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Mitigation of commutation faults in HVDC system

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Abstract: *To transfer large amount of direct current power having high amplitude voltage over long distance, high voltage direct current (HVDC) transmission system is used. This system was introduced 60 year ago and now it is widely used all over the world. Some examples of HVDC systems are following; Voltage-Sourced-Converter (VSC), current commutated converter (CCC) and line commutated converter (LCC) dependent HVDC techniques.VSC method used for multi-terminal Direct Current grid, but line commutated direct current method performs better as compare to VSC in broad distance large amount of power transmission due to its efficiency. When voltage is reduced to 10% to 15% in LCC HVDC system the commutation failure occurs. The LCC HVDC system is having better performance in comparison to others so the analysis is done on this system to mitigate the commutation failure which is very frequent event that occurs in the this system. The DC fault is having less effect on commutation as compare to the AC single and three phase fault. During DC fault only the distortion is occurring which is minimized with the help of DC filter. During AC faults the commutation failure occurs which is minimized using IGBT capacitor circuit. The comparison of systems with and without faults is done and it is concluded that the AC faults are the main reason of commutation failure and mitigation is done using IGBT capacitor circuit.*
Keywords: *HVDC, LCC, VSC, Single phase AC faults, Three Phase AC Faults .*

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I. Introduction

HVDC system is used to transmit high voltage bulk power over long distance [1]. This system was introduced 60 year ago and now it is widely used all over the world. In power transmission field there are various types of High voltage direct current systems [2]. Some examples are following: Voltage-Sourced-Converter (VSC), CCC and line commutated converter (LCC) dependent HVDC techniques [3].

Faults in HVDC system

If a short circuit takes place then the HVDC system of transmission react in different way whereas the AC transmission system reacts in different way [4].The rectifier consists of controller that manages to control the current at pre fault value. If inverter controller of current is also working, the current value at the inverter is preserved and it changes by the rectifier current with the particular current margin [5]. To rectify fault it is required to make the value of current exactly zero and adequate time must be provided to arc path so that it should not contain any ion. In this time duration the energy remained in capacitor and inductor of DC circuit must be discharged by using converters as these inductors and capacitors [6] offers it remained energy to AC circuit. Generally, three attempts are made to start again mechanically with up surging dead time. The enduring error is implied when it does not restart even after three attempts [7] and needs link shutdown until error is recognized and clear. The usual removal of ions and starting the DC link again is equivalent to error clearance and it automatically closes the AC transmission cables [8]. Major dissimilarity between these the two situation is that, though in AC lines breakers are used, in DC system the clearing of fault and starting of system again is performed by using protective relays [9].

1. Direct current cable faults
2. Alternating current network faults
3. Converter station faults

II. Problem Formulation

A commutation fault is a disadvantageous dynamic event that occurs when the converter valve, which should be turned off, continues to operate. Thus, the current is not transmitted to the next valve in the firing sequence. The occurrence causes temporary interruption of transmission power, stressing the converter device. In addition, the direct current may increase drastically and lead to additional heating of the conversion valve. As a result, the lifetime is shortened; most of the commutation faults are caused through voltage disturbance due to AC system failure and cannot be completely avoided. In order to prevent this failure the existing techniques used Thyristors and Vsc control individually. But the heating effect of Vsccould not reduce this failure completely. Moreover, super capacitors were used in the existing systems for balancing of voltage but this specific designed circuit enhanced the complexity of the model. As the complexity increases, so the model becomes expensive. Considering this fact, there is a need of proposing a new technique which should be less costly and complex.

III.Present Work

A new method has proposed where the capacitor and inductor are used rather than a specific circuit designed that reduces the complexity as well as cost of the system. In the traditional system, only single phase analysis was performed whereas in the proposed model, more than one phase analysis is also performed. In the proposed model DC fault is introduced for the simulation purpose. The series placement of the capacitors has placed in order to increase the stability of the system and reduce the effect of commutation failure. Fig. 1 represents the MATLAL Simulink model of HVDC system without any fault.

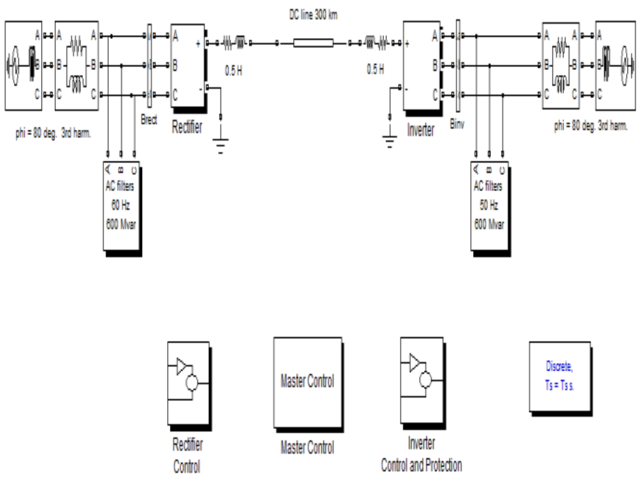

Figure 1: HVDC model without any fault

This model is the simulink model of HVDC system without any fault. The working of this model is similar as that of HVDC system. The commutation is smoother and proper in this model between thyristors switches. In fig. 2 the DC fault is introduce in the DC line.

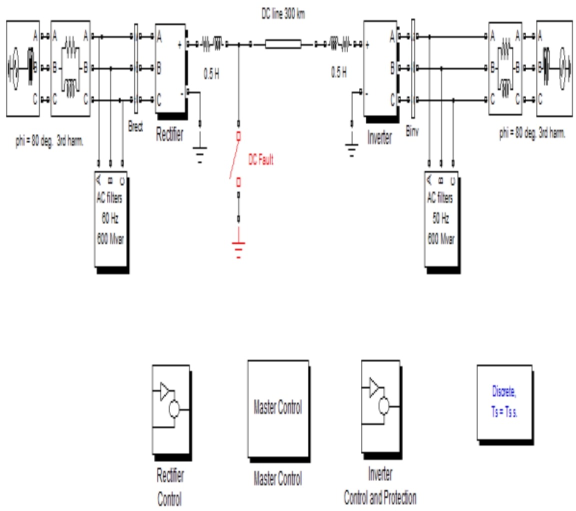

Figure 2: HVDC model for DC fault analysis

By introducing DC faults it is observed that commutation failure does not occur during this fault but the distorted signals appear in the valves during commutation. The distortion can be minimized by inserted dc filters or dc breakers. To minimize the distortion introduced by DC fault, DC filter comprises of inductor and capacitor is introduced.

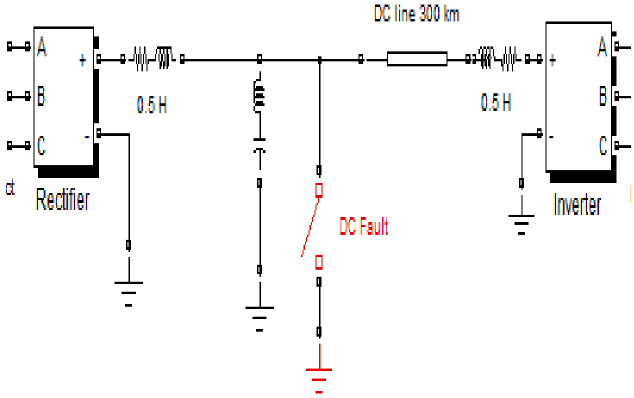

Figure 3: Placement of DC filter analysis

Fig. 3 represents the placement of DC filter to minimize the effect of DC fault. By introducing dc filters the distortion can be decreased by adjusting the values of components of filter such as capacitor and inductor the distortion among valve current can be minimized.

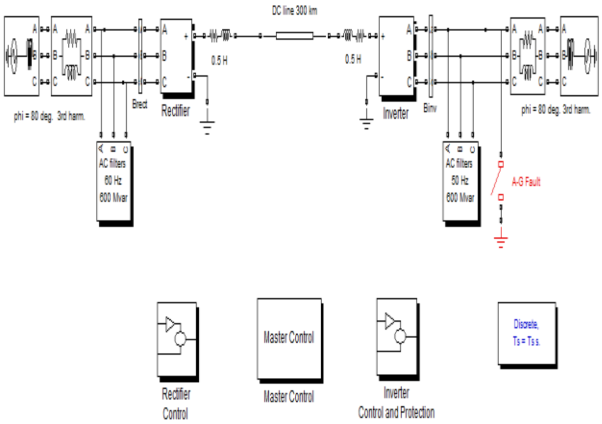

Figure 4: HVDC model for single phase AC fault analysis

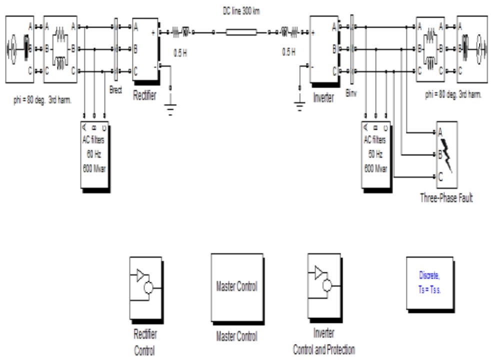

Figure 5: HVDC model for three phase AC fault analysis

AC faults are more prone for commutation failure and it mostly effect on inverter side. Because of this the switching among thyristors gets effected and leads to serious malfunction. So prevention of commutation failure are necessary. In fig. 4 and fig. 5 represent the placement of AC faults in inverter side.

In fig.6 we can see the effect of AC fault. During fault time the sort circuit happened between the valve 1 and 3. This can affect the current and power of the inverter side. To mitigate this effect there is need to modify the present system to overcome the effect of fault. So the special capacitor arrangement is designed to place between valves and three phase transformer.

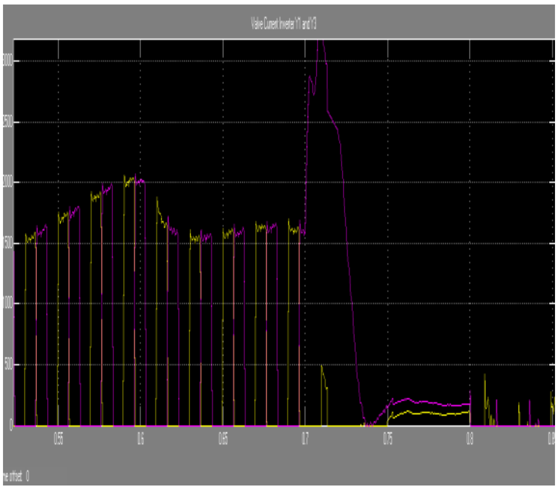

Figure 6: AC fault effect on valve current

This capacitor arrangement is consist of IGBT switches and these give voltage to the thyristors during fault to overcome the effect of commutation failure. Fig. 7 represents the placement of super capacitor in between converter transformer and converter.

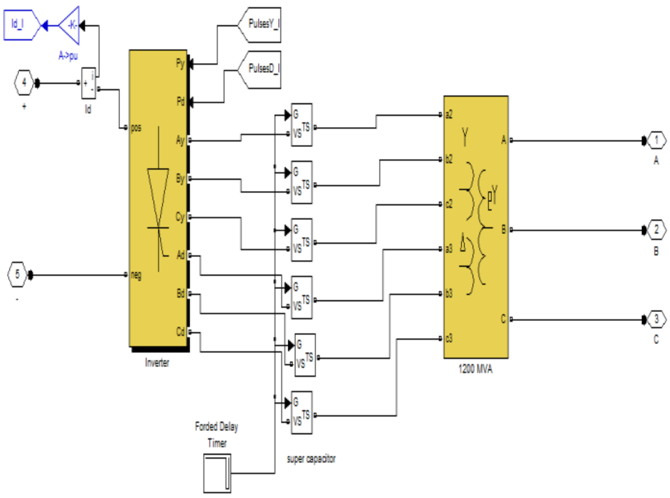

Figure 7: Insertion of super capacitor

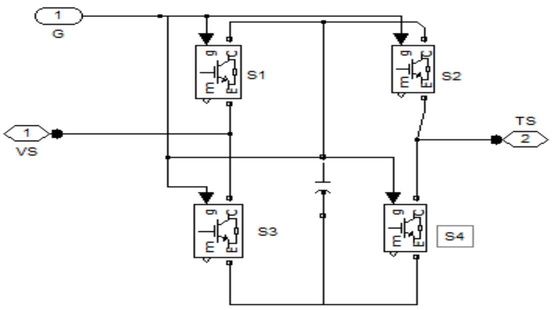

Figure 8: IGBT switches arrangement

Here IGBT switches are used as super capacitor because it also works as capacitors. The voltage loss is recovered with the help of this circuit. WhenS1 S4- ON and S3 S4- OFF the positive voltage appears and when S2 S4- ON, S3 S4- OFF voltage appears and when SI S3- ON or S2 S4- ON no voltage appears. These voltages handle the voltage dips during commutation failure and can able to overcome the commutation failure. Fig. 8 represents the super capacitor arrangement which is used in proposed model to mitigate the effect of commutation failure.

IV. Results

The proposed model is aim to stabilize the model and perform analysis over different faults. The experimental analysis have performed using different faults such as AC and DC fault in order to study the effect of them over the system. Moreover, the motive of this analysis is to understand the fluctuations performed after introducing these faults in the system. The results may vary in the traditional and proposed system and then their performance will conclude the efficiency of the proposed technique with respect to the traditional technique.

The fig. 9 below shows the HVDC model without introducing any AC and DC fault in the system. Thus, the number of fluctuations is less and the system is performing efficiently.

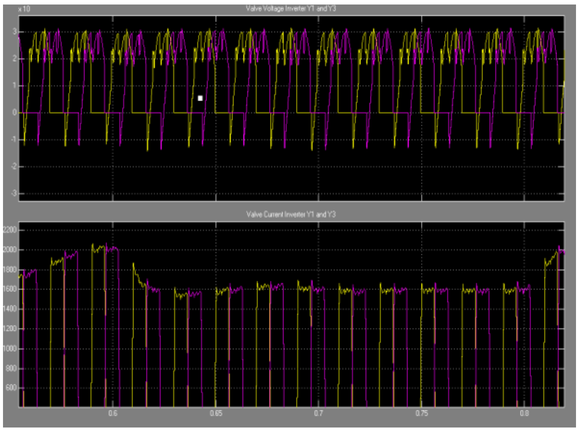

Figure 9: HVDC model without any fault in the system (valves current and voltage)

DC fault analysis

The fig. 10 below shows the analysis the effect of voltage after introducing the DC fault. The output has acquired from valves current and voltage as well as of inverter side. The introduction of the DC fault occurs and the variations come in the system after 0.4.

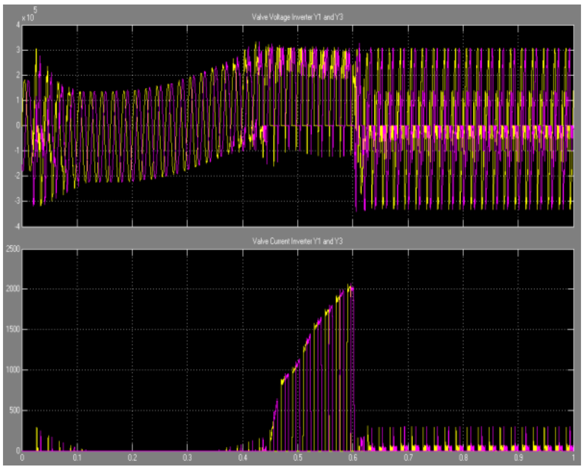

Figure 10: HVDC model with DC fault (valves current and voltage)

With their introduction, the number of variations has done. Consequently, the fluctuations happen in the system. But with the DC fault, the number of variations is lesser in comparison with the AC fault where the number of variations is quite high.

The fig. 11 and fig. 12 below shows the HVDC system with inverter current, voltage and valve current where the DC fault is introduced at 0.7 to 0.8. The voltage is continuously fluctuating from initial to the end and current is increasing and then goes down as the DC fault introduced and distortion among valves is high.

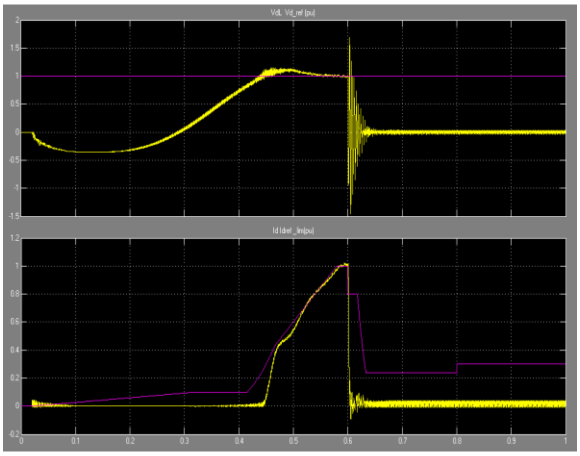

Figure 11: HVDC model with DC fault (Inverter current and voltage)

Refine HVDC model DC fault analysis

The above results of DC fault analysis show the voltage dips because of which fluctuation among the valve current 1 and 3 occur but commutation failure does not happened. To overcome these fluctuations DC filter is introduce and it is observed that DC filter reduce the distortion. From the result, it has been concluded that after applying the DC filter the variations in the signal has reduced and the system becomes more stable. The output of valves current and voltage and inverter has shown the fluctuations in the system. Fig. 13 shows the refine valve current after introducing DC filters.

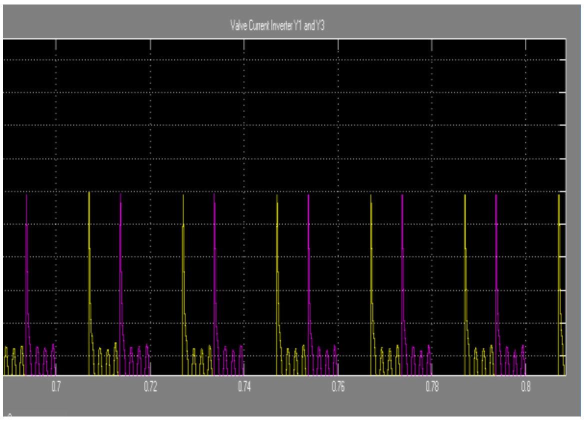

Figure 12: HVDC DC fault model (commutation among valve 1 and 3)

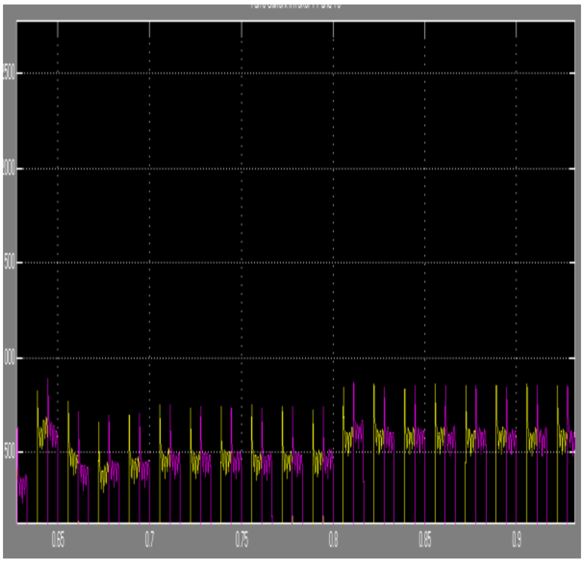

Figure 13: Refine HVDC DC fault model (commutation among valve 1 and 3)

Single Phase AC fault

The below fig. 14 shows the introduction of AC fault which occurs at 0.7 to 0.8 that reflects the number of variations in the system. AC faults are the main cause of voltage dips which further increase the risk of commutation failure. The fig. 14 illustrate the large commutation distortion in the valve currents which indicate the short circuit of the valve branches.

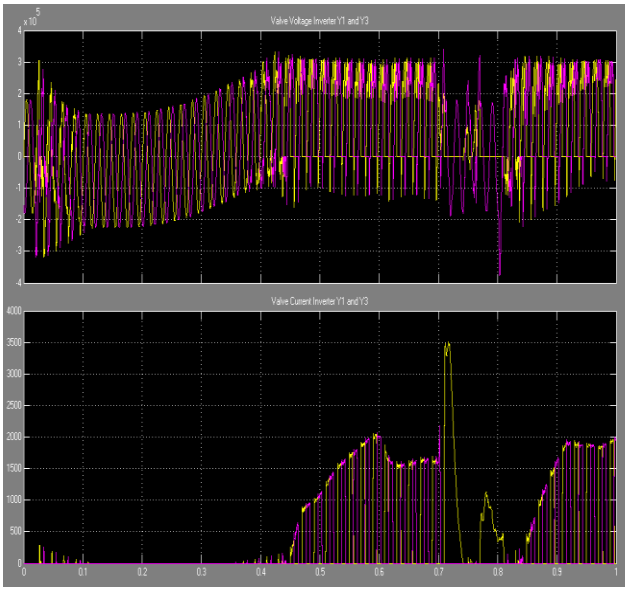

Figure 14: HVDC model with single Phase AC fault (valves current and voltage)

In fig. 15 the voltage immediately reduces and current increases during the fault which further effect the commutation of valves.

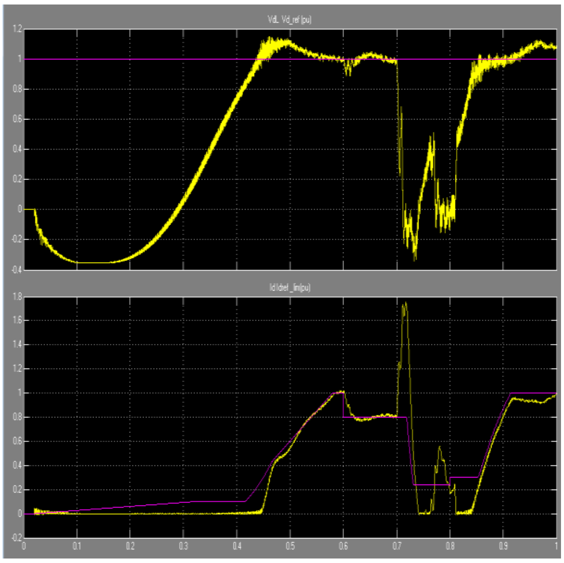

Figure 15: HVDC model with single phase AC fault (Inverter)

Refine single phase fault HVDC model

To overcome the effect of single phase AC fault the IGBT capacitor circuit is designed and place in between the valves and transformer. This circuit gives the negative or positive voltage to the thyristors during voltage dips to start the switching among valves. By introducing this capacitor circuit it is observed that the valves which were short circuited during fault regain its switching characteristics and start working properly. But the distortion is still there which can be minimized by changing the value to capacitors of that circuit. Fig. 16 and fig. 17 shows the valve current and voltage of the valve 1 and 3.

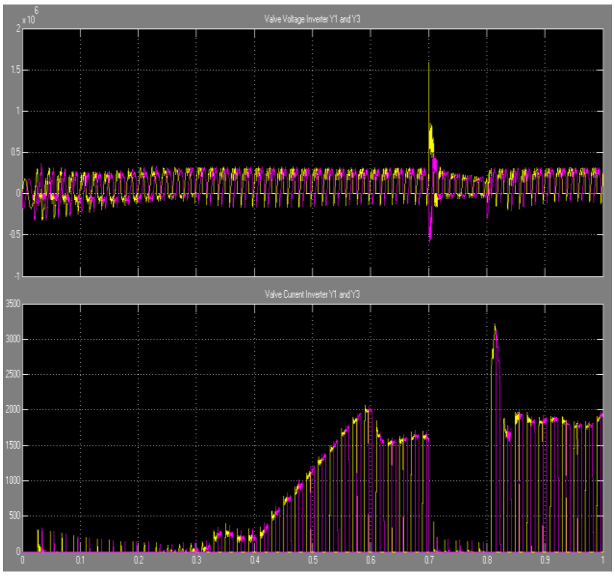

Figure 16: HVDC refine single phase AC model with capacitor circuit (valves voltage and current)

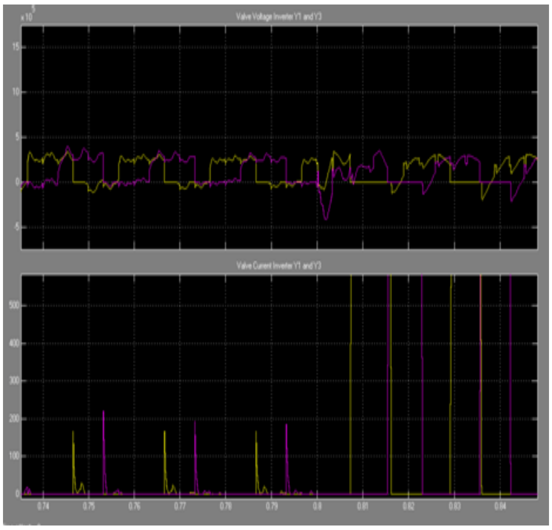

Figure 17: HVDC refine single phase AC model with capacitor circuit (valves current)

Three Phase AC fault analysis

The fig. 18 below shows the three phase AC fault analysis which has reduced at 0.7 to 0.8. The number of fluctuations has occurred at this point in the system. The commutation failure happened in the valve currents at the rectifier side

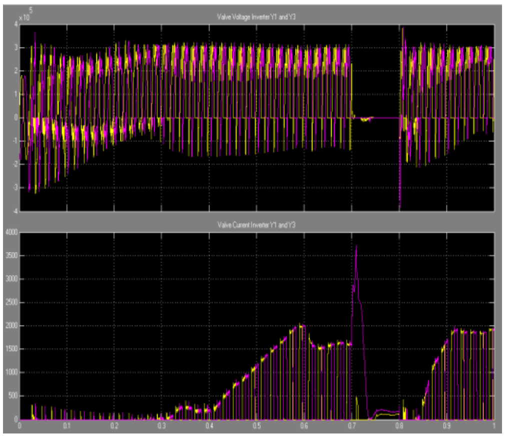

Figure 18: HVDC model with Three Phase AC fault analysis (valves current and voltage)

In this proposed model, 3-phase AC fault has applied to the individual. The resultant shows that the number of fluctuations is more in comparison with single phase AC fault and DC fault.

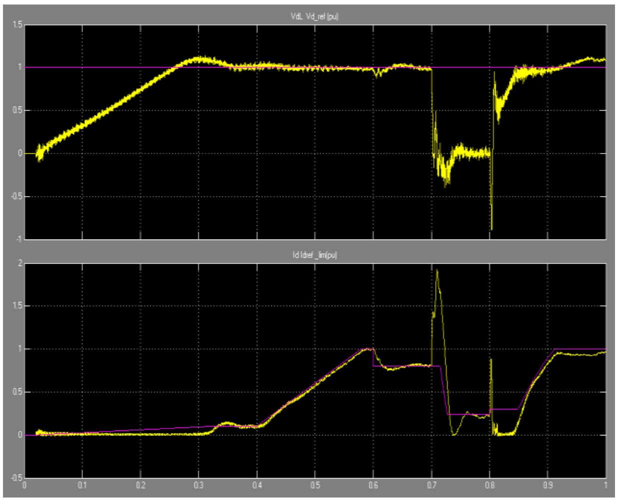

Figure 19: HVDC model with Three Phase AC fault analysis (Inverter)

Refine HVDC AC FAULTS

In above fig. 18 and fig.19 the large distortion is observed in the HVDC system and this distortion is the main reason of the commutation failure. The commutation failure is observed in the fig. 18 and that is mitigating in the proposed model of HVDC.

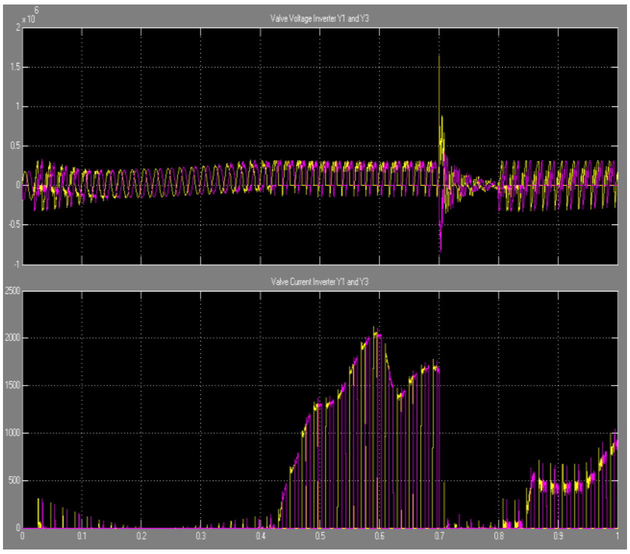

Figure 20: Refine HVDC model with Three Phase AC fault analysis (Inverter)

In fig. 20 shows refine output of valves. The commutation is achieved in proposed model by using the super capacitor circuit. But there is some distortion in the output which can be minimized by adjusting the value of super capacitor circuit.

V. Conclusion

This study has analyzed the effect of Faults over the HVDC system. Initially different faults such as DC fault, single phase AC fault and three phases AC fault has introduced in the system. From the simulation analysis, the numbers of fluctuations are analyzed over different faults. Among the different faults, it has shown that a system with DC fault have high number of fluctuations in comparison with AC faults. For the experimental analysis, DC and AC fault has applied at 0.7 to 0.8and with the application of these faults, the fluctuations happen. In the existing model, the commutation failure is an issue where the voltage goes down and current increases. By the analysis of the proposed model, the variations can be reduced at some extent so as the commutation failure. Furthermore, DC filter has introduced in the system to overcome the problem of distortions in the system. It has been clearly shows that the application of DC fault reduces the distortion with more stability.

The model has been analyzed over different faults; filter has introduced to remove the effect of distortion. Moreover, the capacitor circuit is also presented for the deduction of commutation failure in the HVDC model. As in the present work, the capacitor circuit has used to inject the power to the system so in future this process can be done by using Artificial intelligence or with the help of fuzzy interface system. Consequently, the fuzzy based algorithm can be used to balance the power in the system which has reduced due to the commutation failure.

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