IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 5 December 2023, accepted 13 December 2023, date of publication 19 December 2023,
date of current version 8 January 2024.

Digital Object Identifier 10.1109/ACCESS.2023.3345216

SURVEY

A Comprehensive Review on STATCOM: Paradigm of Modeling, Control, Stability, Optimal Location, Integration, Application, and Installation

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ABSTRACT The Static synchronous compensator (STATCOM) is a renowned FACTS (flexible alternating current transmission system) device used in power grids to cope with protean conditions. This article provides a comprehensive bibliographic review of various aspects of STATCOM developed over the last 16 years. The paper includes a detailed study presenting different models, test systems, and results of various researches. The study covers the modelling, control technology, stability, optimal location, applications, and installation of STATCOM. The modelling of STATCOM is diverse and include various models such as voltage source converters, software-based models, load flow models, pulse width modulation, and modular multilevel converters. The control technology includes a PI/PID controller, fuzzy-based, feedback controller, model predictive controller, sliding mode controller, and miscellaneous controller based on different schemes, algorithms, and controllers. In studying the stability analysis, all stability aspects such as steady-state stability, dynamic stability, and transient stability are considered for the stability analysis. The genetic algorithm, heuristic algorithm, probabilistic technique and branch and bound approach are mainly used for the optimal placement of STATCOM as described in the available research paper. Various applications of STATCOM in power system are identified such as optimal power flow, voltage stability, voltage fluctuation mitigation, fault analysis and total harmonic distortion. This paper, also mentions the current installation of STATCOM is also mentioned with their different locations such as China (2018), and Canada (2019). The current functions of STATCOM still have many limitations. So there is still a lot of room for improvement. This paper will help the researcher finding the reference of a particular topic of interest in different aspects of STATCOM. The finding of different sections of the paper can help the researchers to develop new ideas and work on different prospective of the device.

INDEX TERMS STATCOM, FACTS devices, modeling, control scheme application, renewable, installation.

The associate editor coordinating the review of this manuscript and approving it for publication was Vitor Monteiro.

NOMENCLATURE

3LNPC	Three-level Neutral-point-clamped.
AAC	Alternate arm converter.

ANCF	Adaptive noise cancellation filter.
ANN	Artificial neural network.
APLC	Active power line conditioner.
ASFC	Adaptive Switched Filter Compensator.
AC-PSO	Ant Colony-Particle Swarm Optimization.
BESS	Battery energy storage system.
CHB	Cascaded H-Bridge.
CMC	Cascaded Multilevel Converter.
DQ	Direct-Quadrature.
DOSSR	Damping of sub-synchronous resonance.
DOPSO	Damping of Power System Oscillation.
DSTATCOM	Distribution-type static synchronous compensator.
DEHS	Differential evolution harmony search.
DSP	Digital Signal Processing.
DCMC	Diode clamped multi converter.
EMTP	Electromagnetic Transients Program.
ES-STATCOM	Energy storage and static synchronous compensator.
EPSO	Evolutionary particle swarm optimization.
EMTDC	Electromagnetic Transients including DC.
EO	Energy operator.
FPGA	Field programmable gate array.
FDL	Fault detection and localization.
GDQ-DP	Generalized DQ-dynamic phasor.
HDP	Heuristic dynamic programming.
HVDC	High voltage direct current.
IGBT	Insulated-gate bipolar transistor.
IPCC	Individual Phase Current Control.
LTG	Line–to–Ground IPCC.
LL	Line–to–Line.
LLG	Double Line–to–Ground.
LVRT	Low-voltage ride-through.
MMC	Modular Multilevel Converter.
MVMO	Mean-variance mapping optimization.
MOP	Multi-objective programming.
MOOP	Multi-objective optimization problem.
MMCC-SSBC	Modular Multilevel Cascade Converter Single-star Bridge-cell.
NR	Newton-Raphson.
NAEI	North American Eastern Interconnection.
NERC	North American Electric Reliability Corporation.
NYPS-NETS	New York Power System and New England Transmission System.
PCC	Performance-oriented Congestion Control.
PLECS	Piecewise Linear Electrical Circuit Simulation.
PS	Power System.
PSS	Power System Simulator.
PSCAD	Power System Computer-Aided Design.
PWM	Pulse width modulation.
PV	Photovoltaic technology.
RTDS	Real-time digital simulator.
R-SFCL	Resistive superconductor fault current limiter.
RWNNC	Reduced wide normalized normal constraint.
SHE PWM	Selective Harmonic Eliminated Pulse width modulation.
SHEM	Selective Harmonic Elimination Method.
SIEG	Self- excited induction generator.
SMIBS	Single machine infinite bus system.
SSR	Synchronous Resonance.
SSSC	Static synchronous series compensator.
STFPC	Self-Tuning Fuzzy Logic PI-Controller.
SVPWM	Space vector pulse width modulation.
SVM	Space Vector Modulator.
SPWM	Sinusoidal pulse-width modulation.
SWC	Square Wave Controlled.
SMIB	Single Machine Infinite Bus.
THD	Total Harmonic Distortion.
UKGDS	U.K. generic distribution system.
VFD	Variable frequency drive.
VSI	Voltage Source Inverter.
VSC	Voltage Source Converter.
ZVRT	Zero-voltage-ride-through.

I. INTRODUCTION

In today's world, electricity is everyone's basic need. As a result, demand has risen sharply. To a certain extent, many problems occur in meeting the demand of individuals through our existing electricity system, especially the transmission grid. This can be due to internal faults or external disturbances. These problems include harmonic distortion, reactive power control, active power control, voltage fluctuation, voltage sag, voltage swell, and optimal power flow. In these cases, we need FACTS (Flexible Alternating Current Transmission System) devices to keep our power system in a healthy state. A number of FACTS devices have been developed and manufactured by researchers and scientists. FACTS devices can be divided into four categories: Series FACTS devices, Shunt FACTS devices, Series-Series FACTS devices and Series-Shunt FACTS devices. Series FACTS devices include the Thyristor Controlled Series Capacitor (TCSC), the Thyristor Controlled Series Reactor (TCSR), the Thyristor Switched Series Capacitor (TSSC) and the Static Synchronous Series Compensator (SSSC). The shunt FACTS devices are the Static VAR Compensator (SVC), the Thyristor Controller Reactor (TCR), the Thyristor Switched Capacitor (TSC), the Thyrsitor Switched Reactor (TSR), and the Static Synchronous Compensator (STATCOM). The Interline Power Flow Controller (IPFC) falls into the category of Series-Series FACTS devices. The Unified Power Flow Controller (UPFC) also belongs to the series shunt FACTS devices. If the number of series branches in the UPFC is more than one, it is referred to as a Generalized Unified Power Flow Controller (GUPFC).

In this post, we will focus on a thorough literature review of STATCOM. As we know, STATCOM falls into the category of serial FACTS devices. The main interest in studying STATCOM lies in its uniqueness in the power grid. It is a FACTS device that is capable of solving a number of problems in the power system.

A power electronic shunt device, the static synchronous compensator (STATCOM), belongs to the family of FACTS devices. The operating principle of a STATCOM is related to the operating principle of rotary synchronous compensators or generators. It is more reliable than other generators because it works quickly. This close relationship has given the STATCOM its name. It is superior to static VAR compensators; with which it shares most of its functions. STATCOM (as shown in Figure 1) is generally used to regulate the alternating current in power transmission networks. In figure 1 two diagrams the of STATCOM: first one on the left side shows the voltage source converter and second one at the right side shows the current source converter. They utilize power electronic voltage source converters such as IGBT, GTO, etc. to behave like a source or sink for the AC reactive power of an electrical transmission network. It controls the reactive power flow through electrical grids and improves the transient stability of these grids. It is also capable of delivering active AC power when connected to a power source. STATCOM proves to be more valuable than others, as it is also useful in reducing voltage fluctuations.

A glimpse of recent research paper published on STATCOM is presented as fellows: The enhancement of STATCOM technologies for the betterment of future grid's requirement is described in [1]. STATCOM will help in providing stable operation by feeding the load from conventional and non-conventional energy sources and helping in achieving a carbon-neutral economy. In order to enhance the performance of STATCOM, a capacitor condition monitoring method is explained in [2]. This is a cost-effective method for monitoring capacitor condition online, offering real-time monitoring without extra hardware. The method practices averaged low-frequency signals to recognize ESR and capacitance values, avoiding high-frequency noise, and incorporating antialiasing filters. An artificial rabbit optimizer is used for the tuning of the STATCOM controller, which is based on the PID scheme in [3]. This controller is capable of controlling the frequency of the system within permissible limits. This controller is tested on two area-four machine systems and an IEEE 39 bus system. A wide-area damping controller for STATCOM for inter-area oscillation is exhibited in [4]. The inter-area signals are evaluated on the basis of rotor angle and speed deviation. The IEEE 39-bus test system and practical Iran nation power grid are used to test the effectiveness of the controller. Ref. [5]: In order to minimize the larger oscillation in the capacitor voltage of STATCOM, an optimal third harmonic circulating current is injected. The effectiveness is tested for balanced and unbalanced conditions. A multi-bus bar sub-module for STATCOM with partially rated energy storage is explained in [6]. The module is better at maintaining frequency within the limit and reactive power compensation in comparison to a conventional full-bridge submodule. A star-connected cascaded H-bridge converter-based STATCOM with a single IGBT open circuit fault is proposed in [7]. It uses a modified current regulator and synthesizes output signals to rapidly find the fault IGBT position. The controller can act as a monitor without supplementary sensors. A cascaded H-bridge converter-based static synchronous compensator (STATCOM), which injects virtual synchronous inertial support into the system, is introduced in [8]. It provides reactive power compensation and less frequency deviation. Ref. [9] states the use of a number of STATCOMs to support voltage control in integrated power systems with PV and wind energy sources. The proposal is tested with an IEEE 14 bus system in which three STATCOMs are installed. A selective harmonic voltage control method for STATCOM is proposed in [10]. This method is very effective in mitigating the voltage harmonics. This method is verified using an EMTP simulation. A dynamic voltage equalization control (DVEC) method for distributed STATCOM is proposed in [11]. Experimental results show this method can minimize the negative sequence voltage as well as control voltage unbalance in the event of a fault. A central controller-based Gorilla Troops Optimization (GTO) algorithm for optimal parameter setting of distributed STATCOM is proposed in [12]. This algorithm is tested on an IEEE 33-node system and a North Delta Electrical Distribution Company 24-bus radial network. Simulation results exhibit its effectiveness in controlling the voltage within the permissible limits and minimizing power loss and energy waste. The use of STATCOM in attaining the stability and quality of electrical supply during dynamic interaction between wind turbines, transmission cables, and other electrical equipment is exhibited in [13]. A detection method based on the carrier phase-shifted SPWM technique for CHB STATCOM is exhibited in [14]. Simulation results show its effectiveness in balancing the capacitor voltage. A hybrid controller composed of TCR, TSC, and distributed STATCOM acts as a reactive power and harmonic compensator, as exhibited in [15]. A mathematical model of dissipating energy-based source/sink characterization for STATCOM is formulated in [16]. A numerical case study of the IEEE bus system shows its usefulness in damping low-frequency oscillations. The mismatch between reactive power generation and consumption voltage collapse may take place in a large, high-voltage power network. To deal with this problem, a STATCOM with a low voltage rating is proposed in [17]. For a STATCOM-compensated line, an adaptive network-based fuzzy interface system (ANFIS) is introduced in [18]. This system will utilize the positive and negative sequence voltages and current phasors to find the fault location. The mitigation of unbalanced voltage and power factor correction is done by a hybrid controller with SVC and delta-connected STATCOM for a high voltage distribution system [19]. Simulation results validate the capability of the controller. To mitigate some problems (poor dynamic characteristics, capacity issues, and active power shock) of the SVC installed power network, STATCOM is used in [20]. Experimental results show the effectiveness of the network's power compensation. The reduction of total harmonic distortion is achieved using a quasi-Z-source inverter-based STATCOM, as exhibited in [21]. A dual-layer modulated model predictive control scheme for STATCOM is proposed in [22]. This is very effective in achieving controlled current and voltage balance. A neural network-based approach for the STATCOM controller is proposed in [23]. This approach shows its capability to reduce the computational burden of the conventional control scheme. The evidence of a reduction in torsional damping by the use of STATCOM is exhibited in [24]. It was tested with a French line commutated converter and a new Electro link modular multilevel converter interacting with a grave lines generator. To reduce imbalances in voltage and damping of oscillation, an innovative point-of-common coupling (PCC) voltage controller for STATCOM is exhibited in [25].

A number of review papers are published on STATCOM, like ref. [26]. These papers provide a literature review of less than 50 papers and are not very extensive in nature. Only Ref. [27], a review paper published in 2008, is a very good review paper that provides an extensive review of the paper up to 2008. In our present paper, we have started emerging the paper published in 2008 and will continue until 2024. This paper provides a very extensive review, which will be very beneficial for the researchers.

The specific contributions of the authors in this paper are

1. This paper provides a detailed bibliography on STATCOM.
2. This paper covered all the aspect of the STATCOM: Modelling, Control technique, Stability, Optimal location, Integration with renewable system, application and Installation.
3. This paper Highlighted the different type of modelling of STATCOM done by the different researchers.
4. The control techniques used for the controller of STATCOM with different application. The author also commented for the best control technique used for THD.
5. The major contribution of the paper is to provide the future scope of research on STATCOM.

In this paper, the authors have performed a rigorous and in-depth review of the research done in the field of STATCOM. The various aspects of STATCOM and their major outcomes have been reviewed bibliographically. The paper has tabulated the information gathered by the analysis of the previously published papers. Graphs have been included to provide a better pictorial representation of the data inferred. This work has been done to provide new researchers with ample information about the previous works done, which will aid them in their research.

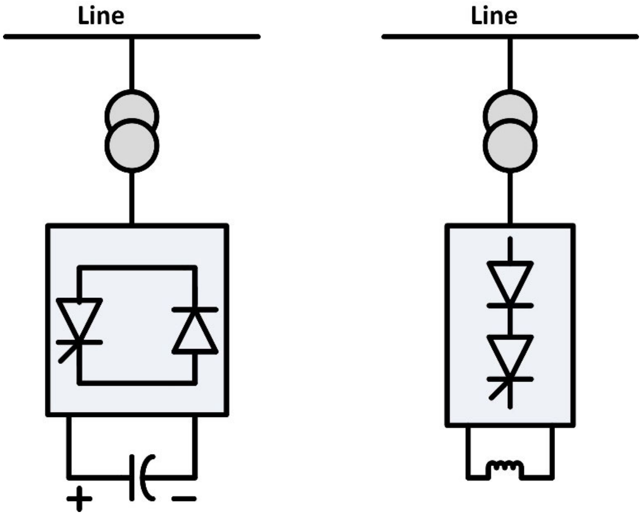


FIGURE 1. The block diagram of STATCOM. (Voltage source converter and current source converter.)

After a detailed review of the work, it was found that the most frequently achieved results were DOPSO, THD, system stability, and improved operational performance. It was described that a considerable number of researchers achieved reduced computation time, minimized functional costs, and reduced losses during the operation of STATCOM. The article is divided into 10 sections. Starting with the introduction as the first section, the bibliography follows as Section II, highlighting the various aspects discussed in the paper. Section III deals with the different modelling types of STATCOM, such as load flow models, software-based models, voltage source converters, and pulse width modulation, while Section IV deals with different control schemes and design techniques for STATCOM, such as proportional-integral controllers, proportional-integral-derivative controllers, sliding mode controllers, model predictive and fuzzy logic, etc. The works that achieve different types of stability, such as stationary, transient, and dynamic, have been discussed in Section V, and the papers with different optimization techniques to find the optimal location and size for STATCOM have been mentioned in Section VI, such as probabilistic technique, genetic algorithm, sensitivity-based index method, mesh adaptive direct approach, branch and bound approach, etc. Section VII of the paper presents work integrating different types of renewable energy sources with STATCOM. Sections VIII and IX deal with applications of STATCOM, including THD, voltage stability, fault analysis, and studies on the installation of STATCOMs in various parts of the world. Section X contains the conclusion of the article and points out future challenges in the field of STATCOM.

The literature review presented on STATCOM concludes that considerable work has been done in developing different

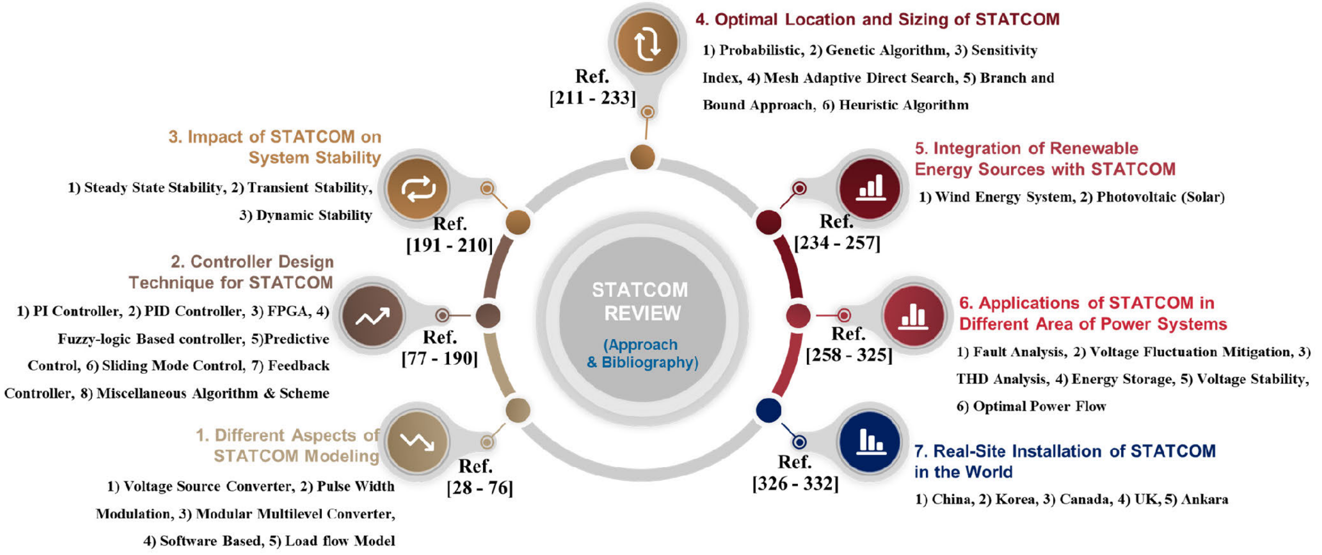


FIGURE 2. A circular representation of the proposed approach and bibliography of the STATCOM.

control schemes and modelling techniques to improve the performance of power systems. Recent publications show remarkable work in increasing the efficiency of renewable energy sources. However, various aspects of STATCOM are yet to be explored.

There are some fields in which very little work has been done. The future scope of STATCOM's research is as follows:

1. Modelling of STATCOM in a Current Source Inverter
2. Implementation of Heuristic Technique with Optimal Sizing of STATCOM
3. STATCOM for problems in power systems such as power swing, power fluctuation, and the Ferranti effect.
4. Integration of STATCOM with PV Cell
5. FPGA for implementation of STATCOM.
6. Integration of STACOM in controller designs using fuzzy techniques

II. PROPOSED APPROACH AND BIBLIOGRAPHY

A comprehensive review of STATCOM with the different paradigms of modelling, control, stability, optimal location, application, and installation is represented in seven sections, as given below in Figure 2:

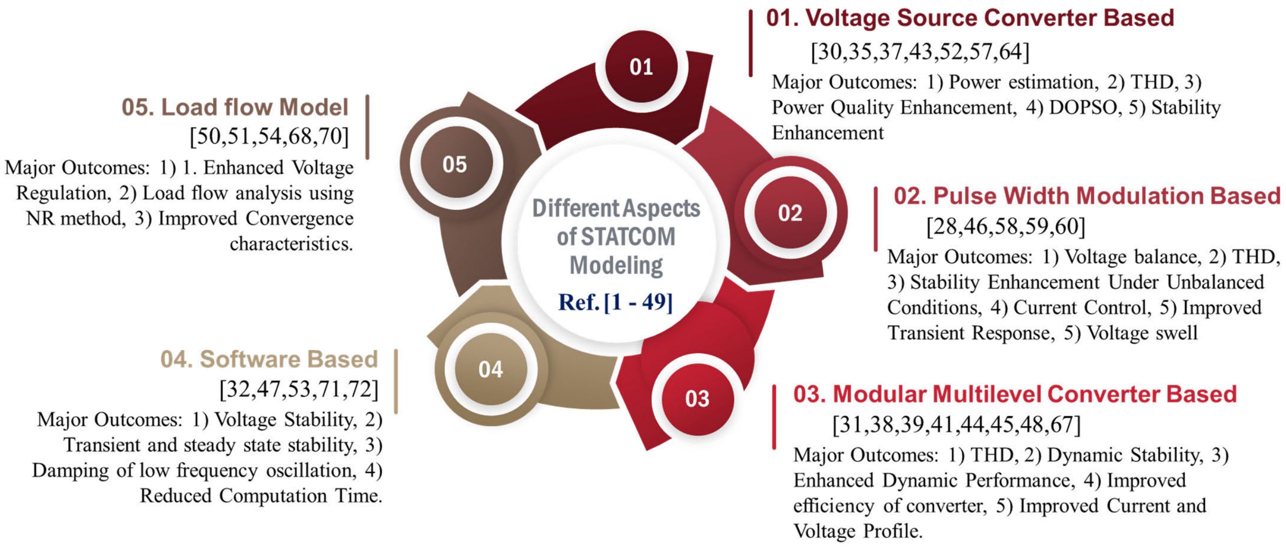
1. Different Aspects of STATCOM Modelling [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76]
2. Controller Design Technique for STATCOM [73], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100], [101], [102], [103], [104], [105], [106], [107], [108], [109], [110], [111], [112], [113], [114], [115], [116], [117], [118], [119], [120], [121], [122], [123], [124], [125], [126], [127], [128], [129], [130], [131], [132], [133], [134], [135], [136], [137], [138], [139], [140], [141], [142], [143], [144], [145], [146], [147], [148], [149], [150], [151], [152], [153], [154], [155], [156], [157], [158], [159], [160], [161], [162], [163], [164], [165], [166], [167], [168], [169], [170], [171], [172], [173], [174], [175], [176], [177], [178], [179], [180], [181], [182], [183], [184], [185], [186], [187], [188], [189]
3. Impact of STATCOM on System Stability [60], [190], [191], [192], [193], [194], [195], [196], [197], [198], [199], [200], [201], [202], [203], [204], [205], [206], [207], [208]
4. Optimal Location and Sizing of STATCOM [209], [210], [211], [212], [213], [214], [215], [216], [217], [218], [219], [220], [221], [222], [223], [224], [225], [226], [227], [228], [229], [230]
5. Integration of Renewable Energy Sources with STATCOM [231], [232], [233], [234], [235], [236], [237], [238], [239], [240], [241], [242], [243], [244], [245], [246], [247], [248], [249], [250], [251], [252], [253], [254]
6. Applications of STATCOM in Different Areas of Power Systems [255], [256], [257], [258], [259], [260], [261], [262], [263], [264], [265], [266], [267], [268], [269], [270], [271], [272], [273], [274], [275], [276], [277], [278], [279], [280], [281], [282], [283], [284], [285], [286], [287], [288], [289], [290], [291], [292], [293], [294], [295], [296], [297], [298], [299], [300], [301], [302], [303], [304], [305], [306], [307], [308], [309], [310], [311], [312], [313], [314], [315], [316], [317], [318], [319], [320], [321], [322]
7. Real-Site Installation of STATCOM in the World [200], [323], [324], [325], [326], [327], [328]

TABLE 1. Summary of different aspects of the STATCOM modelling [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76].

Ref No.	Year	Model Used	Test System/ Software Used	Major Outcomes
[28]	2008	Five-Level Diode-Clamped PWM Converter	200-V 10-kVA Experimental model	Voltage balanced and controlled in transient states
[29]	2008	Averaging Technique	PSPICE and MATLAB	Averaging theorems verified
[30]	2008	VSC	IEEE 14-bus system	Power System State estimated including STATCOM with energy storage
[31]	2008	Cascaded Multilevel Converter	PSCAD/EMTDC	Resonance point is close to second harmonics and can be moved to lower frequency by increasing the inductance.
[32]	2008	Software Based Model	2 bus system EMTP	1. Voltage Stability achieved 2. Analysis of the system in steady and transient state performed
[33]	2008	Multilevel Converter	55 Mvar cascaded multilevel (13 level) STATCOM PSCAD	1. the internal resonant frequency should be in between 3rd and 9th harmonics. 2. Losses minimized
[34]	2008	Cascaded H-bridge multilevel inverter	dSPACE prototype system	1. Cost effective and less complex achieved 2. Voltage Stabilized
[35]	2009	VSC	6.3 kV VSC-based D-STATCOM prototype	Selection of converter switching angle gives some degree of freedom in reduction of THD which reduce the size and cost of filter element
[36]	2009	VSI	1-phase,3-phase DSTATCOM PSCAD/EMTDC	Design Parameter for smooth modulation obtained
[37]	2009	SPWM VSC	PSCAD/EMTDC	The conventional switching function approach is a special case when the maximum harmonic order in the Fourier model is infinite and when cut off frequency is infinite in the hyperbolic tangent model.
[38]	2009	Cascade Multilevel Converter	30-kVAr STATCOM prototype PSCAD/EMTDC	Voltage Stability achieved under unbalanced conditions
[39]	2009	SWC Cascaded Multilevel Converter	MATLAB PSCAD/EMTDC	System in steady and dynamic states analyzed
[40]	2011	Extended MMC	30-kVA laboratory prototype	1. A total harmonics distortion of 18.27%.2. Smoother output current, 3. Smaller power loss.
[41]	2011	Cascaded Multilevel Converter	5 MVA Experimental model MATLAB/SIMULINK	1.Voltage fluctuations suppressed 2.Enchanced performance
[42]	2011	Multilevel Hexagram-Converter	1.4-kVAR prototype	Voltage Stability in steady and dynamic states attained
[43]	2012	VSC	200-kVA system	1. Doubling the output voltage 2. Cancelation of all even harmonics except order of $12k \pm 1$, where k is integer value.
[44]	2012	Cascade Multilevel Converter	65V Experimental setup	Voltage balance on DC capacitor is achieved
[45]	2012	Cascaded H-bridge	220 V and 10 kVA Experimental setup	1.System in steady and transient state analyzed 2.Power losses minimized
[46]	2013	Triangular Carrier PWM	690 Vac, 120kVA system	1. Suitable for inverters operating with a relatively low switching frequency, consists in adding a square wave at six times the output frequency. 2.Voltage balanced
[47]	2013	Surrogate Model using EMTP	20kV prototype PSCAD/EMTDC	1. To help designer in decision making process like below 1.5% of fundamental component. 2. Reduce price of system using smaller size filter. 3.Reduced computation time
[48]	2013	Cascaded Multilevel Converter	SHEM method, 12 kV ±12MVAr,11-level CMC	1. Elimination of 5th 7th 11th and 13th order harmonics 2. Voltage control and switching strategy developed. 3. DSP and FPGA technologies can be used in near future.
[49]	2013	Chopper-Cell-Based MMC	60V 3 kVA prototype	1.Voltage controlled 2.Dynamic stability for unbalanced non-linear load accomplished
[50]	2013	Load flow(Newton–Raphson)	2 bus system	Enhanced Voltage Regulation
[51]	2013	Dynamic PS Simulation	1.IEEE 9-bus system 2.New England test system 3.Utility-level power system	Load flow analyzed using NR method
[52]	2013	Asymmetric-Twin-Converter-Topology-Based	2.3kVA prototype	1. At full-load steady-state operation in capacitive mode, THD is observed to be 4.65%. The fifth and seventh harmonic components of current are found to be 0.33% and 1.2% of the fundamental, respectively. 2 Low distortion in current confirms the usability of the circuit for HV transmission lines.
[53]	2014	RTDS Implementation	MATLAB	1. Enhanced damping of low frequency oscillation 2. Improved system stability
[54]	2014	Load flow(Newton's Method)	IEEE 30 node-system	Optimal power flow observed
[55]	2014	Cascaded Two-Level Inverter-Based Multilevel	2-(IGBT)-two-level-inverter experimental setup MATLAB/SIMULINK	1. Dynamic modelling performed 2. Voltage stability for balanced and unbalanced conditions attained

TABLE 1. ***(Continued.)*** **Summary of different aspects of the STATCOM modelling [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76].**

[56]	2014	AAC -Hybrid Multilevel Converter	20 MW prototype	1. Improved power quality 2.Ability to block DC-Faults noted
[57]	2014	Three-level 24-pulse VSCs-based	MATLAB/SimPowerSystemsToolbox	1. DOPSO 2. Improved dynamic performance
[58]	2015	Cascaded H-Bridge PWM Converter	220V laboratory prototype	Enhanced stability under unbalanced condition of grid
[59]	2015	Phase-Shifted-PWM	140-V 10-kVA experimental system	Current control response improved
[60]	2015	Phase-Shifted-PWM:ZVRT Capability	150 V 10 kVA experimental system	1. Improved transient response 2. Handled asymmetrical AC voltages along with voltage sags
[61]	2015	Phase-Shifted Carrier Modulation Technique	(415VAC)19-level H-bridge STATCOM	1.Voltage balanced 2. Reduced switching loss
[62]	2016	Current Source MMC	PSCAD/EMTDC	Enhanced dynamic performance under different operating conditions
[63]	2017	Diode-clamped MMC	100V experimental prototype	1. Voltage balanced 2. Var compensation and negative-sequence Current compensation
[64]	2017	VSC	SCADA	1.Integrated Micro grid with renewable energy sources 2. Enhanced System stability
[65]	2018	Pseudo-Dynamic Network Modelling	WSCC 3-machine 9-bus test system	Enhanced Steady state and Transient stability
[66]	2018	Hybrid MMC	Mathematical modelling MATLAB	Improved efficiency of the converter
[67]	2019	Hybrid cascaded multilevel converter	PSCAD/EMTDC	Voltage stability attained
[68]	2019	Hybrid active load and ideal synchronous condenser-based	IEEE 14-Bus system	Load flow done using NR method
[69]	2019	Three-Phase, Triple Inverter Modular Topology	MATLAB/SIMULINK	1.Var compensation 2.Improved Voltage regulation
[70]	2019	Holomorphic Embedding Load Flow Method	IEEE 30-bus system	Improved convergence characteristics
[71]	2020	GDQ-DP Model	MATLAB-SIMULINK	THD achieved using both eigenvalues and impedance analysis.
[72]	2020	Simulation Models Based on MMC	100 MVA/33 kV ES-STATCOM	Reduced computation time
[73]	2020	Reliability-Oriented Design of MMC	17 MVA/13.8kV MMC-STATCOM PLECS and MATLAB	1. Reduced cost 2. Improved voltage and Current profile
[74]	2021	Cascaded H-Bridge	400V/7.5 KVAR Prototype	Compensate negative sequence current
[75]	2021	Battery energy storage system	25MVA/75MWH STATCOM connected to 34.5 grid	Optimum submodule voltage reference is obtained.
[76]	2022	Cascaded H-Bridge	MATLAB-SIMULINK	Eliminations of ripple



01. Voltage Source Converter Based
[30,35,37,43,52,57,64]
Major Outcomes: 1) Power estimation, 2) THD, 3) Power Quality Enhancement, 4) DOPSO, 5) Stability Enhancement

02. Pulse Width Modulation Based
[28,46,58,59,60]
Major Outcomes: 1) Voltage balance, 2) THD, 3) Stability Enhancement Under Unbalanced Conditions, 4) Current Control, 5) Improved Transient Response, 5) Voltage swell

03. Modular Multilevel Converter Based
[31,38,39,41,44,45,48,67]
Major Outcomes: 1) THD, 2) Dynamic Stability, 3) Enhanced Dynamic Performance, 4) Improved efficiency of converter, 5) Improved Current and Voltage Profile.

04. Software Based
[32,47,53,71,72]
Major Outcomes: 1) Voltage Stability, 2) Transient and steady state stability, 3) Damping of low frequency oscillation, 4) Reduced Computation Time.

05. Load flow Model
[50,51,54,68,70]
Major Outcomes: 1) 1. Enhanced Voltage Regulation, 2) Load flow analysis using NR method, 3) Improved Convergence characteristics.

FIGURE 3. **A detailed summary of different aspects of the STATCOM modelling.**

Figure 2 shows a summarizing diagram of the comprehensive review of STATCOM. In it, the literature review of STATCOM is divided into seven categories. The first and second branches of the diagram show the various aspects of STATCOM modelling and STATCOM controller development techniques, respectively. The third and fourth branches

TABLE 2. Various controller design techniques of the STATCOM [73], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100], [101], [102], [103], [104], [105], [106], [107], [108], [109], [110], [111], [112], [113], [114], [115], [116], [117], [118], [119], [120], [121], [122], [123], [124], [125], [126], [127], [128], [129], [130], [131], [132], [133], [134], [135], [136], [137], [138], [139], [140], [141], [142], [143], [144], [145], [146], [147], [148], [149], [150], [151], [152], [153], [154], [155], [156], [157], [158], [159], [160], [161], [162], [163], [164], [165], [166], [167], [168], [169], [170], [171], [172], [173], [174], [175], [176], [177], [178], [179], [180], [181], [182], [183], [184], [185], [186], [187], [188], [189].

Ref No.	Year	Controller Design Technique	Test System/ Software Used	Major Outcomes
[77]	2008	Cascaded H-bridge controller	250V DC bus voltage lab setup, MATLAB simulation	1.Voltage balanced under symmetrical and asymmetrical conditions. 2. Equal distribution of reactive power to the H-bridges.
[78]	2008	PI controller	PSCAD/EMTD	1. Interconnection performance enhanced 2. Fast recovery from fault observed
[79]	2008	Root locus method, pole-zero cancellation method	5KVA lab prototype, MATLAB	1. First-order system response without overshoots and oscillations were observed. 2. Fast transient response noted
[80]	2008	Two-leg three-phase inverter control	230KV experimental test setup	Effectively tracked performance between SSSC and STATCOM
[81]	2008	FPGA, multilevel inverter controller	PSCAD/EMTDC	DOPSO
[82]	2008	Neuro-fuzzy controller based on HDP	12 bus system of STATCOM	DOPSO
[83]	2008	PI controller	One-line First-order diagram of SIEG	Frequency controlled
[84]	2008	Voltage and flux modulation scheme	PSCAD/EMTDC	1.Reduced reactive power support during the fault. 2.Higher VSC transient current peak with flux modulation
[85]	2009	Fuzzy-PI based direct output voltage control	300KVAR lab setup, MATLAB/Simulink	Improved static and dynamic performance
[86]	2009	SVM	5 level 1.5MVA/4.16KV STATCOM, PSCAD/EMTD	1.Voltage balanced 2. Control of reactive power
[87]	2009	Non-linear controller	115KV experimental test setup, PSCAD	1.Voltage flicker mitigated 2. Reduced EAF- induced aperiodic oscillations in the system.
[88]	2009	Feedback control, FPGA	MATLAB	Voltage balanced
[89]	2009	Software-based	3 bus system MATLAB/SIMULINK	1. Compensated unbalanced load currents 2. Improved voltage regulation
[90]	2009	Fuzzy- Mamdani Logic Controller	RTDS	1.Power system stability attained 2.DOPSO
[91]	2010	Feedback control	100MVA experimental test setup, MATLAB	1.DOPSO 2. Enhanced transient stability 3. Power quality improved under different operation conditions
[92]	2010	PI controller with particle swarm optimization	1.5K V experimental test setup, MATLAB	Improved dynamic performance
[93]	2010	Damping control algorithm	PSCAD/EMTDC	DOPSO
[94]	2010	Sliding mode controller	3.3KV experimental test setup	DOPSO
[95]	2010	Feedback controller	MATLAB	Improved transient characteristics over a wide range of operating conditions.
[96]	2011	Feedback linearization	IEEE-118 bus system, MATLAB	Enhanced performance and stability of the system under different loading conditions
[97]	2011	I/O linearization	MATLAB	1.DOPSO 2. Improved transient performance
[98]	2011	PI controller	MATLAB	DOPSO
[99]	2011	PID controller	5 bus system	1.DOPSO 2. Enhanced dynamic stability
[100]	2012	I/O linearization	Mathematical modelling	DOPSO
[101]	2012	Heuristic Model Predictive Control	415-V 10-kVA experimental system	1. Voltage stability 2. Current tracking performance enhanced
[102]	2012	Multi-DSP and -FPGA-Based Digital Control	154-kV, 50-MVAr system	1. Improved reliability, ease in implementation 2. Enhanced steady state and transient stability
[103]	2013	Decentralized and hierarchical control	Microgrid,3 bus system	Elimination of voltage harmonics, Optimal power flow
[104]	2013	Model predictive control	415VAC,19 level H-bridge, Saber	THD obtained using two phase-shifted carrier modulation
[105]	2013	PID controller	IEEE-43 bus system, MATLAB	Optimal VAR planning performed
[106]	2013	Dc voltage control	3 KVA lab prototype	Reactive power compensated
[107]	2013	FPGA,DSP	1KVA lab prototype, VSC based STATCOM	Reduced computation time
[108]	2013	Multilevel SVPWM	5 level DCMC machine based	Voltage balanced
[109]	2013	Hybrid PID, fuzzy logic	IEEE-10 bus system, MATLAB/Simulink	Enhanced system stability in different operating conditions
[110]	2013	FPGA	1KVA lab prototype	Low cost FPGA design observed
[111]	2014	SHE-PWM	360KVA D-STATCOM lab setup, MATLAB/Simulink	1.THD without effecting structure of inverter circuit. 2. DC voltage improved
[112]	2014	Average power balancing controller	1KVAR lab prototype	1.Optimal power flow 2. DC voltage balanced under balanced and unbalanced conditions

TABLE 2. ***(Continued.)*** **Various controller design techniques of the STATCOM [73], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100], [101], [102], [103], [104], [105], [106], [107], [108], [109], [110], [111], [112], [113], [114], [115], [116], [117], [118], [119], [120], [121], [122], [123], [124], [125], [126], [127], [128], [129], [130], [131], [132], [133], [134], [135], [136], [137], [138], [139], [140], [141], [142], [143], [144], [145], [146], [147], [148], [149], [150], [151], [152], [153], [154], [155], [156], [157], [158], [159], [160], [161], [162], [163], [164], [165], [166], [167], [168], [169], [170], [171], [172], [173], [174], [175], [176], [177], [178], [179], [180], [181], [182], [183], [184], [185], [186], [187], [188], [189].**

[113]	2014	ANCF control algorithm	STATCOM-VFD system	Voltage and frequency controlled
[114]	2014	Shuffled frog lapping algorithm	Grid-connected wind farm system at Hokkaido Island, Japan, Software: PSCAD/EMTDC	Enhanced transient stability
[115]	2014	LCL filter(Inductor-capacitor-inductor)	PSCAD	DOPSO with reduced weight, cost, rating of equipment
[116]	2014	Indirect current control	IEEE 519 system, MATLAB/Simulink	Voltage balanced under different operating conditions
[117]	2014	Minimum switching loss PWM	150 KVA lab prototype	Reduced power losses
[118]	2014	DQ frame theory based control algorithm	3.7KW,230V lab prototype	1. Suppress the harmonics injected by consumer loads 2. Voltage stability, reactive power compensation. 3.Current balancing capability under unbalanced system
[119]	2014	Adaptive PI controller	100 MVAR lab prototype, MATLAB/Simulink	Enhanced system stability in different operating conditions
[120]	2014	Voltage support control strategies	2.33KVA STATCOM experimental setup	Voltage balance under balanced and unbalanced conditions
[121]	2014	Decentralized and P-Q control	DSP	Voltage balance under unbalanced conditions
[122]	2015	Monte Carlo method	Dongguan city power grid, MATLAB simulations	Optimal capacity, planning and sizing of STATCOM
[123]	2015	Online reference limitation method algorithm	3 bus system	1.Voltage stability 2.Current balancing capability under unbalanced system achieved
[124]	2015	Online reference limitation method algorithm	MATLAB Simulink	Validated voltage and current balancing capability using MATLAB/Simulink
[125]	2015	State feedback control strategy	PSCAD/EMTDC	1.Voltage balanced 2.Remarkable dynamic response was achieved
[126]	2015	Slew reset regulator	PSS	Effective dynamic control observed
[127]	2016	DC voltage control	1140V line grid system	THD and third-order harmonic zero-sequence voltages are spontaneously allocated to fully use the remaining modulation capacity.
[128]	2016	DC voltage balancing control	220V 1KVA star connected H-bridge convertor	Reduced voltage sag
[129]	2016	Decoupled control system	MATLAB	Improved transient response
[130]	2016	Fast model predictive control	100V 2.5KVAR experimental setup, MATLAB	Global optimization of the system
[131]	2016	IPCC	Cascaded 10MVAR /10KV STATCOM,PSCAD	THD achieved unbalanced grid voltage
[132]	2016	Passivity based control	3 bus system experimental setup, MATLAB	Improved transient response
[133]	2016	Sliding mode control	MATLAB/Simulink	THD and provide active power and reactive power with variable solar irradiance
[134]	2017	Deadbeat control	MATLAB/Simulink	Fast voltage regulation during voltage disturbance
[135]	2017	BMI based multi objective control	NYPS -NETS	DOPSO
[136]	2017	Clustered voltage balancing mechanism	400V/15KVAR SCHB STATCOM	Voltage balanced under symmetrical and asymmetrical conditions
[137]	2017	Digital impedance pilot relaying system	PSCAD	Fault analysis using fault location algorithm
[138]	2017	Dynamic state estimation current feedback control scheme	IEEE 39 bus system	1.Voltage fluctuation mitigation 2.Enhanced dynamic stability
[139]	2017	Hybrid communication topology	13 level 6KV/1MVA STATCOM	Fast fault analysis response noted
[140]	2017	Improved robust adaptive backstepping scheme	Mathematical modelling	Enhanced transient and dynamic stability
[141]	2017	Model predictive control(capacitor less)	MATLAB	Reactive power compensated
[142]	2017	New generic plant control scheme	9 bus system, 7.5MVAR STATCOM	Voltage regulated
[143]	2017	PI controller	RTDS/MATLAB	Enhanced voltage and dynamic stability
[144]	2017	Reactive power strategy	PSCAD	Improved active and reactive power control
[145]	2017	Sliding mode control	MATLAB	Improved performance of the system against external disturbance
[146]	2017	SSO suppression method	2 machine infinite bus system	DOPSO
[147]	2017	Synchronization technique using EO algorithm	2 bus system	Stable system under unbalanced conditions

TABLE 2. ***(Continued.)*** **Various controller design techniques of the STATCOM [73], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100], [101], [102], [103], [104], [105], [106], [107], [108], [109], [110], [111], [112], [113], [114], [115], [116], [117], [118], [119], [120], [121], [122], [123], [124], [125], [126], [127], [128], [129], [130], [131], [132], [133], [134], [135], [136], [137], [138], [139], [140], [141], [142], [143], [144], [145], [146], [147], [148], [149], [150], [151], [152], [153], [154], [155], [156], [157], [158], [159], [160], [161], [162], [163], [164], [165], [166], [167], [168], [169], [170], [171], [172], [173], [174], [175], [176], [177], [178], [179], [180], [181], [182], [183], [184], [185], [186], [187], [188], [189].**

[148]	2017	Virtual resistor circuit based control scheme	PSCAD	Voltage balance under symmetrical and asymmetrical conditions
[149]	2017	Voltage balancing technique	7 level MMCC-SSBC convertor	Controlled highest peak current or the maximum modulation index
[150]	2018	Hysteresis control	10 KVA 3 level	Reduce switching losses
[151]	2018	General decentralized control scheme	Cascaded STATCOM in medium/high voltage power system	Improved power quality and reliability
[152]	2018	HHT based online differential relay algorithm	PSCAD	1.Fault analysis 2.Improved power flow control 3.Increased reliability of the system
[153]	2018	Predictive control strategy	MATLAB	DOPSO
[154]	2018	Current limit control using PCC control algorithm	3 bus system, dSPACE DS1103 platform	DOPSO 2.Stable system under balanced and unbalanced conditions
[155]	2018	Type 2 based closed-loop based PI controller	3 bus system, MATLAB/Simulink	Reactive power compensated
[156]	2018	New fault-tolerant strategy with SHE-PWM	PSCAD,3 phase 7 level CHB based STATCOM	Fault analysis
[157]	2018	SHE technique	PSCAD/EMTDC	1. Reduced switching losses, 2. Enhanced steady state and dynamic stability, 3. Increased efficiency
[158]	2019	Hysteresis control	MATLAB/Simulink	Fast dynamic response and inherent protection against over-current
[159]	2019	STFPC	MATLAB	Improved performance of the system against external disturbance
[160]	2019	Adaptive Controller	DIgSILENT PowerFactory	Enhanced steady state and dynamic stability
[161]	2019	Clustered Voltage Balancing	MATLAB	1.Fast dynamic response observed 2.Sytem stability under balanced condition
[162]	2019	Voltage Balancing Scheme	13-level simulated system and 9-level experimental platform	Reactive power compensation in balanced and unbalanced conditions achieved
[163]	2019	Adaptive zero dynamic	Kundur's four-machine two-area, IEEE 39-bus power system	1.Improved Voltage regulation 2.Enhanced transient stability
[164]	2019	PI controller	IEEE standard 421.5-2016	Enhanced dynamic stability
[165]	2019	Model Predictive Control	15-level CHB STATCOM	Enhanced dynamic stability
[166]	2019	Improved Adaptive Backstepping algorithm	Single machine infinite bus system (SMIBS),MATLAB	1.Enhanced the convergence speed 2. Fast system response 3.Enhanced transient stability
[167]	2019	Auto-Tuning Technique	MATLAB	1. Technique meet IEEE 519 Standard for Harmonic Control in Electric Power Systems. 2. Total harmonics distortion with high disturbance rejection.3. Compensates lagging power factor loads using inductive energy storage elements.
[168]	2019	Reactive Power Estimation Method	Hybrid STATCOM in Jeju island power system	Reactive power compensated
[169]	2019	Optimized Pulse Pattern	Mathematical modelling	Enhanced transient stability
[170]	2019	Active Disturbance Rejection Control	MATLAB/Simulink	Improve in capacitor current.
[171]	2020	Hysteresis control	MATLAB/Simulink	1. Four level current hysteresis control, 2. Harmonics current filtering 3. Reactive power compensation and Fast dynamic response.
[172]	2020	FDL with model predictive control	5 level CHB Convertor	1. Improved reliability in the stability of the system 2. Fault analysis
[173]	2020	ASFC Scheme	MATLAB/Simulink	Enhanced dynamic stability
[174]	2020	CHB STATCOM based on DC link voltage shaping	MATLAB/Simulink	1. Harmonics analysis between Conventional LC STATCOM and proposed CHB STATCOM 2. The output voltage THD is capacitive mode is 43.3% for conventional and 29.2% for proposed. 3. In inductive mode 48% for conventional and 33.6% for proposed. 4. control of average current of dc-dc converter
[175]	2020	Incremental Passivity control	1 kVA Prototype	Enhanced transient and steady state stability
[176]	2020	Closed loop Analytic Filtering	MATLAB/Simulink	1. A harmonic-free filtered signal is obtained in the steady-state. 2. It also provides information regarding the state of health of capacitors, which can be used to forecast failures in the converter. 3. Enhanced steady state stability
[177]	2021	Hysteresis control	MATLAB	Reduce the change of reactive power and voltage under variation
[178]	2021	Parallel hybrid converter (PHC)	MATLAB/Simulink	1. Eliminate the requirement of DC-filter inductor 2. Balance capacitor voltage during unbalanced grid conditions.
[179]	2021	Linear Active disturbance rejection controller	MATLAB/Simulink	1. Better tracking performance 2. Better Anti interference performance
[180]	2021	Constrained model predictive control	MATLAB/Simulink	Suppression of induced oscillation
[181]	2021	Broadband Impedance shaping control	Hardware in the loop	Improve system stability

TABLE 2. ***(Continued.)*** **Various controller design techniques of the STATCOM [73], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100], [101], [102], [103], [104], [105], [106], [107], [108], [109], [110], [111], [112], [113], [114], [115], [116], [117], [118], [119], [120], [121], [122], [123], [124], [125], [126], [127], [128], [129], [130], [131], [132], [133], [134], [135], [136], [137], [138], [139], [140], [141], [142], [143], [144], [145], [146], [147], [148], [149], [150], [151], [152], [153], [154], [155], [156], [157], [158], [159], [160], [161], [162], [163], [164], [165], [166], [167], [168], [169], [170], [171], [172], [173], [174], [175], [176], [177], [178], [179], [180], [181], [182], [183], [184], [185], [186], [187], [188], [189].**

[182]	2021	Voltage Sensitivity approach based adaptive droop control	IEEE 39 bus system	Achieving better voltage regulation
[183]	2022	Proportional plus resonant controller	MATLAB/Simulink	Mitigation of voltage imbalance
[184]	2022	One cycle based controller	MATLAB/Simulink	1. Improvement in voltage sag, swell. 2. Reduction in voltage disturbance and harmonics
[185]	2023	PI Controller	MATLAB/Simulink	Mitigation of Ferro-resonance over voltage
[186]	2023	Reinforcement learning based sliding mode control (RL-SMC)	MATLAB/Simulink	1. Reactive power compensation 2. Reduction in cost
[187]	2023	Synchro converter based photovoltaic (PV) system	EMTDC/PSCAD	1. Reactive power compensation in day and night time 2. Enhanced power transfer capability
[188]	2023	LC filter design	MATLAB/Simulink	1. Voltage regulation 2. Cost effective, power quality
[189]	2024	Optimal discontinuous pulse width modulation	Experimental prototype	Reduction in switching losses

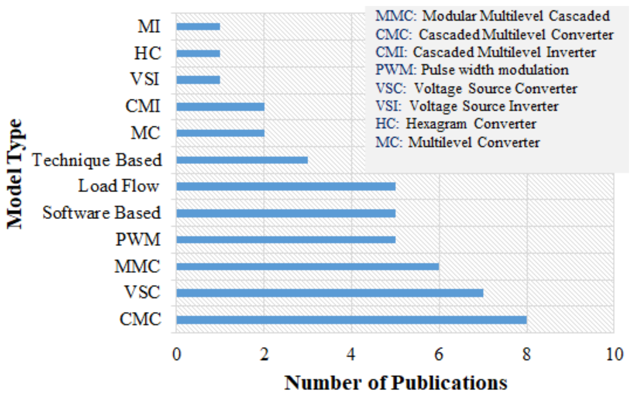


FIGURE 4. **Representation of different types of STATCOM models versus publications.**

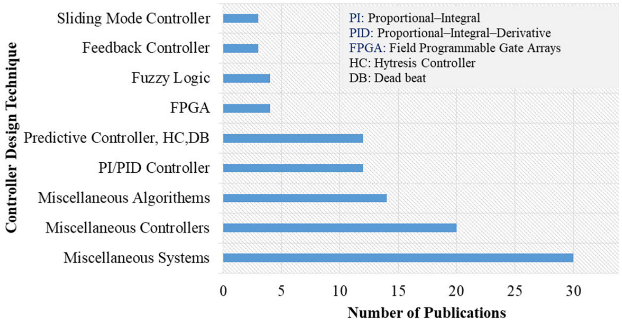


FIGURE 5. **Representation of STATCOM's controller design techniques versus publications.**

deal with the effects of STATCOM on system stability and the optimal location and sizing of STATCOM, respectively. The fifth and sixth branches cover the integration of renewable energy sources with STATCOM and applications of STATCOM in different areas of energy systems. Finally, the seventh branch shows the real installation of STATCOM at various locations.

III. DIFFERENT ASPECTS OF STATCOM MODELLING

In recent years, many modern models and topologies have been developed for STATCOM. A considerable number of publications have been made on cascaded multilevel converters [31], [38], [39], [41], [44], [45], [48], [67]. As shown in Figure 3, good work has been written on VSC [30], [35], [37], [43], [52], [57], [64], PWM [28], [46], [58], [59], [60], MMC [40], [49], [62], [63], [66], [73], software-based [32], [47], [53], [71], [72], and load flow models [50], [51], [54], [68], [70], as shown in Figure 3. Some papers on multilevel converters [33], [56], cascaded multilevel inverters [34], [55], multilevel inverters [69], VSI [36], hexagram converters [42], and novel techniques [29], [61], [65] have been observed. MATLAB, PSCAD, laboratory prototypes, and various IEEE-bus systems are used as test systems to verify the novel techniques and configurations presented by the publications. The majority of the papers focus on enhancing the voltage stability of the system, THD, and minimizing the power losses and cost of the system. Table 1 gives an overview of the different aspects of STATCOM modelling [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76]. Figure 3 shows a summary of the different aspects of STATCOM modelling, while Figure 4 shows the representation of the different types of STATCOM models compared to the publications.

IV. CONTROLLER DESIGN TECHNIQUE FOR STATCO

It can be observed that there have been major developments in control design techniques in the last 16 years, as evidenced by Figure 5. In addition, many new control

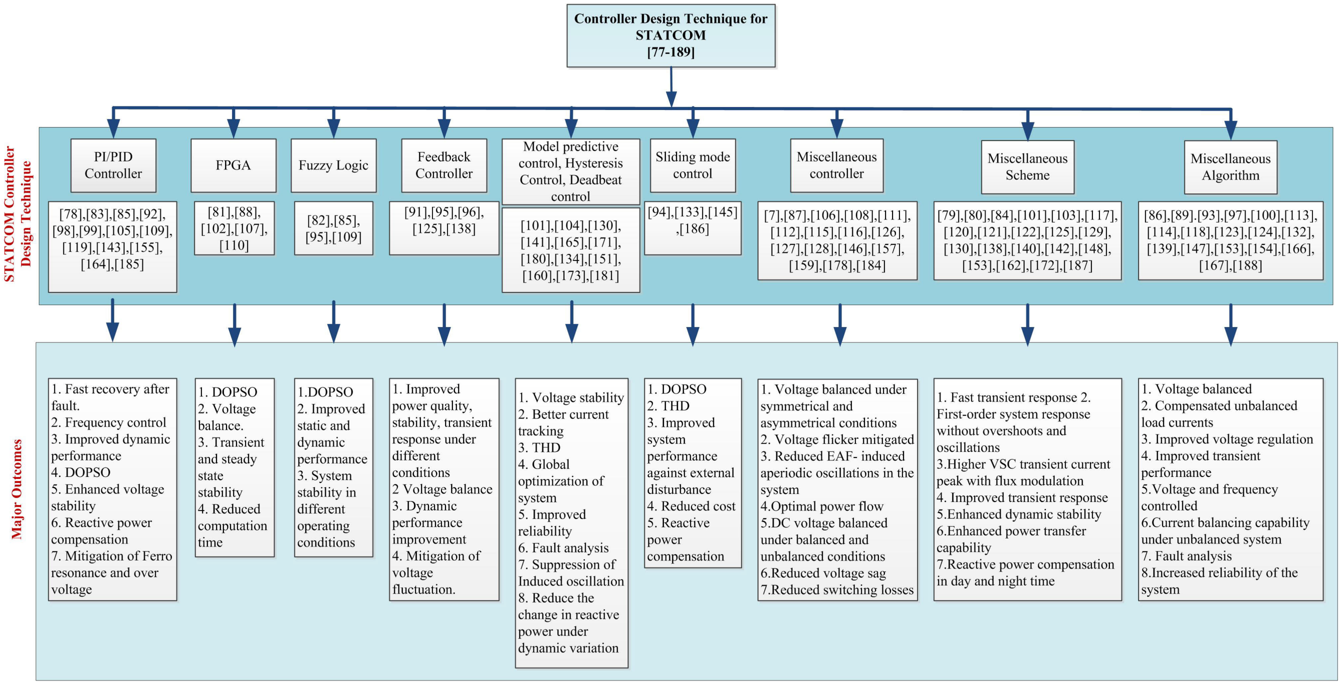


FIGURE 6. An exhaustive review summary of different controller design techniques for STATCOM.

TABLE 3. Impact of STATCOM on electrical power system stability [60], [190], [191], [192], [193], [194], [195], [196], [197], [198], [199], [200], [201], [202], [203], [204], [205], [206], [207], [208].

Ref No.	Year	Test System/ Software Used	Stability			Major Outcome
			SSS	Transient	Dynamic	
[190]	2009	-		√		Uninterrupted operation during faulty conditions and Transient stability is improved.
[191]	2013	PSCAD		√		1. Control the generation of harmonics from STATCOM by managing the switching frequency. 2. Transient stability
[192]	2013	4 parallel 5 bus system			√	DOPSO
[193]	2013	Wind diesel hybrid power system		√	√	Dynamic and transient stability achieved
[194]	2014	PSCAD	√			Healthy parallel operation observed
[195]	2015	MATLAB		√		Reliability and transient response is achieved
[196]	2015	11 bus 2 area system		√		VR in multi-machine power systems is achieved
[197]	2015	10 kVAr prototype	√	√		Enhanced transient as well as steady-state stability
[198]	2016	8 bus system		√		Reduced reactive power burden and optimizes rating
[199]	2016	60 MvAr industrial STATCOM		√		Improved voltage stability
[200]	2017	9 bus system	√	√		Both transient and steady-state stability achieved
[201]	2017	8 MvAr Prototype			√	1. Optimal sizing and rating noted 2. Minimized cost and losses
[202]	2021	SMIB & IEEE 39 bus system	√		√	1. Improvement in damping 2. Overall Dynamic stability improvement.
[203]	2021	Test system			√	Voltage stability improvement.
[204]	2021	New England 39 bus system			√	Improvement in voltage stability index
[205]	2021	MATLAB		√		Dynamic and transient stability improvement.
[206]	2022	IEEE STD 1547-2018 German grid code		√		Voltage stability Improvement
[207]	2022	New England 39 bus system		√	√	1. Eigen Value analysis 2. Computation of participation factor
[208]	2022	EMTP				Analysis of small-signal stability

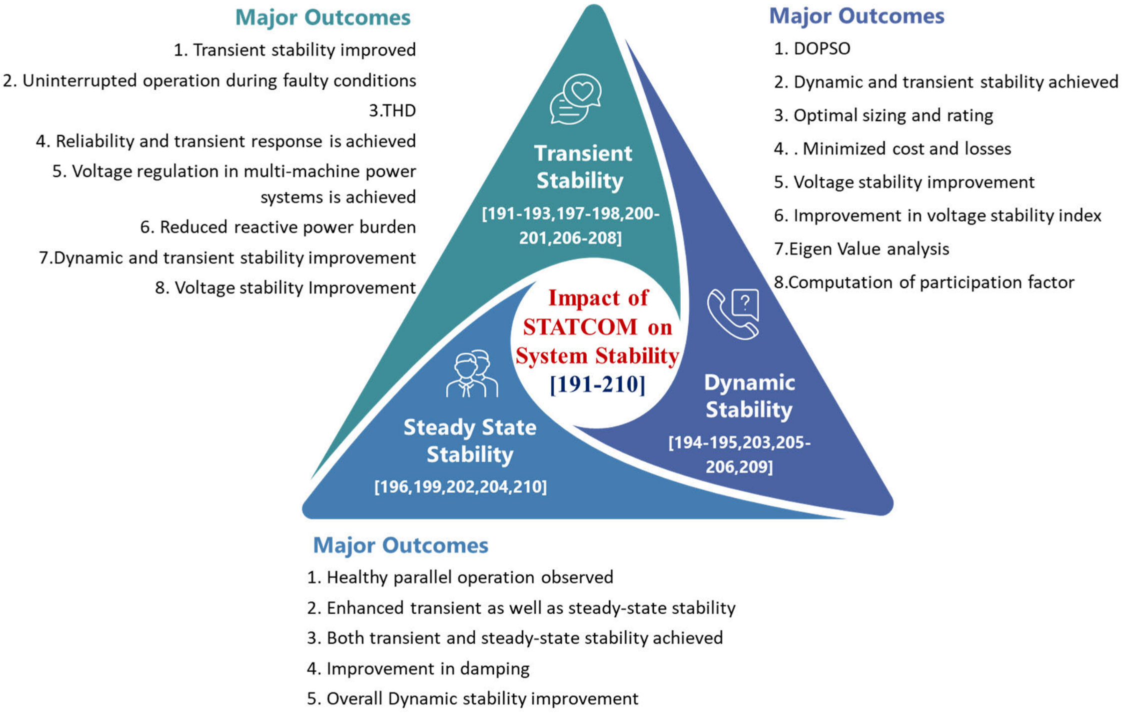


FIGURE 7. A detailed review on the impact of STATCOM on system stability.

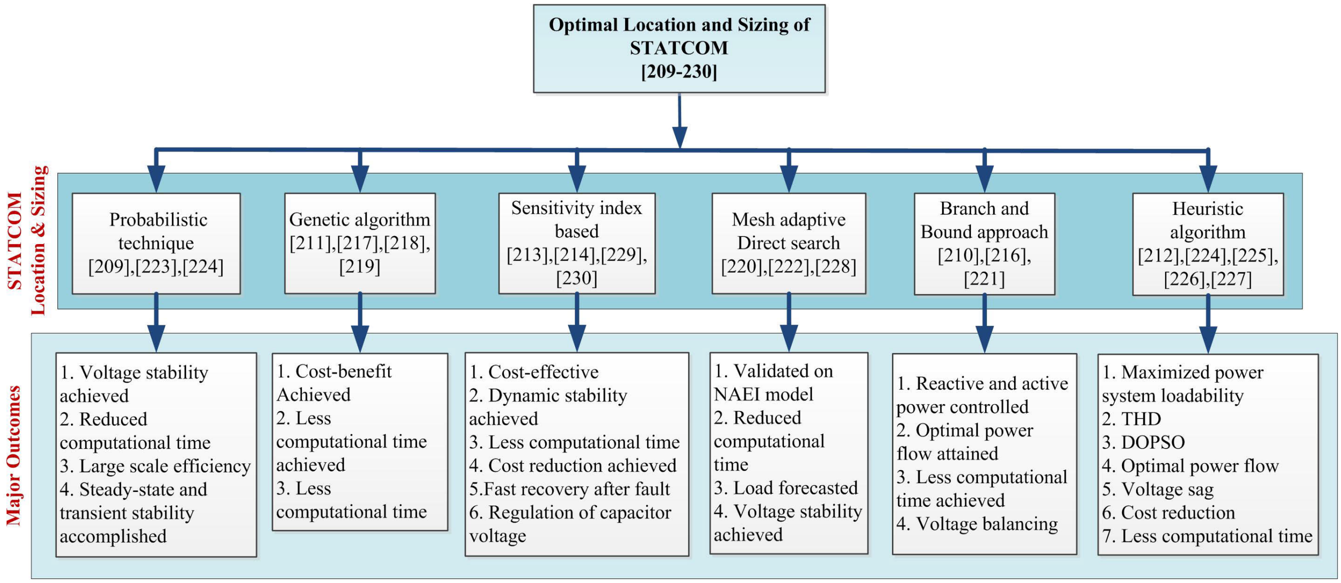


FIGURE 8. An exclusive summary of optimal location and sizing of STATCOM.

algorithms have been formulated and implemented. The most important results were DOPSO, THD, voltage balancing under balanced and unbalanced conditions, and transient and dynamic response improvement. Table 2 summarizes various techniques used to develop controllers for STATCOM [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100], [101], [102], [103], [104], [105], [106], [107], [108], [109], [110], [111], [112], [113], [114], [115], [116], [117], [118], [119], [120], [121], [122], [123], [124], [125], [126], [127], [128], [129], [130], [131], [132], [133], [134], [135], [136], [137], [138], [139], [140], [141], [142], [143], [144], [145], [146], [147], [148], [149], [150], [151], [152], [153], [154], [155], [156], [157], [158],

TABLE 4. Optimal location and sizing of STATCOM [209], [210], [211], [212], [213], [214], [215], [216], [217], [218], [219], [220], [221], [222], [223], [224], [225], [226], [227], [228], [229], [230].

Ref No.	Year	Optimization Technique	Test System/ Software Used	Major Outcome
[209]	2009	Probabilistic technique	24 bus system prototype	Voltage stability achieved and minimize demand response mismatch.
[210]	2009	Load flow study	17 bus system, 24 bus system	Reactive and active power controlled
[211]	2010	Genetic algorithm	modified IEEE 14-bus, 30-bus and 118-bus systems	Applicable for medium and large power system
[212]	2013	Heuristic algorithm	IEEE 118-bus system	Maximized power system loadability
[213]	2013	Sensitivity index based	16-bus system, 43-bus system	Cost-effective
[214]	2014	Decomposition based evolutionary algorithm	IEEE 39-bus system	1. Dynamic stability achieved 2. Less computational time 3. Cost reduction achieved
[215]	2014	Steady-state equivalent circuit	3 bus system	1. Transient stability achieved 2. LVRT capability observed
[216]	2014	Demand response mismatch	16 bus UKGDS	Optimal power flow attained
[217]	2015	EPSO	Portuguese Transmission system	Cost-benefit analyzed
[218]	2015	MVMO	39 bus system	Less computational time achieved
[219]	2015	MOP	39 bus system	Voltage stability accomplished
[220]	2017	Mesh adaptive Direct search	28 bus system	1. Validated on NAEI model 2. Reduced computational time
[221]	2017	Branch and Bound approach	7 level prototype 120V 3.2kVA	1. Less computational time achieved 2. Voltage balancing achieved
[222]	2018	ANN	16-generator, 68-bus power system	1. Stability of the power system observed 2. Load forecasted
[223]	2018	Retirement Driven Dynamic VAR planning	IEEE 39 bus system	1. Voltage Stability attained 2. Steady-state and transient stability accomplished 3. Improved dynamic stability
[224]	2018	APLC	IEEE 519 system	Mitigation of harmonics using DSTATCOM gradient decent back propagation technique. and dynamic stability improvement.
[225]	2020	AC-PSO	MATLAB	1. DOPSO 2. Optimal power flow 3. Transient Stability established
[226]	2020	MOOP	1. IEEE 30 bus system 2. IEEE 118 bus system	1. Voltage sag observed 2. Power quality managed 3. Cost reduction achieved
[227]	2020	Optimization Algorithm	150v+-28kVAr 5 layer prototype	1. FPGA used 2. Less computational time
[228]	2020	DEHS Algorithm	IEEE 30 bus system	1. Voltage stability accomplished. 2. Dynamic stability achieved in unstable conditions
[229]	2020	Reinforcement learning	9 bus system	Reduced recovery time during fault
[230]	2022	Switching Sequences	9-level 2.4 Mvar/11 kV experimental and 9-level 1.25 kVar/220 V in simulation	Regulation of capacitor voltage

which contains information about the year of publication, the name of the controller design technique, the name of the test system or software, and the main results. Figure 6 shows a summary of the different STATCOM controller design techniques in nine different categories. The PI control technique [98], [143], [164], [186] has the main advantage of damping power system oscillations. The feedback controller used in ref no. [88], [91], [95], [96], [125], and [138] has found performance comparable to the PI controller in terms of response dynamics and control effort required. The hysteresis control scheme [151], [158], [171], [177] is very useful in controlling reactive power and voltage variation. A combination of dynamic stability and damping of power system oscillation has been achieved by the PID controller in [99], [105], and [109]. As per the literature available, authors find many control techniques and algorithms for THD improvement, such as the DQ frame theory-based control algorithm, the auto-tuning technique, hysteresis control, and conventional LC-STATCOM. CHB STATCOM is based on DC link voltage shaping and closed-loop analytical filtering. All the techniques provided in the literature review show their usefulness but have some limitations with the order of harmonics. The author strongly recommends the best control technique as CHB STATCOM based on DC link voltage shaping, as it provides the best results and overcomes the conventional LC-STATCOM in both capacitive and inductive modes, as well as being explained in [174]. The output voltage THD in capacitive mode is 43.3% (conventional) and 29.2% (proposed CHB-STATCOM), while the THD in inductive mode changes from 48% (conventional) to 33.6% (proposed CHB-STATCOM). The technique is also effective for different orders of harmonics, such as 3rd, 5th, 11th, and 13th.

V. IMPACT OF STATCOM ON SYSTEM STABILITY

Papers enhancing steady-state, transient, or dynamic stability have been summarized in Table 3. It can be noted that publications have been tested on software like MATLAB [195] and PSCAD [60], [191], [194], as well as industrial prototypes. Various outcomes have been observed, including better

TABLE 5. Integration of renewable energy sources with STATCOM [200], [201], [202], [203], [204], [205], [206], [207], [208], [209], [210], [211], [212], [213], [214], [215], [216], [217], [218], [219], [220], [221], [222].

Ref No.	Year	Types Of Renewable Source	Test System/ Software Used	Major Outcome
[231]	2008	Wind	12 bus system, PSCAD	1.Enhanced performance of the system 2.Reduced voltage fluctuations
[232]	2009	BESS	PSCAD/EMTDC Real-time simulator	1.STATCOM with energy storage 2. Enhanced Voltage Stability
[233]	2010	Wind	VSI based STATCOM	Voltage stability attained using eign structured assignment.
[234]	2010	Wind	2 bus system	1.Voltage stability achieved 2. provides acceptable post fault performance for both small and large perturbations
[235]	2010	Wind	MATLAB	1. Power quality improved 2. Battery energy storage system observed
[236]	2010	Wind	PSCAD	1. Transient Stability accomplished 2. Multi wind turbine system
[237]	2010	BESS	PSCAD	DOPSO
[238]	2015	Wind	14 bus system	Stability of rotor angle observed
[239]	2015	Wind	PSCAD	Fault analyzed
[240]	2015	Wind	4 bus system	1. Improved transient stability 2. Fault analysis observed
[241]	2019	PV	PSCAD	Fault analyzed
[242]	2019	Wind	PSCAD	Optimal power flow noted
[243]	2019	PV	IEEE 4 bus system IEEE 13 bus system	1. improve the short-term voltage stability 2. maximizes the active power support
[244]	2019	Wind	PSCAD/EMTDC	Reactive power support under low voltage condition
[245]	2019	Wind	DIgSILENT /Power Factory platform	1. Cost reduction 2. Voltage stability attained
[246]	2019	PV	1. SMIB 2. 2 area 4 machine system 3.12 bus FACTS power system	1. DOPSO 2. Reduction in cost
[247]	2019	Wind	The wind power system in Jing Xia area	DOPSO
[248]	2020	PV	2 area 4 machine system	1. DOPSO 2. Voltage stability (verified by NERC)
[249]	2021	Wind	Type IV wind turbine	Mitigate resonance
[250]	2021	Wind	50 MW DWF and +/-5Mvar	Suppressing unbalanced grid voltage
[251]	2021	Wind and PV	Experimental setup	1. Regulation of reactive power 2. Improve dynamic performance
[252]	2022	Wind and PV	MATALB	Small signal stability
[253]	2022	Wind and PV	Microgrid in MATLAB	Reducing in power fluctuations.
[254]	2023	Wind	PSS and R-SFCL	Improvement of rotor angle and frequency stability

FIGURE 9. Different types of optimization techniques separated year wise.

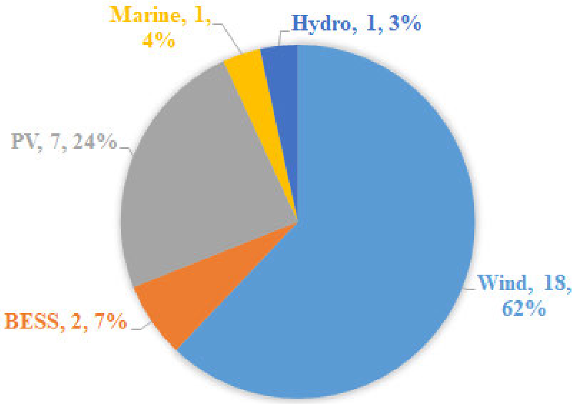


FIGURE 10. Comparison of research in various renewable energy sources.

performances [190], [194], [198] and system stability [60], [193], [195], [197], [199], [200]. Table 3 shows the summary of the impact of STATCOM on electrical power system stability [60], [190], [191], [192], [193], [194], [195], [196], [197], [198], [199], [200], [201], [202], [203], [204], [205], [206], [207], [208], whereas the graphical representation of the review of the impact of STATCOM on system stability is shown in Figure 7.

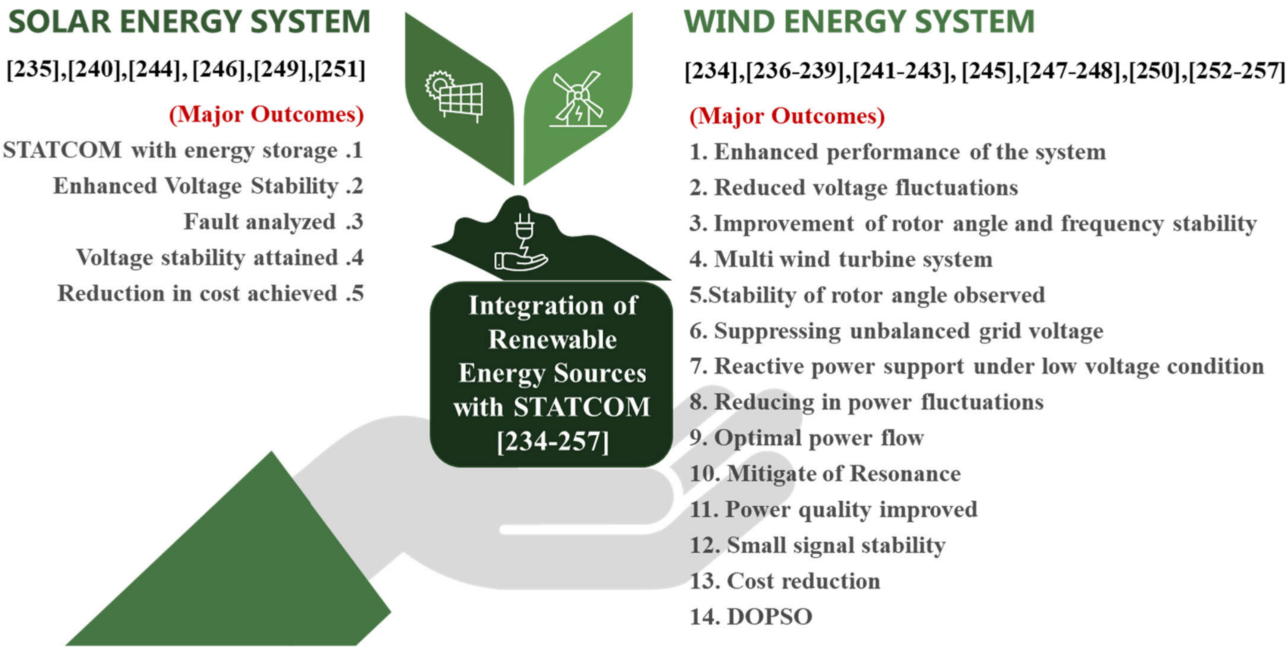


FIGURE 11. A graphical view: Integration of renewable energy sources with STATCOM.

VI. OPTIMAL LOCATION AND SIZING OF STATCOM

All the publications under optimal location and size have unique optimization techniques. They have been tested on MATLAB [225], transmission systems [217], and different bus systems. Major conclusions of these papers include improved system stability [209], [214], [215], [219], [223], [228], reduction in computational time [214], [220], [227], and benefit in cost [213], [214], [216], [226]. Few papers have accomplished multiple objectives [214], [226], [235]. Table 4 and Figures 8–9 show a summary of the optimal location and size of STATCOM [209], [210], [211], [212], [213], [214], [215], [216], [217], [218], [219], [220], [221], [222], [223], [224], [225], [226], [227], [228], [229], [230]. Figure 8 shows the summary of optimal location and sizing of STATCOM under six different categories, whereas different types of optimization techniques separated year-wise are shown in Figure 9. Figure 10 shows the research done on different types of renewable sources. The graph shows that wind and PV are the most renewable systems used by the researchers.

VII. INTEGRATION OF RENEWABLE ENERGY SOURCES WITH STATCOM

Papers that show relations to renewable energy sources have been put together in Figure 10-11. The main subcategories were noticed to be Wind [229], [233], [234], [235], [236], [238], [239], [240], [241], [242], [242], [243], [244], [244], [245], [245], [246], [247], [247], [248], [249], [250], PV [241], [243], [246], [248], and BESS [232], [237]. Papers that have been addressed in different categories but have a hint of renewable energy sources have also been considered in the comparison graph. From table 5, it can be deduced that PSCAD [229], [232], [236], [237], [239], [241], [242], [244] is the most used software for testing. The common interpretation of these papers is that system stability [232], [233], [234], [235], [236], [238], [240], [243], [246], [248] has been achieved, damped power oscillations [237], [246], [247], [248], [251] were observed, and faults have been analyzed [239], [240], [241], [253]. Table 5 represents a summary of the integration of renewable energy sources with STATCOM [231], [232], [233], [234], [235], [236], [237], [238], [239], [240], [241], [242], [243], [244], [245], [246], [247], [248], [249], [250], [251], [252], [253], [254]. Figure 10 shows the main comparison of research on various renewable energy sources, which includes the five main energy resources in this study. Whereas a graphical view (Integration of Renewable Energy Sources with STATCOM) is represented in Figure 11.

VIII. APPLICATIONS OF STATCOM IN DIFFERENT AREA OF POWER SYSTEMS

The work presented in this section projects the various applications of STATCOM in power electronics. Researchers have used various test systems like IEEE bus standards, kV prototypes, etc., and software like MATLAB, PSCAD, and EMTDC to simulate and execute the outcomes. The conclusions from the various papers have been noted to be DOPSO, fault analysis, and THD, transient stability. The major outcomes delivered from the first paper on solar power were the integration of PV-STATCOM and active power enhancement during the day and night. Figure 12 depicts a tree diagram for the application of STATCOM in different areas of power systems, which includes six major areas of applications.

TABLE 6. Applications of STATCOM in different area of power systems [223], [224], [225], [226], [227], [228], [229], [230], [231], [232], [233], [234], [235], [236], [237], [238], [239], [240], [241], [242], [243], [244], [245], [246], [247], [248], [249], [250], [251], [252], [253], [254], [255], [256], [257], [258], [259], [260], [261], [262], [263], [264], [265], [266], [267], [268], [269], [270], [271], [272], [273], [274], [275], [276], [277], [278], [279], [280], [281], [282], [283], [284], [285], [286], [287], [288], [289], [290].

Ref No.	Year	Category	Test System/Software Used	Major Outcomes
[255]	2008	H-bridge, VSC	EMTDC	1.Improved HVDC Transmission 2.Steady State And Dynamic behavior
[256]	2008	H-bridge, VSC	1.EMTDC 2.7-level MLVR–VSC	1.Improved HVDC Transmission 2.Steady State And Dynamic behavior
[257]	2009	Active, Reactive Power Control	PSCAD , EMTDC	DOPSO
[258]	2009	Fault Analysis	11-level 4-kW CM prototype	Balanced Load Voltage At All Operating Conditions
[259]	2010	High Voltage	MATLAB	1.DOPSO 2.Steady State And Dynamic Stability
[260]	2010	Fault Analysis	2 bus system	Fault Analysis Was Done
[261]	2010	Genetic Algorithms Optimization	295 bus system and 278 branches	Voltage Regulation Mitigation Was Done
[262]	2011	Fault Analysis	PSCAD	Transient Stability Achieved
[263]	2011	1.Fault Analysis 2.THD	1. 115KV generator 2.PSCAD 3. EMTDC	1.Transient Stability 2.Voltage was controlled 3. Over modulation required for the 9-level converter increases the content of the lower frequency harmonics. While the third harmonic is quite high during the fault, comes to pre-defined level after clearing the fault, whereas the fifth and seventh remain fairly high due to the over modulation. Even though they are increased over the pre fault value, they still remain under the 1.5%-limit required
[264]	2011	Fault Analysis	12 bus system	Reactive Power Compensated
[265]	2011	Voltage Mitigation	MATLAB	Transient Stability Achieved
[266]	2011	1.Renewable 2.Fault Analysis	PSCAD	Transient Stability Achieved
[267]	2012	Fault Analysis	PSCAD	Error Minimized For Line Parameter
[268]	2012	Renewable	39 bus IEEE	Voltage Stability Achieved
[269]	2013	Fault Analysis	PSCAD	Reduced Voltage Fluctuation And Unbalanced Operating Condition
[270]	2013	Optimal Power Flow	PSCAD	Fault Analyzed Under Unbalanced Operating Condition
[271]	2013	Voltage Mitigation	220 V	Voltage Fluctuation Mitigation
[272]	2013	Fault Analysis	22 KW lab setup	Voltage Stability During Grid Fault Achieved
[273]	2013	Fault Analysis	10KVA	DC Link voltage controlled by ESS and LSC
[274]	2013	Optimal Power Flow	5KVA prototype	Power Factor Close to Unity , THD
[275]	2014	SSR	PSCAD	1.Transient Steady State Attained 2.Fault Clearance
[276]	2014	THD	154KV +- 50M Var	1. Increase in THD not more than 10% in worst case. 2. Elimination of Coupling T/F Core
[277]	2014	Fault Analysis	PSCAD	Transient Analysis Was Done For Fault Analysis
[278]	2014	Fault Analysis	20 MW demonstration equipment	Reduced Fault Current
[279]	2014	THD	11 KV prototype	1.SHE PWM 2. 19th level H STATCOM is analyzed assuming efficiency 98% and Capacitance deviation ±5 %. Decrease THD from 2.20% to 2.03%.
[280]	2015	Energy Storage	75 KVA Lab setup	DOPSO
[281]	2015	Energy Storage	MATLAB	DOPSO, Enhanced Transient Performance
[282]	2015	Fault Analysis	Commercial DSP	Fault And Harmonic Analysis Was Done
[283]	2015	Solar Power	PSCAD , 8 bus system	Integrated PV -STATCOM , Active Power Enhanced In Day And Night
[284]	2015	Optimal Power Flow	MATLAB. 5 bus system	Enhanced Of Active Power For Interconnected Power System
[285]	2016	Load Flow	5 bus system	Load Flow Problem Was Analyzed
[286]	2016	Voltage Mitigation	Delta connected STATCOM	1.Compensated Reactive Power 2.Unbalanced Operating Condition
[287]	2016	Renewable	C++ programming	1.Used for Power Supply 2. DOPSO in Unbalanced Condition
[288]	2016	Power Quality Improvement	230 V prototype STATCOM	Steady State And Transient State Improved
[289]	2016	Current	PSCAD	Technique for Fast Detection of Short Circuit Current in PV Distributed Generator

TABLE 6. ***(Continued.)*** **Applications of STATCOM in different area of power systems [223], [224], [225], [226], [227], [228], [229], [230], [231], [232], [233], [234], [235], [236], [237], [238], [239], [240], [241], [242], [243], [244], [245], [246], [247], [248], [249], [250], [251], [252], [253], [254], [255], [256], [257], [258], [259], [260], [261], [262], [263], [264], [265], [266], [267], [268], [269], [270], [271], [272], [273], [274], [275], [276], [277], [278], [279], [280], [281], [282], [283], [284], [285], [286], [287], [288], [289], [290].**

[290]	2017	Active, Reactive Power Compensation	220 V,1KVA lab setup	Load Compensated Under Unbalanced Condition
[291]	2017	Fault Analysis	PSCAD	Improved Active And Reactive Power Control
[292]	2017	THD	PSCAD	THD and interaction between current and voltage harmonics is analyzed.
[293]	2017	System Stability	Interconnected Of Onshore And Offshore Wind Farms	DOPSO
[294]	2017	System Stability	Interconnected Of Onshore And Offshore Wind Farms	Transient Stability Achieved
[295]	2017	THD	2 bus system	1.Low Switching Loss 2. Effective Switching Frequency analyzed
[296]	2017	THD	3 level/ 15 KV prototype	1. This scheme reduced the 5th and 7th harmonics from the grid currents. The overall THD is 2.8% .2. Transient stability achieved
[297]	2018	Active, Reactive Power Control	SMIB	Active And Reactive Power Controlled
[298]	2018	Voltage Stability	2 bus system	Active Power Flow Controlled
[299]	2018	Voltage Stability	23 bus system	Reduced Losses
[300]	2018	Fault Analysis	7 level delta connection	Fault analyzed
[301]	2018	THD	MATLAB	Optimal Sizing/Rating Attained
[302]	2019	Fault Analysis of Fault-Current	400 MW -300KV MML rating	1.Reactive Power Compensated 2.Validated Fault- Current Blocking Performance
[303]	2019	Fault Analysis	3 LNPC	Low Cost , Fault analyzed
[304]	2019	THD	380 V/15 KVA STATCOM	Third Order Harmonic Current Suppressed
[305]	2019	Renewable (BESS)	32 Bus System	Transient System Stabilized
[306]	2019	Fault Analysis	80 Mvar /33 KV	1.Reactive Power Compensated 2.Grid Fault analyzed
[307]	2019	Power Loss Management	150 KVA STATCOM	1.THD 2.Output Current Quality Improved
[308]	2019	THD	Star/ Delta Connected STATCOM	1.For 3rd harmonics suppression the filter parameter chosen are 1mH, 1 ohm. 2.Compensated unbalanced load current
[309]	2020	1.CHB converter 2.THD	Laboratory scale, 8 machine system	1.Voltage Stability 2. To reduce the effect of 5th and 7th harmonics, two filter bank selected, one notch filter frequency tuned to 4.08 and other high pass filter tuned to 6. For 11th and 13th order the high pass filter tuned to 10.
[310]	2020	Voltage Stability	PSCAD	Voltage Stability Under Unbalanced Condition
[311]	2020	BESS	Reel time simulation	DOSSR
[312]	2020	Multiple STATCOM	IEEE 14 BUS	1.DOPSO 2.Transient stability obtained
[313]	2020	Voltage Load	IEEE New England 39 BUS	Optimal Placement And Operating Rating Of STATCOM
[314]	2020	Optimal Power Flow	PSCAD	Voltage Balanced Under Unbalanced Condition
[315]	2020	Optimal Power Flow	PSCAD	(LTG, LL, LLG) Fault analyzed
[316]	2020	Stability Analysis	MATLAB	1. Active and Reactive Current Controlled 2. Voltage Stability Achieved
[317]	2021	THD	Laboratory Prototype	Elimination of over modulation
[318]	2021	THD	MATLAB	Less change in current di/dt
[319]	2022	THD	MATLAB	1. Distortion of ZERO Harmonics 2. Improvement in power factor
[320]	2022	THD	OPAL-RT Platform	Improvement in static and dynamic performance
[321]	2023	THD	+/- 500 Kv/3000 MW line	Measure of Harmonics Instability
[322]	2024	THD	400V/7.5 kVar prototype	1. Maximize reactive power output 2. Decrease over current and over modulation risks

A detailed analysis of the number of publications published in various categories of the application has been depicted in Figure 13. It was observed that the maximum publication of the papers has been done under the categories of fault analysis, THD, and voltage stability. Table 6 represents a summary of the applications of STATCOM in different areas of power systems [255], [256], [257], [258], [259], [260], [261], [262], [263], [264], [265], [266], [267], [268], [269], [270], [271], [272], [273], [274], [275], [276], [277], [278], [279], [280], [281], [282], [283], [284], [285], [286], [287],

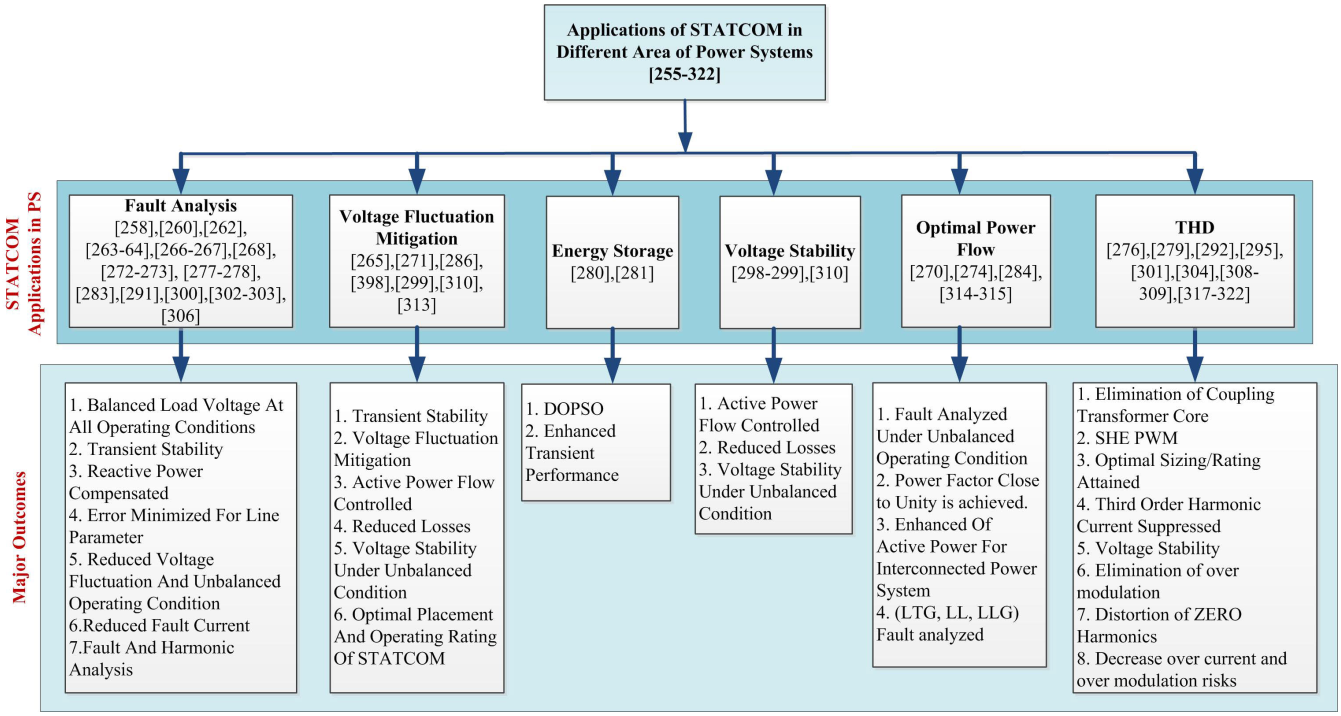


FIGURE 12. A tree diagram: Application of The STATCOM in different areas of power system.

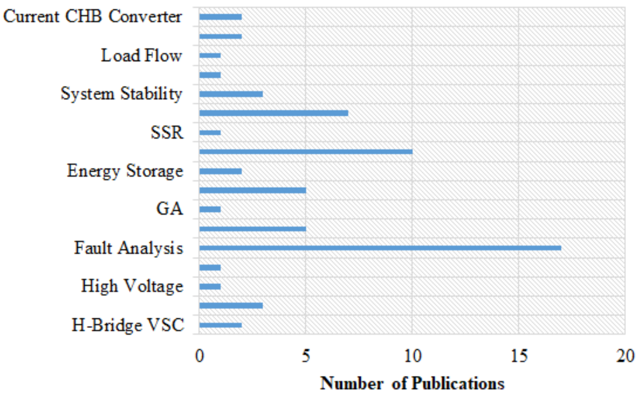


FIGURE 13. Representation of STATCOM's applications versus publications.

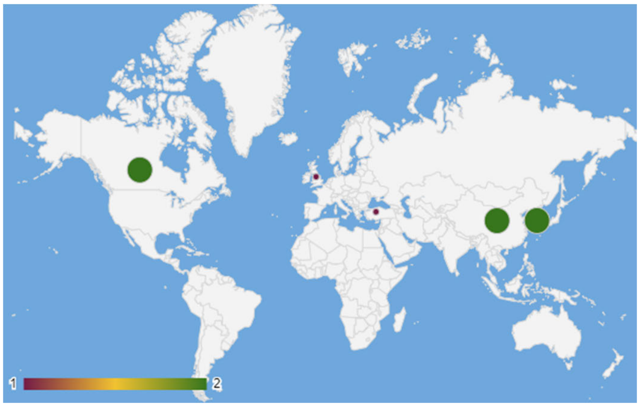


FIGURE 14. Locations over the world where installations of STATCOM has been done.

[288], [289], [290], [291], [292], [293], [294], [295], [296], [297], [298], [299], [300], [301], [302], [303], [304], [305], [306], [307], [308], [309], [310], [311], [312], [313], [314], [315], [316], [317], [318], [319], [320], [321], [322].

IX. REAL-SITE INSTALLATION OF STATCOM IN THE WORLD

Over the past 16 years, few papers showing a detailed study of STATCOM installation have been observed. These papers have shown categorical enhancements in the pre-existing power generation and transmission systems. These enhancements have been in terms of operational experience, stability, voltage regulation, and reactive power compensation. Figure 9 has been attached, displaying the locations of the installed systems around the globe. It is established through the figures that installations have been done in China [200], [327], Korea [323], [326], Canada [324], [328], Great Britain [324], and Ankara [225].

The real installation of STATCOM around the Seoul metropolitan area of north-west South Korea is reported in [323]. A STATCOM of 100 MVAR capacity was installed at Migcum. The main objective was to achieve voltage stability around the Seoul metropolitan area. The operation principle of median voltage STATCOMs and their operation experience, which were actually installed in Great Britain and Canada, are exhibited in [324]. Overall stability, including voltage stability and total harmonic distortion, is achieved in unbalanced grid conditions. STATCOM-based

21-level inverters are implemented on a transmission line of 154 KV+/− 50 Mvar, as showcased in [325]. Active voltage harmonics filtering and dynamic reactive power compensation are achieved. A delta structure connected to +/− 200 MVAr STATCOM based on a cascaded H-bridge converter is installed in China's southern grid, as explained in [200]. In this paper, the use of multi-STATCOMs is explained to improve the stability of both AC and DC power systems. For the full utilization of STATCOM installed at Korean Electric Power, a special protection scheme is explained in [326]. This scheme is very helpful in reducing the tripping of generators during overload conditions. The urgency of the installation of the DC network by replacing the AC/DC interconnected network at the China Southern Grid is exhibited in [327]. In this paper, STATCOM is installed to mitigate the instability that occurs during the faulty condition. A PV solar-based STATCOM to be utilized in the daytime and nighttime is installed in Canada, as explained in [328]. This STATCOM is used with a 10-KW solar system. A continuous, stable operation is achieved for the induction machine during the unbalanced condition.

X. CONCLUSION

This paper has presented a deep analytical review of STATCOM and its associated applications in power systems. In the modelling of STATCOM, different types of modelling schemes used by the authors are reported. The major modelling concepts are based on a cascaded multilevel converter (CMC), voltage source inverter, PWM, software-based model, and load flow model. In controller design techniques, mainly PID, PI, and fuzzy logic-based controllers, feedback controllers, model predictive-based controllers, sliding mode control, and other miscellaneous controllers, schemes, and algorithms are exhibited. A lot of references on the impact of STATCOM on system stability, which includes steady state, transient, and dynamic stability, are reported. After that, optimal sizing and location based on probabilistic technique, genetic algorithm, sensitivity index-based, mesh adaptive direct approach, branch and bound approach have been discussed. Moreover, special attention has been paid to the applications of STATCOM and its use for achieving THD, voltage mitigation, DOPSO, fault analysis, and optimal power flow. After that, the real installation location of STATCOM is cited. Finally, the research gap is identified, and the future scope of STATCOM is explained.

The literature review presented on STATCOM concludes that considerable work has been done in developing different control schemes and modelling techniques to improve the performance of power systems. Recent publications show remarkable work in increasing the efficiency of renewable energy sources. However, various aspects of STATCOM are yet to be explored.

There are some fields in which very little work has been done. The future scope of STATCOM's research is as follows:

1. Modelling of STATCOM in Current Source Inverter: In the modelling of STATCOM, a number of methods are used. Most methods are based on voltage source inverters and PWM; very little work is reported on CSI-based STATCOM. The CSI-based STATCOM needs to be explored more, as CSI has many advantages over VSI, such as: 1) it can be used for high power ratings; 2) there is no need for an anti-parallel diode; and 3) there is a reduction in cost.
2. Implementation of Heuristic Technique with Optimal Sizing of STATCOM: The existing research work mainly focuses on the genetic algorithm and probabilistic approach. No paper reported the use of techniques such as particle swarm optimization or neural networks. Nowadays, mainly heuristic techniques are available that can be used to find the optimal location of STATCOM.
3. STATCOM for problems in power systems such as power swing, power fluctuation, and the Ferranti effect: During this review, the author finds many applications of STATCOM, such as total harmonic distortion, voltage fluctuation, voltage stability, sag, and swell. In very crisp mitigation of power swing, fluctuation is not reported by any researcher. This could also be the probable next area of research.
4. Integration of STATCOM with PV Solar: In this review, a number of papers report on wind farm integration with STATCOM. Very few papers have been reported on the integration of STATCOM with solar. This area can be explored to decrease the load on our conventional power source and get more efficiency with the use of STATCOM.
5. FPGA for implementation of STATCOM: FPGA is a kind of technology that enables researchers to make the hardware of a component at a lower cost. Only one research paper exhibits the use of FPGA technology. So the author strongly recommends the implementation of STATCOM using an FPGA.
6. Integration of STACOM in controller designs using fuzzy techniques: In controller design techniques, very few papers reported work on fuzzy logic. In the design of the controller, the use of fuzzy logic and the FIS editor can be explored more.

Through a rigorous review of the publications, this paper concludes work done on various aspects of STATCOM. The authors have made a sincere attempt to present their findings by referencing multiple research papers on STATCOM and its associated applications. However, some research papers were not used and were hence excluded from our references. The authors apologize for the same. The authors strongly believe that this review paper will prove to be a useful resource for future researchers in this important field of research going forward.

ACKNOWLEDGMENT

The authors extend their appreciation to the Researchers Supporting Project at Intelligent Prognostic Private Limited Delhi, India, for funding this research work. They would also like to acknowledge the support from Universiti Sultan Zainal Abidin (UniSZA), Malaysia; and support from the Department of Electrical Power Engineering, Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia through research projects UTMER (Q.J130000.3823.31J06) and UTMFR (Q.J130000.3823.23H05).

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