Review: Different Technology of Thyristor Voltage Regulator

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Abstract : Greater demands have been imposed on the transmission network in recent years, and these demands will continue to rise as the number of non-utility generators grows, as will rivalry among utilities. This is compounded by the fact that obtaining new rights of way is very complicated. Increased transmission demands, a lack of long-term planning, and the need to provide open access to generating companies and customers have all contributed to a decrease in supply security and quality. FACTS technology is critical for addressing some, but not all, of these issues by allowing utilities to get the most out of their transmission infrastructure while still improving grid stability. However, much of the capacity enhancement requirements would necessitate the construction of new lines or the upgrade of current and voltage capability.

This paper is presented the review of different technology for thyristor voltage regulator (TVR) for transmission line power flow control and voltage profile control. The different technologies is presented and discuss like Automatic voltage restorer, Switched capacitor voltage regulator, Series voltage regulator, teaching learning based AVR, integrated voltage regulator and D-STATCOM.

***Index Terms* – Voltage regulator, Power flow control.**

I. INTRODUCTION

The introduction of cutting-edge semiconductor-controlled systems is critical to the realisation of the intelligent electrical network principle. The use of such equipment allows the electrical network to be adjusted to its current mode of operation, ensuring the best voltage level for users, an efficient allocation of active and reactive power flows in dynamic closed electrical networks, increased transmission capability, and reduced active power losses during transmission. NNSTU has created a thyristor voltage regulator (TVR) that enables the electrical network's parameters to be regulated. TVRs are phase shifting instruments that are used to redistribute power flows, increase power line transmission capability, and stabilise voltage levels [4, 5, 6, 7]. A single-line diagram of a delivery electrical network with TVR is shown in Fig. 1. A parallel transformer T3 and a serial transformer T4 are included in the TVR power segment. The transformer T3's primary windings are attached to the TVR's input terminals (network 6-20 kV). Its secondary windings are attached to the primary windings via the VS control system's thyristor switches.

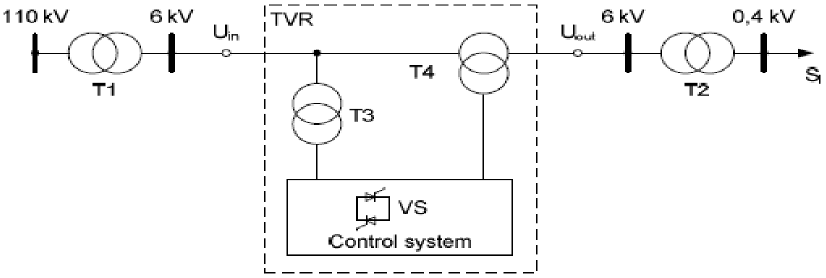

Fig.1 Thyristor voltage regulator single line diagram [1]

The secondary windings of the transformer T4, which are attached between the TVR's input (Uin) and output (Uout) terminals (in the chopping line), produce a longitudinal-transverse portion of the voltage controlled by the thyristor changes in phase and scale. The TVR control system comprises thyristor-based longitudinal and transverse control modules. The magnitude is controlled by the longitudinal control module, while the phases of the TVR output voltage relative to the input are realised by the transverse regulation module. Both modules may be used or omitted from the supply circuit of the transformer T2's primary windings using the approved circuit connections of thyristor switches. The TVR output voltage can be regulated longitudinally and laterally using a combination of transverse and longitudinal control modules.

The magnitude voltage under TVR operation is controlled by adding an additive voltage U2 into each phase line that fits or is out of phase with the phase voltages of the source U1, allowing one to obtain linear voltages in phase with the input voltages at the TVR output and increased U2.

The voltage U3 applied to each line is changed by 90° relative to the phase voltages of the U1 network, allowing line voltages at the TVR output, input voltages lagging or leading in phase by an angle. Inverse transverse-control stresses are used to create lagging voltages, while direct stresses are used to create leading voltages.

This system is designed for use in a medium voltage network (6–20 kV) and can regulate the output voltage value relative to the input voltage by 10% and change the shift angle in the main harmonic of the output voltage relative to the input voltage by 5 degrees.

II. DIFFERENT TECHNOLOGY OF THYRISTOR VOLTAGE REGULATOR (TVR)

The [1] analysis of a three-phase two-zone thyristor AVR with capacitor voltage divider provides a radical development in the usage of voltage valves, enabling the construction of high-voltage regulators without the use of high-voltage thyristors. The voltage on the thyristors now does not surpass the magnitude of the input voltage separated by the voltage regulator's number of areas.

The direct approach is extended to calculate converter energy indicators using a formula with variable parameters, resulting in differential equations with periodic discontinuous coefficients. Accounting for the first terms in the Fourier series expansion of variable coefficients has provided for analytical solutions in near form for first harmonics of both state and output variables, as well as for all of the regulator's key characteristics: load, power, and energy.

The results of the direct calculation process, together with the characteristics based on the results of the software PSIM, showed a correlation of 89 percent to 97 percent in constructed characteristics.

In this paper, we present a switched-capacitor voltage regulator (SCVR) that dithers flying capacitance to minimise output voltage ripple, as well as the benefits of doing so. SC converters are designed to operate at the highest possible frequency, and the flying capacitance for various phases is changed according to load current shift using comparators and a digital controller in the proposed technique. A 65 nm research chip with a 40-phase SCVR, 4b capacitance modulation (CM), and a 2:1 conversion ratio is used to demonstrate the proposed technique. To reliably calculate the extent and effect of ripple reduction, on-chip circuits for ripple estimation and load output monitoring were included. The results show that for an 11–142 mA load, an on-chip ripple magnitude of 6–16 mV at 1 V output is obtained at a 2.3 V input. At a power density of 0.187 W/mm2, peak performance is 70.8 percent.

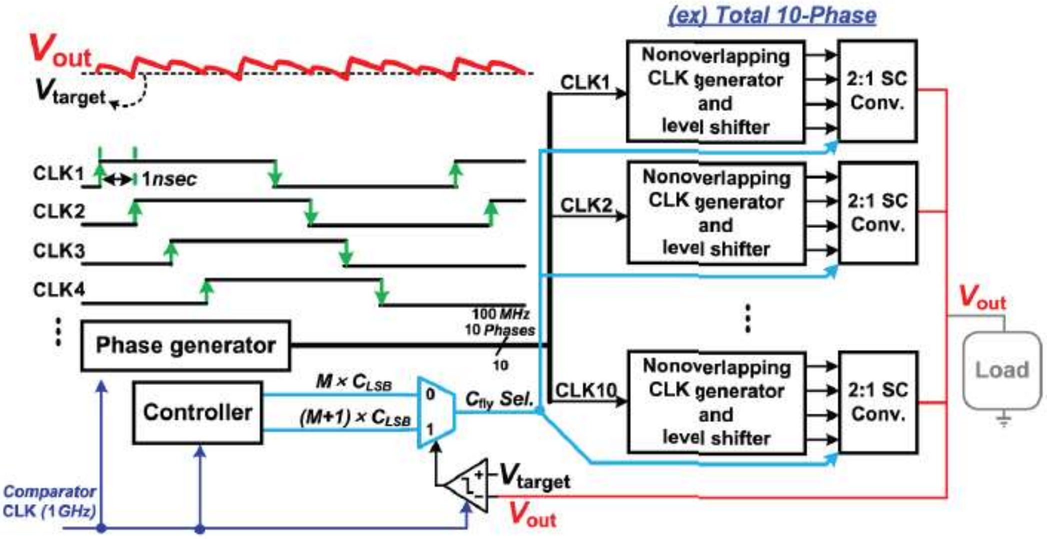

Fig.2 proposed scheme: on-demand CM [2]

The use of DCM to reduce closed-loop ripple in SCVRs with multiphase interleaving is proposed in this paper. At a constant minimum peak output voltage, ripple reduction increases load power usage and efficient input power transfer efficiency (PCEeff), resulting in lower power consumption (Vmin). With an on-chip ripple measurement circuit, a SC converter with 40-phase interleaving and 4b DCM level was implemented in 65 nm CMOS technology to achieve a ripple magnitude of 6–16 mV for load currents ranging from 11 to 142 mA.

Author [3] describes a series voltage regulator for a distribution transformer that solves power quality concerns in the electrical power distribution system. On the secondary side, the planned system consists of a line frequency transformer linked to a power electronic converter that is auto-connected. The use of a high-frequency or medium-frequency converter facilitates this auto-connection. It is explored a simpler approach for compensating for grid voltage sags and swells by supplying continuous ac voltage control. When a voltage sags or swells, the control electronic converter produces a compensating voltage that is vector-added to the grid voltage to control the output voltage to the load. In terms of increased availability, equipment protection, and stability, the proposed solution meets the needs of smart delivery grids.

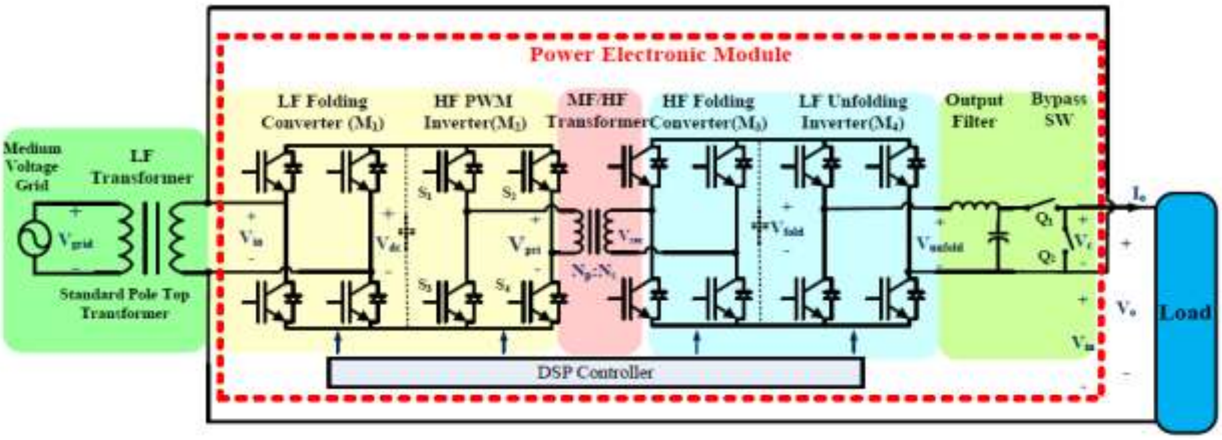

Fig.3. Distribution transformer using power electronics module [3]

A series voltage regulator for the distribution transformer has been proposed by one of the authors [3], along with its control scheme, to compensate for voltage sags/swells. To have sag or swell compensation capabilities for a power grid system, the proposed solution can be conveniently incorporated into existing traditional distribution transformers. Without a dc-link and related electrolytic capacitors, experimental findings show voltage sag and swell compensation. The PE module has a lower voltage rating due to partial power processing, and the MF/HF transformer has a lower VA rating due to the same cause. As a result, the proposed system could be used to retrofit existing distribution transformers to boost power quality in the future grid, particularly as renewable and distributed generation become more prevalent.

The teaching–learning dependent optimization (TLBO) algorithm is presented in this paper as an optimization strategy for tuning the classical controller in an automated voltage regulator (AVR). With a first order low pass filter mounted in the AVR, the proposed TLBO algorithm is used to find the optimum value of proportional integral derivative (PID) controller gains. The AVR system's voltage response as measured by the proposed TLBO-based PID controller with first-order low pass filter. This control technique has the advantage of having strong dynamic responses over a large variety of function parametric variations. The quick acting Sugeno fuzzy logic technique is used to achieve the on-line dynamic responses of the analysed model for on-line, off-nominal operating conditions. In addition, a robustness analysis is performed to evaluate the consistency of the TLBO-based PID controller. With the variations of the model parameters, a study focused on voltage response profile has been investigated.

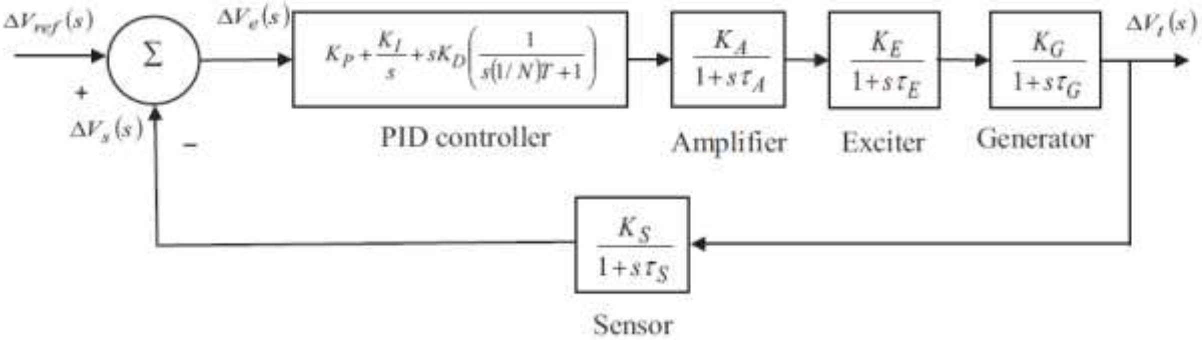

Fig.4. Transfer function block diagram of the AVR system with PID controller [4]

Author [4], TLBO is proposed for tuning the PID controller gains and low-pass filter parameters for the AVR system with off-line nominal input state. As compared to other techniques used in recent state-of-the-art literatures, the dynamic response profile of the terminal voltage obtained using the TLBO based PID controller indicates that TLBO is a significant optimization method for the AVR device. The FOD values also show that the designed controller gains are approaching those that are optimal. Furthermore, a robustness study of the TLBO-based PID controller is performed. Furthermore, a robustness study of the TLBO-based PID controller is performed. It should be remembered that it has generated satisfactory results when parameter uncertainties have varied. Furthermore, with a large adjustment in the device parameters, the tuned values of the controller gains obtained with the nominal parameters do not need to be reset. The SFL in conjunction with TLBO is used in this study to obtain an online hierarchical voltage profile of the investigated AVR model for on-line, off-nominal device parameters. SFL's task is to intelligently and linearly extrapolate the nominal optimal PID controller gains and filter parameters in order to calculate the off-nominal optimal controller gains and filter parameters. The computational pressure of SFL is observed to be noticeably low when used online. As a result, the AVR system's on-line dynamic response is TLBO-SFL based.

Granular power distribution combined with per-core microprocessor power control has the ability to greatly increase future data centre energy usage. Provided a high performance, high power density, quick response time, and high output power converter architecture, on-chip switched capacitor converters will allow such granular power delivery with per-core regulation. The implementation of an on-chip switched capacitor voltage regulator in a 32 nm SOI CMOS technology with deep trench capacitors is defined in this method [5].

For reconfigurable shifted capacitor converters, a novel feed-forward control is presented. Following a transient load stage, feed-forward control reduces output voltage droop. As a result, the minimum microprocessor supply voltage is lowered, lowering the microprocessor's average power consumption. From a 1.8 V supply, the on-chip switched capacitor voltage regulator produces a 0.7–1.1 V output voltage.

This method [5] also concludes that on-chip SCVRs, which have a reputation for being inefficient, low-power, and difficult to regulate in the past, are a viable candidate for granular microprocessor power delivery and per-core regulation. The measured performance of the presented converter places it among the top on-chip voltage regulators in terms of quality, power density, output power, and transient response time.

Author, [6] proposes a 48/1V voltage regulator module (VRM) sigma converter with high performance and power density. The Sigma converter is a quasi-parallel converter that uses a high performance uncontrolled converter to supply the majority of power to the load and a buck converter to control the output voltage. The unregulated isolated converter is an LLC converter with a matrix transformer structure that integrates four transformers into one core structure and integrates Synchronous Rectifiers (SRs) with the winding to reduce transformer termination losses and achieve high performance. To control the output voltage, the buck converter uses discrete GaN devices and a PCB winding inductor. The 48/1V-80A Sigma converter has a power density of 420W/in3 and a maximum performance of 93.4 percent.

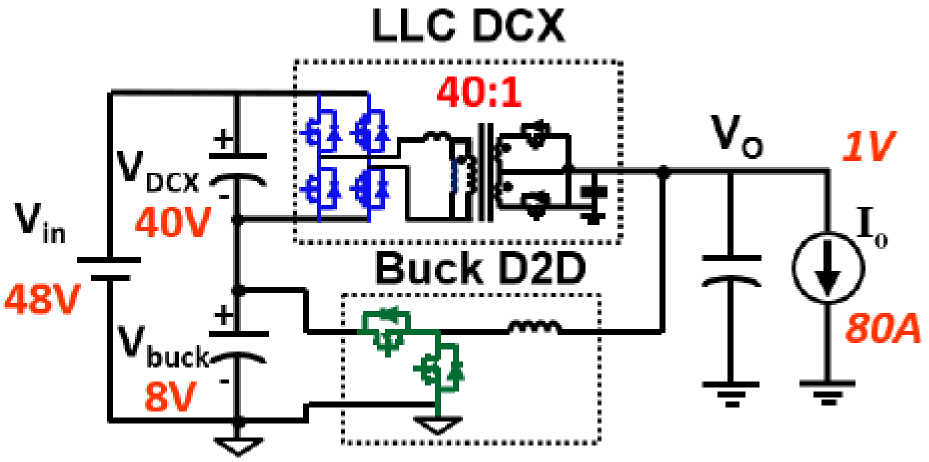

Fig.5 Sigma converter circuit [6]

The architecture optimization for this transformer was addressed in order to minimise overall transformer losses. A matrix transformer configuration for the LLC DCX was suggested, combining four transformers into one central structure and using an improved termination process. For the sigma converter, a buck converter with PCB winding inductor configuration was also presented. The sigma converter has a hardware version that achieves a maximal efficiency of 93.4 percent, a full load efficiency of 91.6 percent, and a power density of 420 W/in3, demonstrating a substantial improvement in efficiency over state-of-the-art solutions.

Control integrity architecture for noise sensitive circuits in the form of integrated voltage regulators is the subject of one of the authors [7]. (IVRs). Orthodox noise reduction and power conversion methods must be combined with IVR control systems to accommodate for dispersed load, parasitic and decoupling, and decoupling. To target noise components based on their electrical proximity to their source and the intervening IVR controls, both passive and active techniques are identified.

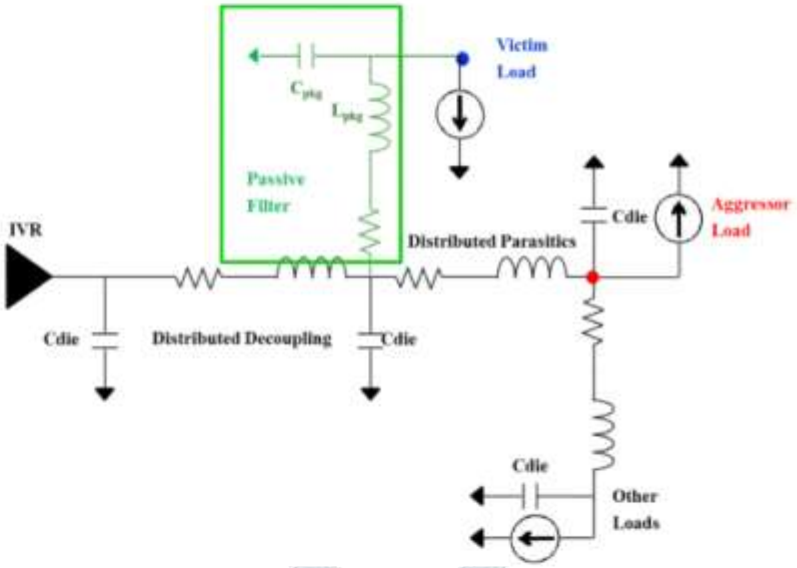

Fig.6. Cross noise suppression via package filter implementation [7]

Traditional power integrity and IVR architecture are combined in this system [7] to provide solutions for noise sensitive circuits in IVR power distribution with applications to microprocessors, FPGAs, and other complex ICs. With the movement toward higher data speeds, which necessitate tighter noise budgets, and more feature convergence, which results in a larger range of analogue and digital loads grouped on the same voltage or electrically coupled through the IVR input supply, these become increasingly necessary.

Solar power is transmitted to the grid through a PV-inverter in a grid-connected solar power station, and the battery is charged and discharged through a bi-directional converter in a traditional energy storage facility.

The battery charging and discharging is handled by an AC voltage regulator attached in series to the line in the proposed setup. Cascaded is the best choice for this device.

A PV-Inverter based on the H-Bridge (CHB) is chosen for a high-power application. Since the voltages of the inverter and the grid are not balanced, it is impossible to connect a solar inverter with the grid if one of the H-Bridges of a CHB inverter fails. The suggested architecture also allows for fault-tolerant operation of the CHB-based PV-inverter. Basic operation and regulation of a voltage regulator, implementation of the voltage regulator in grid energy storage systems, and fault tolerant operation of a CHB inverter through the voltage regulator are all discussed by the author [8]. Real-time digital models are used to verify the output of the proposed controls by interfacing the virtual power circuit with the real controller card using a real-time simulator.

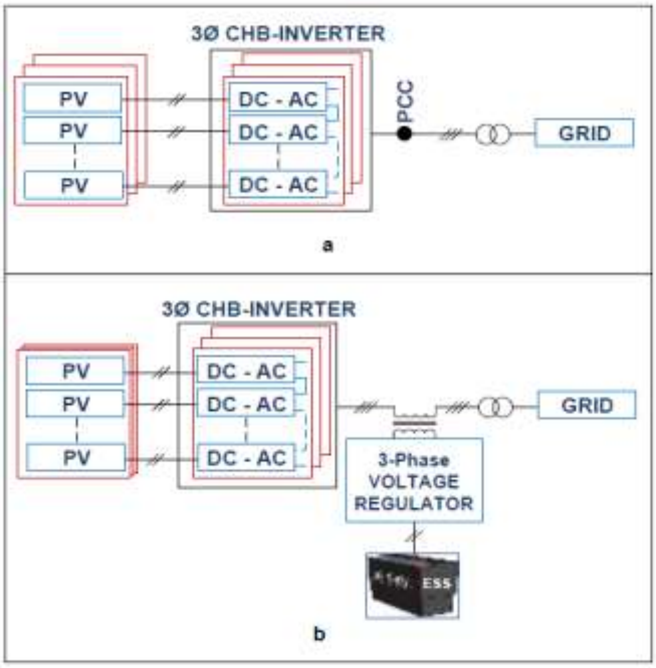

Fig.7. (a) cascaded inverter at AC side (b) CHB based PV-Inverter [8]

The author [8] introduced a voltage regulator-based energy storage device as well as its controls. The controls are implemented on a controller card based on the TMS320F2812 processor and tested in loop simulations by the controller. For a Grid-connected CHB-based Inverter for large-scale PV systems, the proposed solution allows the features of energy storage and fault-tolerant operation. During grid fluctuations, this design also increases device dynamics. The system's key flaw is that the battery charger's power is still linked to the PV-control. inverter's The use and management of the charging and discharging modes was quickly explained. The presented findings validate the systems' transient responses and find them satisfactory.

The Automatic Voltage Regulator (AVR) is a critical local mechanism for synchronous generators that keeps the rated voltage constant and controls reactive power supplied to or collected from the power system. The optimality of the AVR system must be seen as a more critical problem in terms of power efficiency, as well as system protection and reliability. According to the author [9], heuristic optimization approaches such as the Particle Swarm Optimization (PSO) Algorithm and the Global Neighborhood Algorithm (GNA) are used to tune the PID controller parameters of the AVR machine in comparison. The AVR loop's transfer feature is used to model it. Transient reaction analysis is used to compare the optimization performances of the various algorithms.

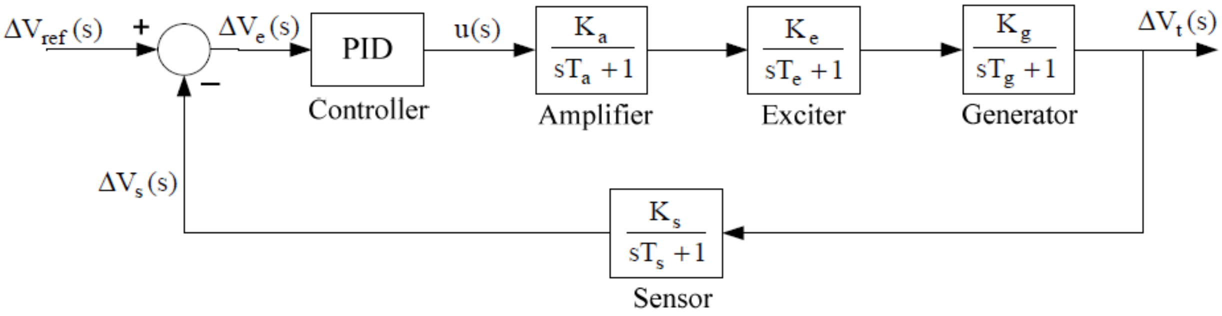

Fig.8. Model of AVR using genetic algorithm [9]

The thesis compares the use of the GNA algorithm to tune the parameters of a proposed PID controller used by an AVR method to a new area of application of the GNA algorithm. The findings of the PSO approach are used to compare the optimization efficiency of the GNA algorithm as part of a self-tuned PID controller in this analysis. While the worse overshoot is interested in the controller modified by the GNA algorithm, the best rise time and settling time are also interested in the same controller, according to the results of transient analysis. The use of the GNA algorithm to tune the parameters of a proposed PID controller used by an AVR system is compared to a new area of use of the GNA algorithm in the thesis. In this study, the PSO findings are used to compare the GNA algorithm's optimization efficiency as part of a self-tuned PID controller. According to the effects of transient analysis, the controller updated by the GNA algorithm is interested in the worst overshoot, but the best rise time and settling time are also interested in the same controller.

A voltage-controlled distribution static synchronous compensator (DSTATCOM)-based voltage regulator for low-voltage distribution grids was proposed by the author [10]. The voltage regulator is intended to meet the grid code temporarily, deferring unplanned expenditures before a permanent solution to the control problems can be anticipated. A three-phase four-wire voltage-source inverter and a second-order low-pass filter make up the power level. Three output voltage loops with active damping and two dc bus voltage loops make up the control strategy. The suggested control strategy also includes two loops: the principle of minimal power point tracking (mPPT) and the frequency loop. The mPPT causes the voltage regulator to run at its lowest power point, reducing the amount of reactive compensation that is circulated. Using only the information available at the point-of-common coupling, the frequency loop allows the voltage regulator to be independent of grid voltage information, especially the grid angle.

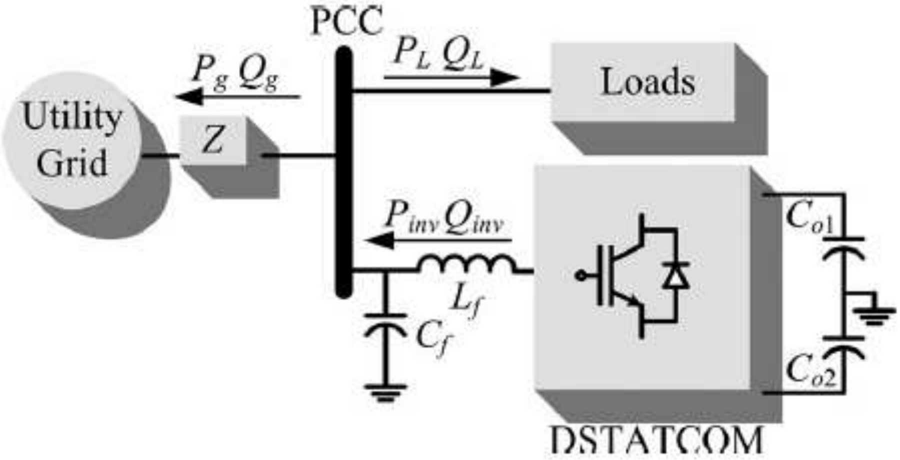

Fig.9. Voltage regulator for low voltage distribution system [10]

With a nonlinear load, the planned amplitude loop was able to decrease the voltage regulator's processed apparent power by 51%, and even more with a linear load (80 percent). When reactive power compensation is not needed, the mPPT algorithm tracked the mPP within the allowed voltage range. The amplitude loop follows the grid code as grid voltage sags and swells. The Mppt can also be used to achieve comparable effects in current-controlled DSTATCOMs.

The frequency loop maintained the compensation angle within analogue limits, raising the voltage regulator's autonomy, and the dc bus voltage was controlled at nominal value, minimising the steady-state error. The mPPT and the frequency loop were also tested at the same time.

The proposed voltage regulator is a shunt-connected solution that provides balanced and low-THD voltages to customers while being connected to low-voltage delivery grids without any power interference to the loads and without any grid voltage and impedance information.

The author proposes a Fractional Nonlinear Synergetic Controller [11] for a three-phase grid Photovoltaic (PV) system to regulate the dc-link capacitor voltage and ensure rapid transient response, low dc link voltage fluctuation, and low Total Harmonic Distortion (THD) in the current injected to the grid even when the irradiance changes. To test the proposed controller, a distinction was made using MATLAB/SIMULINK between the proposed controller and Nonlinear Synergetic and Sliding Mode Control (SMC).

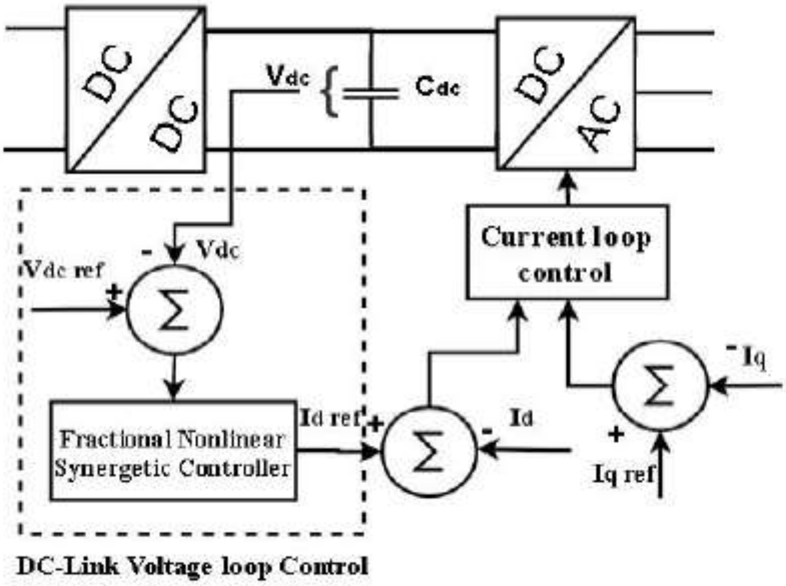

Fig.10. Block diagram of dc-link voltage controller [11]

An improved dc-link capacitor voltage regulator based on a Fractional Non-Linear Synergetic Controller for the Grid connected PV system inverter was introduced to the author [11]. The proposed controller was compared to the Nonlinear Synergetic and SMC controllers, and the simulation results showed that all controllers performed well with a constant dc-link voltage, but the proposed controller had the lowest THD and thus reduced the need for filtering in the power transmission.

A novel controller for automatic voltage regulator (AVR) systems was proposed by the author [12]. The Focused Time Delay Neural Network is used as the controller (FTDNN). The network gradient can be computed without using dynamic Back-propagation. Such complex networks cannot learn as quickly as FTDNN AVR. The simulation was run to see how the load angle and speed compared. The system's efficiency was compared to that of a Conventional AVR (C-AVR) and a Recurrent Neural Network (RNN) AVR. Simulations in Matlab/Simulink demonstrate the efficacy of the FTDNN-AVR architecture and its superior stable performance in a variety of scenarios.

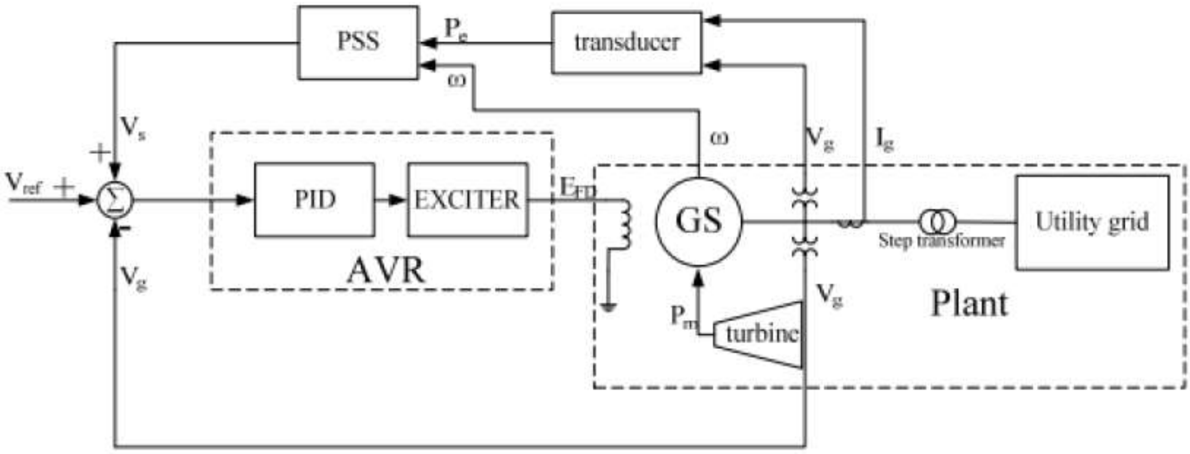

Fig.11. Block diagram of automatic voltage regulator [12]

The author [12] suggested a novel controller for automatic voltage regulator (AVR) systems. The controller is a Focused Time Delay Neural Network (FTDNN). Without using dynamic Back-propagation, the network gradient can be calculated. FTDNN AVR can't learn as well as those dynamic networks. To see how the load angle and speed matched, the simulation was run. The system's performance was equivalent to that of a Recurrent Neural Network (RNN) AVR and a Conventional AVR (C-AVR). In a number of scenarios, simulations in Matlab/Simulink show the effectiveness of the FTDNN-AVR architecture and its superior stable performance.

III. CONCLUSION

A thyristor voltage regulator that can regulate the parameters of a medium voltage electrical network has been developed. The use of TVR allows the harmonic arrangement of current and voltage to be distorted. The mathematical and Simulink models of the distribution grid segment with TVR have been created to determine the levels of harmonic components. The models' findings are almost identical, indicating that their work is right.

This paper has presented a review of different technology for thyristor voltage regulator (TVR) for transmission line power flow control and voltage profile control. The different technologies are presented and discuss like Automatic voltage restorer, Switched capacitor voltage regulator, Series voltage regulator, teaching-learning based AVR, integrated voltage regulator and D-STATCOM. This paper will be very much useful in future for students and researcher those who want to work in the field of thyristor voltage regulator system.

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