Review on Power System Steady State Stability Embedded with Multiple Wind Turbines

S Sunny Vig, Balwinder Singh Surjan

ABSTRACT--- ***Wind energy being the most growing renewable energy resource in electrical engineering having immense environmental and communal advantages. Many researchers attempted to give better solutions related to the usage of wind energy. In a short time period wind energy is accepted by the industry as it is a clean source with no pollutants. Main problem exist with wind energy is its fluctuating nature. Extracting maximum power from wind turbines is the biggest challenge n the field of wind energy. In this paper optimization of wind turbine using pitch angle control is discussed. Various FACTS devices are also discussed for coordinated operation with wind turbines. Importance of integration of FACTS with HVDC link is also discussed. Detailed literature review is also presented in this paper for future research. Model for coordinated operation of UPFC-HVDC Link is also proposed.***

I. INTRODUCTION

Out of all the available renewable energy resources wind energy is one of the largest resource available for the production of electricity. Because of its lowest cost and huge availability wind power plants give their major contribution in generating electricity. According to European Wind Energy Association EWEA, the projection for installed wind capacity at horizon is 180 Giga Watt [1].

As a power source wind energy has two wonderful has two wonderful qualities. First, as compared to any other conventional fossil-fuel-fired generators, it does not emits any air pollution. Secondly, its operating cost is very low; unlike almost all other available conventional source generators, wind farm consumers does not has to pay any fuel cost [2]. Despite of these advantages wind energy also has the following important characteristics that increase their application worldwide as an electricity source.

(i) Limited Power Control: As we know that output of most type of generators is controlled by the operator, whereas the power output of wind farm is purely based on current wind speed i.e. on minute to minute basis and is not in the hands of any human operator. Due to this the output power from wind turbine has limited control.

(ii) Relatively Unpredictable: Wind energy nature is purely unpredictable. As most of the conventional generators are controlled by the operators which is difficult in case of wind farms due to its variable nature. If one can predict the wind speed or forecast the weather conditions wind energy can become predictable.

(ii) Variable: Most of the conventional generators can be controlled with respect to the time i.e. on minute to minute basis. By use of conventional generators output can be maintained at approximate uniform level. But due to the variable speed of wind it cannot be controlled similarly because wind varies with respect to the time very fast and because of this nature of wind speed output power always fluctuates.

II. ISSUES RELATED TO WIND ENERGY

POWER QUALITY ISSUES

According to Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as “The concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment.” Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain.

Power quality can also be defined as “Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy.”

Output power from most of the renewable energy resources is variable or always fluctuating due to the available environmental conditions. Due to fluctuating nature of wind energy the power delivered by wind farms to the power network also fluctuates and power output also gets disturbed [3]. Therefore, there is a need of different systems to be developed to improve the voltage profile, stability of frequency and the quality of power generated by wind power plants. One of the method to improve the stability and frequency of the voltage in wind turbines by using Doubly Fed Induction Generators (DFIG generators), through their decoupled control of active and reactive power [4]. But still due to fluctuating nature of wind energy it has the following defects when connected to power network.

(i) Power Outages:

Means the complete interruptions of electrical supply or also related as complete shutdown of power. Although utilities being aware of these problems has taken many steps to improve the power supply i.e they installed many protective systems which also includes the increase in time to dissipate the disturbance.

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Causes: Wind, lightning, equipment's failure, storms.

Effects: Complete interruption of power supply.

(ii) Voltage fluctuations:

Voltage fluctuations are mostly related to the swings or changes in the condition of steady-state voltage above or below the defined input range for a piece of equipment. It also includes both conditions i.e. sags and swells which is not in favor of constant power supply.

Causes: Load changes suddenly instead of gradually, heavy equipment start-up or shut down.

Effects: motor stalling, memory loss, equipment shutdown, data errors; flickering lights.

(iii) Transients:

Transients, are normally called as "surges," are unwanted disturbances for a very short duration of time whose magnitude vary very fast. When this type of condition occurs in the system, it results in generation of thousands of voltage into the electrical system, causing various problems for different type of equipment's down the line.

Causes: Welding equipment, equipment start-up and shut down, Lighting.

Effects: Damage of equipment, burning of circuit boards, degradation of electrical insulation, processing errors.

(iv) Harmonics:

Normally harmonics are the periodic disturbances in steady-state conditions of the sine wave due to the frequency generated by the equipment's other than the standard fundamental frequency which is 50 cycles per second.

Causes: Non-linear loads, Electronic ballasts; variable frequency drives.

Effects: Hot neutrals, random breakers tripping, overheating of electrical equipment.

III. OPTIMIZING WIND TURBINE BY PITCH ANGLE CONTROL

By changing the wind speed or by changing the pitch angle control the output from wind generator can be increased. The aim of control of variable speed fixed pitch in the partial load regime is to regulate the power coming from wind generators. For every installed wind power plant the aim in particular is to extract maximum power available [5]. Power curves drawn in between wind speed and output power are maximum at a particular value of wind speed. If rotational speed is maintained constant then regulation of pitch angle is necessary particularly for wind speeds above the rated wind speed. It has been observed many times even for small changes in pitch angle results in huge change or affects the output power. Because of this more innovative solutions are required to make these variable speed wind turbines more effective. Many techniques had been used by various authors to overcome these problem. Solutions based on soft-computing technologies like genetic algorithm and artificial intelligence are already being implemented [6].

Power generated by the wind turbine depends on many parameters and equation related to that is given by [7]:

$$P_a = \frac{1}{2}\,\rho\pi R^2 Cp(\lambda,\beta)\ v^3 \qquad (1)$$

Where A = turbine swept area, ρ = air density, Cp s power coeffecient and v = wind speed. Cp being a non-linear function relying upon blade pitch angle denoted as β and also on tip speed ratio denoted as λ [8].

λ is defined as

$$\lambda = \frac{\Omega_T * R}{V_{wind}} \qquad (2)$$

Where R = rotor radius, V_{wind} = wind speed, and Ω_T = rotation speed of the rotor. Torque produced by the wind turbine can be found from the following relationship.

$$T_t = \frac{P_a}{\Omega_t}$$

IV. FACTS WITH HVDC LINKS

As discussed wind energy is one of the most powerfull source of power generation and also the future of electrical power. Despite of many defects still it is the most powerfull source and to increase the applications of wind power plants they are used as a integrated system with the present electrical network and for the purpose of integration HVDC links and FACTS devices are commonly used. To increase the stability of the system and capacity of transmission lines effeciently, power electronics high voltage devices such as FACTS (Flexible AC Transmission Systems) and HVDC (High Voltage Direct Current) are installed. Also these devices has all the necessary and important features to get rid of most types of technical problems when heavily loaded power systems are connected with the system. During cascading disturbances these devices also prevent the system [9]. For more than 600 km transmission distance AC transmission is more costly than DC transmission. With the help of submarines cables transmission of power up to 600 - 800 MW over distances of about 300 km has already been achieved and transmission of cable lengths 2 /10 of up to approx. 1,000 km are already at the planning stage. As it is not possible without HVDC links so HVDC links now a days became a reliable and mature technology [10]. The highest operational bipolar transmission Line is of length 1825 KM situated from Assam to Uttar Pradesh.

4.1 FACTS CONTROLLERS

Since the 1960s, with high ratings of power Flexible AC Transmission Systems have been evolving to a mature technology. FACTS technologies has already been proven reliable in differenet applications. Due to power electronics based FACTS, it is feasible to make long distance AC transmission and they are also been developed to improve weak AC systems performance [11]. Most of the technical problems related to interconnected electrical systems can also be solved with the help of FACTS devices. For parallel, series and combination of both to control load flow and to improve dynamic conditions FACTS devices are available.

Parallel Connection

- SVC, Static VAR Compensator

- STATCOM, Static Synchronous Compensator

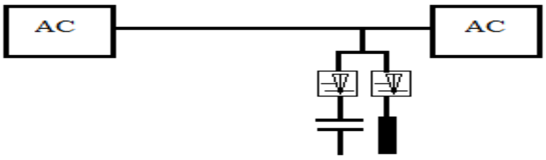

Fig. 1.1 SVC/STATCOM

Series Connection

- FSC, Fixed Series Compensation
- TCSC/TPSC, Thyristors Controlled/ Protected Series Compensation
- S³C, Solid-State Series Compensator

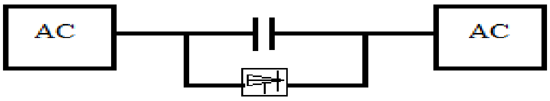

Fig. 1.2 FSC/TCSC/TPSC

Combination of Both (Series and Parallel Connections)

- UPFC, Unified Power Flow Controller
- CSC, Convertible Static Compensator

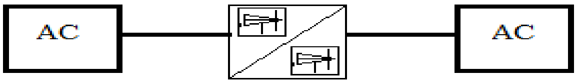

Fig. 1.3 Unified Power Flow Controller (UPFC)

4.2 Unified Power Flow Controller- An Approach

For providing fast-sensation on high-voltage power transimmsion networks an electrical device called as Unified Power Flow Controller (UPFC) is used. In UPFC system a series transformer is used to inject the current produced by using a pair of three-phase controllable bridge into a transmission line. By doing this UPFC is used as a controller which can control the flow of reactive and active power in a transmission line [12]. Moreover UPFC is a combination of static synchronous series compensator (SSSC) and a static synchronous compensator (STATCOM) and both are coupled via a common DC voltage link. This approach increases the compensation capability of the UPFC with respect to other custom strategies that use reactive power only [13].

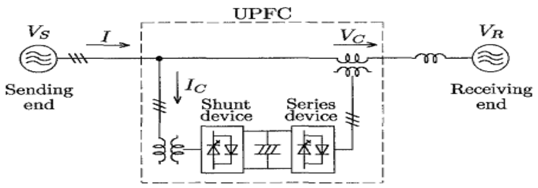

Fig 1.4 Circuit Diagram of UPFC

V. LITERATURE REVIEW

As discussed the impact of non-renewable energy resources is needed into the present grid. Due to environmental conditions the most promising alternate source of energy i.e. wind energy can bring biggest challenges when these sources are connected with present power grids and the main reason is that wind energy is variable in nature as it depends upon the wind speed. Varible nature of wind creates many problems in the power generated by wind turbines to the power network [14]. The problems encountered are cited by the various authors are as follows:

5.1 Power quality

Power quality is one of the most important feature related to the power system. Variable nature of wind causes types of power surges in the power network. Therefore, there is a need of different systems to be developed to improve the voltage profile, stability of frequency and the quality of power generatd by wind power plants.

In this paper many issues related to power quality and also the consequences of bad quality of power on consumer and on electrical utilities are presented. Due to the wind generators and non linear loads connected to the grid it is observed that on the grid source current gets affected and which also affects the waveform purity on both the sides of the power system [15].

Renewable energy sources specifically wind and solar with the most potential for significant penetration in the near term. Future power transmission and distribution network with a high percentage of renewable resources may have more generation sources than existing networks: Scalability or Power quality would be a significant factor [16].

5.2 Voltage Instability

Influence of change in different parameters such as solar radiations, load and temperature on the stability of voltage had been discussed. Durinfg the study of grid impact of integrated wind power stability of volatge is a key or common problem and this is due to the presence of existing wind farms in large numbers and most of them are equipped with induction generators based on Fixed-Speed Wind Turbines (FSWTs) [17]. In this paper author pointed out very important issues rekated to variation of voltage like condition of stable voltage when power is produced continously and voltage variatioms like flicker of light during operation [18].

5.3 Rotor Angle Stability

Stability of the power system connected with multi-machine also depends upon the rotor angle of alternator. If this angle is not maintained or exceeds by an angle of 180° alternator comes out of syncheonism and lose its stability. The reason of losing synachronism is fast voltage drop at common or intermediate points of the network which further affects the stability of voltage [19]. Meegahapola et al. [20] discussed geographical conditions related to wind energy resources based on profiles of past generation of wind for active power network and affect of different geographical conditions on ritor angle and voltage stability had been discussed. Author also analyzed stability issues based on dynamic characteristics developed using novel stability indices.

The investigation of impact of large scale wind power integration on the dynamic performance including stabikity of rotor angle on power system had been done. Also to analyze the system nature behaviour under wind turbine at large scale and for integration of FACTS device eigen value tracking, power factors, simulations dynamic and had been used [21]. El-Sayed et al. [22] introduced a technique which can be used to examine the affect of wind turbine generators on the performance of composite power system when load or large generating unit loss. The technique is composed of probabilistic and deterministic approach. If any of the above said conditions not fullfilled it will lead to stability of rotor angle and also affects the overall stability of the system.

5.4 Potential Assessment of wind energy on large scale

Bu et al. [23] et al. discussed new method i.e probabilistic analysis method to understand the influence of stochastic uncertainty of wind generation which is grid-connected small-signal stability of power system. The proposed method can be implemented on large scale power system to directly calculate the critical Eigen values by using Probabilistic Density Function (PDF).

During fault on grid to know the behaviour of protection strategies and IGBT based back to back converters control double fed induction generators dynamic models were used in [24]. Breban et al. [25] represented results of hybrid micro/wind hydropower system based on some experiments when they are connected to the grid.

Methodology including real time dispatch, regulation processes, scheduling of CAISO'S Aand their timelines based on a mathematical model had been presented in [26]. Davarani et al. [27] discussed interactions between system components like power system controllers and wind farm including non-linear conditons. The result showed that size of wind farm, under stressed conditions and parameters of SVC controller contributed in the non-linear interaction of DFIG-based wind farm.

5.5 Optimizing Wind Power

As we know that it is very exoensive and difficult to maintain and build wind turbines. The power is generated from the wind field which itself is a source of large exhausted loads on the turbine. It also increase cost of maintenance, structural wear and tear and reults in decreasing the lifetime of the turbine. Common techniques i.e pitch control or rotor angle control are used to extract or regulate the power output of wind turbine. The methods proposed by many authors are described as follows:

Belghazi et al. [28] compared genetic algorithm technique with conventional pitch angle control strategies. Results showed that as compared to conventional strategies of pitch angle control GA controller can achieve better control performace.

To extract the maximum power and to maintain the converter effeciency at maximum for independent reactive and active power control a control Scheme had been developed. Developed model consists of pulse-width-modulated current source inverter (CSI), buck converter and a diode rectifier [29]. Design of Wind turbine based on high-fedility aerodynamic of wind turbine blade for extracting maximum power was implemented. At each angle of the attack to get best air foil shape trained Neural Network was coupled woth Genetic Algorithm [30-31].

Ahmed et al. [32] proposed a scheme to produce maximum power based on variable speed control of grid-connected wind power generation system by using squirrel cage-type induction generator, based on a control of fuzzy logic. Ramakrishnan et al. [33] discussed the response of the pitch-controlled system to different wind velocity variations and also described the various components in a pitch controlled wind energy system. Also by reducing the blade angle power injected into the turbine can also be limited.

To optimize energy consumption minimization of wind system algorithm based on ant colony was used. The improved algorithm solved the defect of directly deal with continuous optimization problem by discretizing the solution space of continuous function [34]. Different parameters of blade were optimized to reduce the cost of wind turbine rotor enrgy by using the appproach of Ant Colony Optimization [35].

5.6 Integrated AC/DC Transmission System using FACTS and HVDC Links

To increase the applications of wind power plants they are used as a integrated system with the present electrical network and for the purpose of integration HVDC links and FACTS devices are commonly used. To increase the stability of the system and capacity of transmission lines effeciently, power electronics high voltage devices such as FACTS (Flexible AC Transmission Systems) and HVDC (High Voltage Direct Current) are installed [36]. HVDC and FACTS devices are having all the necessary and important features to get rid of most types of technical problems when heavily loaded power systems are connected with the system [37]. Methods used by many authors for integration of wind power on large scale using FACTS and HVDC links are as follows:

VSC-HVDC were used to integrate AC/DC parallel connected wind farm. By using High voltage direct transmission of voltage source converter (VSC-HVDC) it is possible to supply passive network and because of this power cannot inly quickly transmitted but can also compensated reactive power flexibly to stabilized grid-connected system [38]. Luque et al. [39] presented an enhanced controlled strategies for interconnected offshore wind farm arrays via an HVDC link. A frequency controller was proposed to improve capabilities of wind turbines and fault-ride through HVDC link.

Various FACTS devices which improves the power system performance and transmission efficiency were discussed. Considering the drastic chnage in conditions of large and heavily loaded interconnected system due to uncontrollable cascading which may results in conplete blackouts were also described in [40]. Control schemes based on STATCOM had been used for improvement in quality of grid connected power with non-linear load [41-42].

For enhancement in stability of power system FACTS controllers of different types in terms of compenstaors like series compensators, shunt compensators or combination of both are used. Different types of HVDC technology and its advantages had also been reviewed [43]. Saxena et al. [44]

proposed an additional power oscillation damping controller for damping out the oscillations occurs in power system by using Unified power flow controller.

Golshannavaz et al. [45] solved the problem of Sub Synchronous Resonance (SSR) in wind farm integrations by using Unified Power Flow Controller (UPFC). Shunt branch of UPFC produced the needed reactive power of SEIG and for this UPFC was located at the terminal of the wind of the linking line.

Guo et al. [46] proposed a new method to damp out the oscillations occured in active power and proposed method also maintains the shunt bus voltage of UPFC. The performance of the proposed model when compared with PI controller is very much favorable under various operating conditions.

Sebastian et al. [47] analyzed voltage balance, active power and real power of the unified power flow controller system. To verify the effectiveness of UPFC in power flow control in the transmission line experimental works had been conducted. Various experiments had been performed in which both the series converter and shunt converter had been built as a three-phase PWM converter with IGBT as the power device.

VI. OBJECTIVES FROM LITERATURE RIVIEW

Various objectives can be made according to the problems discussed in the literature review. Authors identified many problems related to wind turbines and power transmission and accordingly objectives can be made in the following manner:

(i) Assessment of wind speed under different climatic conditions.
(ii) Incorporating latest optimization technique to control pitch angle of wind turbine.
(iii) HVDC-link or EHVAC-link can be implemented for transmitting wind power to grid by using Unified Power Flow Controller (UPFC).
(iv) To analyze of proposed system with multi-line, multi-bus, IEEE system can also be done.
(v) Steady state performance of power system in terms of active and reactive power flow of a transmission line can also be evaluated.

VII. METHODOLOGY FOR PROPSED MODEL

For increasing the importance of wind turbines simulation of power system for the proposed system can be done in the following manner:

1. Single wind turbine generator connected to single bus through HVDC can be simulated and tested. Then the multiple turbines connected to single bus system through HVDC can be simulated.
2. Optimization technique can be employed to extract maximum power through control of λ, β (Pitch) angle of wind turbine for both single turbine and multiple turbine connected to single bus system.
3. The optimized wind power injected through HVDC link for single bus system can be extended to multi-bus IEEE system.
4. The UPFC (Unified Power Flow Controller) will be simulated and embedded in single bus and multi-bus system. The active and reactive power control and analysis can be carried out.
5. The power system performance can be investigated in terms of power quality, power congestion and stability.
6. The results obtained can be presented in graphical and tubular forms (Which ever is feasible.)

VIII. FLOWCHART FOR PROPOSED METHODOLOGY & RESULTS

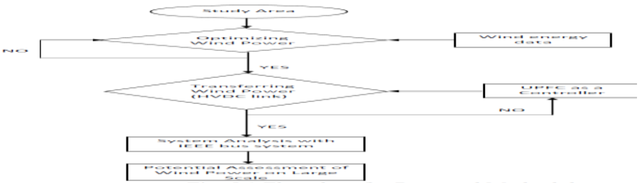

Fig. 5.1 Flowchart for Proposed Methodology.

To control active and reactive power flow Unified power flow controller can be used as a controller to maintain the steady state stability of the system. By use of series transformer current produced can be injected with use of three-phase controllable bridges into a transmission line [48]. Due to this capability to compensate UPFC becomes the better technique as compared to other system that use compensation of reactive power only.

The real and reactive power equations are as follows [49]:

$$P = \frac{V_1 V_2}{x} \, Sin(\delta_1 - \delta_2) \tag{9}$$

$$Q = \frac{V_2}{x} \, (V_1 - V_2) \tag{10}$$

Power flow constraints of the UPFC shunt and series branches are as (11)–(12).

$$P_{sh} + jQ_{sh} = V_{sh} \angle \theta_{sh} \left(\frac{V_i \angle \theta_i - V_{sh} \angle \theta_{sh}}{Z_{sh}} \right) \tag{11}$$

$$P_{ij} + jQ_{ij} = V_i \angle \theta_i \left(\frac{V_i \angle \theta_i - (V_{se} \angle \theta_{se} + V_j \angle \theta_j)}{Z_{se}} \right) \tag{12}$$

Where complex voltages V_i and V_j are at i and j buses respectively [50]. Current flow through the UPFC shunt converter is I_{sh}. Active and reactive power flows through the branch of shunt converter are P_{sh} and Q_{sh} respectively. Direction of flow of power of P_{sh} and Q_{sh} is in the direction of leaving bus i. Currents flow through the UPFC series converter are I_{ij} and I_{ji}. UPFC series branch active and reactive power flow parameters are P_{ij} and Q_{ij}, respectively and both are leaving at bus i. Exchange of active power with DC link of shunt converter is P_{sh} and exchange with series converter is P_{se}.

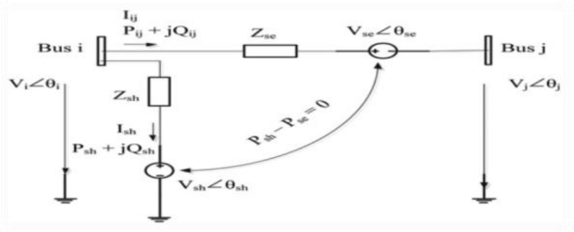

Fig. 5.3 Equivalent Circuit of Unified Power Flow Controller (UPFC)

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An integrated planning and design of UPFC in AC/DC network with tuned controlled parameters may provide a better flexibility to system operator which, in turn, provides power oscillations damping and avoid area tripping.

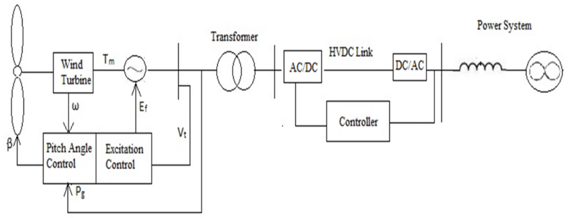

Fig. 5.4 Proposed Model for coordinated operation of UPFC-HVDC Link

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