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RESEARCH ARTICLE

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STABILITY AND POWER FACTOR IMPROVEMENT OF WEAK HYBRID HVDC SYSTEM

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ABSTRACT

HVDC systems are attractive alternatives to increase transmittable power. Hybrid HVDC systems are being suggested for wind power migration application. The Power factor and Dynamic stability of HVDC system which plays a vital role for preserving the system stability and also it improves the system response very effectively. In HVDC link, the Inverter side has been subjected to numerous disturbances. Where the high-magnitude AC voltage oscillations, and rescue are the main practical manifestation of concern. Majority of these problems are caused in weak inverter AC system. This project recommends the extinction angle control for Hybrid HVDC systems and also investigates its fitness under various operating conditions. The projected control employs a control using Extinction angle (γ). A Hybrid HVDC system with Voltage Source Converter (VSC) at the rectifier and Capacitor Commutated Converter (CCC) at the inverter is adopted in this paper. The proposed control is dedicated to the receiving end converter operated in inverter mode. The performance of the proposed control has been examined under different operating conditions including post fault recovery. Also a fault mitigation technique is attempted for various faults. MATLAB software with Sim Power system toolbox has been used.

Keywords—Extinction Angle, Fault mitigation Technique, Hybrid HVDC systems

I. INTRODUCTION

HVDC technology is a proficient and flexible method for bulk power transmission over long distances [1]. Conventional HVDC transmission systems use Line Commutated Converters (LCC) for power conversion and the modern HVDC systems use IGBT based Voltage Source Converters(VSC), which enhance reactive power support in case of weak AC grids. LCC converters exhibit less switching losses and less harmful during mid-link to ground fault conditions. Thyristors being unidirectional, the LCC systems do not encounter reverse power contributions during mid-link to ground fault. However when the associated AC system is weak, there are frequent chances for commutation failure to occur. As an alternative, VSC based systems are increasingly used owing to their special features such as: (i) independent active and reactive power exchange (ii) minimal chances for commutation failure (iii) independent control at the terminal converter stations and (iv) less reactive power requirement. But VSC systems pose a major threat when being used at both the terminals of a HVDC transmission due to the presence of backward diode. The inverter contributes to the fault current on incidence of a midlink to ground fault increasing the fault current. In this context, Hybrid HVDC systems are gaining attraction as an alternative [2]. Hybrid HVDC systems are aimed at combining the advantages of both LCC and VSC based HVDC technologies compensating their drawbacks. Hybrid systems render the advantages such as: (i)LCC converter handles high power levels (ii)VSC converter overcomes the problem of reactive power support at the weak AC system (iii)LCC converter limits the current contribution from the inverter circuit to a DC link to ground fault (iv) and better co-ordination between rectifier and inverter ends is achieved.

In spite of the above mentioned advantages, Hybrid HVDC cannot reverse the power flow as LCC requires a change in polarity of DC voltage while VSC requires a reversal in the direction of DC current. This paper suggests replacing the LCC at the inverter end of the commonly used Hybrid HVDC system with a Capacitor Commutated Capacitor (CCC) unit, when the AC network is weak [3]. The Commutation Capacitor in the CCC inverter helps to improve the stability of the power flow interactions between the inverter circuit and the AC grid.

The proposed control is dedicated to the receiving end converter operated in inverter mode. The performance of the proposed control has been investigated under different operating conditions including post fault recovery. Also a fault modification technique is attempted for various faults. MATLAB software with Sim Power system toolbox has been used.

ii. Capacitor Commutated Converter

A Capacitor Commutated Converter (CCC) is a modified conventional Line Commutated HVDC converter with additional capacitors between the transformer and conducting valves to enhance smooth commutation, as shown in Fig. 1. This configuration gives better reactive power support comparatively and also improves the dynamic performance of the inverter when connected to weak AC systems. Capacitor in CCC configuration increases the commutation margin without any increase in the reactive power consumption of the converter station [3]. This development in commutation margin reduces the chances of commutation failure and hence CCC is dedicated to the inverter station, which is more prone to commutation failure equated to its rectifier counterpart.

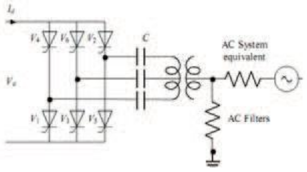


Fig.1. Configuration of CCC HVDC system

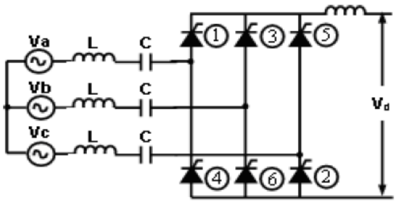


Fig.2. Capacitor Commutated Converter

iii. Extinction Angle Control

Electrical Angle is the time expressed in electrical angular measure from the end of current conduction to the next zero crossing of the idealized sinusoidal commutating voltage, γ depends on the angle of advance β and the angle of overlap □□and is determined by the relation:

$$\gamma = \beta - \mu$$

Extinction Angle Control takes place in the inverter end of the Hybrid HVDC systems in which Capacitor Commutated Converter is used. Delay angle (α) is directly controllable while the Extinction angle (γ) is not directly controllable. The Delay angle (α) could not increase above 180°-γ and could not be reduced below 5°.

Delay angle (α) is used to find the pulse delay of the input pulse given to the IGBT based Capacitor Commutated Converters.

Pulse delay (Δt) = α/ (360*F)

Where F= Frequency of the system

Extinction angle (γ) and Delay angle (α) is used to find the overlap angle (μ). This overlap angle is used to find the pulse width (% of period).

$\alpha = \pi-(\gamma+\mu)$

From the above expression **$\mu=\pi-(\alpha+\gamma)$**

Pulse width (% of period) = (μ/360)*100

By controlling the extinction angle we can control the pulse width of the pulse given to the IGBT. By the above process power factor and stability of the system can be improved.

IV. RESULTS AND DISCUSSIONS

i) Power Factor Improvement

A) Three Phase Inverter with Improvement in Power Factor (α=5, γ=0) c=10 µF

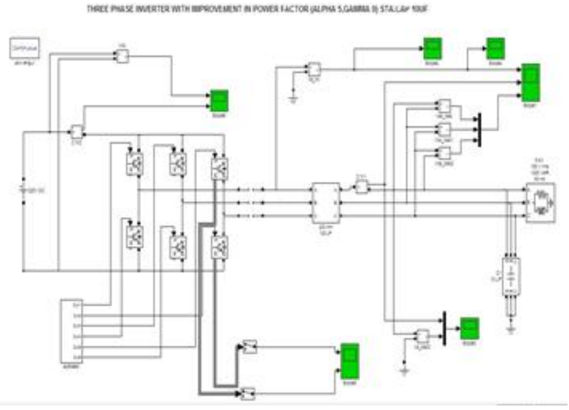
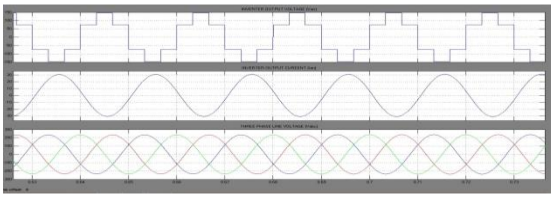


Fig 3: Three phase inverter with lag in power factor (α=5, γ=0) c=10 µF

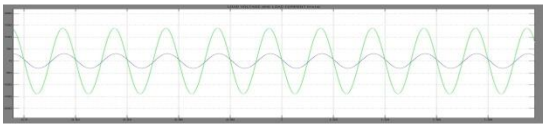
Table 1: Pulse width calculation for three phase inverter with lag in power factor (α=5, γ=0) c=10 µF

α=5°, P.W for γ=0°

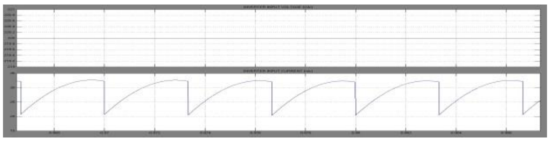
PULSE	α (Deg)		P.W	Total Period
	Deg	in mS	in %ge	in mS
T1	5	0.000277	48.615	0.02
T2	65	0.003611	48.615	0.02
T3	125	0.006944	48.615	0.02
T4	185	0.010277	48.615	0.02
T5	245	0.013611	48.615	0.02
T6	305	0.016944	48.615	0.02



a) Inverter o/p voltage, inverter o/p current, three phase line voltage



b) Load voltage and load current



c) Inverter input voltage and inverter input current

Fig 4: Simulation output of three phase inverter with lag in power factor (α=5, γ=0) c=10 µF

B) Three Phase Inverter with improvement in power Factor

(α=5, γ=15) c=100 µF

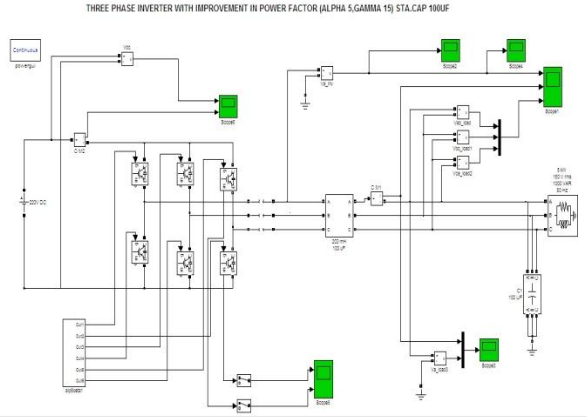


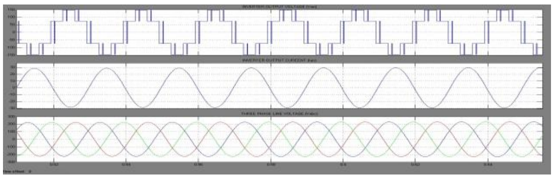
Fig 5: Three Phase Inverter with improvement in power Factor

(α=5, γ=15) c=100 µF

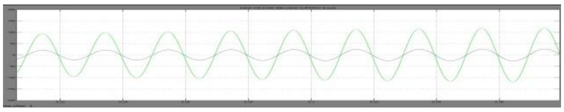
Table 2: Pulse width calculation for three phase inverter with improvement in power factor (α=5, γ=15) c=100 µF

α=5°, P.W for γ=15°

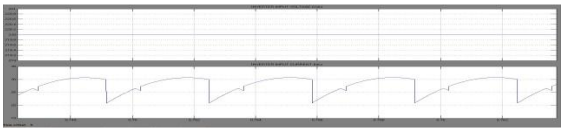
PULSE	α (Deg)		P.W	Total Period
	Deg	in mS	in %ge	in mS
T1	5	0.000277	44.448	0.02
T2	65	0.003611	44.448	0.02
T3	125	0.006944	44.448	0.02
T4	185	0.010277	44.448	0.02
T5	245	0.013611	44.448	0.02
T6	305	0.016944	44.448	0.02



a) Inverter output voltage, inverter output current and three phase line voltage



b) Load voltage and load current



c) Inverter input voltage and inverter input current

Fig 6: Simulation result of three phase inverter with improvement in power factor (α=5, γ=15)

ii) High Impedance Fault

A) Three phase inverter with high impedance fault

(α=5, γ=10)

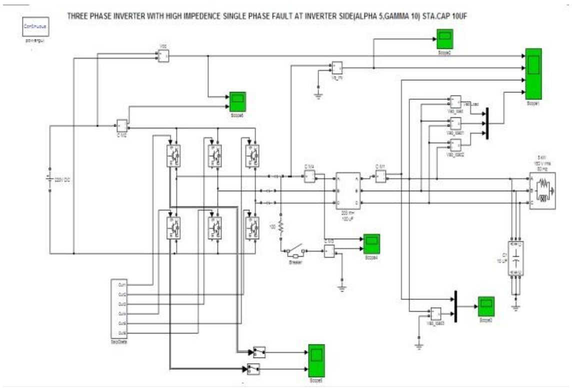
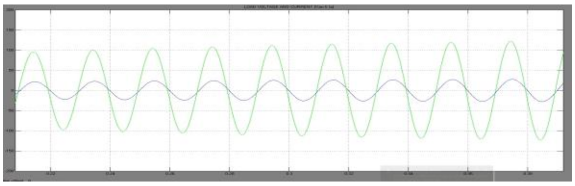


Fig 7: Three phase inverter with high impedance fault (α=5, γ=10)

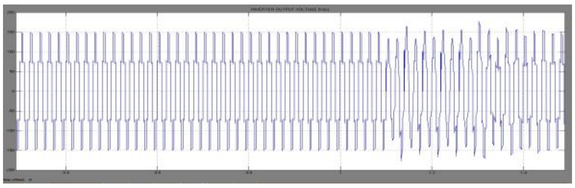
Table 3: PW calculation for high impedance fault (α=5, γ=10)

Table: α=5°, P.W for γ=10°

PULSE	α (Deg)		P.W	Total Period
	Deg	in mS	in %ge	in mS
T1	5	0.000277	45.835	0.02
T2	65	0.003611	45.835	0.02
T3	125	0.006944	45.835	0.02
T4	185	0.010277	45.835	0.02
T5	245	0.013611	45.835	0.02
T6	305	0.016944	45.835	0.02



a) Load voltage and Load Current(Va, Ia)



b) Inverter output voltage(Vdc)

Fig 8: Simulation output of high impedance fault (α=5, γ=10)

B) Three phase inverter with high impedance fault (α=5, γ=18)

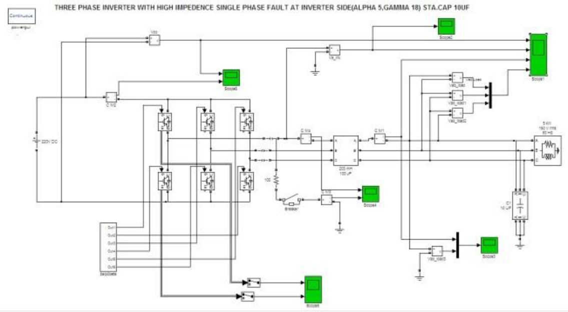
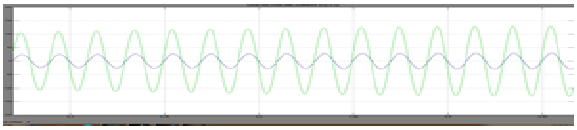


Fig 9: Three phase inverter with high impedance fault (α=5, γ=18)

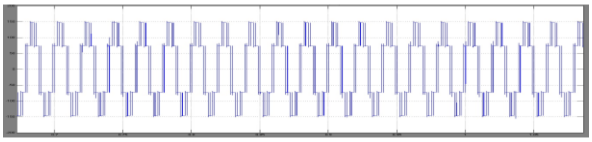
Table 4: PW calculation for high impedance fault (α=5, γ=18)

α=5°, P.W for γ=18°

PULSE	α (Deg)		P.W	Total Period
	Deg	in Ms	in %ge	in mS
T1	5	0.000277	43.615	0.02
T2	65	0.003611	43.615	0.02
T3	125	0.006944	43.615	0.02
T4	185	0.010277	43.615	0.02
T5	245	0.013611	43.615	0.02
T6	305	0.016944	43.615	0.02



a) Load voltage and Load Current(Va, Ia)



b) Inverter output voltage(Vdc)

Fig 10: Simulation output of high impedance fault (α=5, γ=18)

iii) Ground Fault

A) Three phase inverter with ground fault (α=5, γ=0)

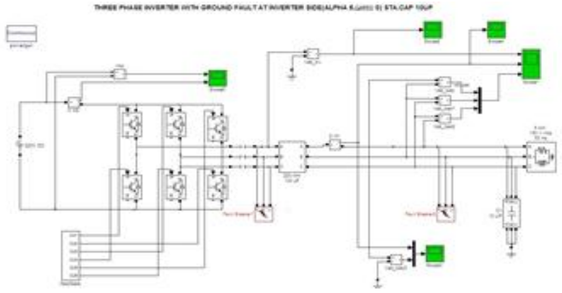
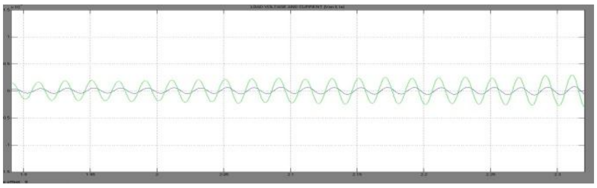


Fig 11: Three phase inverter with ground fault (α=5, γ=0)

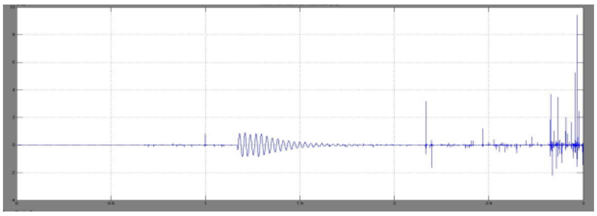
Table 5: PW calculation for ground fault (α=5, γ=0)

α=5°, P.W for γ=0°

PULSE	α (Deg)		P.W	Total Period
	Deg	in mS	in %ge	in mS
T1	5	0.000277	48.615	0.02
T2	65	0.003611	48.615	0.02
T3	125	0.006944	48.615	0.02
T4	185	0.010277	48.615	0.02
T5	245	0.013611	48.615	0.02
T6	305	0.016944	48.615	0.02



a) Load voltage and Load current



b) Inverter output voltage

Fig 12: Simulation output for ground fault (α=5, γ=0)

B) Three phase inverter with ground fault (α=5, γ=15)

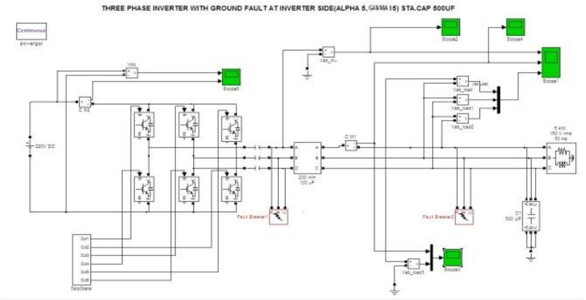
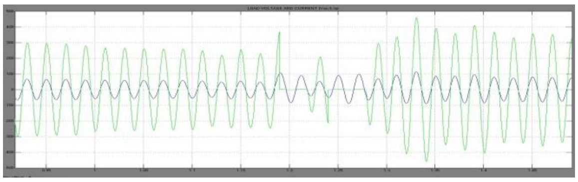


Fig 13: Three phase inverter with ground fault (α=5, γ=15)

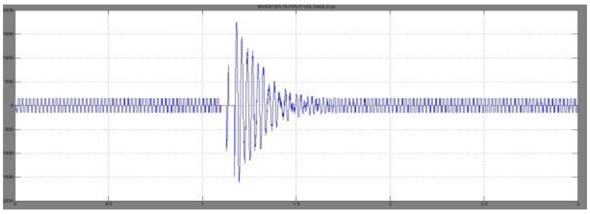
Table 6: PW calculation for ground fault (α=5, γ=15)

α=5°, P.W for γ=15°

PULSE	α (Deg)		P.W	Total Period
	Deg	in mS	in %ge	in mS
T1	5	0.000277	44.448	0.02
T2	65	0.003611	44.448	0.02
T3	125	0.006944	44.448	0.02
T4	185	0.010277	44.448	0.02
T5	245	0.013611	44.448	0.02
T6	305	0.016944	44.448	0.02



a) Load voltage and Load current



b) Inverter output voltage

Fig 14: Simulation output for ground fault (α=5, γ=15)

V. PERFORMANCE ANALYSIS OF SIMULATION RESULTS

i) Analysis of Power Factor Improvement: From figure 4 (b) the lagging in the current to voltage for the normal firing angle. Where as in figure 5 (b) it is evident that the power factor is improved with the new inverter control with control in extinction angle with addition of static capacitor.

ii) Analysis of High Impedance Fault: Figure 8 (b) shows the system response for high impedance single phase fault duration from 1.1 sec to 1.3 sec. The inverter output voltage oscillates to maximum positive and negative from 1.18 sec to 1.2 sec for the firing angle 5º and without extinction angle.

It is evident from figure 10 (b) the stability of the system is improved for the extinction angle of γ = 18°, compared to figure 6.2.1 the attainment of stability of the system is better.

From figures 8 (a) and 10 (a) the system response for the same high impedance single phase fault at inverter side for the duration 1.1 sec to 1.3 sec has been analyzed. From both figure it is evident that the load voltage and current at the inverter side gives better stable response for the extinction angle of γ = 18°, for the firing angle of α = 15°.

iii) Analysis of Ground Fault: Figure 11 and 13 shows the system response with ground fault. This ground fault has been studied for the two cases, one without extinction angle i.e., normal angle control. Another one is with extinction angle of γ = 15°, with addition of static capacitor.

On Comparing the figure 11 (b) and 13 (b) it is evident that the inverter output voltage is oscillatory in figure 11 (b) without extinction angle but the voltage settles faster in figure 13(b) with extinction angle and additional static condensers.

VI. CONCLUSION

This work describes the Extinction Angle control is suitable for the application to the Capacitor Commutated Converter (CCC) based Hybrid HVDC systems. This paper throws light on the CCC based inverter and Voltage Source Converter (VSC) based rectifier as a suitable Hybrid HVDC system to be adopted. Also a performance analysis of the various faults occurs in the inverter end of the Hybrid HVDC system shows the power factor and stability of the system is increased by increasing the extinction angle. This project shows by controlling the extinction angle (γ) , the power factor and stability of the system is increased. By improving the power factor we can reduce the transients occurs in the system. Also a fault mitigation technique is attempted for numerous faults including post fault recovery. By controlling the extinction angle, fault clearing time is increased and the fault current is reduced to one third of the magnitude attained to that of other controls. All the specifications prescribed in the model is simulated using the MATLAB and the voltage and current characteristics of the alternating current input to the rectifier and the out of inverter is shown. The inverter configuration along with the load is studied for numerous faulty conditions and the performance of the system is studied.

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