fault block was used to introduce a three-phase fault contingency in the network between the 20th and 40th seconds of the 50 minutes simulation. The connection of the of the implemented CCC-HVDC to the developed three phase equivalent Simulink model of the Nigeria 330kV network is shown in fig. 3.10. The waveform of the voltage response of simulation before and after the connection of CCC-HVDC to the network is displayed in figures 3.11 and 3.12.

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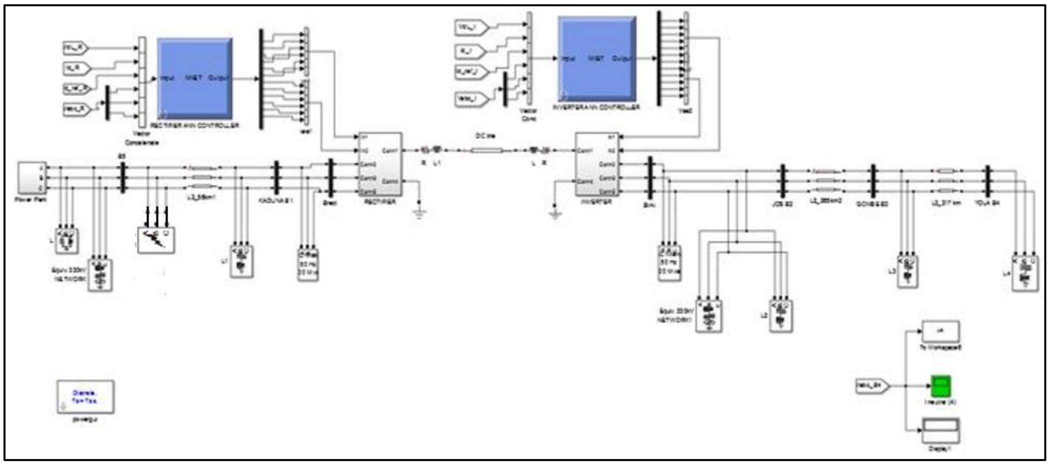

Fig. 3.10 Equivalent network model showing Yola, Gombe, Jos and Kaduna buses with three phase fault with only CCC-HVDC connected.

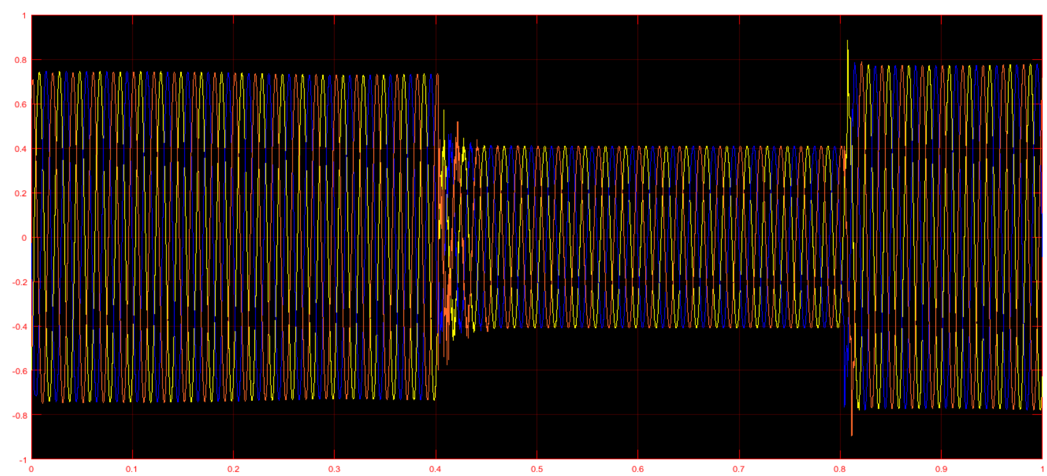

Fig. 3.11: Voltage response for Yola bus with a three-phase fault with no device connected

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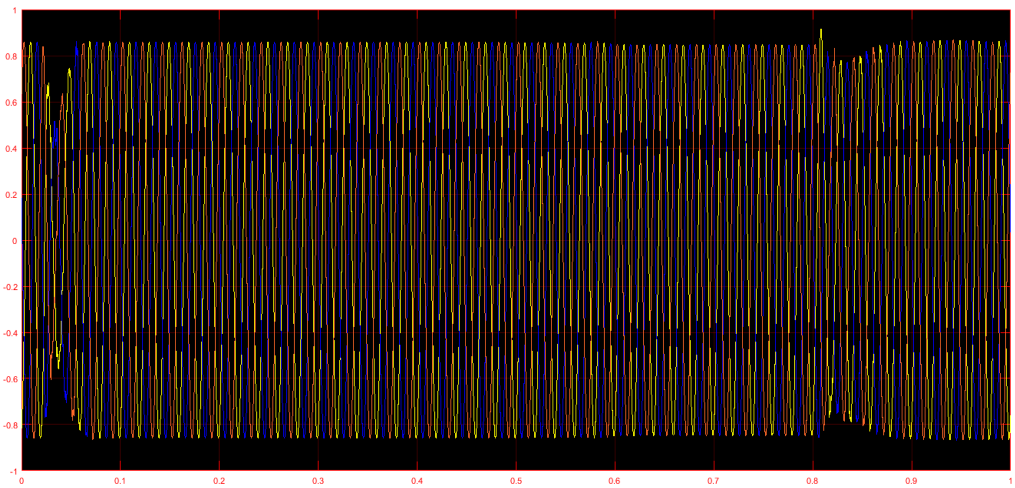

Fig. 3.12: Voltage response for Yola bus with a three-phase fault and with only CCC-HVDC connected.

4 DISCUSSIONS ON RESULTS.

The idea behind this research is to determine whether CCC-HVDC working in the network can improve the network's voltage stability (during contingency of three phase fault) when driven by their ANN controllers.

Figure 3.10 shows the reduced equivalent Nigeria 330kV transmission network with a fault block connected to Kaduna bus with CCC-HVDC not connected. The fault block is configured to introduce a three-phase fault in the line between the 20th and the 40th seconds of the 50 seconds of simulation.

With the connection of CCC-HVDC to the network in the absence of any fault, the weakest bus (Yola) voltage profile was enhanced from 0.8pu to 0.85pu. This represents a 6.25 percent improvement on voltage profile of the weakest bus during normal operation conditions. The waveform of figure 3.11 shows that for the period the three-phase fault lasted (20th to 40th minute), the voltage profile of Yola bus dropped from 0.8pu to 0.4pu on the average. On connecting CCC-HVDC to the network in the presence of three phase fault (See figure 3.12) between the 20th and 40th seconds, the CCC-HVDC connected to the network was able to improve the voltage of the weakest bus from 0.41pu to 0.8pu. This represents a 97 percent improvement on the network's voltage profile during contingency of three phase fault on the network. On removal of the fault at the 40th second, CCC-HVDC restored the voltage profile to 0.85pu till the end of the simulation. This shows the capacity of CCC-HVDC to minimize to the lowest level the tendency of three phase fault to crash bus voltage profile. Table 4.1 and figure 4.1 compares the peak voltage profiles of Yola bus during contingency of three phase fault with and without CCC-HVDC connected to the network.

Table 4.1: Phase Voltage Profiles with and without the CCC-HVDC Connected and with Contingency of three phase fault Imposed on the Network at Yola Bus

SIMULATION TIME (secs)	BASE (NO DEVICE)	CCC-HVDC
1	0.742	0.8575
2	0.7406	0.7955
3	0.7408	0.5289
4	0.7413	0.8508
5	0.7418	0.855
6	0.7421	0.857
7	0.7421	0.8582
8	0.7416	0.857
9	0.7406	0.8567
10	0.7391	0.8573
11	0.7371	0.8573
12	0.7347	0.8573
13	0.7323	0.8574
14	0.7305	0.8574
15	0.7296	0.8574
16	0.7295	0.8574
17	0.7299	0.8574
18	0.7306	0.8574
19	0.7317	0.8574
20	0.7332	0.8573
21	0.3947	0.8573
22	0.4076	0.8573
23	0.412	0.8573
24	0.4044	0.8573
25	0.4037	0.857
26	0.4039	0.8565
27	0.4039	0.8556
28	0.4039	0.8551
29	0.4039	0.85531
30	0.4039	0.8522
31	0.4039	0.8465
32	0.4039	0.8468

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33	0.4039	0.8475
34	0.4039	0.8468
35	0.4039	0.8469
36	0.4039	0.8471
37	0.4039	0.847
38	0.4039	0.87
39	0.4039	0.847
40	0.4039	0.847
41	0.7516	0.847
42	0.7613	0.7949
43	0.7611	0.7594
44	0.7598	0.802
45	0.7589	0.8544
46	0.7593	0.8552
47	0.7613	0.8601
48	0.7645	0.8639
49	0.7686	0.8527
50	0.7727	0.8617

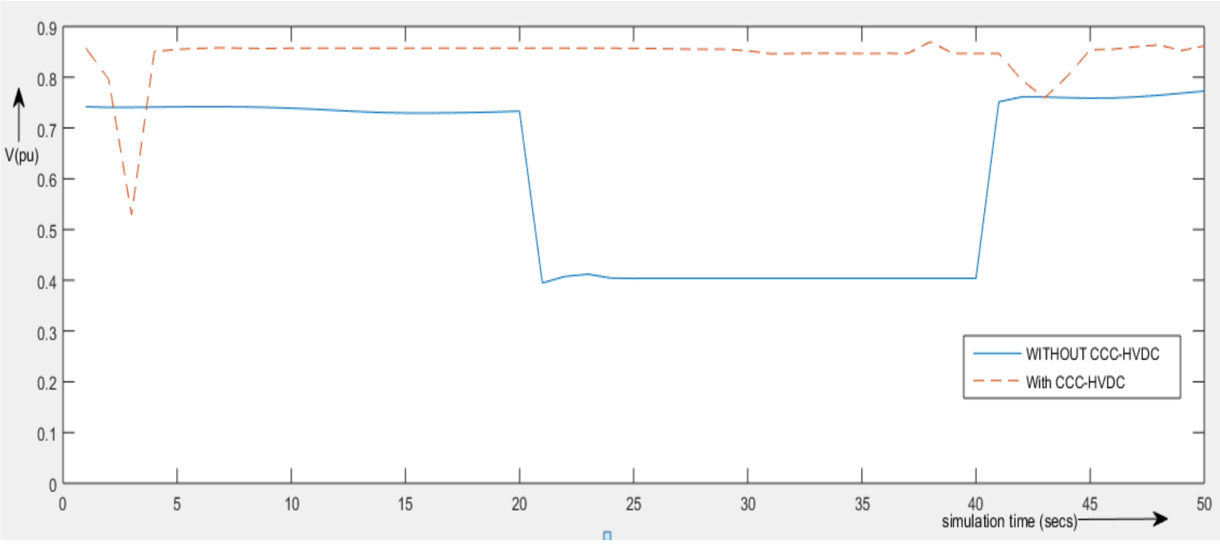

Fig 4.1: A graph of peak phase voltage profiles (with and without CCC-HVDC) against simulation time at Yola Bus with three phase fault contingencies imposed on the network.

5 CONCLUSION

From the results and discussions, it can also be concluded that the CCC-HVDC controlled by neural network was effective in minimizing the impact of three phase faults when connected between the point of fault and bus of interest (weakest bus). ANN controlled CCC-HVDC was able to achieve this by exploiting its capacity to simultaneously control active and reactive power in a network thereby boosting the voltage profile even above its normal operating point when a contingency of three phase fault was introduced. It is recommended that ANN controlled CCC-HVDC be installed in power networks that are prone to three phase fault so as to minimize the impacts of the fault on system performance.

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