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REAL-TIME TESTING AND ANALYSIS OF A GRID-INTEGRATED WIND FARM

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***Abstract*—** This paper presents a Real-Time Testing and Analysis of a Grid-Integrated wind farm. For the analysis a 1.65MW wind power generator has tested. In this testing, there are many types of data collected in this measurements. Some of the data are given in this analysis: wind direction, wind speed, pitch angle, hydraulic system pressure, turbine speed, rotor speed, internal current, active power, reactive power, and grid frequency. The grid integration of the wind farm, sub-station maintenance, real situations, weather conditions, and condition monitoring systems has been studied. Also, precautionary measures have been taken by the operators and authorities have been discussed in this test.

***Index Terms*—** wind power generator (WPG), wind farm, wind turbine (WT), pitch angle, grid frequency.

I. INTRODUCTION

In July 25th 2013, during this visit for the wind farms located in Muppandal and Radhapuram, near Tirunelveli, Tamil Nadu, India. This visit for the real-time testing and measurements made for various parameters on particular 1.65 MW wind power generator. This measurement was made for the purpose of research on the wind power generator. The various types of data measured and plotted. A modeling, simulation and design analysis of different kinds of wind power generating system have been investigated in this section. The wind power generation, with average values of performance parameters such as technical availability, real availability and capacity factor for this wind farm are 95.68% 79.2% and 25.9% respectively. Also, study the stochastic theory to investigate the security, stability, and dynamic performances of wind turbine generator system (WTGS). Model and simulation of the steady state, dynamic and transient behavior of wind power generator is analyzed through EMTP, FEA and MATLAB simulation tools. A wind-based distributed generation (DG) system, sliding mode control, wind speed assessment and estimation, that can be made based on the sensor-less operation. The output as maximum control for wind turbine systems, and maximum power tracking from the wind energy are been studied. A data mining approach has applied to identify and predict the status pattern of the wind turbines. The Condition Monitoring System (CMS) and speed-adaptive reduced-order observer have also been addressed for the wind power generating systems [1]-[5], [9]-[12].

There are many techniques adopted for the modeling of wind energy conversion systems. The design procedure is manipulated through finite element analysis (FEA) / finite element method (FEM) that, wind speed simulation, wind assessment, wind farm design, and wind turbine optimal control. The FEM technique represents, the numerical based magnetic field computations, relating to electrical machines, etc.; generally, the converter models are composed of relatively, simple electrical circuits and control circuits with varying complexity [6]-[8].

A modeling and simulation analysis for the performance calculations of induction machine based wind power generating systems has been studied [13],[14]. The performance analysis of Field Oriented Control (FOC) and Direct Torque Control (DTC) schemes, are evaluated in terms of torque and flux ripples, and also, their transient response to step variations of the torque commands. Both schemes were compared and the FOC alone shows high flux and torque ripples have been studied [15].

A variable speed induction machine based wind power generation system that uses fuzzy logic controllers, power control linear and nonlinear control, space vector approach, and then, the first one tracks to extract maximum power from wind [16].

1.1 CURRENT WIND POWER SCENARIO

India was fifth in the world wind energy ranking. The total installed electrical power generation capacity in India was 144 000 MW, of which 8758 MW (5.6%) came from wind power plants. At the state level, Tamil Nadu has been the leader from the start has twice as much wind power than Maharashtra in the second place as given in Table. 1.1.

Table.1.1. Statewide wind power capacities

S.No	State	MW
1	Tamil Nadu	4566
2	Maharashtra	2004
3	Gujarat	1666

4	Karnataka	1396
5	Rajasthan	840
6	Madhya Pradesh	213
7	Andhra Pradesh	123

In other states with good wind resources, like Kerala and West Bengal, development has hardly started, owing to unfavorable economic terms. Tariffs and rules differ in different states. For an overview of India's currently installed wind power plants of more than 10MW. 'Muppandal Wind Country' on the southernmost tip of the Indian sub-continent, where the major economic development is driven by the wind industry as shown in Table.1.2.

Table.1.2 Yearly power developments

Year	Target (MW/year)	Actual Development (MW/year)
2002-3	200	242
2003-4	250	615
2004-5	300	1111
2005-6	450	1746
2006-7	1000	1742
2007-8	1500	1574
2008-9	2000	1737 and so on.

The big challenge in 2010 is to get back to the growth so that the annual added capacity will be bigger than the target 2000MW and the keep such a growing trend for another decade or two, when it will be the time to start a repowering scheme. It will also be necessary to adjust the incentives, and most important, to invest in the power grid, so that the wind power plants can be connected to feed in the power at all times.

II. POLICY AND INCENTIVES FOR WIND POWER IN INDIA

The total package of incentives has created an attractive investment climate, which has a pawned a surge of investment in the wind power sector. The following strategies of the MNES (now MNRE) have been the reasons of India's successful wind power industry.

(i) Wind resources assessment: MNES established a countrywide network of wind measuring stations and the wind map of India also came into being.

(ii) IREDA: Indian Renewable Energy Development Agency (IREDA), the financial arm of the MNES was instrumental in promoting wind energy, attracting bilateral and multilateral financial assistance from world institutions and the private sector.

(iii) Private investors: In 1990 policy to encourage private sector investments in wind power was announced by which accelerated depreciation of 100% investments in wind power was permitted.

(iv) C-WET: In 1998 the Centre for Wind Energy Technology (C-WET) was set up in Chennai, Tamil Nadu in collaboration with Rise National Laboratory of Denmark. C-WET acts as focal point for wind power development in India and issues type certificates for wind turbines.

(v) R&D: Support through research institutions and national laboratories, etc. Involvement of state electricity boards (utilities), industry and state policies.

(vi) Infrastructure: Encouraging and supporting infrastructure development by state governments.

III. MUPPANDAL WIND COUNTRY

The maximum number of wind turbines is operating in the South Indian state of Tamil Nadu and there also the bulk of the wind power comes mainly from its southern part, i.e. Muppandal, lovingly called by the people as th 'wind country' .Muppandal is one of the key places which goes down into the annals of wind power history of not only India, but also the world. This is one of the windiest parts of India. The steady flow of wind to these WPPs is made possible because the Muppandal wind farm is situated on a mountain pass in the Western Ghats, through which the wind is canalized throughout the year. The average wind velocity in this area is about 12 m/s, which is extremely good for wind power generation.

In the late 1980s and 1990s, the private investors and wind farm developers came nforward to set up wind power projects in Muppandal. The first wind was farm with 10 wind turbines of 55kW was installed at Mullakkadu in1986 and the first private sector wind farm was set up in1990 with two wind turbines of 250kW each at Muppandal. And more and more wind power plants have been installed during the years.

This is next only to the cluster of WPPs installed at California in the USA. Today Muppandal is a permanent large WPP exhibition ground spanning several square kilometres, attracting not only the wind farm developers, but also tourists, researchers and every one interested in seeing different types of wind turbines at a single location.

IV. REAL -TIME DATA MEASUREMENTS

The following real-time measurements were made in the wind farm. The data collected from measurements as follows:

(i) Wind direction,
(ii) Wind speed,
(iii) Pitch angle,
(iv) Hydraulic system pressure,
(v) Turbine-rotor speed,
(vi) Generator speed,
(vii) Internal voltage
(viii) Internal current,
(ix) Active power
(x) Reactive power,
(xi) Grid frequency.

Table. 4.1 Internal wind direction

Time (min)	AI_intern_Wind Direction
0	0.6
10	9.9
20	-7.3
30	1.8
40	-2.0
50	-3.0

Table. 4.1 shows the analog internal wind direction-time measurements. The wind direction changes, with time scales. The wind changes its direction positive or negative directions naturally.

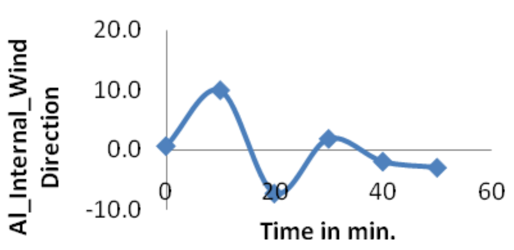

Fig. 4.1 Intern_Wind Direction

Fig.4.1 shows the time-internal wind direction characteristics. The magnitude of the wind varies upstream and downstream directions with respect to time, and by natural causes.

Table. 4.2 Internal wind speed

Time (min)	AI_intern_Wind Speed
06	7.4
10	7.3
20	8.0
30	7.8
40	8.2
50	8.3

Table.4.2 shows the time-analog wind speed measurements. The wind speed gradually increases with slight fluctuations. Then it has settled at its rated level.

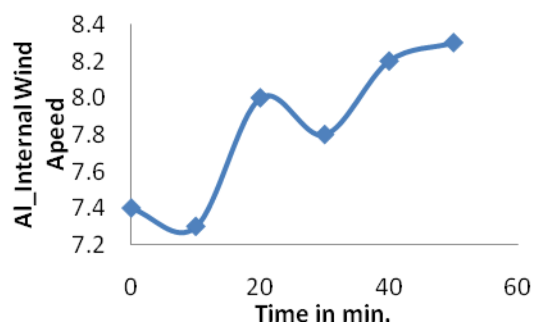

Fig. 4.2 Intern_Wind Speed

Fig.5.2 shows the time-analog wind speed characteristics of the wind turbine generator system. The wind speed gradually increases with the time scale and settled at its rated value.

Table. 4.3 Intern_Pitch Angle

Time (min)	AI_intern_ Pitch Angle 1	AI_intern_ Pitch Angle 2	AI_intern_ Pitch Angle 3
0	-2.0	-1.7	-1.1
10	-1.9	-1.7	-1.0
20	-2.2	-1.9	-1.3
30	-2.1	-1.9	-1.3
40	-2.2	-1.9	-1.4
50	-2.2	-1.9	-1.4

Table.4.3 shows, the analog pitch angle control with respect to time scale, have observed for three modes of operation. The pitch angle is closely tiny changes in each mode of operations.

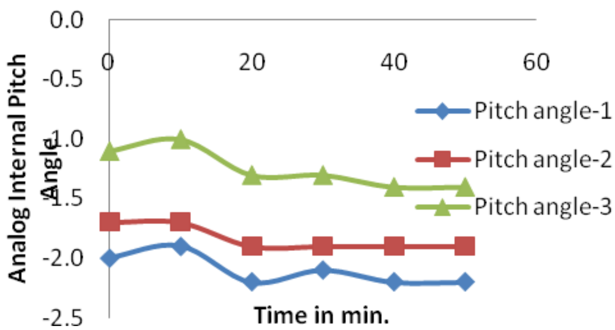

Fig. 4.3 Intern_Pitch Angle

Fig.4.3 shows the time-analog pitch angle performance characteristics of three different observations. There are three curves plotted against time scale, all the curves are almost sustained characteristics.

Table. 4.4 Hydr System Pressure

Time stamp	AI_Hydr System Pressure
0	130.5
10	130.6
20	130.8
30	131.1
40	131.3
50	131.6

Table.4.4 shows the analog values of hydraulic system pressure of the turbine-gear system-generator assembly consisted in the casing of the system, and the pressure has been maintained at rated value with increase of time duration.

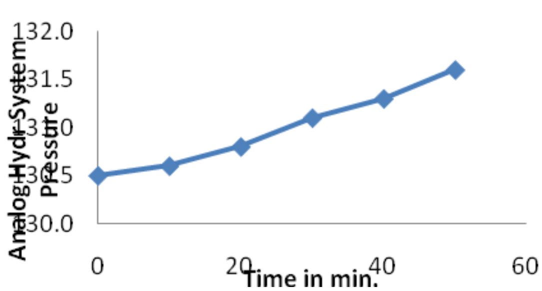

Fig. 4.4 Hydr System Pressure

Fig.4.4 shows, the time-hydraulic system pressure characteristics. The system hydraulic pressure is almost same for the time increase. The pressure is maintained constant for to maintain the temperature constant.

Table. 4.5 Intern_ Turbinr-Rotor speed

Time (min)	Intern_turbine-rotor Speed
0	20.5
10	20.4
20	20.4
30	20.5
40	20.6
50	20.6

Table. 4.5 shows the analog internal turbine-rotor speed with respect to time measurements. The rotor speed almost at constant manner with increase in time durations, except that, a minute variations.

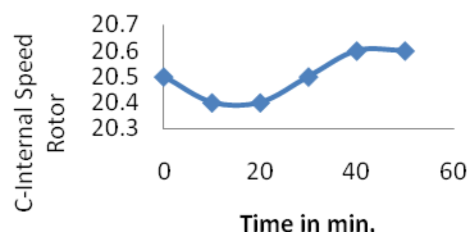

Fig. 4.5_Intern_Speed turbine-Rotor

Fig. 4.5 shows the analog time-internal turbine-rotor speed characteristics. The rotor speed almost at constant manner with increase in time durations, except that, a small fluctuations.

Table.4.6 Intern_Speed Generator

Time (min)	Intern_Speed Generator
0	1538.4
10	1529.7
20	1531.3
30	1537.8
40	1540.1
50	1540.0

Table.4.6 shows the internal generator speed-time measurements. The generator-speed is maintained at most constant except slight fluctuations.

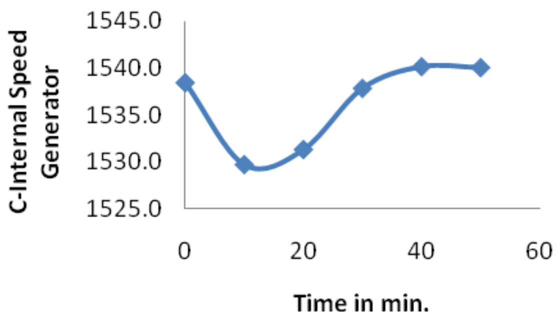

Fig. 4.6 Inten_Speed Generator

Fig.4.6 shows the time-internal generator speed characteristics of the wind turbine generator system. In the graph, initially the generator speed slightly reduces and it is recovered to its rated level and maintained at constant manner.

Table. 4.7 Intern_Voltages

Time (min)	AI_intern_ U1	AI_intern_ U2	AI_intern_ U3
0	750.7	752.3	749.9
10	745.6	747.1	744.6
20	744.6	746.1	743.6
30	745.8	747.3	745.6
40	745.5	747.2	745.2
50	746.7	748.3	745.8

Table.4.7 shows the analog internal voltage measurements with same time scales. The system observations are u_1,u_2 and u_3 are made with respect to time. These three voltage measurements, each voltage scale is initially at higher values and slightly reduces and then maintained at constant values.

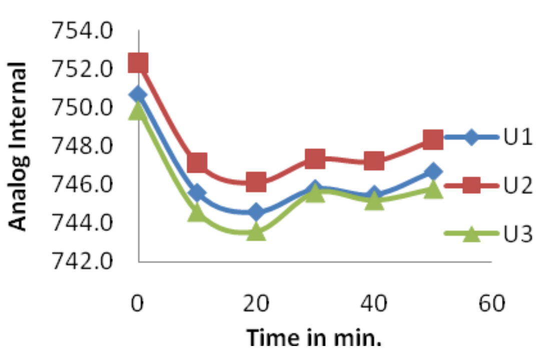

Fig. 4.7 Intern_voltages

Fig.4.7 shows the time-analog internal voltage characteristics of the turbine-generator assembly. These are the three graphs show that for the three voltage variations with respect to time. These three graphs, initially at higher values and slightly reduces and then maintained at constant for the time increase, which is the stable operation of the system.

Table. 4.8 Intern_currents

Time (min)	AI_intern_I1	AI_intern_I2	AI_intern_I3
0	460.4	416.4	422.4
10	511.6	467.8	471.4
20	547.0	504.9	505.8
30	511.1	496.0	485.1
40	571.7	545.9	539.0
50	597.3	552.5	554.5

Tabel.4.8 shows, the analog internal current observations with time increment. There are three mode of currents I_1, I_2 and I_3 are measured with respect to the same time scales. The currents are slightly increases with respect to time scales.

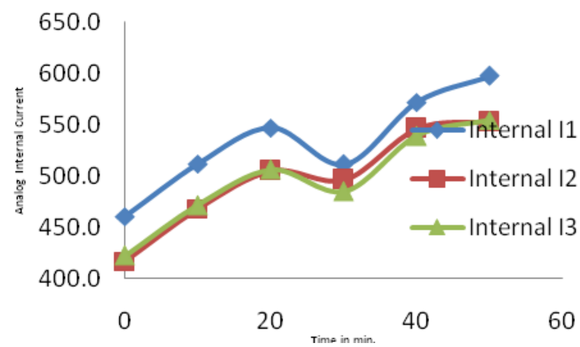

Fig.4.8 Intern_current

Fig.4.8 shows, the time-analog internal current characteristics of the system assembly. There are three currents shows for the three currents variations with respect to time. These three curves increase slightly with respect to time for the stable operation of the system.

Table. 4.9 Intern_Activ Power

Time (min)	AI_intern_Activ Power
0	561.3
10	619.9
20	666.8
30	639.7
40	709.3
50	731.1

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Table.4.9 shows the analog value internal active power of turbine-generator assembly. The active power increases gradually with increase in time. Initially, the reading starts from some residual value and it are increased linearly with respect to time increase.

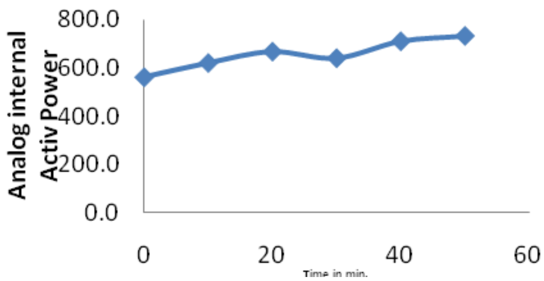

Fig. 4.9 Intern_Activ Power

Fig.4.9 shows, the time-analog internal active power characteristics of the wind turbine-generator assembly, he active power slightly increases with the time increase, which observation shows the good performance of the system.

Table. 4.10 Intern_ Reactiv Power

Time (min)	AI_intern_ ReactivPower
0	6
10	26
20	29
30	18
40	30
50	24

Table.4.10 shows the analog internal reactive power with respect to time scale, observations were tabulated; the reactive power gradually increases with respect to time increase proportionately.

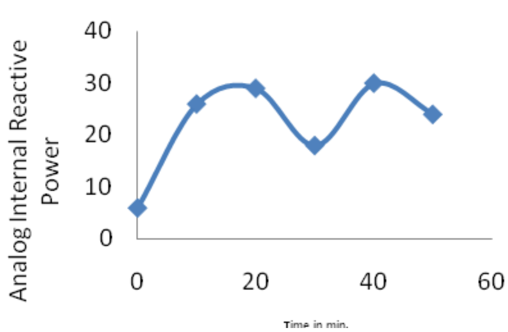

Fig.4.10 Intern_ Reactiv Power

Fig.4.10 shows the analog internal reactive power – time characteristics of wind turbine generator system. The reactive power varies in the injection requirement of the system.

Table. 5.11 Intern_Frequency_Grid

Time (min)	AI_intern_Frequency_Grid
0	50.6
10	50.3
20	50.3
30	50.5
40	50.5
50	50.5

Table.5.11 shows the analog internal frequency measurements with respect to time. The frequency is maintained constant always with the time increases.

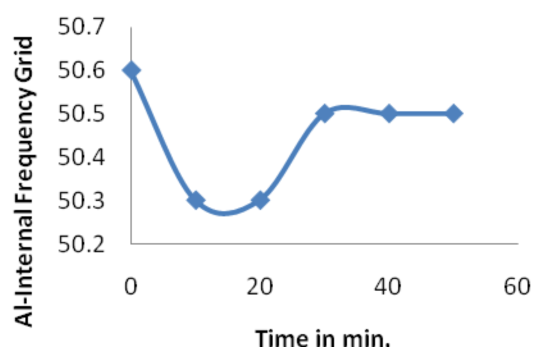

Fig. 5.11 Intern_Frequency_Grid

Fig.5.11 shows the time-internal frequency characteristics. Initially the frequency slightly reduces and settled at its rated value always.

VI. CONCLUSION

This paper is presented for the Real-Time Testing and Analysis of a Grid-Integrated 1.65 MW Wind Power Generator in the wind farm. In this analysis wind power assessment such as wind speed and wind direction were monitored. Also, wind turbine parameters such as pitch angle, torque, mechanical power, friction, coupling factor, and mechanical stress were analyzed. Then, wind generator parameters such that, mechanical power input, generator speed, bearing friction, losses, electrical power output, and efficiency were studied. Finally, gridintegration of wind farm details was analyzed.

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S. Paramasivam received the B.E. degree from GCT, Coimbatore, in 1995, the M.E. degree from P.S.G. College of Technology, Coimbatore, in 1999, and the Ph.D. degree from College of Engineering, Anna University, Chennai, in 2004.

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Presently he is working at ESAB Group, Chennai, as the R&D Head for equipments and cutting systems. He is the Editor-in-Chief of the International Journal of Power Electronics, and an Editorial Board Member of the International Journal of Adaptive and Innovative Systems and International Journal of Renewable Energy Technology. He is also a Reviewer for many IEEE journals, Acta Press, Inderscience journals, Elsevier journals, Hindwai journals, and IEEE conferences.