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Transformer-Less UPFC for Wind Turbine Applications

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ABSTRACT

In this paper, an innovative technique with a new concept of transformer-less unified power flow controller ***(UPFC)*** *is implemented. The construction of the conventional UPFC that consists of two back-to-back inverters which results in complexity and bulkiness which involves the transformers which are complication for isolation & attaining high power rating with required output waveforms. To reduce a above problem to a certain extent, a innovative transformer-less UPFC based on less complex configuration with two cascade multilevel inverters* ***(CMIs)*** *has been proposed. Unified power flow controller (UPFC) has been the most versatile Flexible AC Transmission System* ***(FACTS)*** *device due to its ability to control real and reactive power 80w on transmission lines while controlling the voltage of the bus to which it is connected. UPFC being a multi-variable power system controller it is necessary to analyze its effect on power system operation. The new UPFC offers several merits over the traditional technology, such as Transformer-less, Light weight, High efficiency, Low cost & Fast dynamic response. This paper mainly highlights the modulation and control for this innovative transformer-less UPFC, involving desired fundamental frequency modulation (FFM) for low total harmonic distortion (THD), independent active and reactive power control over the transmission line, dc-link voltage balance control, etc. The unique capabilities of the UPFC in multiple line compensation are integrated into a generalized power flow controller that is able to maintain prescribed, and independently controllable, real power & reactive power flow in the line. UPFC simply controls the magnitude and angular position of the injected voltage in real time so as to maintain or vary the real and reactive power flow in the line to satisfy load demand & system operating conditions. UPFC can control various power system parameters, such as bus voltages and line flows. The impact of UPFC control modes and settings on the power system reliability has not been addressed sufficiently yet. Cascade multilevel inverters has been proposed to have an overview of producing the light weight STATCOM's which enhances the power quality at the output levels.When the multilevel converter is applied to STATCOM, each of the cascaded H-bridge converters should be equipped with a galvanically isolated and floating dc capacitor without any power source or circuit. This enables to eliminate a bulky, heavy, and costly line-frequency transformer from the cascade STATCOM. When no UPFC is installed, interruption of either three-phase line due to a fault reduces an active power flow to half, because the line impedance becomes double before the interruption. Installing the UPFC makes it possible to control an amount of active power flowing through the transmission system. Results has been shown through MATLAB Simulink*

KEYWORDS: *FACTS, UPFC, CMIs, etc.*

I. INTRODUCTION

Power systems in general are interconnected for economic, security and reliability reasons. Exchange of contracted amounts of real power has been in vogue for a long time for economic and security reasons. To control the power flow on tie lines connecting controls areas, power flow control equipment such as phase shifters are installed. They direct real power between control areas. The interchange of real power is usually done on an hourly basis. On the other hand, reactive power flow control on tie lines is also very important. Reactive power flow control on transmission lines connecting different areas is necessary to regulate remote end voltages. Though local control actions within an area are the most effective during contingencies, occasions may arise when adjacent control areas may be called upon to provide reactive power to avoid low voltages and improve system security. This schedule should conform to the provisions of the relevant interconnection agreements and may provide for: (a) The minimum and maximum voltage at stations at or near terminals of inter-area tie lines (b) The receipt of reactive power flow at one tie point in exchange for delivery at another (c) The sharing of reactive requirements of tie lines and series regulating equipment (d) The transfer of reactive power from one area to another. The above statements clearly calls upon the power flow regulating equipment to not only be able to control red power but also simultaneously control reactive power flow rapidly. Further, the voltage at stations at or near terminals of inter-area tie lines should be controlled within limits. Power flow in a network is not easily controlled because line parameters that determine the flow of power in the system are difficult to control. Fortunately, the ability to control power flow at the transmission level has greatly been influenced by the advances made in the field of high power switching devices. Solid state devices provide transmission utilities the flexibility to control the system power flows. Today, with the availability of high power gate turn-off thyristors (GTO) it has become possible to look beyond the realm of conventional thyristors for power flow control. These devices are broadly referred to as Flexible AC Transmission Systems (FACTS). Control of any of the above parameters cm help to control the power flow and the process is known as compensation. FACTS devices could be placed either in series or in shunt with the transmission line with the intention of controlling the power flow in it. If the transmission line impedance is modified by the addition of FACTS, it is termed as series compensation. If the phase angle difference is modified, it is termed as phase angle compensation. Shunt compensation, in which the FACTS device is placed in parallel, is mainly used to improve the system voltage characteristics. Static variable compensator (SVC) belongs to this family of FACTS devices.

II. Details about UPFC

To understand the unified power flow concept, consider a power system with two machines connected by a transmission line of reactance ***X***, (purely inductive) along with two voltage sources $\mathbf{V_{sh}}$ and $\mathbf{V_{se}}$ representing the UPFC as shown in Fig. 1.3. The voltage sources denoted by $\mathbf{V_{sh}}$ and $\mathbf{V_{se}}$ in the Fig. 1 are connected in shunt and series respectively at the mid- point of the transmission line. Voltage source $\mathbf{V_{sh}}$, is connected to the transmission line through a transformer represented as a reactance $\mathbf{X_{sh}}$. It is assumed that the voltage sources denoted by $\mathbf{V_{sh}}$ and $\mathbf{V_{se}}$ have the capabilities of varying their magnitude and their phase angle.

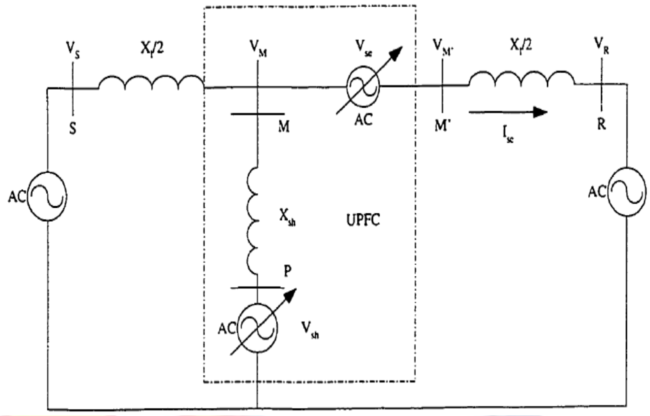

Figure 1 A power system with two machines connected by a transmission line with voltage source Vsh and Vse representing the UPFC

To understand the operation of the source $\mathbf{V_{sh}}$ the source $\mathbf{V_{se}}$ is disconnected Reactive power flows from the voltage source $\mathbf{V_{sh}}$ to bus **M** if the magnitude of the voltage source $\mathbf{V_{sh}}$ is greater than the mid-point voltage $\mathbf{V_M}$, and the phase of them are the same. If the phase angle of the voltage source $\mathbf{V_{sh}}$ leads the phase angle of mid-point voltage $\mathbf{V_M}$, and the magnitude of $\mathbf{V_{sh}}$, is greater than $\mathbf{V_M}$, then real and reactive power will flow from the voltage source $\mathbf{V_{sh}}$ to the bus M. Conversely, if the magnitude of the shunt voltage $\mathbf{V_{sh}}$ is less than the mid-point voltage $\mathbf{V_M}$ but the phase angle difference between them is zero, then only reactive power will flow from the bus M to the bus P. In this process, the voltage source $\mathbf{V_{sh}}$ is consuming reactive power. If the phase angle of $\mathbf{V_M}$ leads the phase angle of $\mathbf{V_{sh}}$ then both real and reactive power will flow from bus **M** to bus **P** and the voltage source is said to be consuming both real and reactive power. In summary, by controlling the magnitude and phase angle of the shunt voltage source $\mathbf{V_{sh}}$ the direction of real and reactive power flow to the bus M can be controlled. Alternatively, the voltage source $\mathbf{V_{sh}}$ can be made to function as a load or as a generator for the power system. In the above operation, if the phase angle difference between the voltage at bus M and that of $\mathbf{V_{sh}}$ is maintained at zero, then by varying the magnitude of V_{sh} reactive power cm either be consumed or generated by V_{sh}. This operation cm be compared with that of a thyristor controller reactor with fixed capacitor (shunt compensator) that generates or absorbs reactive power by altering its shunt reactive impedance. It should be noticed that the function of a shunt compensator is being duplicated by the voltage source V_{sh}.

III. Literature Survey

L. Gyugyi, T.R. Rietman, A. Edris, C.D. Schauder & S.L. Williams in 1995 proposes a New Approach to Power Transmission Control that shows that the Unified Power Flow Controller (UPFC) is able to control both the transmitted real power and, independently, the reactive power flows at the sending- and the receiving end of the transmission line. The unique capabilities of the UPFC in multiple lines Compensation are integrated into a generalized power flow controller that is able to maintain prescribed, and independently controllable, real power and reactive per flow in the line. The paper describes the basic concepts of the proposed generalized P and Q controller and compares it to the more conventional, but related power flow controller such as the Thyristor-Controlled Series Capacitor and Thyristor-Controlled Phase Angle Regulator. [2]

A. Rajabi-Ghahnavieh, M. Fotuhi-Firuzabad, M. Shahidehpour & R. Feuillet in 2010 implements a UPFC for Enhancing Power System Reliability that discusses various aspects of unified power flow controller (UPFC) control modes and settings and evaluates their impacts on the power system reliability. UPFC is the most versatile flexible ac transmission system device ever applied to improve the power system operation and delivery. It can control various power system parameters, such as bus voltages and line flows. The impact of UPFC control modes and settings on the power system reliability has not been addressed sufficiently yet. [3]

Hideaki Fujita, Yasuhiro Watanabe, & Hirofumi Akagi in 1999 proposes Control and Analysis of a Unified Power Flow Controller that presents a control scheme and comprehensive analysis for a unified power flow controller (UPFC) on the basis of theory, computer simulation, and experiment. This developed theoretical analysis reveals that a conventional power-feedback control scheme makes the UPFC induce power fluctuation in transient states. The conventional control scheme cannot attenuate the power fluctuation, and so the time constant of damping is independent of active- and reactive-power feedback gains integrated in its control circuit. [4]

Mahmoud A. Sayed and Takaharu Takeshita in 2014 proposes Line Loss Minimization in Isolated Substations and Multiple Loop Distribution Systems Using the UPFC in which the line loss minimum conditions in isolated substations and same substation multiple loop distribution systems by using the unified power flow controller (UPFC). In each case, the mathematical model is presented and the line loss minimum conditions are obtained based on the line parameters of the distribution feeders. Since multiple loop distribution system is fed from same substation, the line loss minimization can be achieved by compensating the summation of the line reactance voltage drop. In an isolated substation loop distribution system, the line loss minimization can be achieved by compensating the summation of the line reactance voltage drop in addition to the voltage difference of the substations. Realization of both cases can be achieved if the loop current is eliminated from the loop system. [5]

Hideaki Fujita, Yasuhiro Watanabe and Hirofumi Akagi in 1999 implements Transient Analysis of a Unified Power Flow Controller, and its Application to Design of the DC-Link Capacitor in which it shows a transient analysis of a unified power flow controller (UPFC), and design of capacitance of the dc-link capacitor based on that analysis. Active power flowing out of the series device in transient states is theoretically discussed to derive what amount of electric energy the dc link capacitor absorbs or releases through the series device. As a result, it is clarified that the active power flowing out of the series device is stored in the line inductance as magnetic energy during transient states. [6]

Hideaki Fujita, Hirofumi Akagi and Yasuhiro Watanabe in 2006 shows Dynamic Control and Performance of a Unified Power Flow Controller for Stabilizing an AC Transmission System which presents dynamic control and performance of a unified power flow controller (UPFC) intended for installation on a transmission system consisting of two sets of three-phase transmission lines in parallel. When no UPFC is installed, interruption of either three-phase line due to a fault reduces an active power flow to half, because the line impedance becomes double before the interruption. [7]

Liming Liu, Pengcheng Zhu, Yong Kang, and Jian Chen in 2007 proposes Power-Flow Control

Performance Analysis of a Unified Power-Flow Controller in a Novel Control Scheme shows the real, reactive power, and voltage balance of the unified power-flow control (UPFC) system is analyzed. Two important results related to UPFC control are shown in this paper. First, the shunt converter provides all of the required reactive power during the power-flow changes if the UPFC bus voltage is constant. Second, the UPFC bus voltage can be controlled both from the sending side and from the receiving side. Based on the analysis, a novel coordination controller is proposed for the UPFC. The basic control strategy is such that the shunt converter controls the transmission-line reactive power flow and the dc-link voltage. The series converter controls the transmission-line real power flow and the UPFC bus voltage. [8]

S. Kannan, Shesha Jayaram and M. M. A. Salama in 2004 proposes a new real and reactive power coordination controller for a unified power flow controller (UPFC). The basic control for the UPFC is such that the series converter of the UPFC controls the transmission line real/reactive power flow and the shunt converter of the UPFC controls the UPFC bus voltage/shunt reactive power and the DC link capacitor voltage. In steady state, the real power demand of the series converter is supplied by the shunt converter of the UPFC. To avoid instability/loss of DC link capacitor voltage during transient conditions, a new real power coordination controller has been designed. The need for reactive power coordination controller for UPFC arises from the fact that excessive bus voltage excursions occur during reactive power transfers. [9]

IV. Objective

The main objective of this paper is implementing the Unified Power Flow Controller without utilizing the transformer either at the source/grid side or at the load side. The utilizing of the transformer may results in complexity in the circuit resembling in the isolation. Apart from the above, the UPFC uses the dual CMI devices at both the ends supporting the grid as well as the load resulting in less weight & high efficiency. In this concept, the FFM method is also used which segregates. The UPFC can provide simultaneous control of all basic power system parameters (transmission voltage, impedance and phase angle). The controller can fulfill functions of reactive shunt compensation, series compensation and phase shifting meeting multiple control objectives. From a functional perspective, the objectives are met by applying a boosting transformer injected voltage and a exciting transformer reactive current. The injected voltage is inserted by a series transformer. Besides transformers, the general structure of UPFC contains also a "back to back" AC to DC voltage source converters operated from a common DC link capacitor. First converter (CONV1) is connected in shunt and the second one (CONV2) in series with the line. The shunt converter is primarily used to provide active power demand of the series converter through a common DC link. Converter 1 can also generate or absorb reactive power, if it is desired, and thereby provide independent shunt reactive compensation for the line. Converter 2 provides the main function of the UPFC by injecting a voltage with controllable magnitude and phase angle in series with the line via an voltage source. The reactance X_S describes a reactance seen from terminals of the series transformer.

V. Problem Identification

In our concept of UPFC in which the main challenges that arises while designing the simulink of the concept are (a) Total Harmonic Distortion, (b) Efficiency, (c) Undershoots & Overshoots and (d) Settling Time

VI. Methodology

A) Methodology for Conventional UPFC:

In Conventional UPFC, the controller has been designed with the help of transformer for isolation purpose apart from which the operation of the UPFC along with the transformer has efficient output but it costs too high as well as the circuit becomes too bulky and heavier as shown in Figure 2.

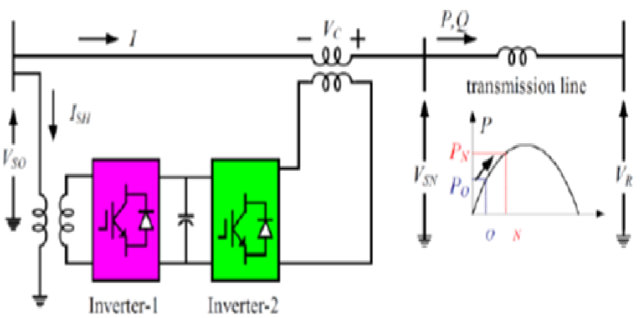

Figure 2 Conventional UPFC

In the Proposed model of the UPFC is following the concept of transformer less which enhances the performance of the model without any sort of bulkiness and less complexity as well as with less cost. In this two CMIs are used to provide proper transmission between grids as well as the load. Total harmonic distortion has been minimized to certain extent as shown in Figure 3.

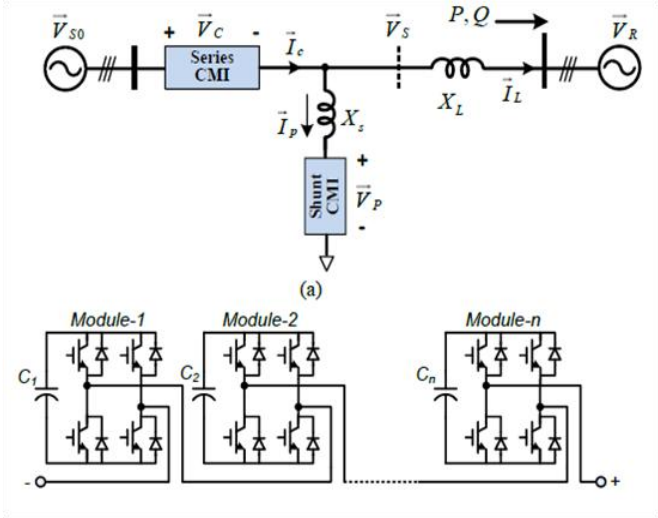

Figure 3 Proposed UPFC

With respect to the Figure 4, the CMIs are connected between the grid and load. Here a circuit breaker is been implemented to verify the actual waveforms at the input and output with or without the effect of UPFC.

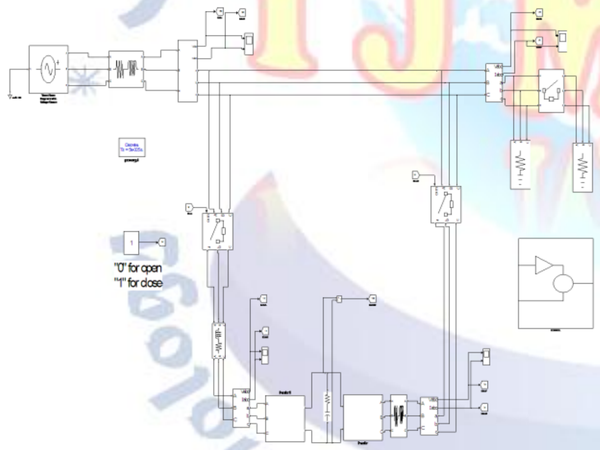

Figure 4 Schematic Diagram of Proposed UPFC

The following simulation parameters has been considered while designing the proposed model,

PARAMETERS	VALUES
Grid Voltage	480V
Rated Frequency	60Hz
Transformer 1	480V / 4160V, 75KVA
Transformer 2	480V / 4160V, 75KVA
Rated Line Current	10A
X1	2.5mH
X2	3.2mH

Table 1 Simulation Parameters

VII. Proposed Model

This paper present a modulation and control method for the transformer-less UPFC, which has the following, features:

(a) Fundamental frequency modulation (FFM) of the CMI has extremely low THD of output voltage, low switching loss and high efficiency.

(b) All UPFC functions, such as voltage regulation, line impedance compensation, phase shifting or simultaneous control of voltage, impedance, and phase angle, thus achieving independent active and reactive power flow control over the transmission line DC capacitor voltage balancing control for both series and shunt CMIs.

(c) Fast dynamic response (<10 ms). The transformer-less UPFC with proposed modulation and control can be installed anywhere in the grid to maximize/optimize energy transmission over the existing grids, reduce transmission congestion and enable high penetration of renewable energy sources.

(d) We can replace the source with Wind Turbine Generator also we can consider the battery source between two inverters.

(e) Apart from the above, THD can be also minimized to certain extent.

VIII. Conclusion, Results & Discussions

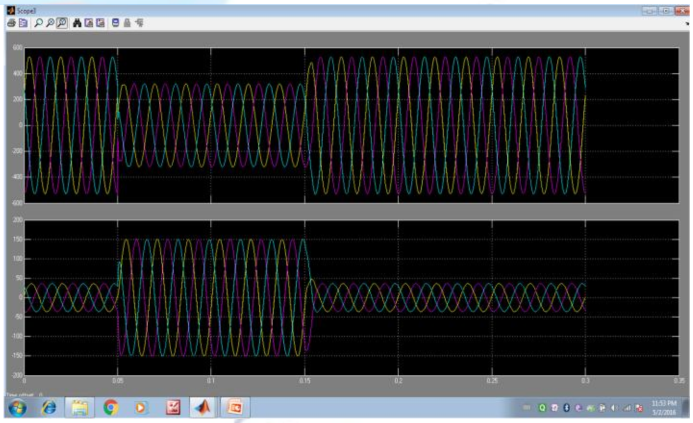

Figure 5 Input Waveform of conventional before using UPFC

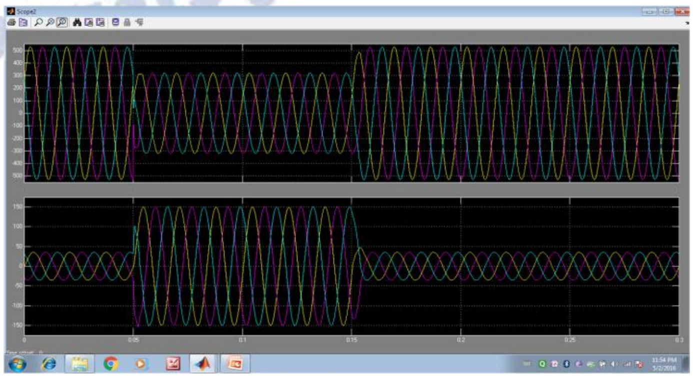

Figure 6 Output Waveform of conventional before using UPFC

As the figure 5, the input waveform is observed and the output waveform is obtained in figure 6 in which the sag is being produced between the interval 0.05 to 0.15 which is been minimized to certain extent using our proposed model which is shown in figure 7.

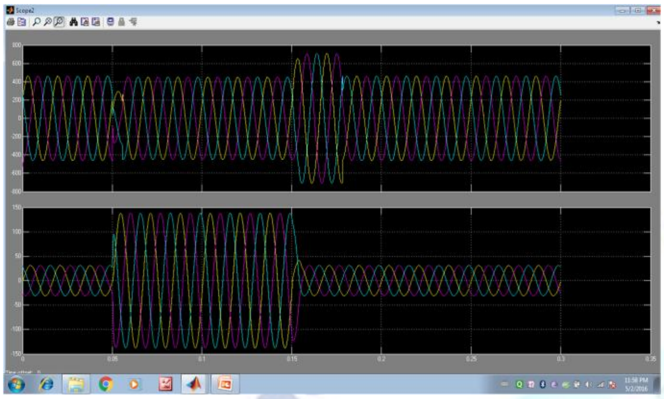

Figure 7 Output Waveform of conventional after using UPFC

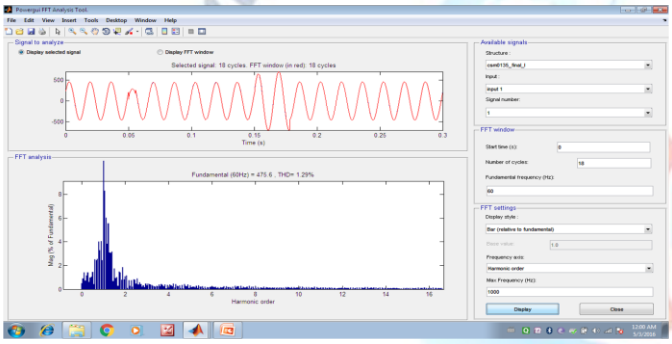

Figure 8 THD of the voltage at the load after using UPFC

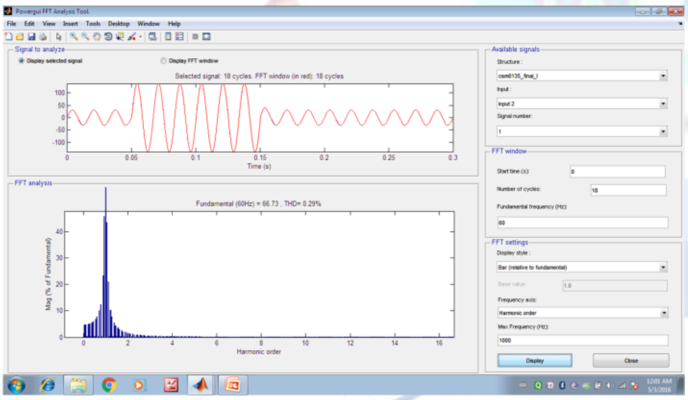

Figure 9 THD of the current at the load after using UPFC

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