Different Techniques for Reducing Swag & Swell in Distribution Transformer: A Review

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Abstract— *A fundamental component in providing reliable electricity to the end-user is that the step-down distribution transformer. Albeit the traditional distribution transformer is comparatively inexpensive, highly efficient, and reliable, it is not bound to protect loads from undesirable events like voltage sags and swells. Voltage sags and swells became one among the foremost critical power quality issues faced by many industrial consumers in power distribution systems.*

As the complexity of the electronics equipment utilized in the economic applications grows, the customer loads were getting more susceptible to voltage disturbances like sags and swells. The voltage sags and swells were often described by two essential characteristics: magnitude and duration. The survey of power quality presents that voltage sags with 40-50% of the par value and with duration from 2 to 30 cycles occurred in about 92% of all power grid events. Hence, it is recommended to think about a deep voltage compensator for a wider range of voltage compensation over an extended steady-state period.

In this paper we present a review of various algorithms for series voltage regulator for reliable operation of distribution transformer.

Key words: Distribution transformer, series voltage regulator,

I. INTRODUCTION

The need in regulation, stabilization and improvement of AC voltage quality is actual for all AC networks, which needs creation of appropriate power electronics converters, including AC voltage regulators (AVR). Such devices often contain transformers, capacitors, inductors, increasing system size and price. Besides, estimating system at the present time is feasible to allocate a number of the foremost important AC voltage regulators: thyristor AC voltage regulators with phase control, with a voltage boost, on gates with full control with PWM control and boost regulators.

With the event of a power smart grid system, highly reliable electricity supply has become a crucial issue. A fundamental component in providing reliable electricity to the end-user is that the step-down distribution transformer. This distribution transformer operates at line frequency 50Hz to step down from medium voltage (MV) to low voltage (LV). Albeit the traditional distribution transformer is comparatively inexpensive, highly efficient, and reliable, it is not bound to protect loads from undesirable events like voltage sags and swells. Voltage sags and swells became one among the foremost critical power quality issues faced by many industrial consumers in power distribution systems. Because the complexity of the electronics equipment utilized in the economic applications grows, the customer loads were getting more susceptible to voltage disturbances like sags and swells.

Voltage sags and swells were often described by two essential characteristics: magnitude and duration. The survey of power quality presents that voltage sags with 40-50% of the par value and with duration from 2 to 30 cycles occurred in about 92% of all power grid events [1]. So as to catch up on voltage sags and swells within the power distribution system, several approaches including on-load tap changer, dynamic sag correctors, ride-through voltage compensator, dynamic voltage restorer and hybrid distribution transformer were developed.

The most common voltage compensator for the distribution transformer is that the automatic on-load taps changers, which were integrated to most distribution transformers throughout the distribution systems.

II. SERIES VOLTAGE REGULTOR FOR DISTRIBUTION TRANSFORMER

One of the techniques presents the dynamic behavior of tap changing operations in Tap Change under Load (TCUL) transformers [2]. Interactions among multiple TCUL controls cause oscillatory behavior in tap changing actions, which unnecessarily increases tap operations before they reach equilibrium. Sufficient conditions for stability were derived and features of the phenomena were examined through theoretical analysis also as through numerical simulation.

Momentary interruptions and voltage sags were liable for many of the facility quality problems found in typical industrial plants. A standard solution to the present problem was that the installation of Uninterruptible Power Supplies (UPS) [3]. However, these were costly and need maintenance. A price effective alternative was that the use of static series regulators rated a fraction of the load power. The regulators provide voltage support by injecting a voltage serial with the load. The structure presented during this paper consists in transformer coupled voltage source inverters fed from a diode bridge rectifier converter connected to the ac supply. A steady state compensation capability curve was presented by author [4]. This method proposed controls algorithms that ensure a quick dynamic voltage restoration and were insensitive to the sort of faults, disturbances and harmonics present on the facility network. Performance was illustrated for typical single and three-phase faults. The dynamic performance was verified on DSP based prototype power compensators.

It was shown that the compensator can support the load voltage for single line to ground faults (90 percent look after faults commonly encountered) with a compensator rated at 50 percent look after the load. Results also demonstrate that the transient response was fast (of the order of two ms).

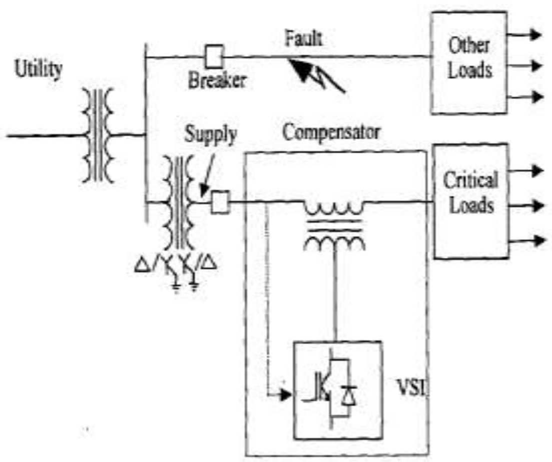

Fig. 1. Single line diagram of the series compensator [4]

The proposed Pulse Width Modulation (PWM) control strategy ensures independent control of every phase and compensates for both symmetrical and asymmetrical voltage sag disturbances [5]. Examples from simulation show good compensation for a 50% symmetrical sag and a 65% asymmetrical sag. Experimental result shows a quick detection and compensation of the disturbances.

An AC-AC three-phase Boost converter has been utilized in the facility stage. A replacement feed-forward space vector based switching technique has been shown to manage each phase independently [5]. The switching technique was predicated on the comparison of the voltages in d-q plane leading to a really fast detection and compensation method. For the implementation, no special energy storage devices were employed within the power stage. Additionally, the negative feedback circuit was predicated on a DSP implementation.

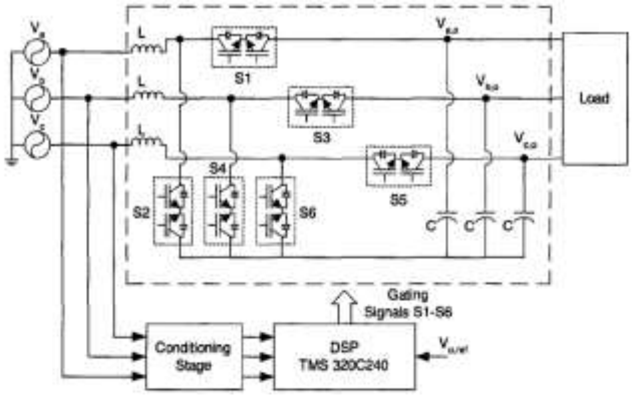

Fig. 2. Block Diagram of the Experimental Setup with Feed-forward Compensation [5]

A pulse width-modulation ac–ac converter (four insulated gate bipolar transistors per phase) alongside an autotransformer was presented by author [6]. During a disturbance like voltage sag, the proposed scheme supplies the missing voltage and helps in maintaining rated voltage at the terminals of the critical load. The approach doesn't employ any energy storage components like bulk capacitors/inductors and provides fast response at low cost. Under normal conditions the approach works in bypass mode, delivering utility power on to the load; this method of control allows the transformer to be rated just for transient conditions, thus reducing its required size. A four-step switching technique to drive the ac–ac converter was used to understand snubber less operation. A design example was presented by author [6], and simulation results were shown for a three-phase 230-V 5-kVA system. The proposed approaches were often easily integrated into a distribution transformer supplying critical loads.

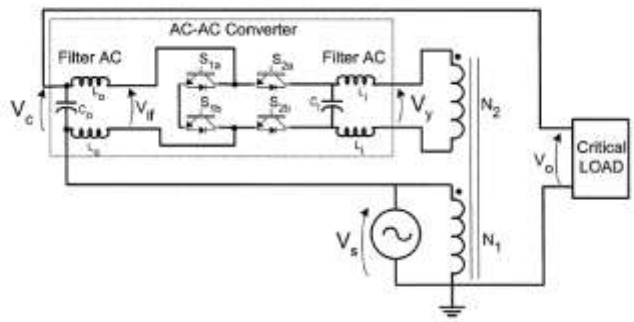

Fig. 3. AC–AC converter Topology for compensation of voltage sags [6]

The scheme employs a PWM ac–ac converter with IGBTs based autotransformer. During the traditional mode, the approach works in bypass mode, delivering utility power on to the load; this method of control allows the autotransformer to be rated just for transient conditions (i.e., for voltage sags), thus reducing its required size. Switching losses were absent during bypass mode [7]. Simulation and experimental results confirm the high speed of the proposed approach. The proposed approaches were often easily integrated into a distribution transformer supplying critical loads.

Dynamic voltage restorers (DVRs) were protecting sensitive loads from the consequences of voltage sags on the distribution feeder. A completely unique voltage sag detection technique to be used in conjunction with the most system of a DVR was presented by author [8]. It was necessary for the DVR system to not only detects the beginning and end of voltage sag but also to work out the sag depth and any associated phase shift. The DVR, which was placed serial with a sensitive load, must be ready to respond quickly to voltage sag if end users of sensitive equipment were to experience no voltage sags. A drag arises when fast evaluation of the sag depth and phase shift was required, as this information was generally embedded within the core of a main DVR control scheme and isn't readily available to either users monitoring the state of the grid or parallel controllers. This controller was required phase and sag depth information to control the injection voltage vector returned by the most controllers so as to stop the DVR injection transformers from saturating. Typical standard information tracking or detection methods like the Fourier transform or phase-locked loop (PLL) were too slow in returning this information, when either applied to the injection voltage vector or to the availability voltages directly.

A method was presented by author [9] in which voltage sag detection was done using matrix method. The matrix method was compute the phase shift and voltage reduction. The tactic also illustrates that the matrix method returns results which will be directly interpreted, whereas other methods like the wavelet transform return results which will be difficult to interpret.

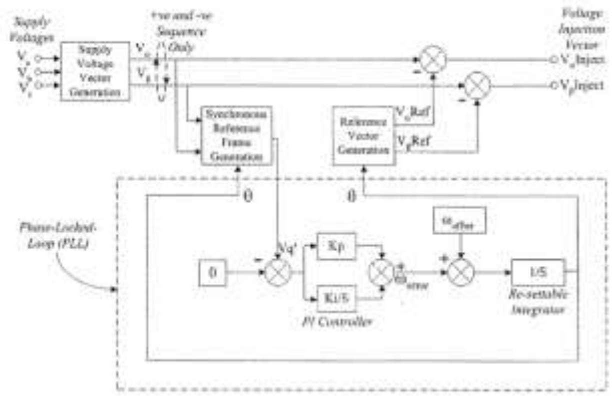

Fig. 4. Main control system topology for dynamic voltage restorer [8]

One of technique presents coordination of DG and step transformer (SVR) operations for improved distribution system voltage regulation [10]. The analysis includes DG with induction and synchronous generators and SVRs with control modes like Normal Bi-directional; Reactive Bi-directional; and Co-generation.

SVRs hold system voltages within predetermined limits and assure consumer voltage magnitudes were kept within standards. Some consumers were often far away from the regulator location, and transmission line drop, voltages at the load location were often below specified limits while voltages at the SVR location were often within limits. The transmission line drop compensation (LDC) feature, which was an integral a part of a SVR control, estimates the road drop and performs voltage corrections supported line current, line R and X parameters, and therefore the load side voltage. When reverse power flow was feasible, LDC must have adequate control algorithms to properly perform voltage corrections. There were several modes of SVR control function and therefore the impact of DG was different on each.

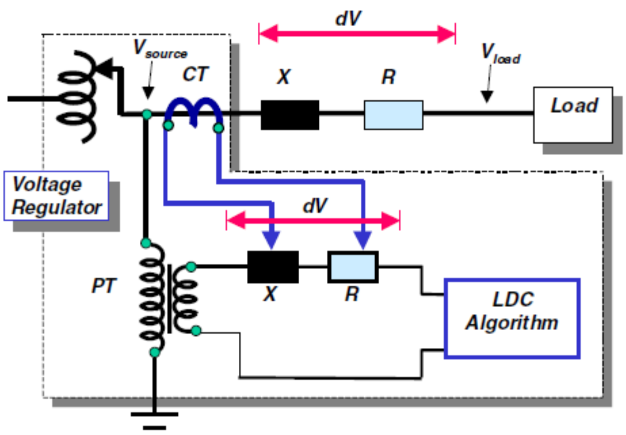

Fig.5. SVR Line Drop Compensation [10]

A single-phase fast transient converter topology with stepping inductance was proposed. The stepping inductance method was implemented by replacing the normal inductor during a buck converter by two inductors connecting serial. One has large inductance and thus the opposite has small inductance [11]. The inductor with small inductance will take over the output inductor during transient load change and speed up dynamic response. In steady state, the huge inductance takes over and keeps a substantially small ripple current and minimizes root mean square loss. It was a low cost method applicable to converters with an output inductor. The author [11] demonstrated a hardware prototype of a 1.5-V dc–dc buck converter anesthetizes a 100-A transient load change has been experimented upon to demonstrate the merit of this approach. It was also a transformer module and powers up an up to date PC computer system.

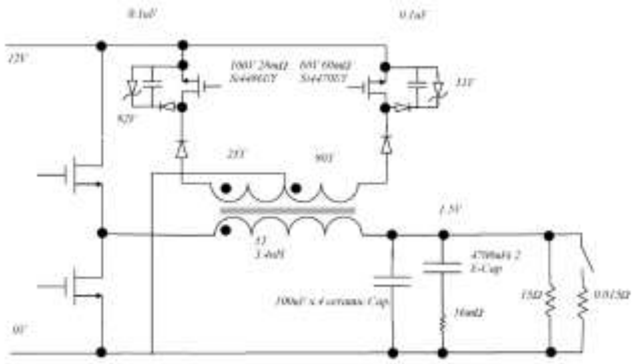

Fig.6. Simplified experimental circuit [12]

The control circuit was additionally easy to implement and may be integrated with a generic buck PWM controller microcircuit. Extra cost and style effort for such an improvement was minimal, as only a coffee cost small size component or logic circuit were needed.

Steady-state performance of the proposed solution was like today's sophisticated SR buck converter, and has, practically, little or no power loss during transient operation. For a multiphase buck converter, the amounts of phases were going to be increased because the current demand increases due to the increasing CPU speed. Consequently, the amount of buck controllers and sensing devices, and hence the value, were going to be increased [13]. But the proposed solution employs only a single-phase buck converter to supply steady-state current and with a stepping inductance circuit to tackle transient load change. It was expected that the dimensions and price was far lower fast loading change applications.

The growth of decentralized generation has consequences on Power Quality causing swells, particularly in no load scenarios. The proposed voltage regulator transformer should be installed within the substation within the low voltage side and it consists of two controlled AC/DC and DC/AC converters with an intermediate DC energy storage link [14]. The connection of these two converters to the electrical grid was performed directly through the distribution transformer and a series transformer which allows the voltage regulation on the distribution line. Additionally, the proposed system also allows the power Factor regulation of the Medium Voltage (MV).

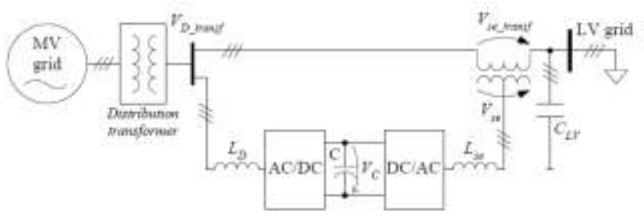

Fig.7. Distribution transformer with active voltage regulator [14]

The proposed system has shown to be an exact solution to manage the distribution line voltages. The proposed regulators present fast response times and therefore the distribution line isn't suffering from disturbances, as voltage sags or voltage swells (up to 30% of rated supply voltage) within the MV grid [15].

The use of PI compensators for voltage control has proved to be adequate showing high potential within the response to different disturbances within the simulated network, thus guaranteeing insensitivity to disturbances and therefore the system stability. The sliding mode control method of the AC/DC converter input currents associated to the space vector representation, proved to be an correct solution, guaranteeing that the converter were often seen as an almost resistive load which nearly unity PF at the input of the converter.

The proposed system has also shown an honest capability to regulate the PF within the MV, guaranteeing that the displacement factor between the voltages and therefore the currents was almost zero. This feature was extremely useful because it may allow the reduction of the MV capacitor banks that were generally improving the PF.

During one of among technique a replacement control design of an Unified Power Quality Conditioner (UPQC) for harmonics and voltage compensation during a power distribution system was presented [16]. The topology of the UPQC was based on a mix of two 3-phase series and parallel active power filters. The determination of voltage references for series active power filter was based on a robust three phase digital phase locked loop (PLL) system using fuzzy regulator. The control strategies related to fuzzy hysteresis band voltage and current control methods, where the band was modulated with the system parameters to require care of the modulation frequency nearly constant were developed. Simulation results supported MATLAB/SIMULINK was presented to verify the effectiveness and thus the viability of the proposed control technique.

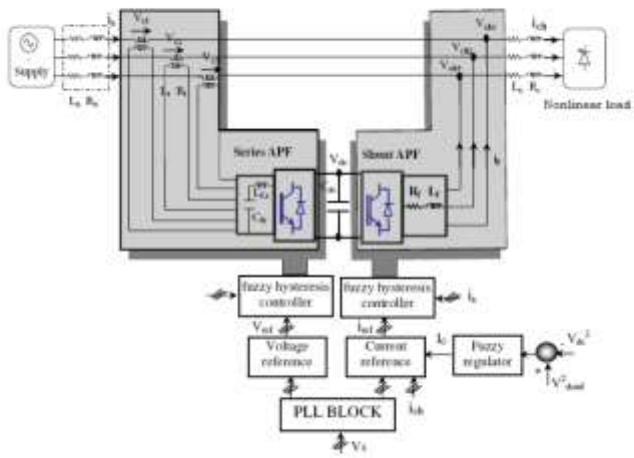

Fig. 8. Global diagram of Unified Power Quality Conditioner [16]

The determination of voltage references for series active power filter supported a strong three phase digital locked loop (PLL) using symbolic logic regulator was presented. The PLL system features a good reliability, quick tracking performances and assures a pure attenuation of undesirable supply voltage frequencies. In other hand, the UPQC has shown the power to compensate sag, unbalanced voltages and current and/or voltage harmonics supported a replacement hysteresis fuzzy band voltage and current control. The voltage bands were often easily implemented with symbolic logic to take c were of the modulation frequency nearly constant for every control. Simulation results confirms the viability of the proposed approach and proves that the UPQC, because of robust voltage and current controllers, allows to enhance power quality by maintaining the load voltage at desired level even during unbalanced, distorted or supply voltage sag conditions.

Plants and processes with a high level of commercial automation were most severely suffering from short-duration power disturbances. Such plants were frequently fed from highly reliable utility grids, with measured reliability levels that were consistently in more than 3–5 times resulting from short-duration voltage sags. Extensive data confirm that such plants experience, on the average, 30 power disturbances annually, of which over 95% were short-duration disturbances lasting for no quite six cycles on the average. Data also confirm that over 90% of those disturbances were asymmetrical faults. a replacement approach to guarding industrial plants from power disturbances by building on the very fact that it was prohibitively expensive to protect against all possible power disturbances which the cost-effective protection was predicated on a statistical assessment of disturbances recorded and equipment susceptibility [17]. This method also shows that it was possible to use a replacement family of zero-energy sag correctors to understand protection against over 96 of all power disturbances. The planning guidelines for such sag correctors (ZESC), along with simulation and experimental results for the new dynamic voltage restorer system, were provided [18].

Based on a knowledge set of over 1500 power disturbances recorded at large industrial plants, a singular and novel way of watching the widely occurring asymmetrical faults from a 3-D perspective was proposed. The proposed three-axis mag–dur plot was during a position to reflect the presence of asymmetrical faults that cannot be observed in standard 2-D mag–dur plots. This allows engineers to effectively design equipment that's more appropriately rated to handle the operating region during which the equipment were getting to be installed, thereby curbing cost. A sag severity index termed the MEI was defined supported the extent of energy required to revive all three phases to their nominal pre-sag value. Reviewing these data helped realize the concept of a ZESC, which could provide levels of protection that were comparable other sag correction solutions, but promise a system that's more compact and has fewer catastrophic failure modes.

The topology of a converter to know the ZESC function was introduced that does not require bulk energy storage devices like in other popular sag correctors, resulting in a compact, more reliable, and cost-effective sag corrector. The converter can catch abreast of even the worst case sags discussed, with the only limitation being posed by subsequent current stresses on the devices. The proof of concept of the ZESC topology was realized through an example design, simulation, and a prototype [19].

The DVR could also be an influence electronics device that's able to compensate voltage sags on critical loads dynamically. By injecting an appropriate voltage, the DVR restores a voltage waveform and ensures constant load voltage. The compensating signals were determined dynamically supported the difference between desired and measured values. The DVR consists of Voltage Source Converter (VSC), injection transformers, passive filters and energy storage (lead acid battery). The efficiency of the DVR depends on the efficiency of the control technique involved in switching the inverter. During this paper a totally unique structure for voltage sags mitigation and for power quality improvement were proposed.

There was an increasing trend of using space vector PWM (SVPWM) which easier digital realization and better dc bus utilization [20]. Technique was replacement of control algorithm supported Space Vector Pulse Width Modulation (SVPWM) technique to urge the pulses. The proposed control algorithm was investigated through simulation by using PSCAD/EMTDC software. From simulation the results show a very good compensation for compensating voltage sags.

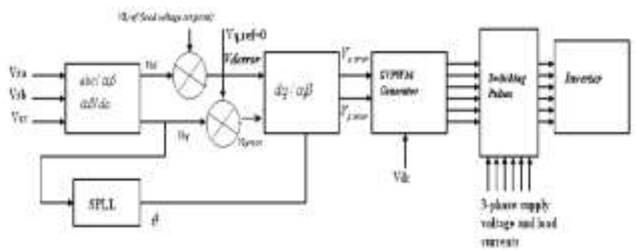

Fig.9. Control block diagram of DVR Implemented [20]

The modeling and simulation of a DVR using PSCAD/EMTDC has been presented. The simulation results showed clearly the performance of the DVR in mitigating voltage sags. The DVR handled both balanced and unbalanced situations with none difficulties and injected the acceptable voltage component to correct rapidly any anomaly within the supply voltage to stay the load voltage balanced and constant at the par value. The efficiency and therefore the effectiveness in voltage sags compensation showed by the DVR makes it a stimulating power quality device compared to other custom power devices. The results of the PSCAD/EMTDC simulation also verify the proposed control algorithm supported SVPWM technique to get the pulses for mitigating voltage sags.

A new compensator consists of input/output filter, series transformer and direct ac-ac converter, which can be a single-phase back-to-back PWM converter without dc-link capacitors [21]. Advantages of the proposed compensator include: simple power circuit by eliminating dc-link electrolytic capacitors and thereby, improved reliability and increased life time of the entire compensator; simple PWM strategy or compensating voltage sag/swell at the same time and reduced switching losses within the ac-ac converter.

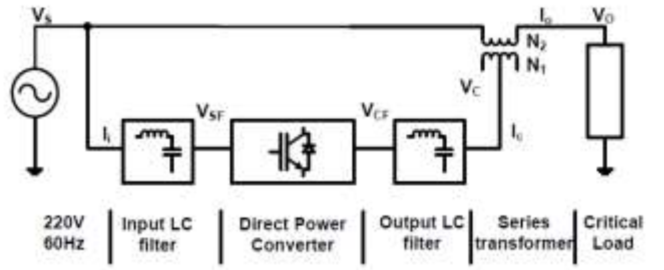

Fig.10. Proposed voltage sag/swell compensator (N1/N2 = 1) [21]

The proposed compensator has been shown to take care of the rated voltage magnitude for the critical load under the both voltage sags and swells [22]. Further, the direct power converter related to the proposed PWM strategy has resulted in elimination of bulky dc-link capacitors, improved reliability and increased life time of the whole compensator, reduced switching losses within the rectifier stage and simplified switch commutation method without requiring complex four-step commutation method. Simulation and experimental results have confirmed the seamless compensation within the case of voltage sags also as swells. The proposed compensator were often easily extended to a 3 phase direct power compensator and applied to D-UPFC for distributed power grid.

A 20kVA Solid State Transformer (SST) supported 6.5kV IGBT was proposed for interface with 7.2Kv distribution system voltage [23]. The proposed SST consists of a cascaded multilevel AC/DC rectifier stage, a Dual Active Bridge (DAB) converter stage with high frequency transformers and a DC/AC inverter stage. Supported the complete phase d-q vector control, a totally unique control strategy was proposed to balance the rectifier capacitor voltages and thus the important power through the DAB parallel modules. Furthermore, the power constraints of the voltage balance control were analyzed. The SST switching model simulation demonstrates the effectiveness of the proposed voltage and power balance controller. A 3kW SST scale-down prototype was implemented [24].

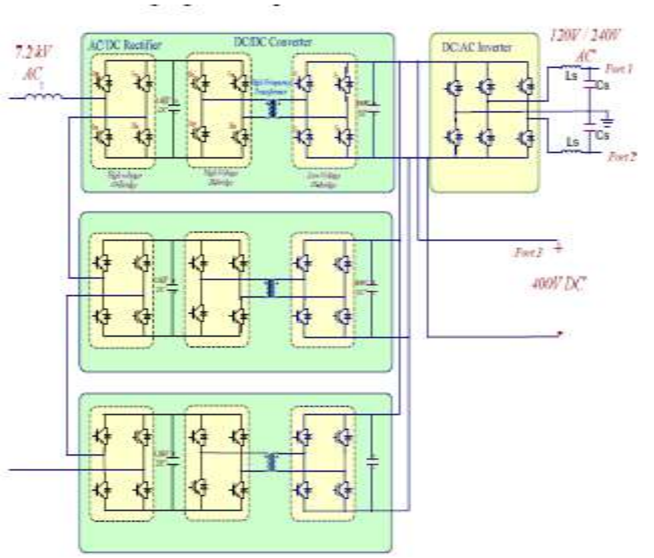

Fig. 11. Topology of Solid State Transformer [23]

The single phase d-q vector control was applied to the cascaded H Bridge rectifier in SST. A totally unique voltage control strategy was proposed to balance the rectifier capacitor voltages [25]. The constraints of the voltage balance control for the cascaded H Bridge rectifier was analyzed in details. An influence balance control was proposed to balance the important power through the DAB parallel modules. The SST switching model simulation verifies the proposed voltage and power balance controller.

Design of Load side compensation topology of Dynamic Voltage Restorer using Z source Inverter was presented by author [23] which was able to compensate voltage sag and swell at sensitive load terminals. Supported this topology, the DVR consists of uncontrolled rectifier for giving DC supply to Z Source converter through DC link. Z- Source Converter based topology was proposed so on reinforce the voltage restoration property of the device. By controlling the shoot through capability of ZSC system using IGBTs provide ride-through capability during voltage sag, swell and provides high reliability. Additionally, an impression scheme called hysteresis Voltage loop controller was proposed to synthesis the required injecting voltage.

The large number of computers and other sensitive electrical loads connected to power system were directly suffering from grid disturbances. The overwhelming majority of those disturbances were said with voltage transients, like voltage sags. One of the technique deals with a step-dynamic transformer designed to guard the load against the consequences of those voltage transients [26]. The idea was to use an easy structure supported the insertion of cascaded reduced-power series transformers between grid and cargo. It makes possible the utilization of actual mains voltages to compensate and mitigate the disturbances. It was shown that the proposed solution can fully compensate or mitigate the faults that occur more frequently in power systems.

A DVR with hysteresis voltage controller was designed for voltage regulation with explicit robustness within the face of system parameter variations. A correct selection of weighting functions would specify the robustness and error tracking performance and therefore the synthesized hysteresis controller were often tuned with significant gains at positive and negative line frequencies in order that, it might effectively regulate the positive and negative sequence components [27-29]. An inner current loop was additionally designed and embedded within the hysteresis voltage loop.

III. CONCLUSIONS

In this paper a review of different techniques like hysteresis controller, solid state transformer topology, dynamic voltage restorer, active voltage regulator, unified power quality conditioner, static voltage restorer for series voltage regulator controlling for reliable operation of distribution transformer. Several research directions by creation of new AC-AC converters were distinguished, like voltage stabilization, voltage regulation to nominal values and also increasing of voltage with gain greater than unity, reactive compensators and soft start of electrical motors devices.

In this paper, actual solutions converters were considered, topologies of which may be divided into following: AC voltage regulators with isolation transformer, shifting phase and series injecting transformer, half bridge transistor modules. Also transformer-less AVR with bidirectional switches, four quadrant switches, switching of power source

Quasi-impedance, input capacitor potential divider, switched and by-pass capacitors and high-frequency ac link were discussed. Several methods that have already found practical implementation replaced conventional active voltage series regulators. In future we will implement series active power filter based on voltage hysteresis controller.

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