

*Research Paper*

## MODELING, SIMULATION AND CONTROL OF THE ALTERNATE ARM CONVERTER

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**Abstract**— The The Modular Multilevel Converter has been one of the frontrunner in the emerging topology of VSC implemented in High Voltage Direct Current applications for a decade because of its innumerable advantages like excellent performance, reduced level of harmonics in the converter output without the necessity of filters, controllability, scalability, high power handling and high voltage capability and the foremost application in HVDC, the DC fault blocking capability and so on. A new hybrid topology of MMC called the Alternate arm converter which is designed with the combination of MMC and a two level converter possessing the ability to generate higher AC output voltage than the DC input voltage at a critical point of the converter called the sweet spot where the energy transfer between the AC and DC side of the converter is achieved is discussed in this paper. The reduction in the number of switching devices is achieved in AAC due to the alternate conduction of the director switches (two level converter) in the arms leading to a significant reduction in power loss. This paper presents a review on the operation principles and theoretical analyses of the Alternate Arm Converter (AAC). The mathematical model of the AAC has been designed and simulated with the help of Matlab for three phase Converter. The THD for the reduced model of AAC was also calculated and analyzed. **Keywords:** Modular multilevel converters, isomorphic circuits, electromagnetic transients, periodic small-signal analysis.

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### I. INTRODUCTION

Nowadays The substation converter can connect and convert high voltage alternating current (HVAC) and HVDC links and vice versa. Two types of the converter topology are used nowadays. Line commutated converters (LCC) and voltage source converters (VSC) [4]. Nowadays VSC can be divided into proven two types of the converters: two level converters and modular multilevel converters (MMC). The new topology of VSC arises, which is a hybrid of merged two of mentioned VSC types. It is known as alternate arm converter (AAC) and was firstly introduced in [13]. The converter type is under investigation nowadays and not yet proven technology to be used commercially. The study aims to create a MATLAB/Simulink model to test the behaviour of the converter. First the model of AAC will be created in Simulink, together with a simple control schemes. Then it will be tested in the island mode, by observing its operation and understanding its working principle. After that the connection to the grid and implementation of the improved control will be observed. Finally the simulation

of the converter will be used in the point to point connection. The connection scheme are illustrated in Figure 1.1. As it can be seen in this case the wind turbine park is considered operating in offshore. The wind turbines are connected to the substation, which is placed in offshore. The connections of the wind turbines to the substation are through AC submarine cables. The distance between the wind park and the offshore substation is feasible to still use AC voltage. Offshore and onshore converter stations converts AC to DC and DC to AC, respectively. LCC and VSC topology can be used in these converter stations. The converters are connected through the HVDC link. The HVDC link consist of the HVDC submarine cables and transfers power to the onshore substation.

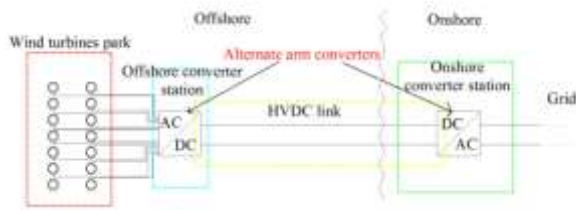


Figure 1: Example of the possible realization of the AAC.

HVDC schemes are moving toward dc-fault-tolerant, compact and low-loss VSCs.

The Alternate-Arm Converter (AAC) promises  $\approx 50\%$  fewer sub-modules (SMs) than an MMC, inherent dc-side fault blocking, and low switching loss thanks to director switches (DS).

However, the arms conduct the ac current only “one at a time”; therefore the continuous circulating current available in an MMC is missing.

→ Energy naturally drifts between the upper and lower arms, producing capacitor-voltage spread, device over-rating and ultimately tripping.

→ There is no universally accepted, experimentally validated “small-signal / large-signal” model that lets control engineers predict that drift and design stabilising controllers.

## II. LITERATURE SURVEY

The Sood et al. – “HVDC Transmission...” (Wiley, 2009)

A 350-page monograph that merges academic rigour with vendor data. Chapters 1-3 derive average-value CSC and VSC models; chapters 4-5 treat harmonics and filter design with worked PSCAD cases. Control philosophies (vector, direct-power, gamma and extinction-angle) are coded in MATLAB. Protection chapters map dc line faults, commutation failures and capacitor-bank flashovers to relay settings. Economic screening curves update the Bahrman breakeven to 600 km. Appendices tabulate every commissioned link up to 2008, including the 6 GW Itaipu bipole. The book is still the default course text for graduate HVDC classes and the jumping-off point for AAC-related small-signal modelling.

Greenpeace – “Lessons from Fukushima” (2012)

An advocacy report that translates the 2011 nuclear accident into energy-policy recommendations. It claims the external cost of the disaster exceeds US \$250 billion, argues that a 20 km evacuation zone was insufficient, and presents a renewables roadmap for Japan to phase out all 54 reactors by 2012. Technical annexes compare levelised cost of nuclear (14  $\text{¢/kWh}$ ) with wind (9  $\text{¢/kWh}$ ) and solar (13  $\text{¢/kWh}$ ). While overtly anti-nuclear, the document is cited in HVDC literature to justify long-distance transmission of remote renewables that replace baseload atomic plants.

Shafiee & Topal – “When will fossil-fuel reserves be diminished?” (Energy Policy, 2009)

A logistic-depletion study that aggregates BP, IEA and USGS data to project peak oil in 2012, peak gas in 2051 and peak coal in 2090 under 2006 consumption growth. Monte-Carlo sensitivity gives 95 % confidence intervals; carbon-tax scenarios accelerate renewable uptake and delay depletion by only 5–8 years. The paper is frequently referenced in HVDC grant proposals to frame offshore wind and desert-solar super-grids as infrastructure responses to imminent scarcity rather than to climate concerns alone.

Trainer et al. – Cigre 2010 – “A new hybrid voltage-sourced converter...”

The seminal disclosure of the Alternate-Arm Converter (AAC). Each 640 kV, 1 GW valve combines director switches (4.5 kV IGCTs) and half-bridge MMC sub-modules. Director arms conduct alternately, cutting SM count to  $\approx 40\%$  of a full MMC while retaining dc-fault blocking. Offline simulations show 1 kHz effective switching,  $<1\%$  THD and 98 % efficiency. The paper closes with a 30 MVA down-scaled prototype waveform, first proving the soft-switching concept that underpins every later AAC publication.

A historical essay that recounts the 1880–1895 battle between Edison’s 110 V dc and Westinghouse’s 3 kV ac. Original photographs of the 1891 Frankfurt a.M. 15 kV, 175 km three-phase link and the 1906 100 kV Thury dc series scheme are reproduced. The author argues that the present return to HVDC is technologically circular but economically justified by silicon rather than mercury valves. The paper is a favourite opener in theses to show that the “ac vs dc” debate is 130 years old.

Hingorani & Gyugyi – “Understanding FACTS” (Wiley, 2000)

The canonical reference on flexible ac transmission systems. Chapters 2-4 derive static-var compensator (SVC) and static-synchronous compensator (STATCOM) models; chapter 8 introduces unified power-flow controllers (UPFC) that combine series and shunt VSCs. Control block diagrams are given in dq-frames identical to those later adopted for HVDC. Although focused on HVAC, the book is cited in AAC papers because the arm-energy balancing problem is mathematically analogous to dc-capacitor regulation in a STATCOM.

Padiyar – “HVDC power transmission systems...” (New Age, 1990)

The first Indian textbook on HVDC, still reprinted unchanged. Chapters 3-5 derive the Graetz bridge, overlap angle  $\mu$  and power-factor equations used in every CSC study. Control hierarchies (constant-current, constant-extinction-angle, dc-power) are explained with Laplace blocks; transient-overvoltage case studies use the 200 km, 400 kV Vindhyaachal link. Appendices give FORTRAN source for harmonic-penetration algorithms. Though pre-VSC, the CSC models remain relevant because hybrid AAC schemes still employ thyristor-based director switches.

Olaf Saksvik – “HVDC technology and smart grid” (IET APSC, 2012)

A conference keynote that reframes HVDC links as enablers of the European “smart grid” rather than mere point-to-point bulk transfers. Saksvik quantifies how 5 GW VSC corridors provide frequency-response reserves to asynchronous AC zones, presents Statnett’s 1.4 GW NordLink as a case study, and introduces the term “digital substation” based on IEC-61850-9-2LE process buses. Control diagrams show outer-loop frequency droop ( $\pm 2\%$ ) superimposed on inner-loop vector current control. The paper is frequently cited to justify AAC research by arguing that future multiterminal DC grids will require converters which can simultaneously balance energy, provide ancillary services and ride-through dc faults.

Mohan, Undeland & Robbins – “Power Electronics...” (Wiley, 1995)

The undergraduate bible that unifies converter topologies under a switch-averaging lens. Chapters 6-8 derive buck, boost and full-bridge models whose averaged equations reappear in AAC arm-level papers. Switching-loss curves for 1.2 kV IGBTs and snubber design nomograms are still used to dimension director-switch RC-RCD networks. The text introduces the “current-source vs voltage-source” duality that underpins the choice between thyristor and IGBT stacks in hybrid HVDC topologies. Despite its age, the solved homework problems on two-quadrant operation are assigned in graduate HVDC courses because the same dynamics re-emerge in AAC overlap-period control.

] Vijay K. Sood – “HVDC and FACTS Controllers” (Springer, 2006)

A design-oriented monograph that maps every static converter to its TNA/EMT equivalent circuit. CSC chapters give the 6-pulse and 12-pulse harmonic spectra used in filter sizing; VSC chapters present the two-level SPWM and three-level NPC that preceded today’s MMC. Controller layers—inner current, outer power, tap-changer and gamma—are coded in PSCAD and MATLAB. Appendices list vendor datasheets for 3 kV/1.5 kA IGCTs and 4.5 kV/2 kA IGBTs, numbers that resurface in AAC director-switch papers. The book is the most common bridge between classical thyristor HVDC and modern IGBT-based AAC literature.

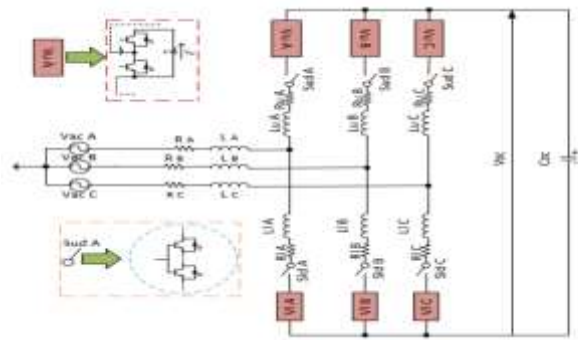


Figure 2 Alternate arm topology

III. CONCLUSION

An alternate arm converter was firstly introduced, where it was represented in the Cigre conference as a hybrid voltage source converter. The AAC topology is pictured in the Figure 3.1. A 3-phase converter consist of 3 legs, one leg per-phase. One leg consist of the 2 arms: upper and lower. The arms are identical and has arm resistor, arm inductor, director switches and submodules. The submodule of the upper arm VuA is illustrated in the Figure 3.1, where u indicates upper arm and A denotes phase. Several submodules are connected in the series in order to generate close to the sinusoidal stepped voltage signal. The director switches in each arm are IGBT connected in series, which also are represented in the Figure 3.1. Each arm has an inductor and the resistor, which shows arm resistance and director switch resistance combined together.

Operation principle of the AAC is similar to 2-level converter 3.2.1, it has so called director switches, which direct current to the upper or lower arms. The director switches are IGBT, connected in series, because of to withstand higher voltage ratings, when they are open. Like the MMC 3.2.2, the hybrid model has stack of cells in each arm responsible for the multistep voltage generation. The main advantage is, that only half of the voltage period is generated in one arm, therefore allowing to reduce amount of the cells in stack. Unlike the MMC the AAC current does not flow continuously, because the director switches can interrupt it, therefore the AAC has a turn-on and turn-off states for the flowing current

IV. RESULT ISCUSSION

The operations are implemented in 10 s simulation, where each of the operating points are presented. Transition points of the operation are illustrated in Figure 6.2. The simulation is divided in the sections by the time. A operating point section simulation runs from 0 2 s with the unity power factor, with active power flow from T1 towards T2. The B operating point simulation section takes time from 3 3, 5 s with the power factor of 0. C operating point is simulated between 4, 5 5 s and shows reversed full active power flow with 0 reactive power. D operating point takes time in 6 6, 5 s, which represents the full reversed reactive power only. E operation is between 7 7, 5 s, with the half of the reversed active power flow and half of the reactive power 10 MW and 10 MVar respectively, total injected apparent power consists of 14, 14 MVA. F operation is between 8, 5 9 s with not reversed active power of 10 MW and not reversed 10 MVar, with the same total apparent power of 14, 14 MVA. The last operating point tt takes time between 9, 5 10 s and shows operation of 0 powers injection. The behaviour of the powers, AC voltages, AC currents, DC voltages, arm voltages, arm currents, circulating currents are represented of the each operation points cases.

Figure 3: Operation points during 10 s simulation

Active power flow and reactive power generation or absorption are illustrated in Figure 6.3. The blue curves represent active and reactive powers measured at terminal 1, while the red curves represent active and reactive powers measured at terminal 2. As it can be seen the active power is a bit lower, than 20 MW due to the droop control, which regulates DC voltage. Furthermore the active power never drops to 0, because the droop control gain with 5% of  $\rho$  value will provide  $\pm 20$  kW margin of the power

## V. CONCLUSION

The development of a digitally controlled low-power single-phase inverter for grid-connected solar panels with PSO optimization techniques represents a significant step forward in the design of efficient, cost-effective, and high-performance solar power systems. PSO optimization can enhance various aspects of inverter operation, including waveform quality, efficiency, and grid synchronization, providing a more robust and reliable solution for solar power generation. However, challenges such as computational complexity and convergence issues need to be addressed in future research. The integration of PSO with advanced modulation techniques and real-time implementation is an exciting area that holds great promise for the future of solar energy systems.

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