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Power Factor & Re-Active Power Control By D-SVC System

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***Abstract*—**The Stability of power factor and management of reactive power play a crucial role in support of the efficiency and reliability of contemporary industrial power systems. Poor management of reactive power in a high-voltage distribution system might result in conditions characterized by voltage instability, harmonic distortion, and energy inefficiency, particularly in the distribution system serving non-linear, rapidly varying loads, like Electric Arc Furnaces (EAFs). Such dynamic conditions are frequently not well served by conventional compensation techniques, such as capacitor banks and thyristor-based SVCs. This paper explores the use of a Dynamic Static VAR Compensator (DSVC) system in a 33 kV industrial distribution system to address areas of such difficulties. The DSVC was also simulated and tested in a realistic industrial operating environment, and its efficiency in converting power factor, Total Harmonic Distortion (THD), and power stability of the voltage were tested. Parameters of interest, such as reactive power flow, harmonic analysis based on FFT, and voltage flicker, were fitted with data. The findings indicated that the 5th harmonic of 2.3% was reduced to 0.4%, and there was an observable enhancement in the power factor. These results establish that DSVC is a quick, versatile, and dependable approach to reactive power control within complicated industrial setups.

Keywords*—Power Compensation, Power Factor Correction, Dynamic Static VAR Compensator (DSVC), Harmonic Mitigation, Electric Arc Furnace (EAF), Total Harmonic Distortion (THD).*

I. Introduction

The task of reactive power compensation has become crucial in electrical networks of the present day, aiming to maintain voltage stability and ensure reliable electrical power delivery. The study was undertaken to regulate both reactive and active power in a 33 kV industrial distribution environment using a Dynamic Static VAR compensator (D-SVC) system, which was capable of 40 MVA, both positive and negative. Good reactive power management has a beneficial impact not only on power factor and on a better voltage profile but loss reduction as well as easy handling of the loads and better power quality, notably when affected by nonlinear and time-altering loads [1][2]. A reliable and consistently balanced supply of energy at a certain frequency and voltage is the fundamental function of every electric power system. Among all the solutions available for RES, dependable and efficient Power Systems (wECS) are among the most alluring. After enhancing the electric power network, reactive power compensation is a useful strategy. It must be controlled and may be accomplished using synchronous condensers, static VAR compensators (SVCs), or static synchronous compensators.

The power quality in the transmission lines has been deteriorating as a consequence of the fast expansion in the usage of semiconductor switching equipment, including diodes and thyristor rectifiers, in response to the constant demand for electric power. Investments in harmonics, voltage distortions, interruptions (both temporary and permanent), and other issues have arisen as a consequence of large businesses' poor power quality. The power quality has also deteriorated as a consequence of the introduction of linear loads. The power quality would be excellent if the electrical supply were continuous, with consistent voltage and frequency values. But in reality, the electric power system is disrupted by variations in energy needs and defects, which deviate from its usual features. The following factors contribute to transmission lines' poor power quality [3]:

- As a result of fluctuations in the supply
- Fluctuation in the frequency
- When the waveforms of voltage and current from the required source are irregular
- Unbalanced loading on the distribution transformers.

There are several ways in which the SVC can enhance the performance of power systems. Voltage regulation, transient stability, gearbox capacity, reduction of transitory overvoltage, dampening of power oscillations, synchronous resonances, and torsional oscillations are all areas where SVCs excel. The SVC is a remedy for power quality issues that have arisen as a result of global economic strain on electrical energy networks. To determine the proper use of the compensator, a comprehensive grasp of the control architecture and dynamic behavior of SVCs is required. It is possible that this objective may be met with the use of computer simulations, which are valuable tools in the creation and improvement of devices such as SVCs.

Power Filters, Power Line Conditioners, Power Quality Conditioners, Active Harmonic Filters, Active Self-commutated SVC, and many more terms are used to describe active filters [4]. The term "active filter" describes a broad category of power electronic circuits that use passive components like capacitors and inductors for power switching and energy storage. Their primary function is to reduce or eliminate power system harmonics. The H3 and H72 active filters were used to reduce the complete harmonic distortion (THD) to values within the limit in IEEE 519:2014 and considerably enhance the power quality in the system by cancellation dominant harmonic components. They are usually ideal alternatives to passive filters due to their drawbacks, including being cumbersome, heavy, and prone to mistuning.

Such drawbacks have given rise to other improved solutions like the Dynamic Static VAR Compensator (DSVC). The DSVC uses state-of-the-art power electronic equipment and smart control systems to provide rapid, responsive, and reactive support in real time. It has also included active filtering features, which are crucial for mitigating harmonics and improving overall power quality. Active filters, also known as power quality conditioners, suppress switching components dynamically by a combination of switching devices and passive components. When correctly planned, these systems are able to minimise the Total Harmonic Distortion (THD) to acceptable limits that are stipulated by IEEE 519:2014 standards.

In this paper, a case study of DSVC installed in a 33 kV industrial power distribution network serving a high-demand non-linear load is presented. The paper aims to assess the system's performance by implementing DSVC and comparing it to the system without DSVC implementation, with the goal of identifying improvements in power factor, reactive power control, harmonic mitigation, and voltage stability.

A. Structure of the Paper

The outline of the structure of this work follows below: Moreover, Section II presents the boundaries of conventional compensating measures along with providing the background knowledge regarding challenges of reactive power and power factor control in modern electrical networks. In the third section, a detailed description of the Dynamic Static VAR Compensator (DSVC) is provided, i.e., its architecture, its components, and major characteristics of its operations. Section IV provides the means and mechanisms involved in simulation as well as real-time evaluation of DSVC functioning. In section V, a situation study has been given on how DSVC is implemented in 33 kV industrial distribution, and how it affects power factor, harmonic distortion, and voltage stability. Related research is reviewed in this section VI in the area of reactive power compensation and contemporary FACTS devices. Lastly, the paper concludes in Section VII with the findings and recommendations for future work.

II. BACKGROUND OF THIS STUDY

A. Reactive Power

The primary method used in power networks to manage voltage is reactive power regulation. Although reactive power by itself does not directly assist the system, properly managed reactive power minimizes active power losses and improves the system's capacity to transmit active power [5]. The exchange of reactive power by compensating devices like DSVCs (Dynamic Static VAR Compensators) is governed by the relationship as shown in Equation (1):

$$Q = -|V|^2 . B_{SVC} \quad (1)$$

Where Q is reactive power in kVAr, |V| is the RMS bus voltage in kV, and B_{SVC} Is the controllable susceptance of the DSVC in Siemens? This nonlinear equation shows that reactive power Q varies with the square of terminal voltage, allowing the DSVC to inject or absorb VARs based on the sign and value of B_{SVC}. This enables dynamic voltage support under rapidly fluctuating loads like Electric Arc Furnaces.

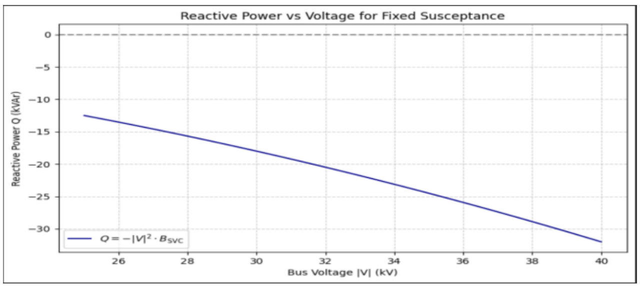

Fig. 1. Quadratic Dependence of Reactive Power on Bus Voltage in a Fixed-Susceptance DSVC Model

The graph present in Figure 1 shows the quadratic relationship between reactive power Q and bus voltage |V| for a fixed DSVC susceptance. As voltage increases, the DSVC injects more capacitive reactive power, enabling dynamic voltage regulation and improved power factor control.

B. Power Factor in Power System

Power factor (PF) is a key indicator of electrical system efficiency and is defined as the cosine of the phase angle (ϕ) between the voltage and current waveforms in Equation (2):

$$Power\ Factor\ (PF) = \cos \emptyset \qquad (2)$$

A power factor closes to 1 indicates efficient utilization of electrical power [6]. Where most of the current contributes to real work. However, in systems with inductive or non-linear loads such as motors or arc furnaces, power factor often drops below unity, leading to increased losses, reduced capacity, and voltage instability. Maintaining a high power factor is therefore essential for minimizing transmission losses and ensuring stable, cost-effective grid operation. Such devices as DSVCs play a crucial role in real-time by providing or withdrawing reactive power as needed.

1) Challenges in Reactive Power and Power Factor Control

Maintaining a steady voltage profile and functioning well is becoming increasingly difficult in contemporary power systems. Poor reactive power management, especially in aging electrical grids, is a major cause, as is low power factor. These problems are enhanced by the high inclusion of non-linear and time-varying loads, including large motors and electric arc furnaces (EAFs) that are common in industrial environments.

Poor reactive power management can lead to voltage instability, unnecessary power losses, and loss of efficiency in the system. Furthermore, it increases the pressure on gearbox lines, leading to overheating in the generators and resulting in significantly more maintenance. This is a technical and financial problem for industrial users, as a low power factor may result in increased utility expenditures and fines.

2) Need for Modern Compensation Techniques

The current power grid is as dynamic as ever due to the switch to cleaner and flexible energy systems such as solar, wind, and electric cars. Such technologies are too variable and unpredictable to make maintenance of voltage and the power factor within reasonable limits anything more than a complex exercise. Traditional compensation methods, such as tap-changing transformers or capacitor banks, are too slow and rigid to respond to sudden variations. They may function well in steady-state scenarios, but they are unable to handle sudden variations in generation or load. The modern grid requires real-time, faster, smarter, and more flexible solutions.

3) Reactive Power Compensation Technologies

The most commonly used devices for reactive power compensation included:

- **Capacitor Banks –** Simple and affordable, but they provide only fixed compensation and lack flexibility during load variations [7].
- **On-Load Tap Changers (OLTCs) –** Useful for adjusting transformer voltage, but they react slowly and are not ideal for dynamic conditions [8].
- **IGBT-Based Systems (e.g., STATCOMs, DSVCs) –** Modern solutions with fast response and built-in harmonic filtering, ideal for dynamic load conditions and real-time power quality control [9].

As the grid becomes more dynamic and decentralized, these older technologies are struggling to meet the demands. Their slow response time, limited adaptability, and high maintenance needs highlight the need for a better solution. That's where Dynamic Static VAR Compensators (D-SVC) come in. D-SVC systems are designed to handle rapid changes in reactive power by using fast-acting power electronics. They offer real-time compensation, precise voltage regulation, and improved power factor, making them highly suitable for today's and tomorrow's grid challenges. Their ability to switch between supplying and absorbing reactive power in milliseconds gives them a big advantage over traditional systems.

III. D-SVC OVERVIEW

The D-SVC architecture is derived from the VSC design, which primarily relied on Insulated Gate Bipolar Transistors (IGBTs) for switching purposes. Injecting leading or lagging current at 90 degrees while converting DC from its DC capacitors to AC allows the D-SVC to regulate reactive power. The high-speed IGBTs allow the D-SVC to respond quickly to voltage changes. This D-SVC system (see Table I), designed with a compact, free-standing cabinet and fast-response IGBT-based architecture, was specifically implemented to control voltage fluctuations and improve power quality in the 33 kV industrial distribution network. Figure 2 shows that the D-SVC requires very little room for installation due to its compact design, which consists of a single, free-standing cabinet.

Fig. 2. Overview of D-SVC

There are two main ways of control for the D-SVC. There are three distinct voltage control modes available for autonomous operation, each tailored to deal with a certain duration of voltage fluctuations [10]. The second is the ability to regulate voltage across several D-SVCs remotely using the built-in communication capability. Here, the ideal reference voltage for every D-SVC is determined and sent over the communication facility by a central server known as D-VQC (Voltage Power and Reactive Power (Q) Control System for Distribution Grid). This is followed by the Reactive Power output by each D-SVC being coordinated. A feeder's voltage headroom may be increased and power loss reduced by utilizing several D-SVCs to change the voltage at various points on the feeder. Table I details the item specs.

TABLE I. D-SVC SPECIFICATION

Item	Specification
Rated Voltage	33 kV
Frequency	50Hz
Topology	VSC-based architecture using IGBT switching
Harmonic Filtering	Active harmonic filtering (with H3 & H72 filter references)

A. Components of D-SVC

A complete structure that will help to define how a Distribution SVC system is meant to provide fast and flexible Reactive Power compensation at the distribution level. The primary components of a D-SVC will be TCR, TSCs, and a Digital Control Unit, typically using Digital Signal Processors [11]. A reactor linked in series with a bidirectional thyristor valve allows for continuous adjustment of an inductive reactive power source's output voltage by modifying the firing angle of the valve's thyristors. The Digital Signal Processor (DSP)-based controller ensures precise regulation of the IGBT-based converter modules to maintain the desired power factor and voltage profile, while dynamically responding to variations caused by non-linear and time-varying loads within the system. The DSP would maintain continuous readings of bus voltage, reactive power flow, and load conditions from the distribution network and compensate for such by controlling the IGBT-based converter modules and associated reactive power control functions. This coordination ensures that each required component performs independently, allowing the end user to expect reliability, safety, and operability from remote access. Figure 3 illustrates the key components of the Dynamic Static VAR Compensator (D-SVC), which includes the DSVC transformer, reactors, IGBT converters, DC bus capacitors, and associated power electronics.

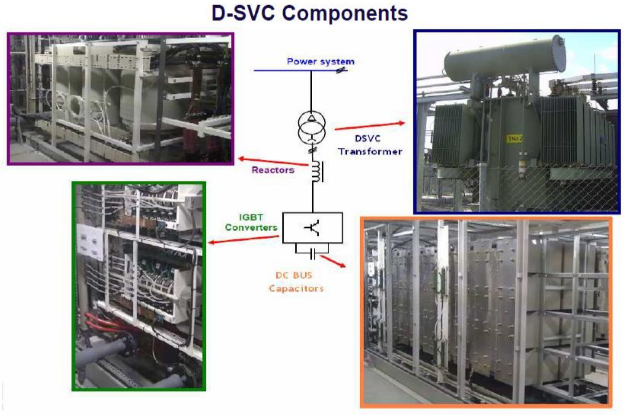

Fig. 3. Components of D-SVC

The DSVC transformer interfaces with the power system to regulate voltage levels, while reactors assist in controlling the reactive power flow. IGBT (Insulated Gate Bipolar Transistor) converters play a pivotal role in the rapid switching and dynamic control of voltage support. The DC bus capacitors serve as energy storage elements that help stabilize voltage fluctuations and support transient response. These components are integrated into cubicles for modular deployment, enabling the D-SVC to effectively manage power quality by compensating for reactive power, reducing flicker, and filtering harmonics in industrial power systems.

Traditional Static VAR Compensators (SVCs) are composed of two key components: Thyristor-Controlled Reactors (TCRs), which consist of antiparallel thyristors in series with a reactor, and Thyristor-Switched Capacitors (TSCs), which use antiparallel thyristors in series with capacitors [12]. To safely operate under inductive loading, snubber circuits are typically placed in parallel with the thyristors. Switching actions, especially in TCRs, generate significant harmonic content, necessitating the inclusion of harmonic filters in the system design. In high-power industrial applications, the thyristors are cooled using demineralized water to manage the high thermal load [13]. These SVC systems provide reactive power compensation by supplying or absorbing VARs as needed, helping to reduce line current and improve power factor. Although effective under steady-state conditions, traditional SVCs have limitations in dynamic performance. Figure 4 illustrates the harmonic filters typically associated with such compensation systems.

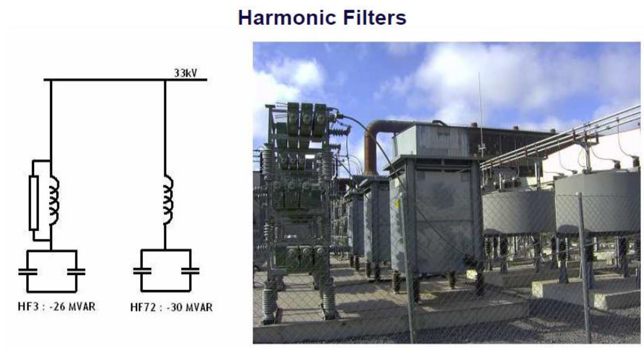

Fig. 4. Harmonic Filters

The implementation of harmonic filters in a high-voltage substation environment, designed to mitigate harmonic distortions and enhance power quality. The single-line diagram in Figures 4 and 5 shows two harmonic filter banks, HF3 rated at 26 MVAR and HF72 rated at 30 MVAR, connected to a 33kV bus. These filters are typically composed of tuned passive components, such as reactors and capacitors, which are visible in the accompanying photograph. The physical infrastructure includes large capacitor banks and inductors mounted on steel frames within a fenced yard, reflecting an outdoor installation that supports efficient dissipation of harmonic currents generated by nonlinear loads. Such filters are essential in industrial and utility-scale power systems to reduce total harmonic distortion (THD), protect equipment, and maintain voltage stability.

B. Architecture of DSVC Deployment

In this case study, the DSVC is connected to a 33kV distribution network, providing compensation at a sub-transmission level where reactive power issues are most prevalent. The architecture is illustrated in the Single Line Diagram in Figure 5. The system employs both inner and outer control loops, where:

- The outer loop manages voltage regulation based on grid conditions.
- The inner loop controls current flow to ensure stable compensation and avoid oscillations.

Additional features include:

- **Voltage Current Regulation Algorithms:** The system stabilizes and operates within the targeted voltage, while also ensuring that the reactive current flow is minimized to safe thresholds.
- **Pulse Interlacing Logic:** Advanced pulse-width modulation methods are designed to minimize ripple and loss switching, resulting in high efficiency.
- **Harmonic Filtering Modules:** These are mounted in strategic locations within the circuits, and they counter harmonics induced by non-linear loads or switching activities.

This architecture enables the DSVC to work with complex and dynamically changing grid scenarios, such as industrial zones and regions interfaced with renewable energy, with good confidence.

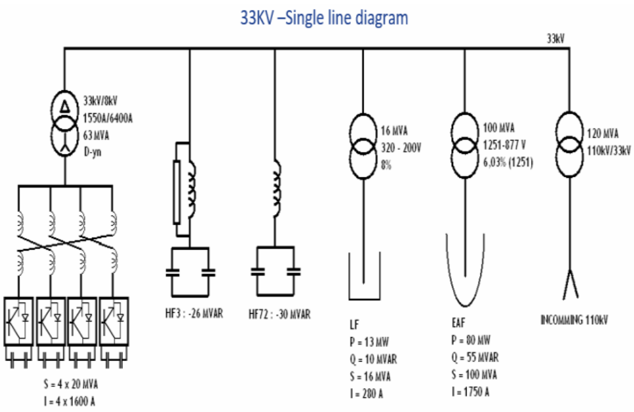

Fig. 5. Single-line Diagram of DSV

The single-line diagram of a 33 kV distribution system that had a Dynamic Static VAR Compensator (DSVC) technology installed is shown in Figure 5. It illustrates important parts such as two harmonic filter banks (HF3 26MVAR and HF72 30MVAR), load feeders (LF), Electric Arc Furnace (EAF), and externally sourced power on a 110 kV grid through a 120MVA transformer. The EAF will be rated to 100MVA with the required reactive power of up to 50MVAR, and the DSVC system will be strategically placed to mitigate voltage instability and harmonic distortion in this high-stress industrial location.

C. Features and Advantages of DSVC

There are some features of the DSVC system that contribute to its high performance when solving the problem of reactive control and power factor correction:

- **Real-Time Dynamic Response:** DSVC can respond to any change in the grid in milliseconds, as compared to traditional systems, which could take seconds or even longer to make the corresponding adjustment.
- **Bidirectional VAR Compensation:** It will be able to supply and absorb reactive power depending on the load and the state of the grid, therefore, providing full flexibility.
- **Voltage Stabilization and Power Factor Correction:** Since DSVC ensures salvaging the perfect level of voltage and power factor of unity, the overall efficiency of the used energy and the reduced losses are guaranteed.

- **Harmonic Mitigation and Flicker Reduction:** The system actively minimizes the occurrence of harmonics and minimizes voltage flicker due to the sudden change in loads, which increases equipment lifespan and overall system reliability.
- **Modular and Scalable Design:** The DSVC units can be implemented in the form of modular blocks; therefore, they can be applicable to a vast variety of usages, including a single industrial plant and a massive smart grid [14].

IV. Methods and Materials

The study aimed to assess the effectiveness of the DSVC system in enhancing power factor and reactive power control in an industrial plant connected to the 33 kV distribution network. Verification of the system was conducted under practical working conditions, utilizing both simulation-based modelling and actual implementation. Before and after the use of DSVC, performance was tracked using data acquisition systems and using software that was also standard across the industry. The dynamic control of the system, as well as its overall impact on increasing grid stability and efficiency, was measured by monitoring and continuously recording selected power quality measures, including power factor, reactive power, harmonic distortion, and voltage flicker.

A. System Implementation and Simulation

The simulation software was used to build the DSVC system and compare it to operational data from an industrial site connected to the 33 kV network. It included:

- **Simulation Software (MATLAB/Simulink, ETAP):** Models of the system were modeled with electrical simulation industry-standard software to model the dynamic behavior of the DSVC and analyze the response of the system to ratable loads.
- **Real-Time Monitoring (SCADA & Smart Meters):** Supervisory Control and Data Acquisition (SCADA) systems and advanced smart energy meters were deployed to record when important parameters such as voltage, current, power factor, and the harmonic content changed with time. This gave credible information on the performance before and after DSVC [15].

B. Parameters and Metrics Monitored

The corresponding works were monitored and analysed in a range of specific parameters of power quality to determine the success of the DSVC system. In practice, such metrics provide insight into how effectively the system manages reactive power loads, increases power factor, suppresses harmonics, and reduces voltage flicker.

1) Power Factor (cos φ):

A severe indicator was monitored before and after DSVC implementation to assess its effectiveness.

2) Reactive Power (kVAr):

Inductive type VARs, capacitive type VARs were measured to evaluate the dynamic reactive load balancing capability of the system. One can determine Reactive Power (Q_j) in SVC via Equations (3).

$$Q_j = -|V_j|^2 B_{SVC} \qquad (3)$$

3) FFT Harmonic Spectrum:

Fast Fourier Transform (FFT) analysis measured the degree of harmonic distortion created by the nonlinear loads, in addition to the cancellation of the harmonic distortion created by the operation of the DSVC.

4) Voltage Flicker Index:

Measured up to the point of standard invoked by sudden loads such as those caused by large motors or arc furnaces that cause an excess of voltage flicker.

This set of parameters builds a solid backdrop against which the effectiveness of the DSVC system in improving the power quality and stability of operation under industrial load can be tested.

V. Case Study

This Case study presents a performance assessment of a Dynamic Static VAR Compensator (DSVC) grid installed in a 33 kV industrial distribution system serving a high-demand, non-linear load, specifically an Electric Arc Furnace (EAF). Low power quality, a poor power factor, and harmonic pollution previously characterized the system's power quality. Additionally, the voltages flickered due to the highly variable and impulsive nature of EAF operations.

A. Pre-DSVC Performance – Harmonic Distortion Analysis

Prior to the introduction of DSVC, the 33 kV industrial network had a history of frequent power quality problems, especially because load conditions were extremely fluctuating due to its load, that is, the Electric Arc Furnace (EAF). The system had no active filtering, resulting in susceptibility to problems of harmonic distortion and voltage instability. Such situations were not only causing poor equipment performance but also adding to the operational losses. To understand the severity of the distortion, an FFT analysis was carried out under these pre-DSVC conditions, as shown in Figure 6 below.

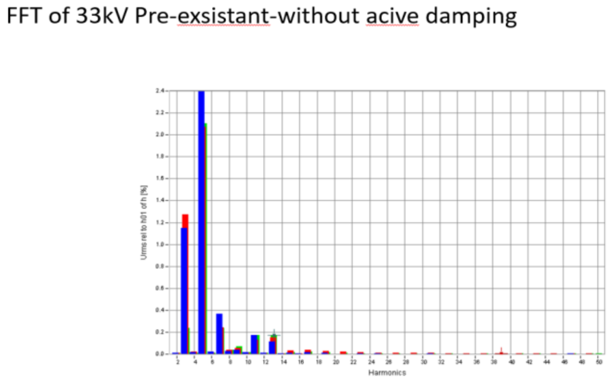

Fig. 6. FFT Spectrum of 33 kV System Before DSVC Integration – Without Active Filtering

Figure 6 illustrates the Fast Fourier Transform (FFT) analysis of the 33 kV industrial system prior to DSVC implementation, under non-linear loading conditions. The spectrum reveals a pronounced presence of low-order harmonics, particularly the 3rd (triplen) and 5th, with the 5th harmonic component exceeding 2.3% of the fundamental voltage. These elevated harmonic levels are indicative of significant waveform distortion caused by the operation of heavy non-linear loads such as Electric Arc Furnaces (EAFs). The absence of active damping or filtering leads to increased Total Harmonic Distortion (THD), resulting in degraded power quality, elevated thermal losses, and potential resonance conditions in the power system. This data establishes the baseline for evaluating the effectiveness of active harmonic mitigation through DSVC integration.

B. Post-DSVC Performance – Harmonic Mitigation and Power Quality Improvement

Once the DSVC system was installed, equipped with active harmonic filtering, the power quality across the 33 kV network improved considerably. The system began responding dynamically to reactive power demands and non-linear distortions, stabilizing the voltage and cleaning up the waveform. The improvement in harmonic performance can be clearly seen in the FFT results obtained after DSVC integration, presented in Figure 7.

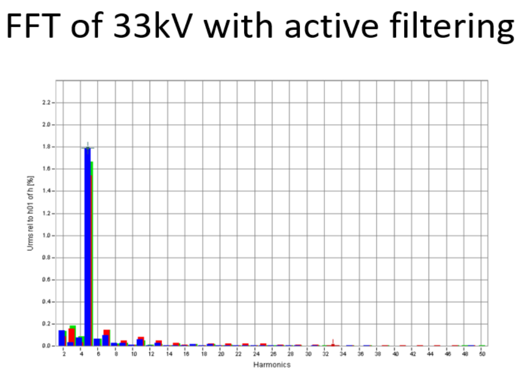

Fig. 7. FFT Spectrum of 33 kV System After DSVC Integration – With Active Filtering

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Bioenergy refers to electricity and gas that is generated from organic matter, known as biomass. This can be anything from plant and timber to agriculture and food waste, and even sewage. Bioenergy includes the production of fuel from organic matter as well. Energy from biomass can be used for electricity, heating, and transportation, and can be replenished anywhere. Around seventy-five percent of the world's renewable energy is composed of biomass energy due to its potential and wide use [7]. Also, it is carbon-neutral, meaning that it adds no net carbon dioxide to the atmosphere. In addition, it reduces the level of trash in the ground by as much as 90 percent by burning solid waste. Biomass fuels, on the other hand, are not completely clean and can also cause deforestation. They are also less efficient than fossil fuels. But proper management and planning of its disadvantages will improve its potential.

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The Fast Fourier Transform (FFT) spectrum of the 33kV industrial distribution system with a Dynamic Static VAR Compensator (DSVC) that has active harmonic filtering is shown in Figure 7. It is noticed that there is a considerable decrease in the harmonic components, particularly the 3rd and 5th order, compared to before DS VC. The 5th harmonic, which was greater than 2.3 percent of the fundamental component, has also been suppressed to about 0.4 percent, demonstrating that DSVC has an effective harmonic suppression ability. The higher-order harmonics phrased all over the spectrum are also diminished, which leads to a more sinusoidal waveform. This is explained by the fact that the DSVC can filter in real time, which significantly reduces Total Harmonic Distortion (THD). As a result, the global power quality is improved, which then facilitates increased stability of work and security of sensitive industrial devices. This is provided by a DSVC IGBT-based voltage source converter (VSC) and active filtering under real-time correction control.

VI. LITERATURE REVIEW

This section provides a literature study of power factor and reactive power regulation through the D-SVC system, accompanied by a summary in Table II.

Belhamidi et al. (2023) describe the effects of a DSTATCOM with a 3MVAR to 3MVAR, 25 kV capacity on improving voltage stability in 120-kV, 60 Hz distribution networks with fluctuating loads fed by 9-MW wind power. After integrating the device, the load voltage, which was 0.5pu without FACTS, has improved to 1pu, as demonstrated by the MATLAB/Simulink that follows the energetic response of D-STATCOM. The simulation results for electrical networks with and without D-STATCOM were presented in the last section [16].

Dang et al. (2023) suggest an approach to minimising transient voltage dip instability using a differentiated dynamic reactive power compensation architecture. Using multiple-two-element notation, the approach first creates a dynamic reactive power device configuration indication system. Next, it creates a differentiated dynamic reactive power compensation device configuration model based on the risk characteristics of node instability. In order to achieve differentiated dynamic reactive power compensation, the model accepts the investment cost and suppression effect as optimisation objectives and flexibly modifies the optimisation weights of its cost and suppression effect based on the high or low risk of the transient voltage instability of the compensation node. The financial advantages of reactive power compensation arrangements can be significantly enhanced by adopting differentiated compensation over conventional techniques. Lastly, the enhanced TLBO technique is applied to solve the model using the IEEE39 node test system as an example. With a comparable suppressing effect, the cost of differentiated compensation is lowered by 22.13%, confirming the efficacy of the approach suggested in this research [17].

Kumar et al. (2023) the levels of renewable power penetration have a significant impact on a crucial component of the Power System. A development of problems with dynamic/transient stability and steady-state voltage has followed from this. Maintaining and controlling adequate reactive power reserves is important for ensuring a dependable and sustainable power system. A comprehensive literature evaluation on the subject of "Management of Reactive Power in renewable-rich power networks" is the highlight of this research. This study included a thorough literature evaluation of 75 research publications, with concise summaries of each component [18]

Aboshady et al. (2023) recommended that PV inverters provide a mechanism to control the injection and consumption of Reactive Power; this would mitigate overvoltage issues and lessen the system's efficiency loss. This is achieved by the proposed controller periodically sending the Reactive Power setpoints and employing a real-time volt/var algorithm. The solution that has been suggested takes into consideration the uncertainty in PV production and load demand by using probabilistic distributions. A lower computational cost and a simplified communication platform are the results of implementing the controller at the lateral level. Coordinating an operation of several inverters in real-time, the volt/var control minimizes voltage growth and Reactive Power consumption in the event of an overvoltage [19].

Wang et al. (2021) used Reactive Power demand modelling to determine the wind power plant's efficiency. The SVC is required to balance the reactive power needs of the wind unit, and this model offers a probabilistic approach based on prediction intervals to characterize these demands better. This is made possible by an NN-based model that employs the LUBE approach, which stands for lower and upper bound estimation. Combined prediction intervals are utilised to sidestep the instability that may arise from the complex and nonlinear nature of NN [20].

Huang and Zhang (2021) proposed a distribution-network-applicable reactive power regulation technique that takes wind turbine power predictions into account. Responsive power control approach architecture consists of three levels: Reactive Power Prediction, Reactive Power Setting, and Reactive Power Distribution. Reactive Power Prediction accounts for the wind speed's variable and changing qualities, continuing the power forecast of wind turbines. Evidence from ultra-short-term wind turbines' reactive and active power data indicates this will reduce voltage variations caused by time-dependent changes in wind speed. Taking into consideration different time scales, the Reactive Power setting layer proposes an improved method for Reactive Power setting [21].

Ayala-Chauvin et al. (2021) suggested a model for a static reactive power compensator using typical sources of direct current voltage. In order to meet standards, converter parameters were computed and developed. They created the model's power and control circuits in MATLAB Simulink to determine the device response for various operating modes, such as reactive power consumer and generator. The circular power chart and the current and voltage waveforms were derived by running simulations under various situations. This study has demonstrated theoretically that using ordinary DC voltage sources and a static reactive power compensator, it is feasible to generate or consume just active or reactive power [22].

Table II summarizes the research on controlling power factor and reactive power using a D-SVC system. It includes the study's methodology, key findings, challenges, and potential future directions.

TABLE II. SUMMARY OF RELATED WORK BASED ON POWER FACTOR AND REACTIVE POWER CONTROL BY D-SVC SYSTEM

Author	Study On	Approach	Key Findings	Challenges	Future Directions
Belhamidi et al. (2023)	Integration of D-STATCOM (±3 MVAR, 25 kV) in a 120 kV system with 9 MW wind generation	MATLAB/Simulink-based modeling; load voltage performance evaluated with and without D-STATCOM	Voltage magnitude improved from 0.5 pu to 1 pu after D-STATCOM integration, showing effective voltage stabilization.	Non-linear and fluctuating load conditions in wind-integrated systems pose control difficulties.	Develop hybrid D-STATCOM controllers integrated with renewables for grid-tied systems.
Dang et al. (2023)	Differentiated reactive compensation to	Developed a reactive power configuration model using instability risk indicators; solved via	Achieved a 22.13% reduction in cost vs. traditional reactive power strategies,	Model complexity and optimization under	Real-time control strategy deployment with adaptive economic

	suppress transient voltage dips	TLBO algorithm on IEEE 39-bus	maintaining suppression quality	uncertainty in grid states	scaling for dynamic grids
Kumar et al. (2023)	Reactive power control in power networks with a lot of renewable energy	Comprehensive literature survey (75 papers) on reactive power in renewable networks	Identified major challenges in maintaining reactive reserves; stressed the importance of control to prevent instability	High uncertainty in renewable generation affects system stability	Develop hybrid control strategies combining forecasting with dynamic compensation
Aboshady et al. (2023)	Reactive power control for PV inverters	Real-time volt/var control with probabilistic setpoints	Reduced power loss and overvoltage; coordination among PV inverters achieved with minimal reactive usage	Uncertainty in PV generation and load demand	Scalable control for multi-inverter environments under uncertainty
Wang et al. (2021)	Reactive power modeling for wind farms	Neural Network (LUBE method) with static VAR compensator (SVC) support	Improved accuracy in reactive power demand prediction for wind units; ensured compensation using SVC	Non-linear behavior of NN models causes instability	Combine AI models with robust compensation mechanisms for reliable prediction
Huang and Zhang (2021)	Reactive power control in wind-based distribution networks	Three-layer control (prediction, setting, distribution) with time-varying input	Successfully reduced voltage fluctuations by predictive control of reactive power in wind systems	Fluctuating wind characteristics and prediction uncertainties	Enhance multi-layer control schemes for other renewable energy types
Ayala-Chauvin et al. (2021)	Modeling a static VAR compensator with common DC sources	Power and control circuits were designed in MATLAB; simulation under varied modes	Demonstrated capability for pure active/reactive power control using shared DC link; reliable waveform responses	Accurate control of dual operating modes and design complexity in converter sizing	Expand to multi-terminal DC systems and test under fault or grid-code scenarios

VII. Conclusion and Future Work

Electrical power systems cannot be maintained efficiently or reliably without controlling Reactive Power and Power Factor. This study evaluated the effectiveness of a Dynamic Static VAR Compensator (DSVC) system in enhancing power factor and reactive power control within a 33 kV industrial distribution network supplying a non-linear, high-demand load, specifically an Electric Arc Furnace (EAF). Prior to DSVC deployment, the system experienced severe power quality issues, including voltage instability, high harmonic distortion, and poor power factor. Following the integration of the DSVC, significant improvements were observed. The system exhibited dynamic voltage regulation, real-time reactive power compensation, and substantial harmonic mitigation, particularly in reducing the 5th harmonic from 2.3% to 0.4%. These enhancements led to a notable reduction in Total Harmonic Distortion (THD), improved operational efficiency, and more stable grid conditions. The results confirm that DSVC technology is highly effective in addressing the limitations of traditional compensation methods, especially in environments characterized by fluctuating industrial loads.

Looking ahead, future research can explore the integration of AI-based control mechanisms such as fuzzy logic and neural networks to enhance the adaptability and intelligence of DSVC operation. Further studies could also investigate DSVC coordination with renewable energy sources and storage systems, as well as the deployment of multi-node DSVC networks for grid-wide reactive power balancing. Economic optimization, payback period analysis, and cyber-physical system integration are also promising areas for expanding the scope and value of DSVC applications in modern smart grid infrastructures.

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