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Micro-Grid Performance Analysis And Evaluation Of Parameters Affecting Wind Turbine Power Generation

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ABSTRACT

Around the world, conventional power system is facing the problems of gradual depletion of fossil fuel resources, poor energy efficiency and environmental pollution. These problems have led to a new trend of generating power locally at distribution voltage level by using non-conventional/renewable energy sources like natural gas, biogas, wind power, solar photovoltaic cells, and fuel cells. This type of power generation is termed as distributed generation (DG) and the energy sources are termed as distributed energy resources (DERs). Micro-grids are small-scale, LV CHP (combined heat and power) supply networks designed to supply electrical and heat loads for a small community. The generators or Micro-sources employed in a Micro-grid are usually renewable/non-conventional DERs integrated together to generate power at distribution voltage. the present paper, the Micro-grid considered is having a wind farm as a micro-source and a mathematical model is developed to study the parameters that affect the electrical power generated by the wind turbines of a given Micro-grid. The considered parameters are turbine swept area, air density, wind speed, and power coefficient as a function of pitch angle and blade tip speed. This study shows that the operational parameters has a direct effect on the generated power which will lead the developers and researchers to focus on the highest priority parameter that should be considered for manufacturing and optimizing the new generations of wind turbines.

KEYWORDS: Micro-grid, WECS, Wind turbine; Power generation;

INTRODUCTION

Micro-grids are small-scale, Low Voltage (LV) CHP (combined heat and power) supply networks designed to supply electrical and heat loads for a small community, such as a housing estate or a suburban locality, or an academic or public community such as a university or school, a commercial area, an industrial site, or a municipal region. Micro-grid is essentially an active distribution network [1][4].The generators or Micro-sources employed in a Micro-grid are usually renewable/non-conventional distribution energy resource (DERs), integrated together to generate power at distribution voltage. From operational point of view, the micro-sources must be equipped with power electronic interfaces (PEIs) and controls to provide the required flexibility to ensure operation as a single aggregated system and to maintain the specified power quality and energy output.

MICRO-GRID CONFIGURATION

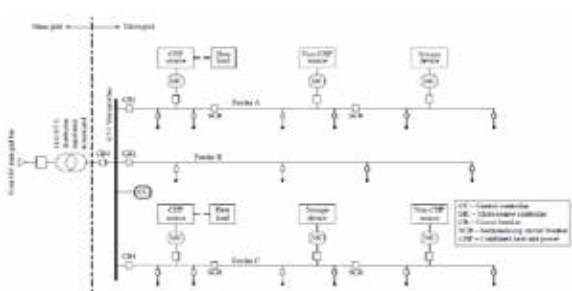


Fig.1. A typical Micro-grid configuration [1]

In the above fig., the Micro-grid consists of three radial feeders (A, B and C) to supply the electrical and heat loads. It also has two CHP and to feeders A and C through micro-source controllers (MCs). Some loads on feeders A and C two non-CHP micro-sources and storage devices. Micro-sources and storage devices are connected are assumed to be priority loads (i.e. requiring uninterrupted power supply), while others are non-priority loads. Feeder B, however, contains only non-priority electrical loads. The Micro-grid is coupled with the main medium voltage (MV) utility grid (denoted as 'main grid') through the PCC (point of common coupling) circuit breaker CB4 as per standard interface regulations. CB4 is operated to connect and disconnect the whole Micro-grid from the main grid as per the selected mode of operation. Feeders A, B and C can however be connected and disconnected by operating ttbreakers CB1, CB2 and CB3, respectively. Although the control of power flow and voltage profile along radial feeders is quite complicated when several micro-sources are connected to a common radial feeder and not to a common generator bus, this configuration is necessary to avail the plug-and-play feature of the micro-sources. The Micro-grid is operated in two modes: (1) grid-connected and (2) standalone. In grid-connected mode, the Micro-grid remains connected to the main grid either totally or partially, and imports or exports power from or to the main grid. In case of any disturbance in the main grid, the Micro-grid switches over to stand-alone mode while still feeding power to the priority loads. This can be achieved by either (i) disconnecting the entire Micro-grid by opening CB4 or (ii) disconnecting feeders A and C by opening CB1 and CB3. For option (i), the Micro-grid will operate as an autonomous system with all the micro-sources feeding all the loads in feeders A, B and C, whereas for option (ii), feeders A and C will supply only the priority loads while feeder B will be left to ride through the disturbance.

AN OVERVIEW OF WIND ENERGY CONVERSION SYSTEMS [1] [7]

A wind energy conversion system (WECS) is different from a conventional power system. In a conventional power plant, the power generation can be controlled. But, the power output of a WECS fluctuates with the wind. This variable power generation nature makes it difficult for analysis, design. While conventional power plants use synchronous machines as generators, a wind power plant uses induction machines as one of the major modern wind power generating facilities. There are basically two ways of wind power generation using induction machines. One uses traditional fixed-speed induction generators and the other uses double-fed adjustable speed induction generators [2].

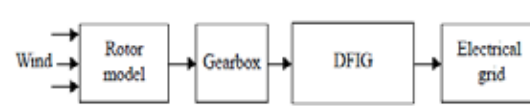


Fig. 2 Wind Energy conversion System block diagram [1][7].

Power from a wind turbine

The mechanical power extracted from the wind is expressed by the well known cube law equation [3][6][7] :-

$P = 0.5\ \rho air\ A rotor\ Cp\ (\lambda\ \beta)\ v3$

$\lambda = R blade\ \omega m / Vw$

Cp = Extracted power/ power in wind

= Protor/ Pwind
Mathematically,
Cp (λ, β) = c1 {(c2/ λ)-(c2/ λ)-(c3*β)-(c4*βC5)-c6}*eC7/λ

Here value of Cp is kept at its maximum value to obtain the maximum power output from the turbine. Value of Cp is generally kept in the range of 0 to 1.The maximum possible theoretical value ever achieved by any wind power generating company is at 0.593, referred a Bentz limit, i.e. 59.3% of wind speed can be converted to useful work [7][3].

Low speed & high speed shaft torque [3][7]:
Pw = 0.5 ρair Arotor v3
Trotor = Paero / ωrotor = TL
Paero = Cp Pw
TH = TL / ηgear

Where, ρair is the air density [kg/m3], Arotor is the area covered by the rotor blades, Cp is the turbine performance coefficient, and vw is wind speed, & Rblade is the blade radius. The performance coefficient, Cp, is a function of the tip speed ratio [8][9], λ, and the pitch angle of the rotor blades, β, ηgear is gear ratio, Paero is aerodynamic power in W, ωrotor is angular frequency of rotor in rad/s, TL is low speed shaft torque in Nm, and TH is high speed shaft torque in Nm.

EVALUATION OF PARAMETERS AFFECTING WIND TURBINE POWER GENERATION IN SIMULINK

Proposed technique:

A wind turbine captures energy from moving air and converts it into electricity. The captured energy is affected by factors like air density, turbine swept area, air velocity and power coefficient as in the following equation [3][6][7].

P = 0.5 ρair Arotor Cp (λ β) v3
λ = Rblade ωm/ Vw
1/ λi = 1/ (λ+0.08* β)-{0.035/(β3+1)}

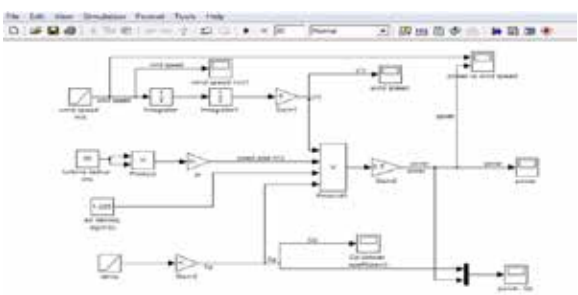


Fig.3. MATLAB/Simulink model

The Simulink model is valid for wide ranges of wind turbines. It is tested on V52 wind turbine as an example.

The specifications of V52 wind turbine:
Table – 1
General details

Rotor diameter	52m
Area swept	2,124 m^2
Number of blades	3
Power regulation	Pitch/Opti-Speed
Air brake	Full blade pitch
Cut-in wind speed	4 m/s
Nominal wind speed	16 m/s
Cut-out wind speed	25 m/s
Nominal output	850 kW
Power coefficient	0.5

(Source: Enercon India Ltd.)

Effect of Swept area on generated power
Fig.4 (Simulation results at wind speed 5m/s)

A. Effect of Wind speed on generated power

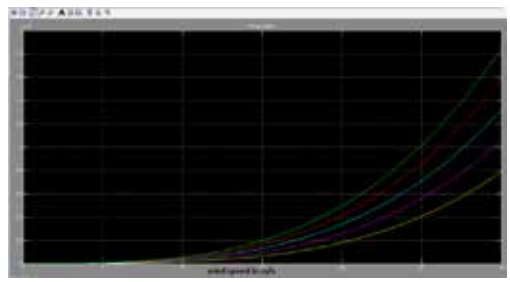


Fig.5 (Simulation results at different wind speeds, air density 1.225kg/m3, Cp= 0.005)

A. Effect of Air density on generated power

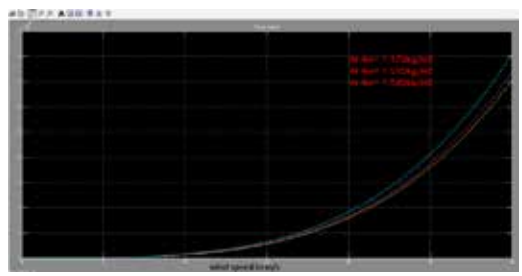


Fig.5 (Simulation results at wind speed 5m/s,
Cp = 0.005)

A. Power coefficient vs. tip speed ratio (λ) at different pitch angles(β)
Optimized values of Cp are given below:

C1	C2	C3	C4	C5	C6
0.517	116	0.4	5	21	0.0068

(Ref. data: Matlab simulink, wind turbine model)

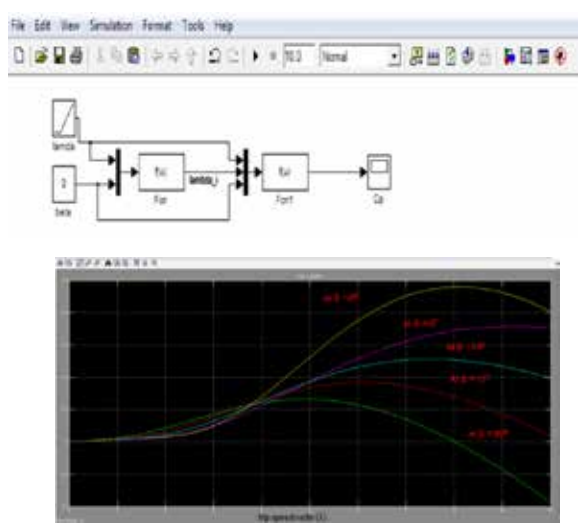


Fig.6 Power coefficient vs. tip speed ratio (λ) at different pitch angles (β)

The maximum value of Cp (Cp max = 0.48) is achieved for β = 0 degree and for λ = 8.1. This particular value of λ is defined as the nominal value (λ nom).

A. Low speed & high speed shaft torque
Pw = 0.5 ρair Arotor v3

Trotor = Paero/ ωrotor = TL
Paero = Cp Pw
TH = TL / ηgear

where, ηgear is the gear ratio, Paero is the aerodynamic power in W, ωrotor is angular frequency of rotor in rad/s, TL is low speed shaft torque in Nm, TH is high speed shaft torque in Nm.

Gear Model:

(i) Simulation model for P_{aero} & low speed shaft torque & result: GEAR RATIO

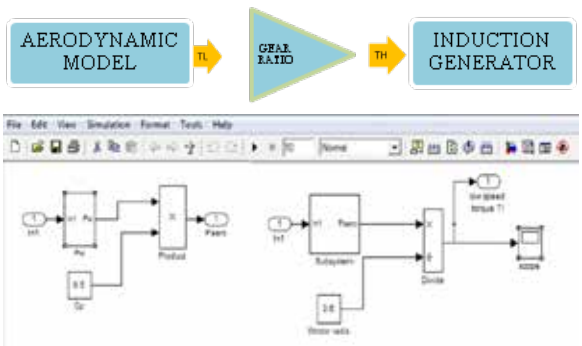


Fig.7 (Simulation results at wind speed 1m/s, Cp= 0.5)

(i) Simulation model for high speed shaft torque and result:

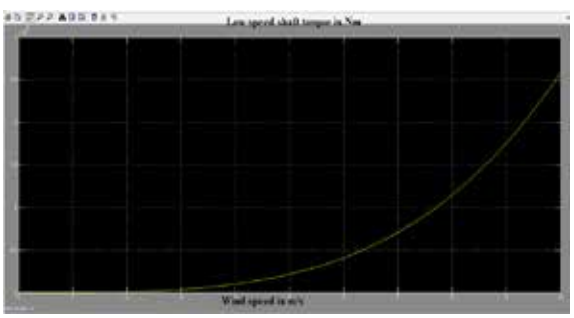


Fig.8 (Simulation results at wind speed 5m/s, Cp = 0.5, gear ratio=0.001)

SIMULATION RESULTS AND DISCUSSION

Wind turbines should be optimized, by taking swept area into consideration, in terms of the local area conditions to capture power as maximum as possible. As can be seen, the output power of a wind turbine is directly related to the wind speed as well as to the swept area of its blades. The larger the blades diameter, the more power can be extracted from the wind. The wind turbine power produced increases from zero at the threshold wind speed (cut in speed) (usually around 5m/s but varies with site) to the maximum at the rated wind speed. But above the rated wind speed, (15 to 25 m/s) the wind turbine continues to produce the same rated power but at lower efficiency until shut down is initiated if the wind speed becomes dangerously high, i.e. above 25 to 30m/s.

CONCLUSION

Wind energy is a promising source of renewable energy and the most efficient WECS is the DFIG. The good exploitation of wind energy may increase the renewable power generation capabilities, maximize its capacity factor, and participate in generating electricity at good costs.

Thus, many factors have to be considered during manufacturing or installation of wind turbines, i.e., (turbine swept area, air density, wind speed, and power coefficient as a function of pitch angle and blade tip speed).

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