

# VFT Configuration for Decoupled Active-Reactive Powers Transfer Control

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**Abstract**— Variable frequency transformer (VFT) integrates the basics principles of rotary transformer and phase shifting transformer to control active power transfer between the two electrical networks. The active power transfer control concepts, design, and transient produce of the VFT have been deliberate in summary and are reported in the literature. However, reactive power flow through the VFT has not been appreciates so far. In the live installations, in order to encounter the VFT internal reactive current needed (magnetizing), switched capacitor banks are being used on the two sides of the VFT. These switched capacitor banks are outside to deal with uncontrolled reactive power interchange that can happen between the two networks through the VFT. This may attain desired power factor operation, but cannot avert the undesired reactive power exchange. These paper represent the detailed study on reactive flow through the VFT. The paper also proposes a new VFT configuration (with integrated partially-rated series voltage compensation strategy) to achieve a total control over reactive power flows. Thereby, the proposed design can achieve the bidirectional and decoupled active and reactive power flow through VFT. **Keywords:** Asynchronous Grid Interconnections, Decoupled Active-Reactive Powers Transfer, Reactive Power Exchange, Variable Frequency Transformer (VFT)

## I. INTRODUCTION

The controlled bidirectional power transfer connecting the asynchronous power networks was conventionally efficient by establishing the line commutated converter (LCC) based back-to-back connected HVDC link [1]. In wound of its numerous installations, the LCC-based HVDC link suffers from setbacks such as big reactive power need, high harmonic pollution, lower thermal time constant (i.e. lack of over current carrying ability), and lack of inertia for natural damping [2-3]. Over the time, the concern of reactive power requirement and harmonic pollution are approach to some extent, using the voltage source converter (VSC) based HVDC link.

On the other hand, the variable frequency transformer (VFT) is being examines as a new alternative for the asynchronous grid interconnections [2-18, 20]. A single line diagram of the VFT system configuration is represents in Fig. 1. The VFT consists of three-phase stator and rotor windings (build of Roebel bars), magnetically coupled through the air-gap. These stator and rotor windings are electrically connected to disparate power networks on the particular sides. The dissimilarities in electrical frequencies of these asynchronous networks is requite by relative mechanical speed of the rotor to attain synchronization between stator and rotor fluxes in the air-gap. The torque controlled coaxial devices (in general, a dc motor drive) combine to the rotor controls the phase angle shift between

the rotor and stator fluxes. The phase angle shifts, cooperatively with the VFT parameters regulate the magnitude and direction of active power transfer through the VFT [2-3]. Thus, the VFT act like a controlled (continuous) phase shifting transformer, connected between two asynchronous networks.

Examine of the VFT system during steady-state, dynamic and transient conditions is convey out in [7-13] using the simulation studies. The performance appraisal of VFT in collation with the LCC-HVDC link can be found in [6]. The significance of the VFT inertia offering and control to moist out the wind park power variation connected to main grid is presented in [14]. The operating performance and maintenance features of a 100MW VFT installation are discussed in [16-17].

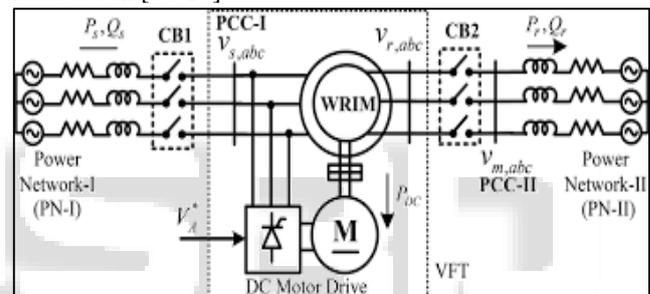


Fig. 1: VFT system configuration.

That paper is organized as follows: At first, the VFT steady-state equivalent circuit and the steady-state power flow equations. The matter of uncontrolled reactive power exchange is examines by obtaining the reactive power characteristic curves of a typical VFT system. Later, to disc the issue of uncontrolled reactive power exchange, a new VFT configuration with integrated partially-rated series voltage compensation scheme, that

- 1) Empower the use of fixed capacitor banks on one or both sides of VFT to encounter the VFT internal reactive power requirements.
- 2) Provides the ability to control reactive power transfer connecting the two power networks through the VFT, decoupled from (without affecting) the active power transfer control.

## II. VFT STEADY-STATE OPERATION

The equations presenting the power transfer through the VFT, available in literature [4, 18], are insufficient to analyse the reactive power flow as they basis on active power only by neglecting the leakage and magnetizing inductances and magnetizing inductances.

Therefore, in order to determine the reactive power flow through the VFT at each and every operating point, a clarify single-phase equivalent circuit of a typical wound rotor induction machine (WRIM) referred to the stator-side. In which, the expression  $v$ ,  $i$ ,  $R$ ,  $L$ ,  $Z$ , and  $s$  represents the

voltage, current, resistance, inductance, impedance, and slip respectively. Whereas, the subscripts r and s refers to the stator and rotor side quantities, while the superscript ' means the rotor quantities referred to the stator side.

### III. REACTIVE POWER FLOW IN THE VFT SYSTEM

To signify the uncontrolled reactive power exchange through the VFT, a 3.7kW WRIM is examine during this study. Specifications and machine variable are given in the Appendix.

#### A. Grid Voltage(s) Deviation from the Nominal Value:

The grid voltage magnitudes at transmission level swing to drift from their nominal values within the pre-specified limits (tolerance band of +5 to -5 , in general). The collusion of such small grid voltage deflections(in one or both the networks) at VFT interconnections could lead to big changes in reactive power flow (or exchange) through the VFT. This can be envisage from the VFT reactive power characteristic curves get with the variation in grid voltages by +5 to -5 . In this study, rotor side voltage is varied linking 0.95p.u. and 1.04p.u.while protection the stator side voltage unaltered at 1p.u. to obtain the reactive power characteristics in Fig. 2. These graphs are obtained during 0.85p.u. active power transfer through the VFT from stator to rotor side.

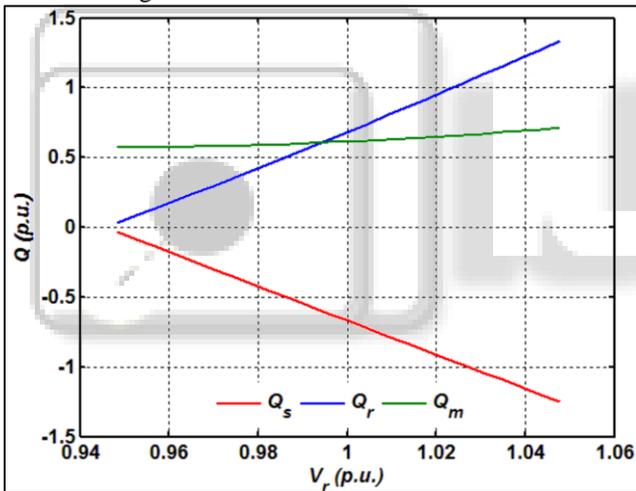


Fig. 2: VFT reactive power characteristics (with fixed capacitor banks) during 0.85 p.u. active power transfer from stator to rotor side.

#### B. Magnitude and Direction of Active Power Transfer:

The coupling result of active power transfer control on the reactive power flow across the VFT can be seen from VFT reactive power characteristic curve drawn in Fig. 3. To transform this characteristic from previous case, the grid voltages are maintained at their nominal values i.e.  $V_s=1$  p.u. and  $V_r=1$  p.u. while the active power transfer prescribe is slowly changed from  $P_s=0.85$  p.u. to  $0.85$  p.u. In spite of no deflection in grid voltage magnitudes, uncontrolled reactive power exchange (about 0.4p.u.) can be shown in Fig. 3.

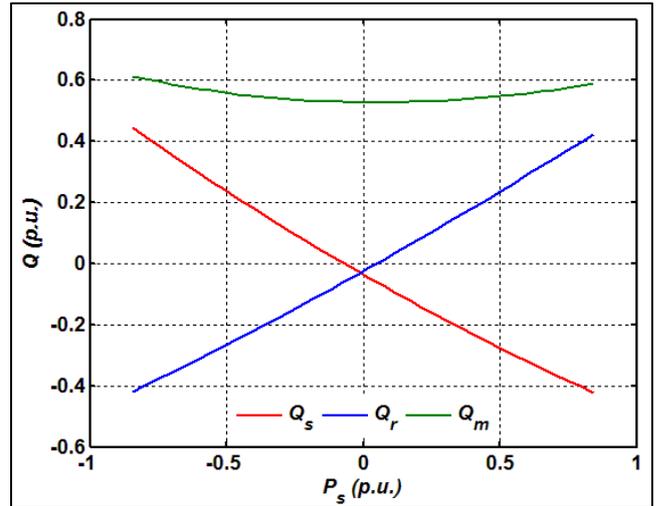


Fig. 3: VFT reactive power characteristic (with fixed capacitor banks) under varying active power transfer.

### IV. PROPOSED VFT CONFIGURATION FOR DECOUPLED ACTIVE-REACTIVE POWERS TRANSFER CONTROL

Based on the examination and discussion presented in the previous section, it can be conclude that the main cause for uncontrollable reactive power exchange through the VFT is the slight variation in grid voltage magnitudes from their nominal values. The ideal solution for this case is to have a control over the constructive grid voltage magnitudes seen by the VFT. This can be notice by having a small series voltage compensation scheme in series with the VFT which compensate the grid voltage deviations.

Other cause for the uncontrollable reactive power exchange through the VFT is the change in active power transfer commands (magnitude and directions). This can also be approach by utilizing the dependency of reactive power characteristic of the VFT on the grid voltage magnitudes. With the control over the constructive grid voltage magnitude shows by the VFT (using the series voltage compensation scheme), the reactive power exchange through the VFT can be controlled whatever of the magnitude and direction of active power transfer through the VFT. Moreover, accomplish the control over effective grid voltage seen by the VFT could empower the capability to have a controlled bidirectional reactive power transfer through the VFT as long as the total VFT current does not overshoot its rating.

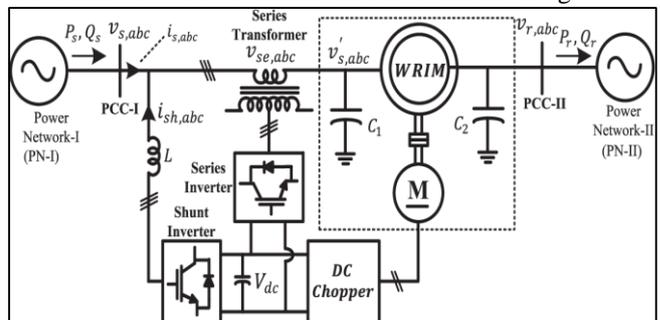


Fig. 4: Proposed VFT configuration for decoupled active-reactive power transfer control.

V. CONTROL OF THE ADVANCE VFT CONFIGURATION FOR DECOUPLED ACTIVE-REACTIVE POWER TRANSFERS CONTROL

The overall control construction of the proposed VFT configuration for decoupled active-reactive power transfers control is as shown in Fig. 4. The control part for the proposed VFT design is divided into three subsections as: 1) shunt inverter control, 2) DC chopper control, and 3) series inverter control.

A. Shunt Inverter Control:

The shunt inverter is supervise to regulate the dc link voltage to its reference value whatever of the direction of power flow. From Fig. 4, the voltage balance equation across associate inductor ( $L$ ) with an internal resistance ( $R$ ) in synchronous reference frame.

The d-axis of the reference body of shunt inverter control is aligned with the grid voltage at PCC-I i.e., voltage-oriented vector control.

B. DC Chopper Control:

The DC chopper is a full-bridge buck converter that controls the armature voltage of the DC motor to synchronize the rotor speed/torque. Hierarchical control scheme proposed in [18] is used to generate the reference armature voltage that found the VFT connection with two asynchronous power networks, and smooth the bidirectional active power transfer control through VFT.

C. Series Inverter Control:

The reactive component of the stator current is directly proportional to the reactive power living supplied by power network-I. The value of current reaches zero only when the whole VFT reactive power needs are encountered by the fixed capacitor banks placed on two sides of the VFT (zero reactive power exchange). Ideally, this condition occurs when sending voltage and receiving voltage are at their nominal values and  $P_s = P_r = 0$ .

1) Performance during the Changes in Magnitude and Direction of Active Power Transfer:

This presentation of the conventional and proposed VFT configurations during the changes in active power transfer command are represented in Fig 5. The grid voltages are sustain at nominal values ( $|V_s|=1p.u.$  and  $|V_r|=1 p.u$ ) during the test. Both the VFT configurations are in steady-state preceding to time sending to time  $t_1$  the active power  $P_s=0.85 p.u$ . At  $t_1$ , active power sending command is changed to  $P_s=-0.85 p.u$ . As the advance time between two stead-states is in few seconds, both new and old steady-state performances have been flash in separate windows named as shown in Figs.5.

the configurations did maintain the steady-state active power transfer at  $P_s=0.85 p.u$  preceding to (seen from Figs. 5 and at  $P_s=-0.85 p.u$ . after ( in also Figs.5).

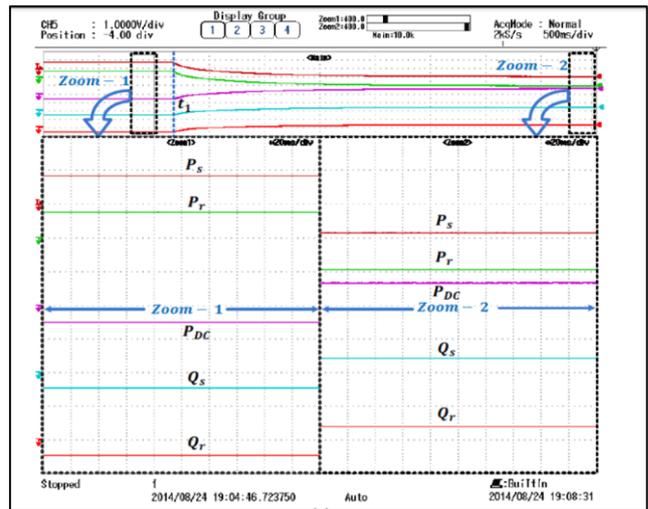


Fig. 5: Performance of the conventional VFT configuration during active power transfer command change.

2) Presentation during the Severe Grid Voltage(s) Deviation from Nominal Value:

During the grid voltage(s) deviation, the ordinary VFT configuration follows ac network rules (in steady-state) and let the reactive power to flow from the network with comparatively high voltage magnitude to the other side. This can be observe as natural voltage support movement as long as the total (active plus reactive) current is within VFTs transfer capacity. If the VFT is transferring the active power be up to its capacity, even the small reactive power interchange gets stratified over it and cause over currents.

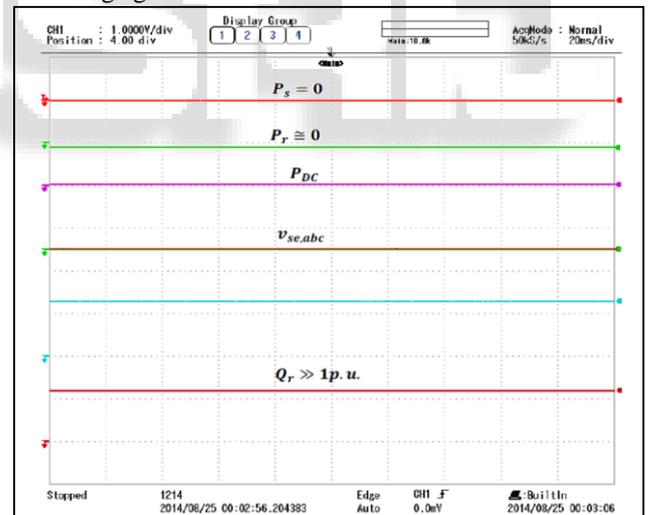


Fig. 6: Performance of the conventional VFT configuration under severe grid voltage deviation.

3) Presentation during the controlled reactive power transfer:

The result presented in Fig. 7 return the ability of the proposed VFT configuration to reach the decoupled active-reactive powers transfer control. During this test, the  $P_s$  set at 0 per unit and the grid voltages are at their nominal levels. At first, the reactive power transfer command of  $Q_s=0.85$  per unit was in effect preceding to time  $t_2$  and is changed to  $Q_s=-0.85$  per unit . The acceptable performance of the suggest VFT configuration both active and reactive power transfer commands concurrently can be seen from the discover of  $P_r, P_s, Q_s$  and  $Q_r$ , and in Fig. 7.

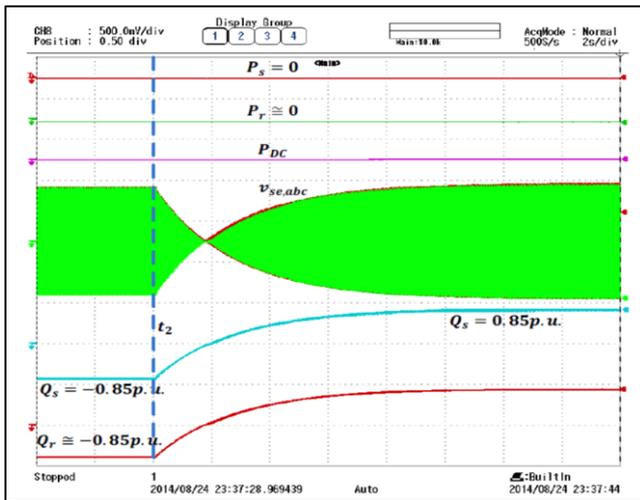


Fig. 7: Performance of the proposed VFT configuration during controlled reactive power transfer.

## VI. CONCLUSION

This paper represented with the issue of uncontrolled reactive power exchange through the VFT in asynchronous grid interconnections. The sensitivity of this uncontrolled reactive power interchange through the VFT to 1) the little changes in grid voltage magnitude on two sides, and 2) the direction and magnitude of active power transferred, is discussed in brief. A new VFT design has been proposed, that integrates the relatively rated series voltage compensation strategy into the conventional VFT configuration, to reach the control over the reactive power flow through the VFT without trouble the active power transfer. The control planning for the new VFT configuration has been offers to perform decoupled active-reactive power transfers control concurrently. A new decoupled active-reactive power transfer control capacity of the VFT, it can be supposed that VFT technology is one-step closer to be the most recommended choice for asynchronous grid interconnections.

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