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Performance of Cascade Interconnected Wind Turbines Topology for Grid Connected Wind Energy Conversion System

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Abstract*: *Paper This paper gives conceptual idea and investigation of wind turbines interconnection for future wind energy conversion system. A grid connected direct driven PMSG based wind turbine system a variable speed is presented in this work. In the initial step, a simulation model of grid connected wind energy conversion system with cascade connected wind turbines is developed. In the later step, advanced controllers are developed for the above said simulation model. The generator side control is modified for cascade connected wind turbines topology and a common grid side inverter control is implemented. The whole simulation model along with their control strategies are implemented in SimPowersystem MATLAB software.

Keywords: DC-Link, Permanent Magnet Synchronous Generator, Maximum Power Point Tracking, Rotor Speed, Reference Rotor Speed), Wind Energy Conversion System, Wind Turbine, Unity Power Facto Operation..

I. INTRODUCTION

In recent years, the renewable electrical power generation by using wind turbines is still promising technology due to its huge potential. A lot of advancement has been happened in its Multi megawatt ratings, especially for large wind farm system. The wind turbine generating units which interconnected in a large wind farm having integration issue [1-4].

For fixed and variable speed operations, some well-established options are available for wind energy conversion system. For any offshore/onshore WECS its size, weight, repair and maintenance play very important role in term of its reliability and overall efficiency [5-7]. At offshore, the equipment transportation, installation and maintenance cost of wind energy conversion system is a quite big challenge due to its hard windy geographical location [4]. Moreover, today most of the turbine system operations are at variable speed and its controllers have to regulate the switching of power converters under extreme conditions. A lot of research and development has been going on to reduce the size and weight of drive train and gearbox system. A significant advancement in designs and large global market production of permanent-magnet, the cost and weight is expected to be lower in future [8].

The latest technology available at variable speed for wind turbine is a PMGS based direct drive operation with grid integration via power electronic interface. Now a day, the switching of IGBTs at very high frequency can be possible with large power rating. Therefore it may be possible to integrate the wind turbine system with grid with back to back converter topology [9-12].

This work provides an overall perspective on a wind turbine cascade interconnection for the existing WECS with best possible solution. The dynamic performance and some other issues are also discussed like active and reactive power control, frequency and voltage, harmonics filtration.

II. MODELING AND CONTROL STRATEGIES OF PROPOSED SYSTEM

In the proposed system, a variable speed PMSG (type4 direct driven) based off-shore/onshore grid connected with back to back DC-link WECS has been considered due to its well established benefits. Here, the wind turbines with their controlled converters connected to common DC link with MPPT control algorithm. The grid side inverter and their controllers are used to synchronize the wind power flow from generator to grid and the power handling capacity of IGBT based inverter is enough at very high switching frequency.

Proposed Cascade Connected Wind Turbine Topology

Generally, an optimal interconnection among the different wind turbines output terminals always result better efficiency and good dynamic performance of the wind farm. The proposed system consists of many wind turbine units connected in Cascade manner and each unit comprises of a variable speed PMSG based wind operation system as shown in fig 1. Here, each respective wind turbine-generator unit required individual converter interface system and with their control scheme in order to extract optimum DC-Power on DC-link side. Whereas only one grid inverter interface required and their control algorithm has been used for grid synchronization as shown in fig 1.

In cascade type topology, a high voltage can be attained by connecting a number of wind turbines in cascade manner. But simultaneously have a problem of insulation due to high voltage level. In this proposed cascade/series topologies, the output terminals of many off shore/onshore wind turbines units have been connected in cascade manner to get the desired DC-link power at a rated high DC-Voltage which results in reduction of current stress on the operating devices. As mentioned above, only one unit of grid-side converter with high power handling capacity has been used to deliver the generated power to the grid at unity power factor (UPF) under linear/nonlinear load conditions as shown in fig 3b. Here also the control schemes have been designed for optimum DC-Power at common DC-link.

In this research work, the purposed topology also analyzed for DC-Power which

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is collected at common DC link and successfully transfers from offshore to onshore grid.

The proposed topology explores the potential in terms of reduction in cost and size of various electrical equipment, power electronics devices and their respective platform's constructions. This results less maintenances cost and increase overall efficiency of the whole system. The scope of this work is to explore the technical feasibility of the proposed system topology for integrating power generation from offshore/onshore wind farms to connected grid system. This method uses dc-dc converters to create a DC-link converter between wind turbines. Generally in wind farm, the wind speed varies from one wind turbine unit to another through the whole time. Therefore at variable wind speed each generator-side converter has capable to adjust the PMSG speed in order to produce the desire DC output Power at given rated DC- Voltage so that the grid-side inverter is able to deliver this power to the grid. So in this topology, all the wind turbine units collectively generate the DC-Power at their respective rated DC voltage for successfully transfer of electrical power to the grid.

The total DC-Power collected from 'n' number of wind turbine units connected either in cascade is given by

$$P_{dc} = P_{dc_1} + P_{dc_2} + \ldots\ldots\ldots\ldots\ldots\ldots + P_{dc_n} \qquad (1)$$

Alternatively, $P_{dc} = I_{dc}\, V_{dc}$ (2)

Where

P_{dc_1} = DC-Power collected from 1st wind turbine unit

P_{dc_2} = DC-Power collected from 2nd wind turbine unit

P_{dc_n} = DC-Power collected from nth wind turbine unit

Total DC Voltage built across common DC Link at all generators- side converters,

$$V_{dc} = V_{dc_1} + V_{dc_2} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots + V_{dc_n} \qquad (3)$$

Where

V_{dc_1} = DC-Voltage builds across 1st Generator side converter

V_{dc_2} = DC-Voltage builds across 2nd Generator side converter

V_{dc_n} = DC-Voltage builds across nth Generator side converter

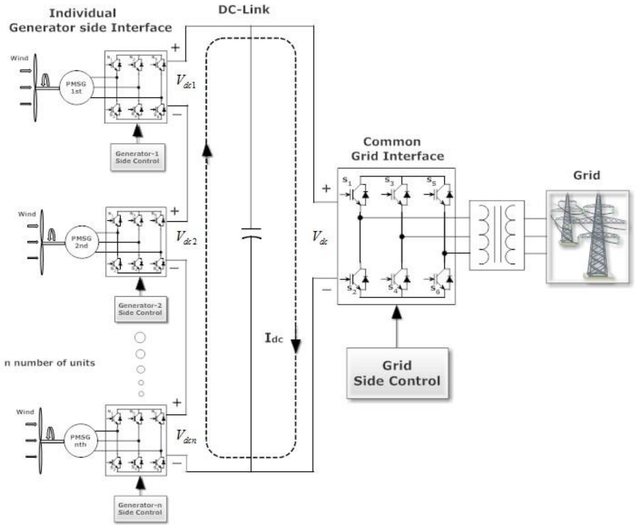

Fig 1: Proposed Cascade Connected Wind Turbines Topology

A brief description and the feasibility of this topology has shown in Fig 1, which have many number of wind turbine units connected in cascade manner whereas each wind turbine unit operates at variable wind speed for maximum shaft power extraction and their respective generator operates at corresponding rotor speed independently. Each generator requires individual converter interface with their control scheme in order to extract optimum DC power at common DC-link. The DC-Power collected from each turbine unit will determine their reference speed from its power- speed characteristics curve which in turn gives the reference q-axis current and d-axis current component set to zero for minimum copper losses and maximum torque component of current in the generator as shown in fig 2.

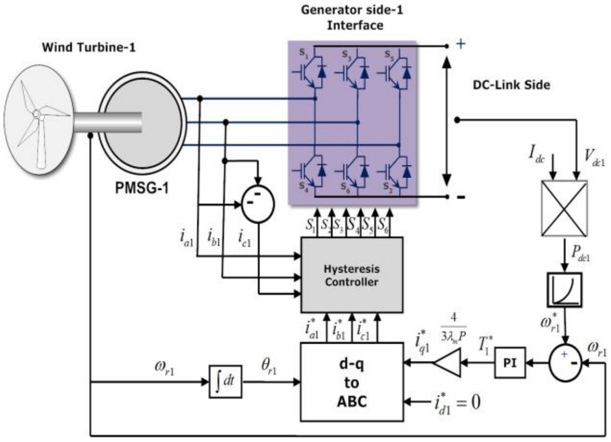

Fig 2: Individual Generator Side Control Strategy of Each Unit for Cascade Connected Wind Turbine System

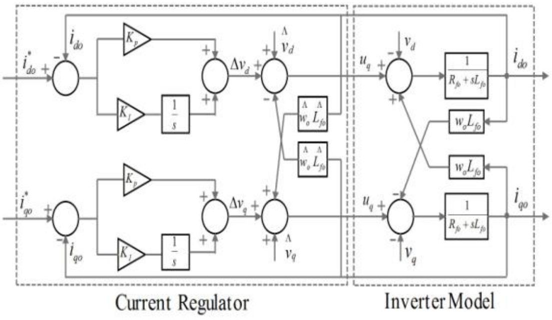

Fig 3a: Inner Current Control Loop Strategy for Grid Inverter

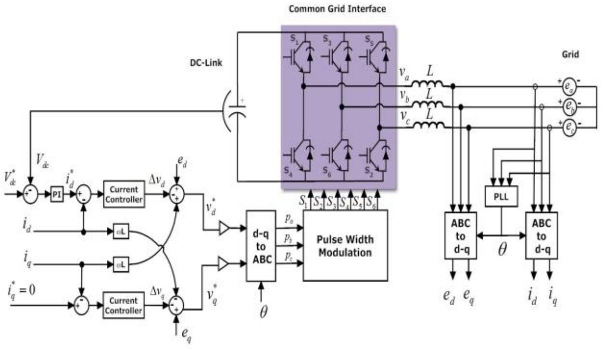

Fig 3b: Common Grid Interface Control Strategy for Cascade Connected Wind Turbine System

Here, a common grid interface is used to handle the power balancing between DC-link and grid under fluctuating wind conditions so that DC link voltage can be maintain at its rated constant value.

There are two control loop utilized for the PWM switching of common grid inverter. The inner current controller loop adjusts the ac voltage and reactive power demand while outer loop regulates the active power demand as shown in Fig 3a and 3b

III. SIMULATION RESULTS AND DISCUSSION

The proposed WECS system topology has been designed and simulated in MATLAB Simulink using SimPowerSystem toolbox. To demonstrate the feasibility and application of the proposed system, the extensive simulation was carried out at variable wind speed as shown in Fig.

Here, the WT units are run at different wind speeds as these are installed at different locations and wind vary abruptly from one location to other. Therefore each wind turbine run at different variable wind speeds $W_{r_1}\, and\, W_{r_2}$ respectively and W_{ref_1} , W_{ref_2} are reference speed of WT Unit-1 and Unit-2 respectively

For $n=2$, Total DC-Power of Two WT Units at variable wind speed is given by

$$P_{dc} = P_{dc_1} + P_{dc_2} \qquad (4)$$

When, Two WT units are connected electrically in cascade manner

Then, Total DC Voltage builds across the terminal of Generator side converters,

$$V_{dc} = V_{dc_1} + V_{dc_2} \qquad (5)$$

Unity power factor operation under nonlinear load

The system under consideration is simulated using MATLAB software with SimPower System toolbox. The simulation results exhibit the effective implementation of MPPT control algorithm on each respective generator interface. The effectiveness of the controllers are to be evaluated by analyzing the different parameters like generator current (I_{gen}), generator-speed (Wr), dc-link voltage (V_{dc}), inverter-current (I_{invt}), grid-current (I_{grid}), load-current (I_{load}) respectively. For grid synchronization, smooth power flow from cascade connected wind turbines system to grid is also analyzed with variable wind condition under non-linear load conditions.

The detailed simulation results of variable speed PMGS based operation for cascade connected wind turbines in a wind energy conversion system are shown in fig 4 The main objective of the proposed system is to extract the maximum power at variable speed, maintain DC-link voltage and smooth power flow from dc-link to grid under variable speed condition fig 5. The wind speed has been varied of both the turbine in random fashion due to its inherent fluctuating nature. In the simulation results both actual and reference generator speeds are shown in figs4 endorse the effective implementation of speed control strategy.

Simultaneously, the voltage source inverter is able to deliver smooth power by injecting a harmonic free and a sinusoidal current in the grid at constant voltage along with constant system frequency as shown in fig 6 which validates the effectiveness of inner current loop controller strategy.

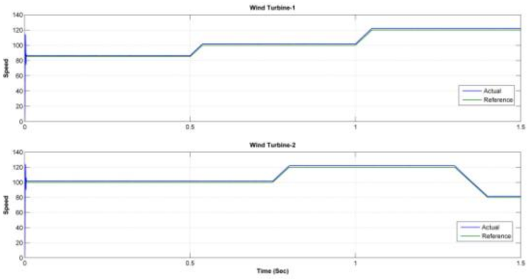

Fig 4: Variable Speed Operation for Cascade Connected Wind Turbine System

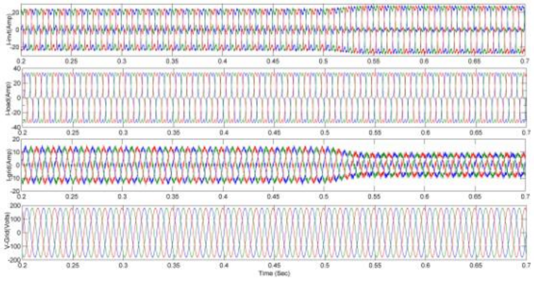

Fig 5: DC Voltage Profile of Individual Unit and DC-Link Voltage

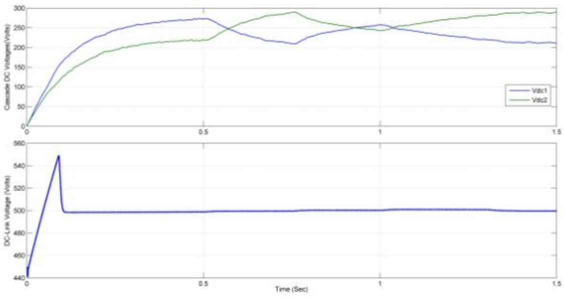

Fig 6: Current and Voltage Waveform of Grid, Load and Inverter

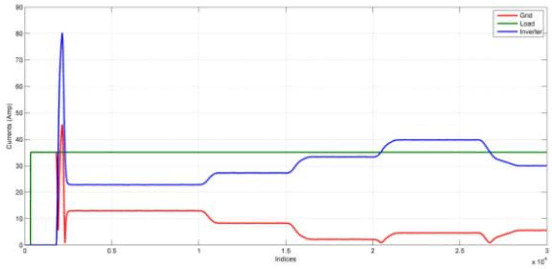

Fig 7: Current Profile of Grid, Load and Inverter

Actually under normal condition, the current controlled voltage source inverter injects a current to grid which consists of a current component for compensation of non-linear load and active current component in proportional to DC link power. One portion of active component of inverter is used to feed the connected load and remaining goes to grid.

Here, the grid inverters not only injects active current proportional to generated wind power but simultaneously it also feed the required harmonic and reactive currents components for the non-linear load.

In this case, the grid system deals with only remaining portion of active current and needs to deliver it to the load at PCC as shown in fig 6 and fig 7.

The Current of grid side inverter is given by

$$I_{invt} = I_{load} \pm I_{grid} \qquad (6)$$

$$I_{load} = I_{linear} + I_{non\ linear} \qquad (7)$$

$$I_{non\ linear} = I_{active} + I_{reactive} + I_{harmonic} \qquad (8)$$

Where, I_{invt} = grid side inverter current, I_{grid} = grid current, I_{load} = load current, $I_{non\ linear}$ = non-linear component in load current, I_{linear} = linear component in load current, I_{active} = Active load current, $I_{reactive}$ = Reactive component in load current, $I_{harmonics}$ = Harmonics reactive component in load current respectively.

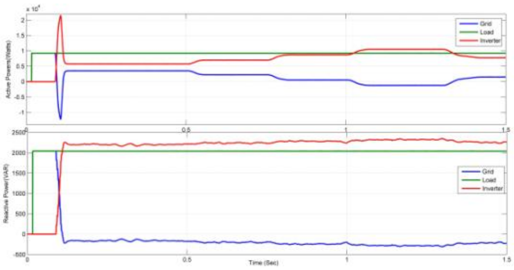

Fig 8: Active-Reactive Power Profile of Grid, Load and Inverter

Therefore, when cascade connected wind turbines power generation exceeds to the required load demand, and then inverter will also feed the grid. When power generation by the wind turbines system is below than load demand then both will feed the load in order to maintain the grid synchronization as shown in fig 8. But here grid feed active power only and reactive power is still injected by the inverters in order to meet the load demand.

IV. CONCLUSION

In this work, a cascade type of wind turbine topology has been implemented which comprises a variable speed PMSG based grid connected WECS. From the simulation results, it is clear that the dynamic performance of the system has given satisfactory performance under non-linear load condition and validates the unity power factor operation. The machine side controller of each wind turbine unit has shown the maximum power point tracking performance at variable speed and able to deliver DC power to common DC link. The grid side results show that controller of common grid interface is able to maintain the DC-link voltage by evacuating the DC link power and deliver it to the grid at its rated voltage and frequency. Under reactive or nonlinear load conditions, the controller of grid side inverter also ensured unity power factor operation of the grid and has to deal with only active power. The harmonic and reactive power demand has been compensated by the grid inverter. Finally, it is concluded that the proposed cascade connected wind turbine topology system may be a cost-effectives solution to achieve the requirements of new wind farm.

REFERENCES

1. I. Dincer, “Renewable energy and sustainable development: A crucial review,” Renewable Sustainable Energy Reviews, vol. 4, no. 2, pp. 157–175, 2000.
2. S. Bull, “Renewable energy today and tomorrow,” Proceeding of IEEE, vol. 89, no. 8, pp. 1216–1226, Aug. 2001.
3. Z. Chen and F. Blaabjerg, “Wind energy-the world’s fastest growing energy source,” IEEE Power Electron. Soc. Newsletter, 18, (3), pp. 15–19, 2006.
4. H. J. Bahirat, B. A. Mork and H. K. Høidalen, “Comparison of wind farm topologies for offshore applications,” 2012 IEEE Power and Energy Society General Meeting, San Diego, CA, pp. 1-8, Jul., 2012.
5. J. G. Slootweg and E.de Vries, “Inside wind turbines—fixed vs. variable speed,” Renewable Energy World, vol. 6, no. 1, pp. 30–40, Jan.–Feb.2003.
6. H. Li and Z. Chen, ‘‘Overview of different wind generator systems and their comparisons,’’ IET Renewable Power Generation, vol. 2, no. 2, pp. 123–138, June 2008.
7. J. Marques, H. Pinheiro, H. Grundling, J. Pinheiro and H. Hey, “A Survey on Variable-Speed Wind Turbine System,” Brazilian Conference of Electronics of Power, Vol. 1, pp. 732-738, 2003.
8. A. Grauers, “Design of direct-driven permanent-magnet generators for wind turbines” Ph.D. dissertation, Chalmers Univ. Technol., G¨oteburg, Sweden, 1996.
9. A.Miller, E. Muljadi, and D. S. Zinger, “A variable speed wind turbine power control,” IEEE Trans. Energy Conversion, vol. 12, pp. 181–187,June 1997.
10. F. Blaabjerg, M. Liserre, and K. Ma, “Power electronics converters for wind turbine systems, IEEE Transactions on Industry Applications,” vol. 48, no. 2, pp. 708–719, March 2012.
11. Z. Chen and E. Spooner, “Wind Turbine Power Converters: A Comparative Study,” 7th International Conference on Power Electronics and Variable Speed Drives, No. 456, pp. 471-476, Sept.1998
12. R. Semken, M. Polikarpova, P. Roytta, et al.: “Direct-drive permanent magnet generators for high-power wind turbines: benefits and limiting factors”, Renewable Power Generation, IET, 6, (1), pp. 1–8, 2012.

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