Variable Frequency Transformer - State of Review

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Abstract

This paper represent a new model of the variable frequency transformer (VFT).The variable frequency transformer is basically bidirectional, controllable transmission device. It transfer power between two networks. The construction of VFT is similar to conventional asynchronous machines, where the two separate electrical networks are connected to the stator winding and the rotor winding, respectively. The core technology of the VFT is a rotary transformer with three-phase windings on both stator and rotor. A motor and drive system are used to adjust the rotational position of the rotor relative to the stator, thereby controlling the magnitude and direction of the power flowing through the VFT.

This paper gives an overview about core components, mechanical design, commissioning, model, operation, analysis and applications of VFT.

I.INTRODUCTION

A variable-frequency transformer (VFT) is used to transmit electricity between two (asynchronous or synchronous) alternating current frequency domains. The VFT is a relatively recent development. Most asynchronous grid inter-ties use high-voltage direct current converters, while synchronous grid inter-ties are connected by lines and "ordinary" transformers, but without the ability to control power flow between the systems.

It can be thought of as a very high power synchro, or a rotary converter acting as a frequency changer, which is more efficient than a motor–generator of the same rating.

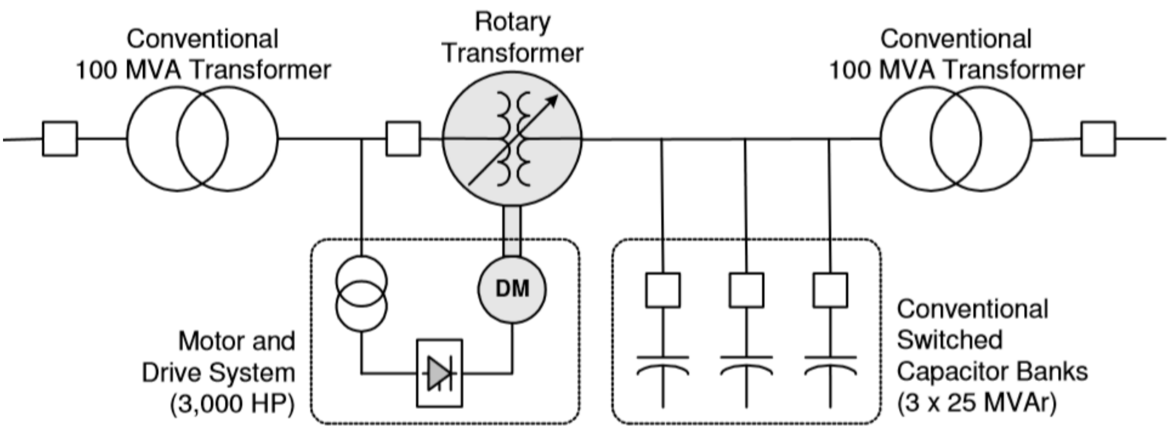
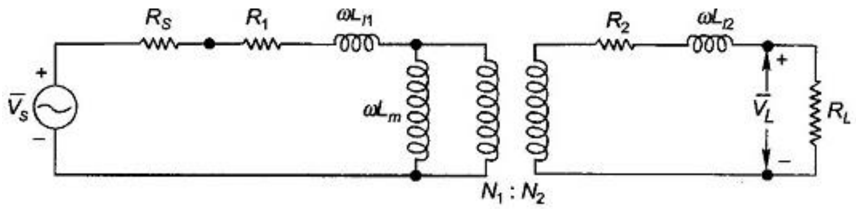


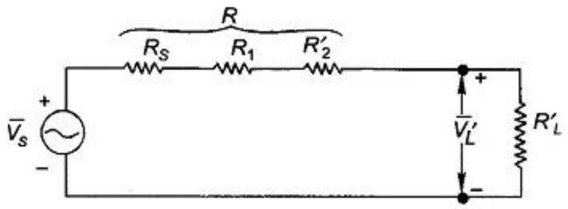
FIG -One line diagram of VFT

II. VARIABLE FREQUENCY TRANSFORMER OVERVIEW

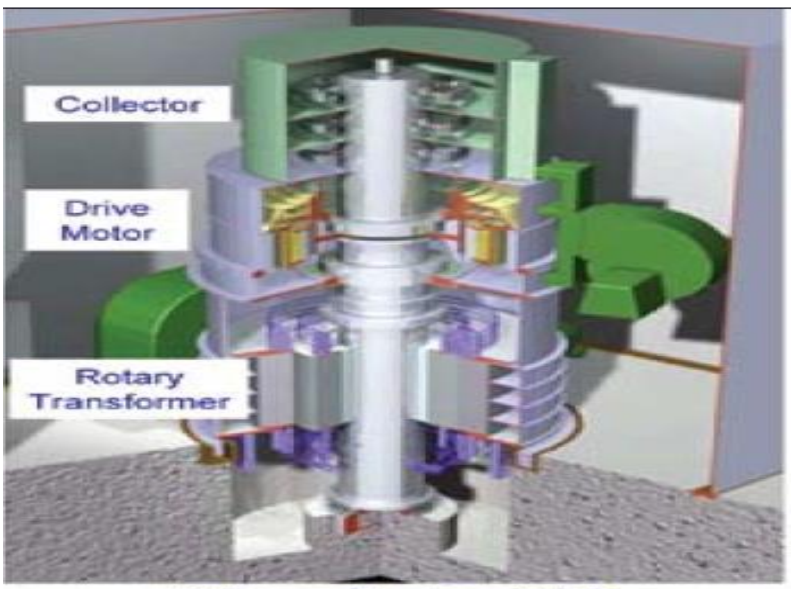
The core technology of the VFT is the rotary transformer with three phase windings on both rotor and the stator. A three phase collector system conducts current between the three phase rotor winding and its stationary bus duct. The two separate electrical networks are connected to the stator and rotor respectively. Electrical power is exchanged between the two networks by the magnetic coupling through the air gap. A drive motor and a variable speed drive system is used to apply torque to the rotor of the transformer and adjust the rotational position of the rotor relative to the stator, thereby controlling



(a) Circuit model of transformer



The magnitude and direction of the power flow through the VFT. Fig 1 shows the core components of the VFT. Fig. 2 illustrates a conceptual system diagram of the VFT. Conventional transformers are used to match the transmission voltage to the machine voltage. Shunt capacitors are used to compensate for the reactive magnetizing currents. As with any other AC power circuit, the real power flowthrough the rotary transformer is proportional to the phase angle difference between the stator and the rotor. The impedance of the rotary transformer and AC grid determine the magnitude of phase shift required for a given power transfer. Reactive power flow through the VFT is determined by the series impedance of the rotary transformer and the difference in magnitude of voltages on the two sides.



Cut-away Drawing of VFT

If torque is applied in the opposite direction, then power flows from the rotor winding to the stator winding. Power flow is proportional to the magnitude and direction of the torque applied. The motor and drive system are designed to continuously produce torque while at zero speed (standstill). If no torque is applied, then no power flows through the rotary transformer. When the two systems are no longer in synchronism, the rotor of the VFT will rotate continuously and the rotational speed will be proportional to the difference in frequency between the two power grids. During this operation the load flow is maintained. The VFT is designed to continuously regulate power flow with drifting frequencies on both grids. Regardless of power flow, the rotor inherently orients itself to follow the phase angle difference imposed by the two asynchronous systems.

III. MECHANICAL DESIGN OVERVIEW

It is composed of three main components i.e. rotating transformer, drive motor and collector system (discussed earlier). These various are shown in Fig. 3 [7]. A dc drive motor is used for the VFT application. Different considerations are required while designing a dc drive motor. For the given application the dc drive motor should have a very high level of reliability and unit availability, while requiring a minimum number of maintenance outages for servicing of the drive. High overall system efficiency is also extremely important for the successful design of a VFT system. Therefore, the loss incurred by the dc drive becomes an important design consideration.

It is composed of three main components –

(a) Rotating transformer

(b) Drive motor

(c) Collector

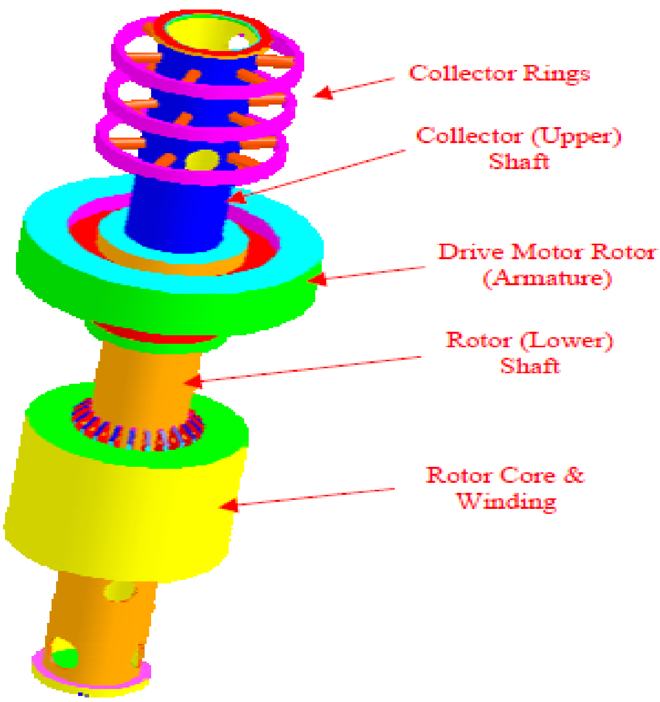


Fig : VFT rotating component

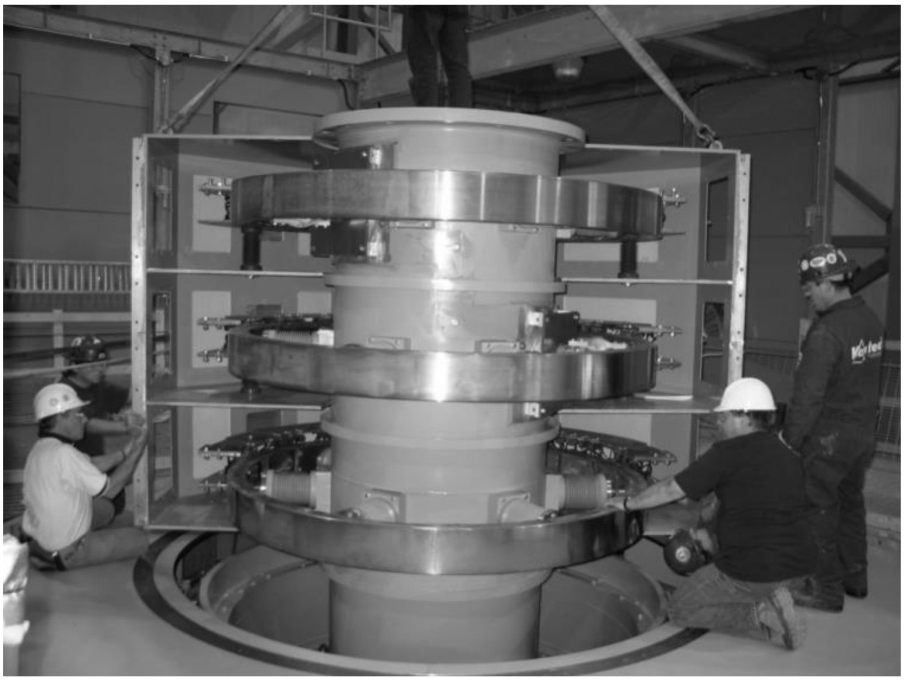


Fig: A typical assembly of VFT three phase collector

The three phases collector is at the top of the rotary system. The collector comprises of conventional carbon-brush technology on copper slip rings. The collector rings are connected to the rotor windings via a three phases bus that runs through the hollow shaft. Fig. 5 shows the site assembly of a typical collector system. The drive motor is a conventional dc motor. The rotating components, since they have very little self-cooling capability because of the low rotational speed, are force-air cooled. The inertia of the total rotary system is rather large. Typically, in per-unit on a 100 MVA base, it has an equivalent H-factor of about 26 pu-sec. This large inertia helps to maintain stability during grid disturbances.

IV. VFT MODEL AND OPERATION

The VFT can be modelled as a doubly-fed wound electrical machine (WRIM) with three phase windings provided on both stator side and rotor side [9]. The power system#1 is connected to the stator side of the VFT, energized by voltage, VS with phase angle, θ_S. The power system#2 is connected to the rotor side of the VFT, energized by voltage, Vr with phase angle, θr. The two power systems (#1 and #2) are connected through the VFT as shown in Fig. 6. A drive motor is mechanically coupled to the rotor of WRIM. A drive motor and control system are used to apply torque, TD to the rotor of the WRIM which adjusts the position of the rotor relative to the stator, thereby controlling the direction and magnitude of the power transmission through the VFT. Here, in the power transfer process, only real power transfer is being discussed.

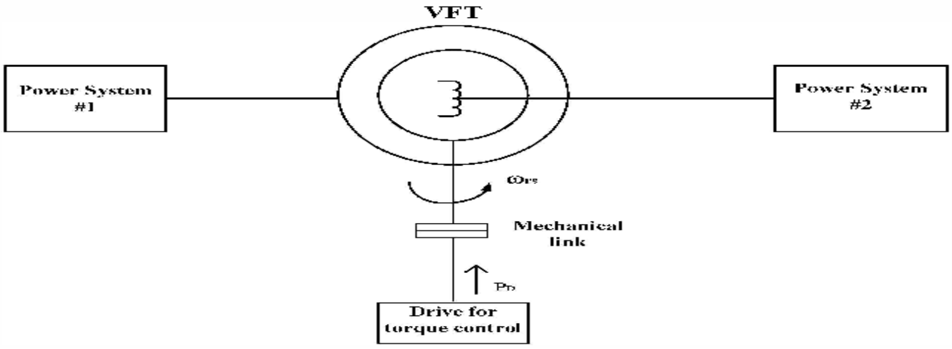


Fig: The VFT model representation

A stable power exchange between the two asynchronous systems is possible by controlling the torque applied to the rotor, which is controlled externally by the drive motor. When the power systems are in synchronism, the rotor of VFT remains in the position in which the stator and rotor voltage are in phase with the associated systems.

V. VFT ANALYSIS

The power transfer through the variable frequency transformer (VFT) can be approximated as :

$$P_{VFT} = P_{MAX} \, Sin \, \theta net$$

P_{VFT} = Power transfer through VFT from stator to rotor,
P_{MAX} = Maximum theoretical power transfer possible
VFT in either direction which occurs when the net angle θ *net* is near 90°. The P_{MAX} is given by:

$$PMAX = Vs \, Vr / Xsr$$

Vs = Voltage magnitude on stator terminal,
Vr = Voltage magnitude on rotor terminal and
Xsr = Total reactance between stator and rotor terminals.
Also

$$\theta net = \theta s - (\theta r + \theta rs)$$

θs = Phase-angle of ac voltage on stator, with respect to a reference phasor,
θr = Phase-angle of ac voltage on rotor, with respect to a reference phasor and θrs = Phase-angle of the machine rotor with respect to stator.
Thus, the power transfer through the VFT is given by:

$$P_{VFT} = ((Vs \, Vr/ Xsr) \, sin(\theta s - (\theta r + \theta rs))$$

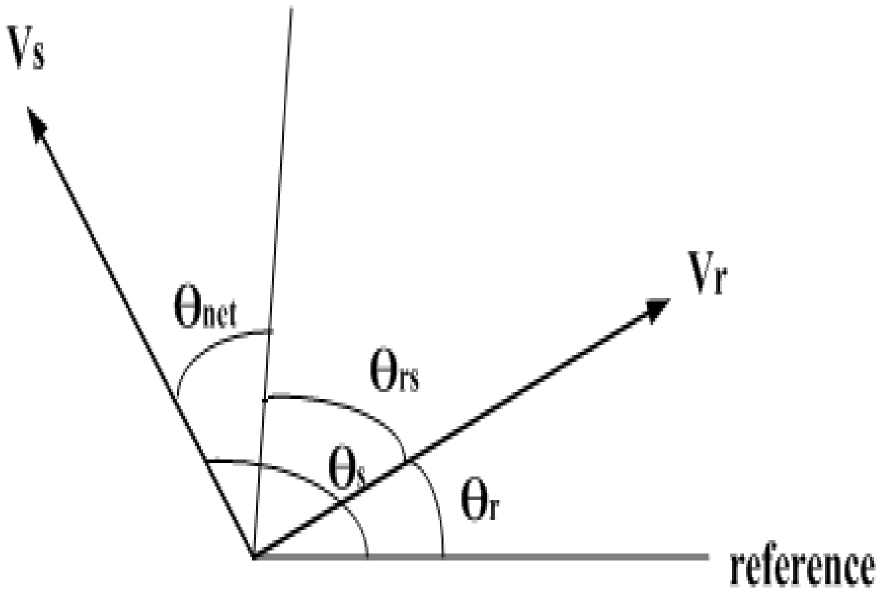


Fig :Phasor diagram

The power flow directions shown in are based on generator convention with positive sign indicating power flowing out of the machine windings and into the shaft through the drive system. The actual power flow direction may be either positive or negative depending on the operating condition.

Power balance requires that the electrical power flowing out of the stator must flow into the combined electrical path on the rotor and the mechanical path to the drive system:

$$Ps = P_D - Pr$$

where,

Ps = electrical power out of stator windings

Pr =electrical power out of rotor windings

P_D = mechanical power to the torque-control drive system, eventually appearing as electrical power exchanged with the power system to which the drive system is connected.

CONCLUSION

VFT technology is a viable technology for achieving real power transfer control between two or more asynchronous power system networks. Moreover, the direction and the magnitude of power transfer can also be controlled.

For Future application of the VFT would be to utilize the dual ability to control the phase as well as to compensate for the frequency variation. This could be used to operate pumps or hydro turbines closer to their maximum efficiency conditions. It could also be used to stabilize or absorb load swings in a power system, which would permit operation with a lower spinning reserve.

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