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SIMULATION BASED HYBRID DISTRIBUTION TRANSFORMER

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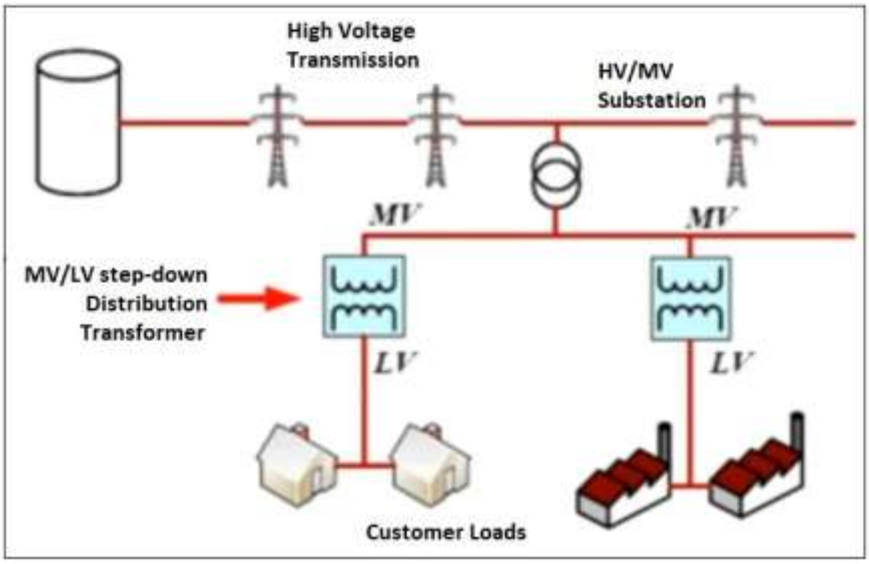
ABSTRACT

This study presents a novel approach to distribution transformer design, combining traditional transformer technology with modern power electronics to create a hybrid system. The proposed hybrid distribution transformer aims to enhance efficiency, reliability, and flexibility in power distribution networks. Through computer simulations, we analyse the performance of this innovative design under various operating conditions and load profiles. The hybrid transformer incorporates solid-state switching devices and advanced control algorithms to dynamically adjust voltage levels and power flow. This allows for improved voltage regulation, reduced losses, and better integration of distributed energy resources. The simulation model accounts for factors such as harmonic distortion, reactive power compensation, and fault tolerance.

I. INTRODUCTION

A simulation-based hybrid distribution transformer integrates traditional electromagnetic components with power electronics, offering enhanced functionality for modern power distribution systems. Simulations are used extensively to model, analyze, and optimize the design and

performance of these transformers before they are physically built, helping engineers predict their behaviour in real-world scenarios. This process ensures that the transformer operates efficiently in both normal and stressed conditions. Additionally, simulation tools enable optimization of key design parameters, such as transformer winding configurations, power electronic components, and cooling systems, which are essential for improving efficiency and reducing operational costs. Control systems that manage voltage, current, and frequency can also be validated through simulation, ensuring precise operation. Thermal management is another important aspect addressed through simulation, as power electronics can generate significant heat. Simulations help optimize cooling strategies to avoid overheating, ensuring long-term reliability. Harmonic analysis is also performed to ensure the transformer maintains power quality and does not introduce harmonics into the grid. By simulating various fault conditions and grid disturbances, engineers can anticipate potential failure points, allowing for better predictive maintenance strategies. In summary, simulation-based hybrid distribution transformers leverage virtual environments to design efficient, reliable, and cost-effective transformers, reducing risks and enabling faster deployment in complex power grids.



Hybrid Distribution Transformer is an advanced solution that enhances traditional transformer technology by integrating power electronics for improved grid performance, efficiency, and flexibility. This can decrease the

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efficiency of the system which causes to the equipment. Hybrid distribution with their integrated power electronic, can filter out or mitigate harmonics.

II. HYBRID DISTRIBUTION TRANSFORMER- CONCEPT

A hybrid distribution transformer is an advanced type of electrical transformer that combines conventional transformer technology with modern power electronics. These transformers are designed to enhance the performance, efficiency, and control capabilities of traditional distribution transformers. The concept of hybrid distribution transformers is becoming increasingly important as power grids transition to handle more renewable energy sources and complex loads.

At its core, a traditional distribution transformer steps down voltage from the lines to a voltage suitable for use in, businesses, industries. This is done through electromagnetic induction, where alternating current (AC). They have limitations in terms of adaptability, and control, especially in modern power systems that face fluctuating power demands and distributed energy resources (DERs). Non-linear loads (such as those caused by computers, LED lighting, and variable speed drives) can introduce harmonics—a distortion in the waveforms of electrical power. They are essential for modern power distribution systems, especially in the context of smart grids and renewable energy integration. Hybrid

A hybrid distribution transformer is an innovative type of transformer that combines conventional transformer technology with modern power electronics. These transformers are designed to address some of the challenges faced by traditional distribution systems in today's evolving power grid

III. HDT CONFIGURATIONS

HDT configurations categorization is based on the power source of the convert unit, that is, whether the energy comes from the auxiliary winding (AW). At the same time, according to how energy injected into grid by the converter is performed, that is, in series into grid, compensation level depends on the configuration as well as the type of converter used. Certainly, the compensation that can be given by each configuration is as described. The classifications can be established as follows: without CT with the shunt, and series and the compensation.

IV. PROBLEMS IN DISTRIBUTION TRANSFORMER

Harmonics:

In comparison to electrical generators, the AESER finds that microgrid managed electricity consumption differentiates both towards controlled and uncontrolled super node due to legal omnipotence and out of the ordinary market mechanisms. Furthermore, for a primary synchronous machine, it either monopolizes or exploits tepid buses. They concluded that while electricity consumers are managed, generators and microgrid controlled consumers alternately become autonomously managed.

The power issue of deviation in profile voltage, used frequencies has become quite complex in identifying its root causes due to the evolution in electric load profile from a linear system to a nonlinear system. Power quality is normally associated with the problems of disturbance in the equipment malfunction voltage with time, current, or frequency. The growing problems concern in power issues presence of unwanted harmonic currents which are a result of distorting non-linear loads. Such loads are highly prevalent in all forms of commercial and industrial activities.

Voltage Swelling:

Voltage swelling caused by harmonics can lead to several negative effects on transformers, including **Increased heat and power losses** Harmonics can cause additional power and heat losses in transformers. **Reduced component life** Harmonics can accelerate the aging of transformers and reduce the life expectancy of their components. **Increased load noise** Harmonics can increase the load noise level of transformers. **Insulation oil quality reduction** Harmonics can reduce the quality of the insulation oil in transformers. **Voltage distortion** Harmonic currents flowing through transformers can cause voltage distortion at the transformer's secondary terminals.

Temperature Rise:

Harmonics can cause a transformer to overheat and fail due to a temperature rise:

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Harmonics are a result of non-linear loads in electrical systems. They can cause high- frequency currents and voltages to flow through the transformer's windings, which can lead to localized heating. This can damage the transformer, reduce its capacity, and increase operating costs. The temperature rise can cause the insulation properties of the transformer to deteriorate, which can lead to insulation breakdown. For every 10°C temperature rise, the transformer's life is reduced by half.

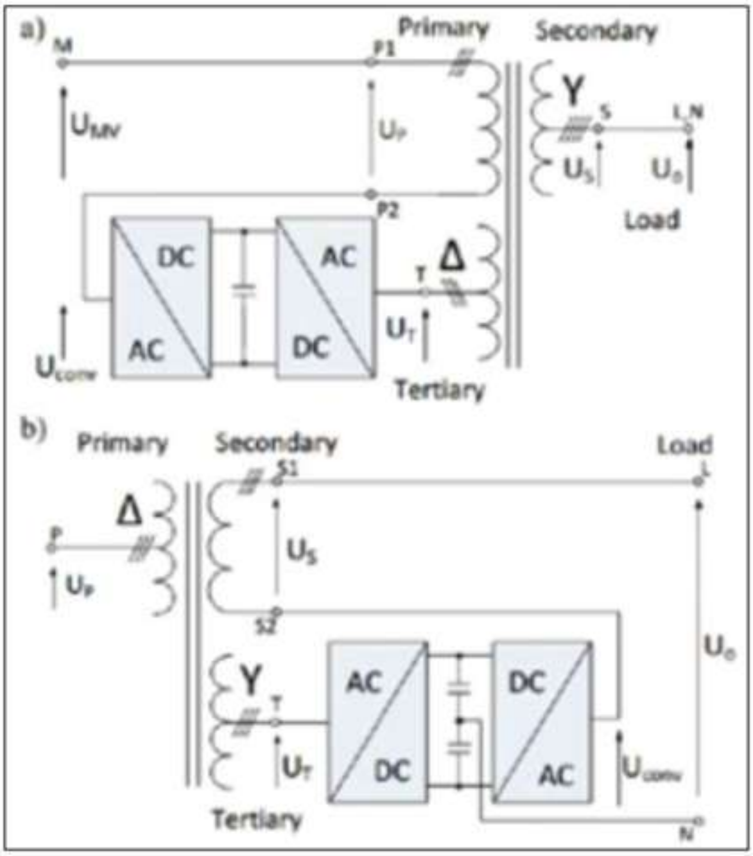
Mitigation:

1. Use magnetic shields to contain stray flux
2. Use non-magnetic materials in the transformer tank walls
3. Use laminated steel for structural components Ensure components are placed to minimize the impact of stray flux Design the magnetic core to minimize leakage flux
4. Use efficient cooling systems to dissipate heat

V. POWER ELECTRONIC

While it is economic, dependable, and logical, there are some other undesirable characteristics that are becoming more and more critical as the insight of distribution age units grows. The position of unpleasant things of the transformers cover lack of possibility for adjustment of the voltage, inadequate entertainment under set and unbalances, responsive to harmonics, and proportionate large, heavy size. The PET, an electronic transformer capable of providing separation of changing level at the intake and source side.

Power Converter Topology for Hybrid Distribution Transformer



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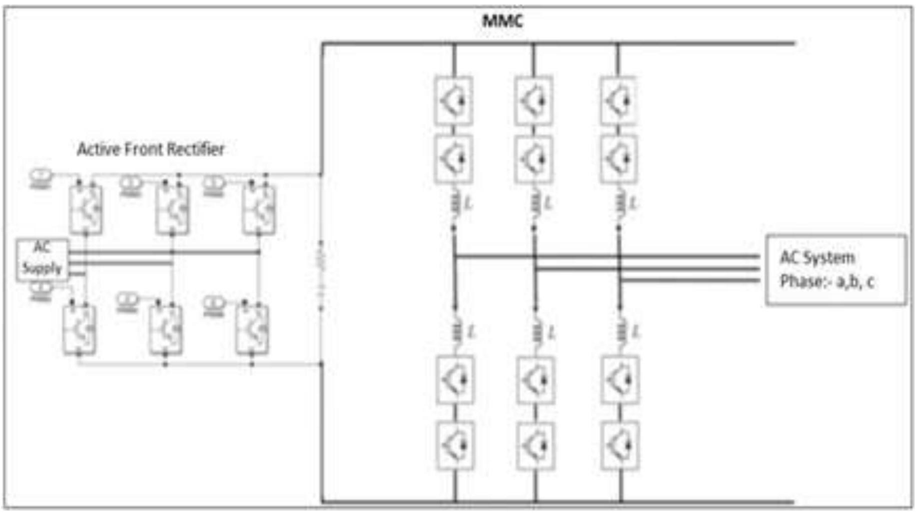
Proposed Back-To-Back Converter



This converter (also called an AC-DC-AC converter) is a power electronics system where two converters are connected in series.

This configuration allows flexible control of voltage, frequency, and phase, making it useful in various applications like motor drives, renewable energy systems, and power transmission.

Design the Proposed Converter:

- The design of the MMC will be dependent on the capacitance merit of the submodule, inductor size, number of submodule.
- The numeral of the submodules is determined by dividing the DC-link voltage by voltage of submodule capacitor.
- SM capacitor depends on capacitor voltage, voltage ripple , current ripple, and SM voltage capacity.

$$C \geq \frac{\sqrt{2NI_{ac}}}{\omega V_{\max p.u} V_{dc}} f_{max}(m, \varphi)$$

- Suppressing second harmonic among the arm limiting fault in the end of a short circuit faults are the main functions of arm inductance.

$$L_{arm} = \frac{1}{8\omega^2 C V_c}\left(\frac{P_s}{3I_{2f}} + V_{dc}\right)$$

- The design of the rectifier is based on value of the DC-link.

$$C = \frac{Vdc}{2R * fsw * \Delta Vdc}$$

Control Proposed Hybrid Transformer:

- The first part was to control the active front rectifier which was responsible for regulating the voltage. The desired voltage was dependent on the supply voltage.
- There were equations based on the supply voltage for each case to determine the desired DC-link voltage.

$$V_{DC} = \frac{3}{2} * \left(\frac{11000}{\sqrt{3}} - V_s\right) * \sqrt{2} + \left(\frac{3}{2}\right) * \frac{11}{}$$

$$V_{DC} = -\frac{3}{2} * \left(V_s - \frac{11000}{\sqrt{3}}\right) * \sqrt{2} + \left(\frac{3}{2}\right) * \frac{11}{}$$

$$V_{DC} = \left(\frac{3}{2}\right) * \frac{1100 * \sqrt{2}}{\sqrt{3}}; (nor$$

- The second part was to control MMC which was responsible for balancing the voltage through the submodule and regulating the AC output voltage. The control of the MMC was based on the d-q reference.

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- There are 2 submodules per arm. If the current is positive, submodule of the arm is ON, the capacitors will be charged.
- If the current was negative, submodule is ON, the capacitor of the submodule will be discharged.
- If the submodule was off, the capacitor voltage would remain constant.
- Submodule voltage of each arm will be sorted in the descending order.
- The required numeral working submodules are in the upper arm
- (nupper), in the lower arm (nlower) and (nupper + nlower = 2), and the voltage of each submodule should be regulted to (VDC/2).

VI. METHODOLOGY AND COMPONENTS

MATLAB/Simulink:

1. Primary tool for modeling, simulation, and analysis of the hybrid distribution transformer.
2. Used for circuit design, signal processing, and system-level analysis.
3. Simscape Electrical: Enabled the simulation of electrical components, power systems, and energy conversion processes.
4. Control System Toolbox: Used to design and analyze control strategies for voltage regulation and load management.
5. Power Electronics Models: Simulated converters, inverters, and other power electronic interfaces.
6. Data Visualization Tools: Plotted and analyzed simulation results, including voltage, current waveforms, and efficiency metrics.
7. Optimization Techniques: Employed for tuning parameters and achieving optimal system performance. These tools and techniques facilitated the efficient simulation and evaluation of the hybrid distribution transformer system.

SOFTWARE/TOOLS REQUIREMENT:

- Operating System- Windows 7 and above.
- IDE: MATLAB IDE
- Programming Language: MATLAB
- Platform: MATLAB 2018

VII. SIMULATION AND RESULTS

Simulation Result of Proposed Hybrid Transformer. The first simulation part was divided into three cases. The values of the parameters in the propose converter.

Parameters	Values
Voltage Supply	11kV
Submodule Capacitance	1.9mF
Arm Inductance	0.01mH
Submodule Voltage	1000V
DC-Link Capacitance	500μ F
Load Resistor	100Ω
Load Inductance	30mH

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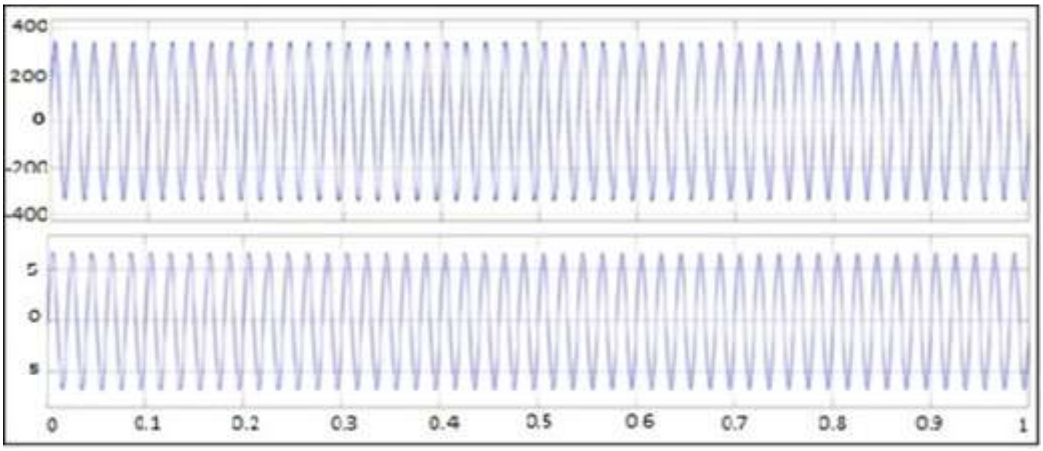

Fig. The current waveform and output voltage of the phase A

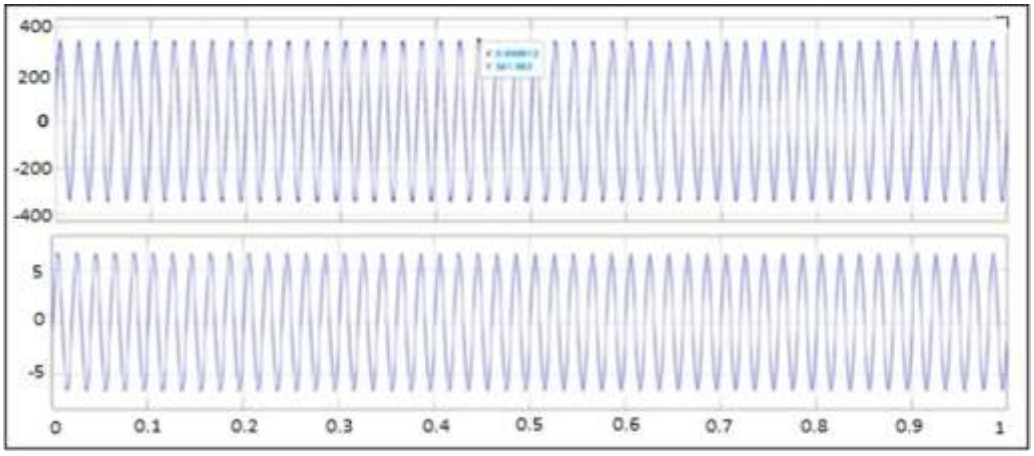

Fig. The O/P voltage and waveform of the load resistors 50 Ω

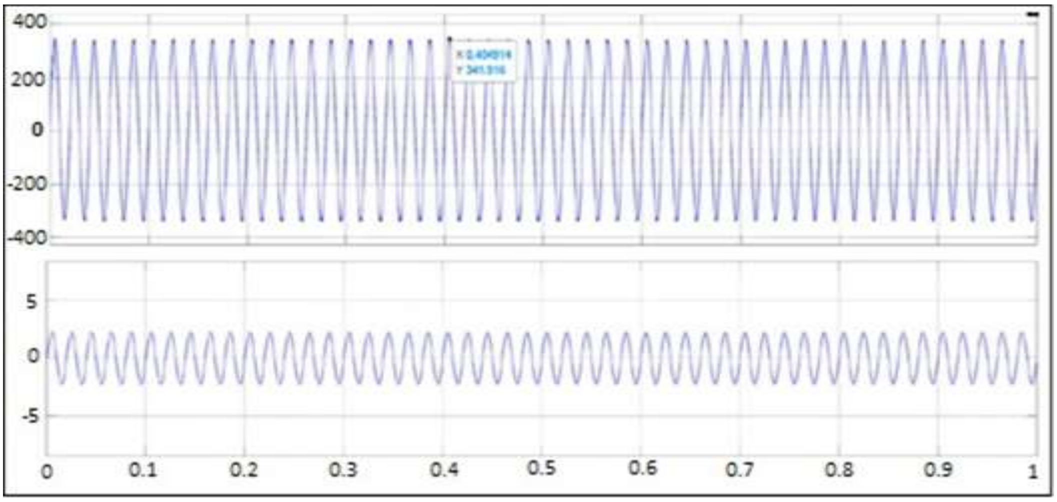

Fig. The output voltage and current waveform of load resistors 150 Ω

The proposed hybrid distributed transformer was 90% to provide load through distribution transformer and 10% of the supply power to feed the proposed converter. The proposed hybrid transformer was simulated under 3 cases (normal voltage, sag voltage, swell voltage), unbalance phase voltage and under various load resistors to represent the sag and swell conditions. The result verified that the proposed hybrid transformer has the ability to compensate for the output voltage of the load side with ±10%.

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VIII. CONCLUSION

Demonstrated the potential of integrating hybrid technologies, The key findings of the project include Enhanced Efficiency: The hybrid distribution transformer achieved improved efficiency in energy distribution by reducing power losses and optimizing energy flow through intelligent simulation-based control algorithms, providing a sustainable and eco-friendly energy solution.

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