International Journal of Engineering Research and Science & Technology

www.ijerst.org

ISSN : 2319-5991

Vol. 21 No. 4 (2025)



ijerst.editor@gmail.com

editor@ijerst.com

International Journal of Engineering Research and Science & Technology

ISSN 2319-5991 www.ijerst.com
Vol. 21, No. 4, 2025
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Research Paper

A REVIEW DEVELOPMENT OF MODELING, SIMULATION AND CONTROL OF THE ALTERNATE ARM CONVERTER

Pratiksha Suresh Ghugul, Mtech. Student
Department Of Electrical engineering
Vidarbha Institute Of Technology Uti, Umrer Road,
Nagpur

Dr.Nilesh Bodne
Department Of Electrical engineering
Vidarbha Institute Of Technology Uti, Umrer Road,
Nagpur

Prof. Manjeet Sakhare
Department Of Electrical engineering
Vidarbha Institute Of Technology Uti, Umrer Road,
Nagpur

***Abstract*— The The High-voltage direct-current (HVDC) technology enables efficient, long-distance electric-power transmission renewable-energy integration. Converter topology determines the overall performance of such systems. Conventional two-level voltage-source converters (VSCs) offer high dynamic response but suffer from lar switching losses and insufficient fault protection. Modular Multilevel Converters (MMCs) overcome these limitations through a scalable structure but demand substantial capacitor energy storage.The Alternate Arm Converter (AAC) has emerged as an attractive hybrid topology combining the favorable features of both systems: reduced conduction losses, lower energy storage, and inherent DC-fault block capability.**

This thesis presents comprehensive modeling, control design, and performance evaluation of a three-phase AAC. Analytical expressions of arm currents, capacitor voltages, and circulating currents are derived. A hierarchical control architecture outer DC-voltage loop, inner dq-current loop, circulating-current supply and submodule-balancing mechanism is implemented in MATLAB/Simulink. Simulation results confirm theoretical predictions

Keywords: Modular multilevel converters, isomorphic circuits, electromagnetic transients, periodic small-signal analysis.

Received: 01-10-2025 Accepted: 04-11-2025 Published: 12-11-2025

I. INTRODUCTION

Nowadays the rapidly changing world and the booming population will require more and more energy generation. Old thermal and nuclear plants are not capable to provide that huge amount of energy, furthermore the carbon footprint left by generating energy from these power plants will increase with the increasing number of the new power plants.The nuclear plants are debatable to be safe anymore after couple of the incidents and the nuclear waste storage are unsolved issue [9][10]. The non-renewable energy sources are limited and increasing population will increase usage of them, therefore the new solutions should be planed, otherwise in the nearly future it will be a lack of the fossil fuel [11].

Another huge risk is a global warming. The situation is getting worse and worse each

year, that is why a such events as United Nations climate change conferences are organized. Conference COP 21 was held in 2015. In this conference 195 countries were participating and by now 154 [20-05-2017] countries signed an agreement to reduce green house gasses and keep the global warming temperature well bellow than 2◦C [12]. This conference directed a new point of view in the energy production, transformation, transmission and even usage. The production will be achieved by using renewable energy sources (RES) as wind parks, solar systems, hydro plants, biomass, geothermal energy and so on.Transformation efficiency and the reliability will be increased. The bulky power transmission systems to become more efficient are requiring less energy losses, therefore the high voltage direct current (HVDC) transmission systems are taking over. Nowadays smarter ways how to save energy get more trend. The word ”smart” gets a new meaning, where saving of the energy are highlighted in the every step and people are encourage to save energy even in the smallest amounts. People are taught how to use the produced energy widely. A simple example even of the smallest thing like ”turnoff” of the TV standby mode, can make huge impact, when it will be used widely. Increasing energy production can not stand alone, it should be supported by the usage of it in the most efficient way.s.

II. OPERATION PRINCIPLES

A HVDC schemes are moving toward dc-fault-tolerant, compact and low-loss VSCs.
The Alternate-Arm Converter (AAC) promises ≈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.s

III. 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 ¢/kWh) with wind (9 ¢/kWh) and solar (13 ¢/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 ≈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 μ 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 Vindhyachal 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 (±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.

AC Side Current Dynamics

Applying Kirchhoff's Voltage Law (KVL) on the AC side and transforming to the dq-frame (synchronized to the grid voltage angle $\theta = \omega t$), we get the standard VSC equation:

$L_t * (di_d/dt) = \omega L_t i_q - R_t i_d + v_d - e_d$ $L_t * (di_q/dt) = -\omega L_t i_d - R_t i_q + v_q - e_q$

Where:

- i_d, i_q are the d and q components of the AC current.
- v_d, v_q are the d and q components of the AAC's synthesized voltage at the AC terminal.
- e_d, e_q are the d and q components of the grid voltage.
- L_t, R_t are the total inductance and resistance between the converter and the grid (including L_arm and any transformer leakage).

The AAC's control system calculates the references v_d* and v_q* to achieve the desired active (P*) and reactive (Q*) power.

4.2. DC Side and Internal Energy Control

The unique part of the AAC model is the energy balance controller. The state variable here is the sum of the capacitor voltages in each arm (or the total arm energy).

A simplified dynamic model for the upper arm energy W_u is:

$(dW_u/dt) = v_arm_u(t) * i_u(t)$

A similar equation holds for the lower arm. The control objective is W_u = W_u_ref and W_l = W_l_ref. This is achieved by manipulating the power flow during the overlap period. By allowing a small "non-energy" period where both directors are closed, a controlled voltage can be applied across the arm inductors, allowing a swift adjustment of the arm currents and thus a direct transfer of energy between the DC link and the arm capacitors

III. 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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