Var Control Capability Analysis for a Hybrid Voltage Regulation Transformer

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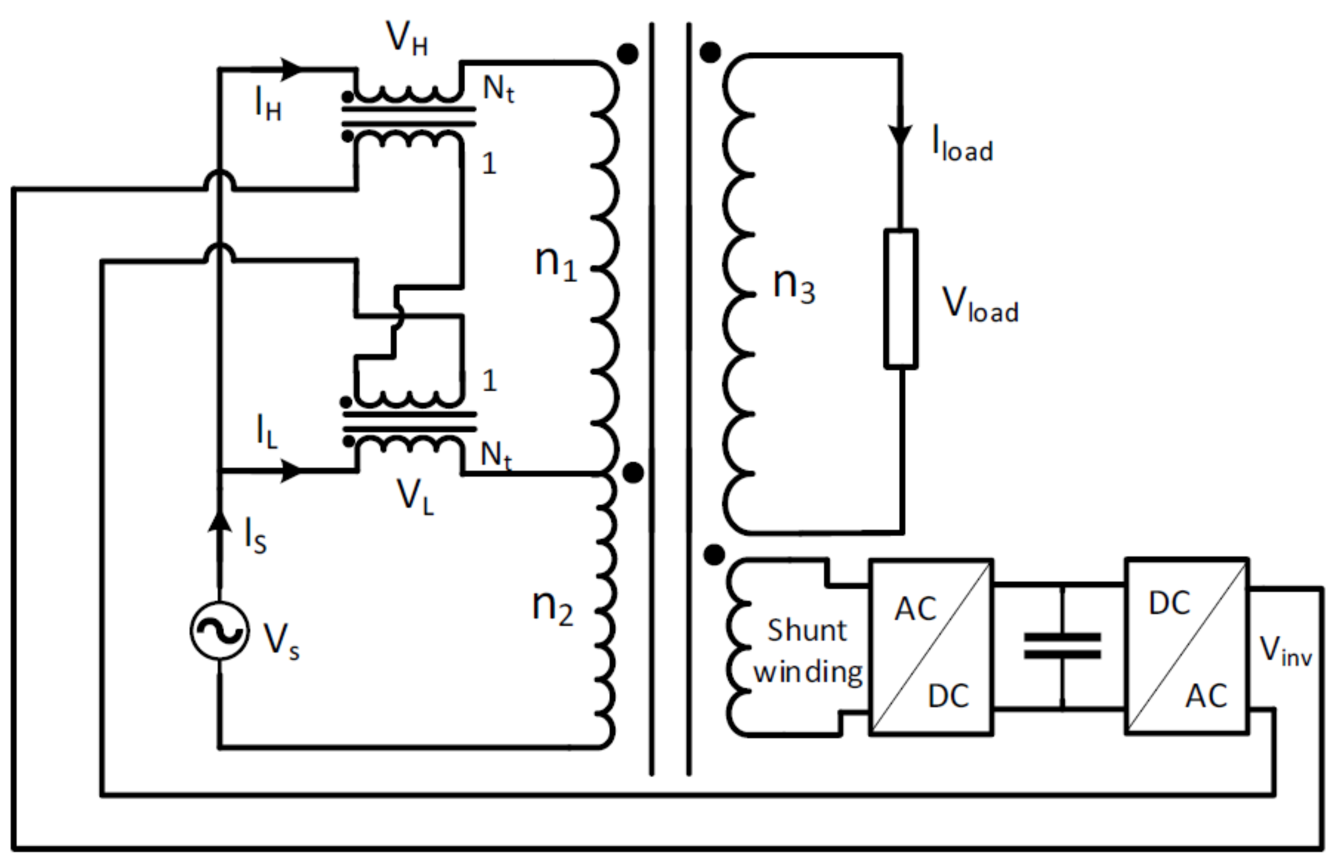
Introduction

- Voltage regulation is necessary from portable electronic devices to the power distribution systems to maintain the voltage magnitude.
- Voltage variation can be observed more frequently due to renewable energy penetration and the power generation variation from distributed energy resources (DERs).
- Power electronics-based voltage regulators have been proposed to provide fast voltage regulation and meet the increasing challenge in the grid integration of renewables.
- Var control capabilities and limits have not been investigated when the voltage magnitude regulation is implemented and takes part of the converter capacity.
- A new hybrid transformer topology is proposed for the voltage regulation at the medium voltage side of the distribution transformer.

Proposed Hybrid Voltage Regulation Transformer (VRT)

- Voltage regulation is implemented at the primary (medium-voltage) side with two windings in parallel.
- Shunt winding is connected with the power converter to provide constant voltage regulation.



- Based on the configuration of the VRT, load voltage can be derived as equation (6) which is related to the source voltage, inverter voltage and transformer winding turns ratio.

$$I_H = I_L = 0.5\, I_S \tag{1}$$

$$0.5\, n_1 I_S + n_2 I_S = n_3 I_{load} \tag{2}$$

$$I_{load} = \frac{n_2 + 0.5 n_1}{n_3} I_S \tag{3}$$

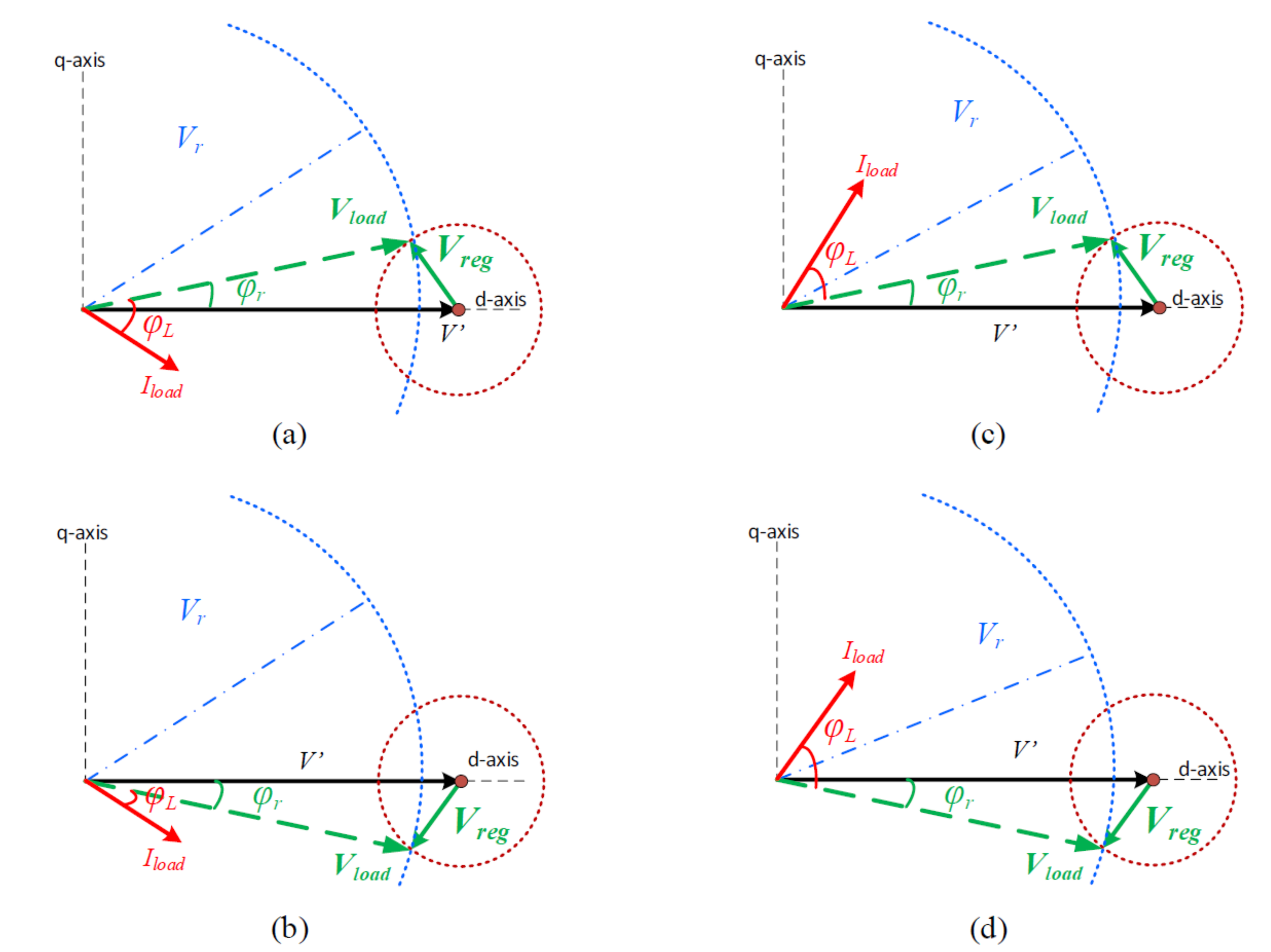
$$V_H + V_L = N_t V_{inv} \tag{4}$$

$$V_{load} I_{load} = V_S I_S + 0.5 I_S (V_H + V_L) \tag{5}$$

$$V_{load} = \frac{n_3}{n_2 + 0.5 n_1} (V_s + 0.5 N_t V_{inv}) \tag{6}$$

Var Control Capabilities

- **Condition I**: Fixed Load Voltage Magnitude



Voltage regulation vector analysis: (a) inductive load (+φ_L) leading regulation (+φ_r), (b) inductive load (+φ_L) lagging regulation (-φ_r), (c) capacitive load (-φ_L) leading regulation (+φ_r), (d) capacitive load (-φ_L) lagging regulation (-φ_r)

$$P_L = V_{load} I_{load} cos(\varphi_L) \tag{11}$$

$$P_s = V' I_{load} cos\,(\varphi_L - \varphi_r) \tag{12}$$

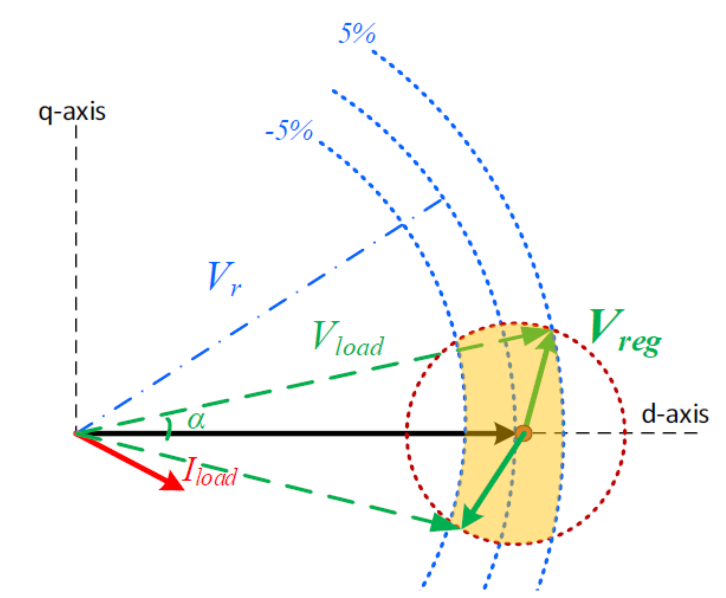
$$\varphi_r = sin^{-1}\left(\frac{y}{V_{load}}\right) = sin^{-1}\left(\frac{\pm\sqrt{\left|120^2 - \left(\frac{7128}{V'} + \frac{V'}{2}\right)^2\right|}}{V'}\right) \tag{13}$$

$$P_{inv} = P_L - P_s = V_{load} I_{load} cos\,(\varphi_L) - V' I_{load} cos\,(\varphi_L - \varphi_r) \tag{14}$$

$$Q_{max} = 2\sqrt{0.1 S_{sys}^2 - P_{inv}^2} = 2\sqrt{0.1 S_{sys}^2 - [V_{load} I_{load} cos\,(\varphi_L) - V' I_{load} cos\,(\varphi_L - \varphi_r)]^2} \tag{15}$$

Inverter active power can be calculated as equation (14) and the maximum var control capability can be derived as equation (15).

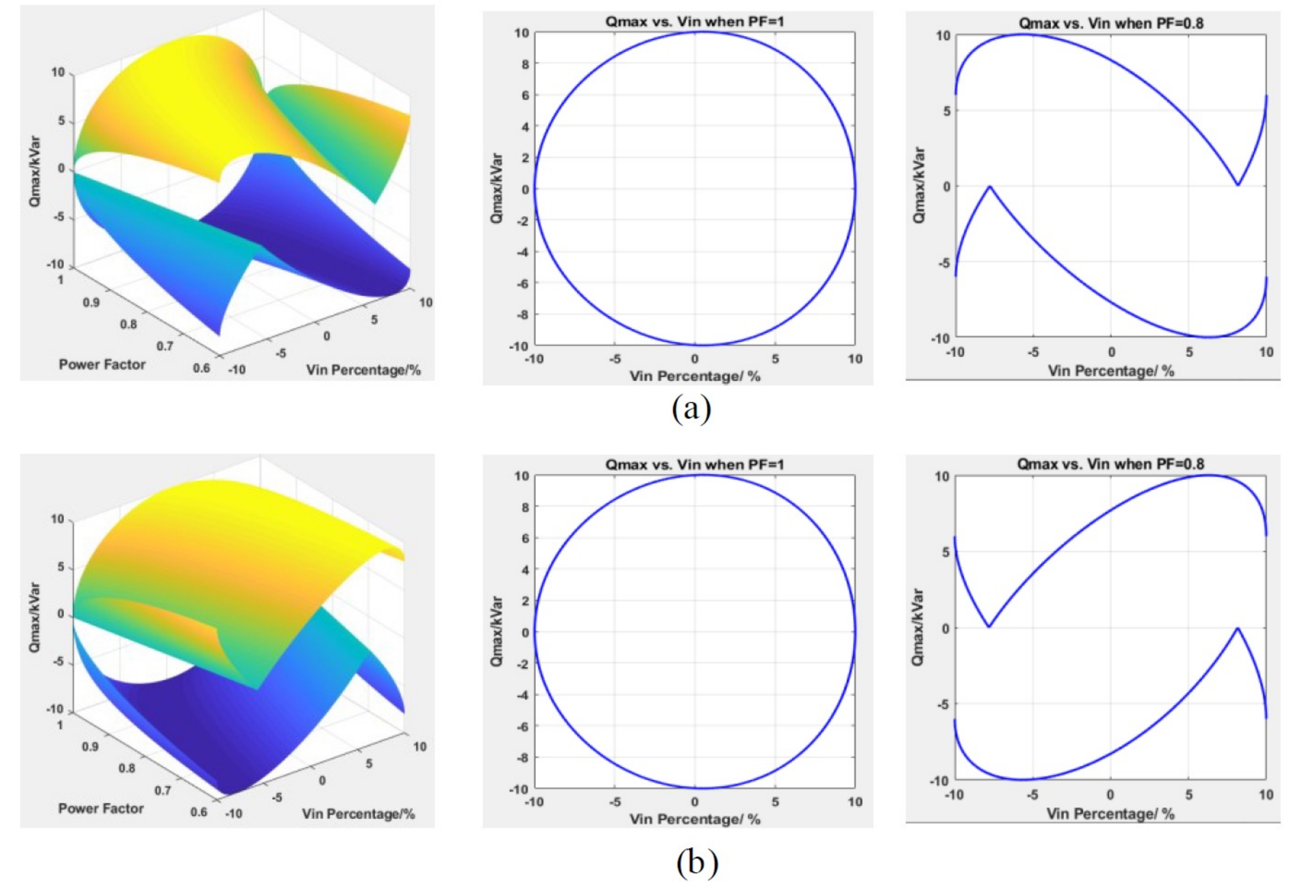
- **Condition II**: Load Voltage with Band Limits



The figure presents the vector analysis when the load voltage is regulated within ±5% band limit, which provides a more flexible var control range for the transformer. The shaded area is where the load voltage can be regulated.

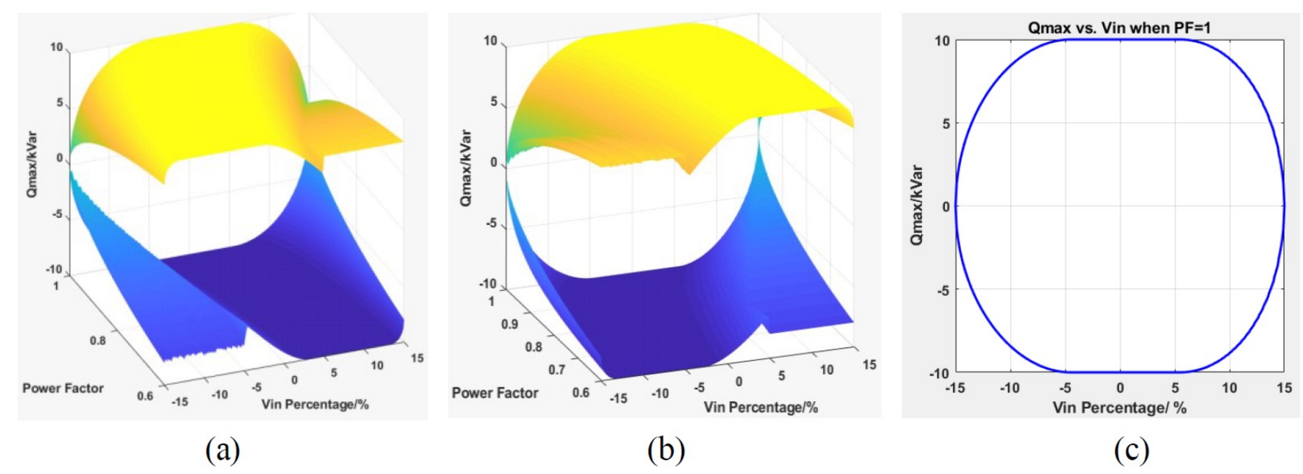
Simulation Results

- **Simulation Specifications:** 50kVA load, 5kVA converter capacity, 7.2kV source voltage, 120V load voltage
- **Condition I**: Fixed Load Voltage Magnitude



Based on equation (15), 3-D plot of the var control capabilities for fixed load voltage magnitude with (a) inductive load (+φ_L), (b) capacitive load (-φ_L)

- **Condition II**: Load Voltage with Band Limits



Based on equation (15), the var control capabilities are illustrated for (a) inductive load and (b) capacitive load. The converter can obtain maximum var control when the source voltage is within ±5% range.

Conclusion

- A new voltage regulator topology is proposed for hybrid voltage regulation transformer.
- The simulation results validate the feasibility of implementing var control while the load voltage is being regulated..
- The var control capability analysis are functionally verified and provide a realistic approach to applying distributed var control in distribution transformers.
- Var control capability of the VRT can expand the reactive power control capacity of the distribution system and relieve the var control stress on the dedicated conventional var control devices in the distribution system.

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