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# Comparative Analysis of Integrating WECS with PMSG and DFIG Models connected to Power Grid Pertaining to Different Faults

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***Abstract :*** *In the present centaury wind propelled power generator has become the most challenging with the power system in terms of power quality and harmonic distortion control. These challenges are now overtaken by the advancement of power electronic technology with its rapid growth and improvement, leading to the growth of wind propelled power generator with variable speed. Even then the power quality has been an issue to be addressed among the researchers. In this paper, a comparative study of wind propelled power generator with PMSG and DFIG is presented. These two generator types are connected with the power system using the conventional back to back converters and the unconventional power electronic interface. To study the effect of proposed unconventional power electronic interface, tests are conducted with both generator types. Active power, reactive power and speed control are taken as the comparative factors for the tests with both type of generators by performing transient fault simulations under the condition of sudden short circuit disturbance. The comparison brings out the ways to reduce Total Harmonic Distortion at various fault locations and buses to improve the quality of power generated.*
***Keywords:*** *DFIG, Harmonic Filter, PMSG, Total Harmonic Distortion, Transient Fault*

## I. Introduction

Wind propelled power generation with the advancement of power electronic technology seems to dominate the power generation profile in future. This under exploited potential as of now uses two types of power generators, the DF-induction generator with variable speed technology and PM-synchronous generator with the similar variable speed technology.[1] The first that is the DF-induction generator though provides variable speed operation the speed is restricted with certain limiting ranges. But even then, provides high controllability, maximum power extraction, smooth grid connection and compensation for reactive-power using the back to back power electronic converters that are commonly placed with the rating of 25-30% of the generator capacity.[2] The later one that is the PM-synchronous generator has eliminated the use of gear box and uses the poles in large numbers elevating its generation efficiency.[4,5] They are the most emerging power generator model in the recent trend and the preferred technology.[3] WECS has been modeled for both the power generator types in this paper using conventional power electronic interface and unconventional power electronic interface with simulations. Factors like quality of power, speed control and re-active power are compared for the performance evaluation of both DF-induction generator and PM-synchronous generator in four cases. Organization of the paper is as follows, first section presents the objective and introduction in the beginning of section. Second section describes the proposed model with all the four cases. The next section details the simulation model and compares the result obtained from the simulations. Section four draws the conclusion for the work.

## II. Design Parameters of Wind Turbine

Design for the four different cases are as given in Table 1, for proposed power electronic interface of both conventional back-to-back and unconventional power electronic interface that are to be checked for their effectiveness on both DF-induction generator and PM-synchronous generator.

**Table 1:** Design parameters of wind turbine

| | |
|---|---|
| Nominal Turbine Mechanical Power | 3 MW |
| Wind Speed (base) | 9 m/sec |
| Pitch angle controller Integral Gain | 5 |
| Pitch angle controller Proportional Gain | 25 |
| Maximum Pitch Angle | 45 deg. |
| Maximum Rate of change of pitch angle | 2 deg./sec |

**Table 2** Design Parameters of DFIG

| | |
|---|---|
| Nominal Electrical Power $P_{nom}$ | 3.33 MVA |
| Stator Resistance $R_s$ | 0.023 p.u. |
| Stator Inductance $L_s$ | 0.18 p.u. |
| Rotor Resistance $R_r$ | 0.016 p.u. |
| Rotor Inductance $L_r$ | 0.16 p.u. |
| Magnetizing Inductance $L_m$ | 2.9 p.u. |
| Inertia Constant (h) | 0.685 |
| Pairs of Poles (P) | 3 |

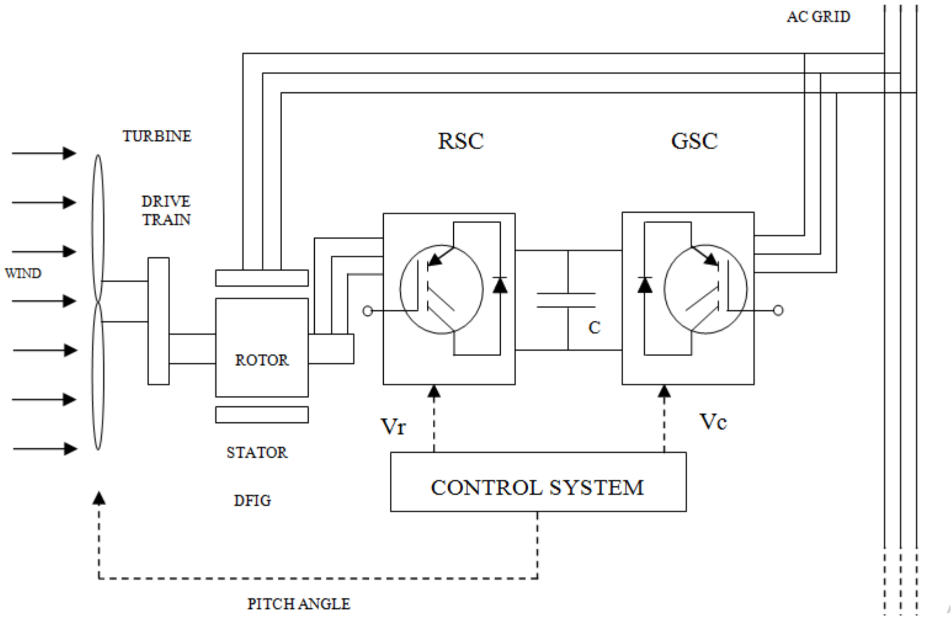


**Fig. 1.** Wind energy conversion system with DFIG and conventional converters

**2.1 Case 1: Back-to-Back converters conventionally used in WECS for DF-induction generator**

This section exposes the effect under transient fault condition in a DF-induction generator integrated Wind power plant when connected with the grid using conventional Back-to-Back converters. The propose model of Wind propelled power generating plant consists of three 3MW wind turbines summing to a total of 9MW overall power generation. Power is exported to 220KV grid via 30 km line from 33KV distribution system where the WPP is connected, resistive load of 500KWand MVAR of 0.9(Q=50) connected at 440V bus. Grounding transformer is connected at 33KV bus. The fault is simulated on 132KV line for the analysis, the layout of the proposed model[7]. In DF-induction generator the rotor is wound round connected to external frequency source and external voltage source through slip rings, providing an option to alter rotor-reactance using inductors with effective modulation in series with the existing rotor-reactance. Whereas the stator winding of DF-induction generator are directly coupled with the grid. Generator conventions are used while modeling the DF-induction generator, the output is current instead of being as input and positive sign is given to reactive-power and real power when fed to grid. Parameters required for designing DF-induction generator is in Table 2. Fig 1, the DF-induction generator with rotor side converter and grid side converter that is used for analysis for WECS is shown. Greatz bridge configuration is used in connecting the IGBT-Diode of three phase rectifier for rotor side converter. Converter also consists of capacitance and snubber resistance. At a sample time of 2 micro-seconds the circuit is discretized. Same Greatz bridge configuration is used in stator side converter too, grid side converter regulates DC bus capacitors voltage. At high wind speeds the power extracted is controlled using angle of pitch control. Torque control mechanism is used to regulate the speed of rotor. MVAR is regulated at a value of zero for the wind turbine.

**2.2 Case 2: Back-to-Back converters conventionally used in WECS for PM-synchronous generator**

Analysis model considered here is PM-synchronous generator driven by wind turbine for wind propelled power generation connected using Back-to-Back conventional converter. Modelling remains same as of DF-induction generator except the replacement of DFIG with PMSG. So modelling of PMSG alone is discussed below rest all are as same as of case1. Parameters for designing are listed in Table 3.

**Table 3** Design Parameters of PMSG

| | |
|---|---|
| Nominal Electrical Power | 3.33 MVA |
| Stator Resistance $R_s$ | 0.006 p.u. |
| Friction Factor f | 0.01 p.u. |
| d-axis Inductance $I_d$ | 0.00415 p.u. |
| q-axis Inductance $I_q$ | 0.0015 p.u. |
| Nominal Frequency | 50 Hz |

### 2.3 Case 3: Unconventional power electronic interface for wind propelled power generator using df-induction generator

The case considered here is a DF-induction generator propelled by wind, rotor side converter with DC_DC interface and converter for grid side, schematic representation of UPEI and DF-induction generator [6]. Greatz bridge configuration is used in connecting the IGBT-Diode of three phase rectifier for rotor side converter. Converter also consists of capacitance and snubber resistance. At a sample time of 2 micro-seconds the circuit is discretized. Rotor side converter has regulator for VAR and voltage.[6] Speed of tracking characteristics is $w_d$ that is the desired speed, until to get this speed equalled by speed $w_r$ angle of pitch is regulated at zero degree. Beyond this speed $w_{d,}$ the angle of pitch is directly proportional to deviation in speed from desired speed. Wind propelled power generator with UPEI coupled to 33KV distribution grid that injects power to 220KV grid. At $B_3$ a transient fault is simulated at t=0.104second for 3ms. Speed is maintained at 1 p.u. by control-systems and reactive power is also regulated to be at 0 MVAR.

### 2.4 Case 4: Unconventional Power Electronic Interface for wind propelled power generator using PM-synchronous generator

Analysis is done for wind propelled power generator using PM-synchronous generator with rectifier of three phase, DC intermediate circuit and inverter using PW-modulation technique. PMSG with UPEI for wind propelled power plant is illustrated.[6]

## III. Comparison of Different Cases

Induction generators were dominating the wind power industry for the past decades with its SCIG model, but since DF-induction generators were introduced SCIG had been outdated by the new comer with its dominating advantages. Especially the variable speed operation led to the domination and flexibility in controlling reactive power. Though DF-induction generators had a dominating era the new variant that is the PM-synchronous generators are now on a competitive track with DF-induction generator. Comparison study between both generator variants is done in this section. Fig.2 and Fig.3 exposes the comparative study for active power and reactive power of the two generators. Comparison rotor speed between both generators is in Fig.4.

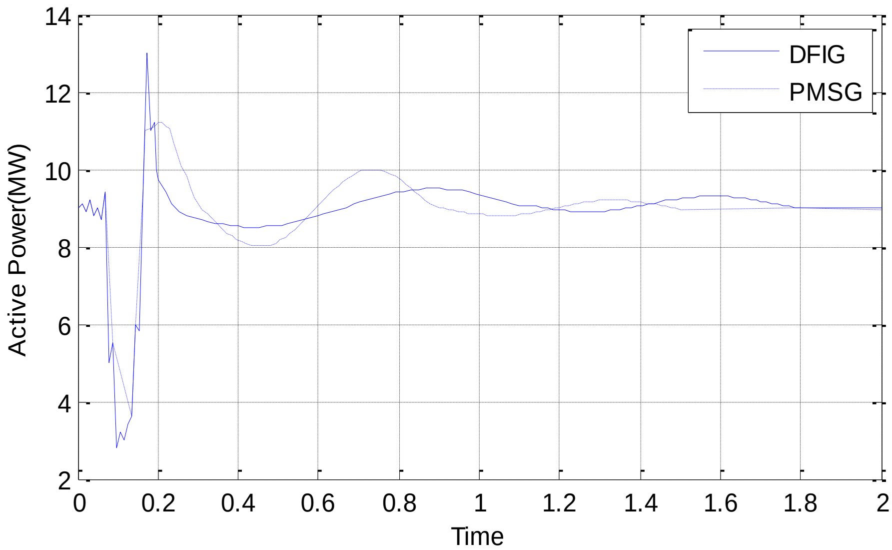


**Fig. 2**. Comparison of active power

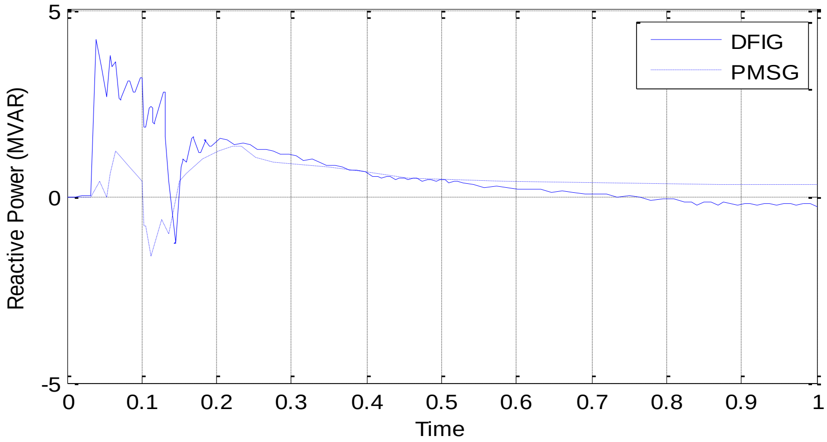


**Fig. 3**. Comparison of reactive power

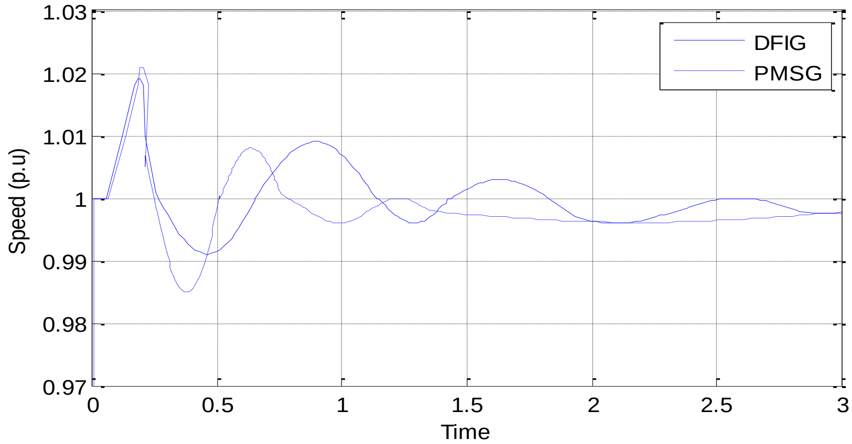


**Fig. 4.** Comparison of generator rotor speed

Active power oscillations are more in DFIG during fault then PMSG. Even then time taken to reach value of steady state i.e., 9MW is same for both variants of generator. Reactive power regulation of DFIG is not better as PMSG at zero MVAR, exposed in Fig.3. Deviation from zero MVAR reactive power is more in DFIG during fault than PMSG, but when compared for fault clearance PMSG take longer time then DFIG to return to zero value. If the need is to regulate reactive power at zero MVAR but sudden deviations and more time is allowed then DFIG is a better option. Whereas if sudden raise in deviation is not allowed but settling time is concerned then PMSG is the best option. Rotor speed comparison is in Fig.4. Rotor speed of DFIG takes long time to settle than PMSG, gives PMSG a lead over DFIG. Steady-state value is reached at t=1.5s in PMSG whereas the other case its even not steady at t=3s keeps oscillating, So if speed is important we should not opt DFIG. From Table 4 to Table 11 values for THDs during different faults for various location of fault and different cases considered in this paper has been given.

**Table 4:** WECS using Back to Back converter for DFIG (3L - Fault)

| | THD Measuring Location | | | |
|---|---|---|---|---|
| Fault (3L) Location | BUS - 1 | BUS - 2 | BUS - 3 | BUS - 4 |
| Bus 1 | 6.32 | 4.86 | 3.31 | 0.11 |
| Bus 2 | 7.35 | 7.26 | 7.25 | 0.2 |
| Bus 3 | 9.69 | 6.19 | 3.97 | 0.15 |
| Bus 4 | 9.82 | 5.24 | 2.21 | 0.1 |

**Table 5:** WECS using Back to Back converter for DFIG (3LG - Fault)

| | THD Measuring Location | | | |
|---|---|---|---|---|
| Fault (3LG) Location | BUS - 1 | BUS - 2 | BUS - 3 | BUS – 4 |
| Bus 1 | 6.61 | 4.95 | 3.27 | 0.1 |
| Bus 2 | 7.34 | 7.25 | 7.23 | 0.2 |
| Bus 3 | 7.26 | 4.9 | 4.42 | 0.15 |
| Bus 4 | 9.81 | 5.23 | 2.21 | 0.1 |

Table 4 and Table 5 expose the THDs of various buses for both symmetrical fault and unsymmetrical fault at various locations for case 1. B1 shows the maximum harmonics distortion during single phase fault when occurs at B3. B4 shows minimum THD when two phase fault occurs at B1. Observations also exposes that THD at B1 remains same irrespective of any type of fault occurring at B4. The same happens from B2 to B4. At B1 the THD is more, increase in bus voltage leads to decrease in THD becomes minimum in B4.

**Table 6:** WECS using Back to Back converter for PMSG (3L - Fault)

| | THD Measuring Location | | | |
|---|---|---|---|---|
| Fault (3L) Location | BUS - 1 | BUS - 2 | BUS - 3 | BUS – 4 |
| Bus 1 | 1.9 | 3.97 | 1.34 | 0.11 |
| Bus 2 | 3.7 | 5.52 | 4.3 | 0.2 |
| Bus 3 | 2.45 | 4.21 | 1.1 | 0.15 |
| Bus 4 | 3.07 | 4.36 | 0.9 | 0.03 |

**Table 7:** WECS using Back to Back converter for PMSG (3LG - Fault)

| | THD Measuring Location | | | |
|---|---|---|---|---|
| Fault (3LG) Location | BUS - 1 | BUS - 2 | BUS - 3 | BUS – 4 |
| Bus 1 | 1.95 | 4.05 | 1.65 | 0.09 |
| Bus 2 | 3.51 | 3.95 | 1.41 | 0.11 |
| Bus 3 | 1.48 | 3.8 | 1.28 | 0.13 |
| Bus 4 | 3.09 | 4.35 | 1.1 | 0.06 |

THD measured for case 2 is in Table.6 and Table 7, measured at different locations for symmetrical and unsymmetrical faults in various buses. Comparing to case 1 its clear that all the THD measurements are less in case 2 for different types of faults, its approximately a reduction of 40% to 60% then case 1. THD measured for case 3 is in Table 8 and Table 9, Compared to case 1 THD here at different locations for various faults at various busses has reduced to 80% approximately, thus its concluded that adding unconventional power electronic interface with DF-induction generator drastically reduces the THD in place of conventionally used Back-to-Back converters. Effectiveness of using unconventional power electronic interface is clearly exposed here for using DF-induction generator.

**Table 8:** WECS using Unconventional PE Interface for DFIG (3L - Fault)

| | THD Measuring Location | | | |
|---|---|---|---|---|
| Fault (3L) Location | BUS - 1 | BUS - 2 | BUS - 3 | BUS – 4 |
| Bus 1 | 1.1 | 0.21 | 0.25 | 0.01 |
| Bus 2 | 1.58 | 0.22 | 0.22 | 0.02 |
| Bus 3 | 1.98 | 0.28 | 0.31 | 0.01 |
| Bus 4 | 1.35 | 0.26 | 0.25 | 0.01 |

**Table 9:** WECS using Unconventional PE Interface for DFIG (3LG - Fault)

| | THD Measuring Location | | | |
|---|---|---|---|---|
| Fault (3LG) Location | BUS - 1 | BUS - 2 | BUS - 3 | BUS – 4 |
| Bus 1 | 1.1 | 0.22 | 0.22 | 0.01 |
| Bus 2 | 1.96 | 0.21 | 0.28 | 0.02 |
| Bus 3 | 1.97 | 0.28 | 0.3 | 0.02 |
| Bus 4 | 1.32 | 0.24 | 0.21 | 0.01 |

THD measured for case 4 is in Table 10 and Table 11, it reveals the THD measured for different faults like symmetrical and unsymmetrical faults simulated in different buses for case 4. From the observations, its exposed that THD measured reduces more than 80% as compared with case 2 that uses conventional Back-to-Back converter for PM-synchronous generator. Also, when case 4 is compared with case 3, case 4 has the lest THD leading to the conclusion that PM-synchronous generator with unconventional power electronic interface is the most effective for a wind propelled power generating plant instead of DF-induction generator with the same unconventional power electronic interface.

**Table 10:** WECS using Unconventional PE Interface for PMSG (3L - Fault)

| | THD Measuring Location | | | |
|---|---|---|---|---|
| Fault (3L) Location | BUS - 1 | BUS - 2 | BUS - 3 | BUS – 4 |
| Bus 1 | 0.58 | 0.23 | 0.24 | 0.01 |
| Bus 2 | 0.72 | 0.22 | 0.21 | 0.02 |
| Bus 3 | 0.77 | 0.28 | 0.30 | 0.01 |
| Bus 4 | 0.62 | 0.23 | 0.21 | 0.01 |

**Table 11:** WECS using Unconventional PE Interface for PMSG (3LG - Fault)

| | THD Measuring Location | | | |
|---|---|---|---|---|
| Fault (3LG) Location | BUS - 1 | BUS - 2 | BUS - 3 | BUS – 4 |
| Bus 1 | 0.58 | 0.23 | 0.24 | 0.01 |
| Bus 2 | 0.72 | 0.24 | 0.25 | 0.02 |
| Bus 3 | 0.78 | 0.28 | 0.30 | 0.01 |
| Bus 4 | 0.62 | 0.23 | 0.21 | 0.01 |

## IV. Conclusion

Power quality, active power, reactive power and speed control factors are used here to make a comparison to find the performance of both PMSG and DFIG in wind propelled power generating plants. MATLAB/Simulink is used for developing system models. Detailed model of both DF-induction generator and PM-synchronous generator with unconventional power electronic interface and conventional Back-to-Back connected to power grid was presented in this paper as different cases. The paper also addresses the schemes for controlling the wind propelled turbine in terms of pitch angle control, DC&AC voltage regulation, regulation of VAR and regulation of current for converter systems. Comparison was made for four different cases and the result shows that the choice of selecting PMSG or DFIG depends on the need. The comparative study has clearly shown that in case 4 that is the choice of opting unconventional power electronic interface with PM-synchronous generator is the best among all other cases and is the most efficient in terms of quality of power.

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