IMPLEMENTATION OF VARIABLE FREQUENCY TRANSFORMERS TO STABILIZE ELECTRIC POWER SYSTEMS

By

Eng. Islam Saad El-Sayyed Emam

A Thesis Submitted to the

Faculty of Engineering at Cairo University

In Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

In

Electrical Power and Machines Engineering

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Title of Thesis:

Implementation of Variable Frequency Transformers to Stabilize Electric Power Systems.

Key Words:

Variable Frequency Transformer (VFT); Wound Rotor Induction Machine (WRIM); Asynchronous Network Interconnections; Power Flow; Synchronization; Wind Energy Farm

Summary:

This thesis presents new technique for controlling power flow to stabilize power systems including wind energy farms. Variable Frequency Transformer (VFT) consider one of the important and new applications of slip ring induction machine. This technique can be implemented to stabilize unique and different frequencies electric power systems. Also, it can be applied with wind energy farms to improve its characteristics and performances.

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LIST OF SYMBOLS AND ABBREVIATIONS

VFT	Variable Frequency Transformer
WRIM	Wound Rotor Induction Machine
HVDC	High Voltage Direct Current
d-q	Direct-Quadrature
RPM	Repulsion Per Minute
Hz	Hertz
W	Watt
VAR	Voltage Ampere Reactive
RMS	Root Mean Square
pu	Per Unit
Deg.	Degree
DFIG	Doubly Fed Induction Generator
EHV	Extra High Voltage
H.V	High Voltage
IPB	Isolated Phase Bus
SLG	Single Line to Ground
AC	Alternating Current
DFIM	Doubly Fed Induction Machine
GE	General Electric
SRIM	Slip Ring Induction Machine
AEP	American Electric Power
CFE	Comisión Federal de Electricidad
ERCOT	Electric Reliability Council of Texas

ABSTRACT

The Variable Frequency Transformer “VFT” provides bidirectional power flow for High Voltage (H.V) transmission systems. The VFT can transfer power between asynchronous networks. Basically, it is a rotating transformer whose torque can be adjusted to control in the power flow. This technique has many of advantages over the conventional technique of HVDC link. It depends mainly on a rotating machine which has many advantages over another method as its controllability, operating flexibility, compact design and its stability.

The proposed application technique provides VFT theory of operation, construction, and component and built VFT model (Built In) based on MATLAB- SIMULINK and SIM Power System toolbox for studying its performance characteristic, operation and control technique.

Also, the proposed technique provides VFT response for any changing in power system parameters (frequency, loss of main H.V.” High Voltage” line and line and earth faults).

This technique shows that VFT can be implemented between networks to isolate them. This isolation extended from frequency disturbance till phase line and earth faults. Also, VFT can be applied to connect two asynchronous networks like Egypt network with 50 Hz and Kingdom of Saudi Arabia network 60 Hz.

Built mathematical model based on MATLAB/SIMULINK and SIM Power System toolbox for whole system for studying VFT dynamic response during starting and power flow transferring. Results show that VFT has excellent dynamic response during power system disturbances. Results of VFT shows that it damps any disturbance at any connected network due to its internal impedance and its rotating inertia.

The proposed model integrated with Doubly Fed Induction Generator to provide new technique for controlling power flow through wind turbine. It studies some of disturbance that can be occurred in power systems and wind turbine. Due to limitations of electronic circuit –Rectifier and Inverter- that integrated to the rotor circuit of Wound Rotor Induction Machine, this new technique provided to overcome all these limitations.

VFT is considered as a new important tool that can be used to stabilize electric power system and control power flow. This tool does not less than the conventional transformers and generators inventions.

Thesis will start from basics of power flow step by step and accumulate information till draw the full picture for VFT and its characteristics. Results and figures will be integrated internal each chapter to try to draw each chapter structure and architecture.

CHAPTER 1: INTRODUCTION

Due to the extra growing in generation of electricity in the last years, the need for stable and economic interconnections between asynchronous networks becomes high. These interconnections between synchronous or asynchronous network were provided to reduce the cost of electricity and to improve power system reliability and stability.
Two types of interconnections between networks can be classified as the following:
First type is to connect two synchronous networks with Alternating Current (AC) transmission lines. This type is simple and economic, but it increases the networks complexity and decreases the stability of the two networks under serious faults. So, the AC interconnections are replaced by HVDC interconnections. HVDC has the capability to connect synchronous and asynchronous networks.
Second type of interconnections is to connect two asynchronous networks by HVDC link or by a new technology known as VFT. HVDC link and VFT technology provide these interconnections. Each method has its benefits and advantages, also has its berries and limitations. Power system, protection system and machine system become nowadays very sensitive. Each system has its effect on the other systems. It is become necessary to provide a research at any system and study its effect on the other systems. The three systems are collected to provide new technology named by Variable Frequency Transformer. Each system has its touch on this equipment. Rotary transformer (Wound Rotor Induction Machine) and DC drive system is the core technology for VFT. Interconnection between asynchronous networks using VFT technology shall be studied by power system and protection systems. These studies provide stability, load flow and short circuit evaluations for VFT.

1.1 Power flow concept

Power flow in the grid from system to another system depends up on the differences between voltage angles of the two systems as the active and reactive power flow law are [1]:

At V_2 terminals

$S = P + JQ = V_2 * I^*$ ………. (1.1), Apparent Power Equation.

$P = \frac{V_1\, V_2}{X_{12}}\, sin(\delta)$ ………. (1.2), Active Power Equation.

$Q = \frac{V_1\, V_2 \cos(\delta) - V_2^2}{X_{12}}$ ………. (1.3), Reactive Power Equation.

Where:
- V_1 is the magnitude voltage for system 1.
- V_2 is the magnitude voltage for system 2.
- P is the power flow magnitude from V_1 to V_2.
- Q is the reactive power flow magnitude from V_1 to V_2.
- δ is the angle difference between V_1 and V_2.
- X_{12} is the total reactance between system 1 and system 2.
  The power circuit and phasor voltage are shown in figs. (1-1) and (1-2).
  By assuming V_1, V_2 and X_{12} are constants, the power flow can be fully controlled by controlling in the angle between the two voltage systems. By the same concept, if the angle of voltage system 1 (V_1) is constant –Infinite Bus (Constant Voltage & Constant Frequency), the power flow can be controlled