Preliminary Assessment of the Potential for Wind Farm Development in Southern Sri Lanka

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Abstract

This paper presents preliminary study done to asses the potential wind power at southern region of Sri Lanka and the effects when connecting it to the national grid.

In this assessment wind pattern of the region was analysed, selected a suitable turbine depending on the plant factor and the suitable site was found to locate the turbines. Then a method to connect the wind plant to the national grid was proposed after carrying out a load flow and fault analysis. Financial analysis was carried out to find out the project viability. Power system stability was assessed using the Matlab/Simulink software.

I. Introduction

Sri Lanka is a developing country, which has the electricity demand of about 1450MW. The demand for electricity is annually growing at a rate of 8%. According to the National Power and Energy Demand Forecast, peak demand of the country will be around 2500MW by 2010.

In order to cater this increasing demand, the duty of the CEB is to increase the installed capacity. According to the Long Term Generation Expansion Plan prepared by the Generation Planning Branch, it can be seen that most of the portion is planned to be supplied by thermal power generation. When the oil prices and the environmental effects of fossil fuels are considered it is worthy if it is possible to take the maximum of renewable sources.

Since the higher percentage of available hydro potential has already been used, attention should be paid on other renewable sources. Wind energy is the fastest growing renewable energy technology during the last decade and worldwide wind capacity has doubled approximately every three years. Although there is only one grid connected wind power plant in Sri Lanka, the studies have revealed that the total potential of wind power generation in the South-eastern part of the country to be 200 MW.

This project is mainly a preliminary assessment of the potential for wind farm development in southern region. We started the project to give the guidelines in preliminary level. Although we have done it in preliminary level, it is necessary to do a detailed analysis in the feasibility level.

II. Wind Data Collection & Analysis

The purpose of the wind speed analysis was to identify the behaviour of the wind in the Hambantota area during a period of one year including the two monsoons.

For this, we took hourly wind speed data (32.5m, 20m, 10m heights) measured at the measuring mast in metrological station in Hambantota starting from October 1996 to December 1997.

Since some data were missed due to a malfunction of the data logger in some months, data patching had to be done to fill those blanks. Unusual data was also identified by plotting the diurnal curves for several months and those data also patched. For data patching, daily wind run was used, which was taken from the meteorological department.

After data patching, behaviour of the wind was analysed. Under this monthly behaviour, sector wise behaviour and diurnal behaviour were considered. The following figures show the different wind behaviours.

A. Behaviour of the Wind

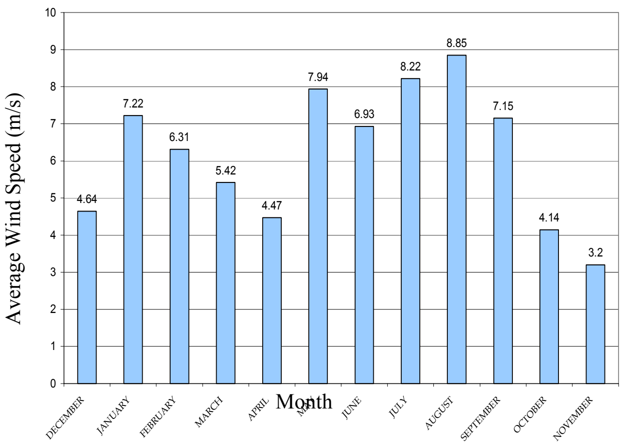

Fig. 1 Monthly Wind Pattern in Hambantota

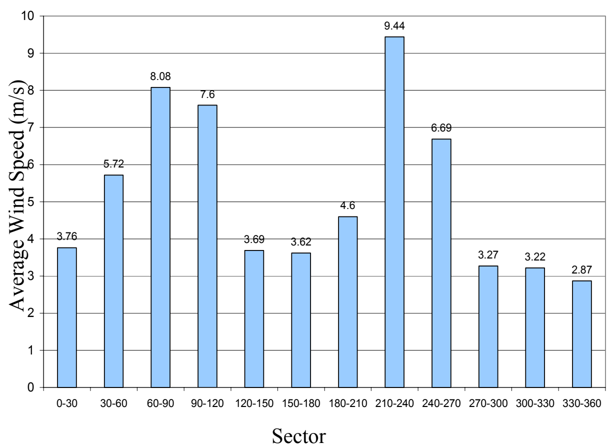

Fig. 2 Percentage Duration of Wind from Different Directions

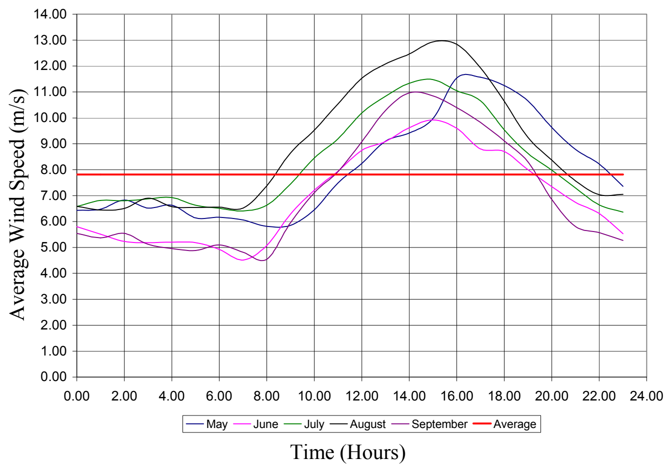

Fig. 3 Diurnal Curves in South-West monsoon

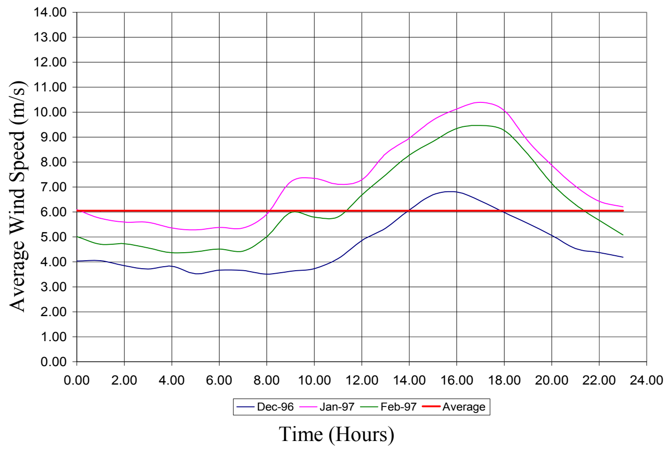

Fig. 4 Diurnal Curves in North-East Monsoon

B. Mathematical Description of Wind Regime

Wind speed frequency distribution could be mathematically described using the so-called Weibull distribution function using only two parameters, i.e. Weibull shape factor (k) & Average wind speed (V) at the site.

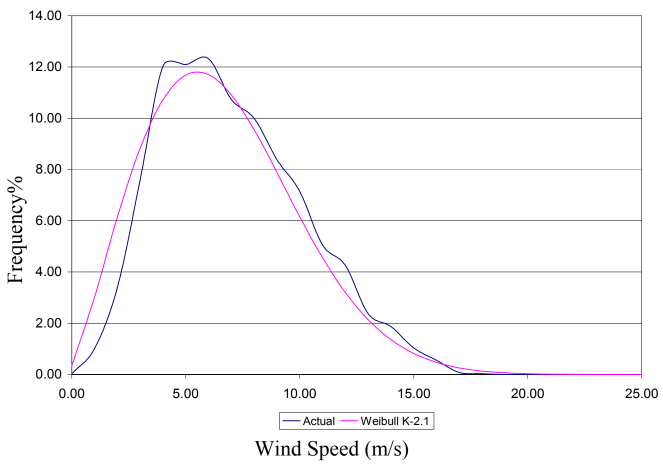

Fig. 5 Annual Frequency Distribution

Weibull shape factor (k) could be calculated for a given wind regime using hourly wind data available. Equation for calculating the k value

$$F(V)=1-e^{[-(V/c)k]}$$

Weibull shape factor (k) also be calculated from another method using the standard deviation σ of the annual or monthly hourly wind speed data set. **k** could be estimated for the calculated **σ/V** using the graph plotted ratio **σ/V** against **k.** First method was used to find k values manually. Second method was used in the VB programme since it was difficult to solve the of 5th order polynomial in the first method. Annual k value 2.1

III. Wind Turbine Selection & Average Energy Production

A VB program was developed to analyse wind data and to find the energy generated from different Wind turbines. This program eases up the complexity of extrapolating of the wind data to a required hub height. Important functionalities of the program are as follows.

- Analysis the entered data & generate the frequency distribution for each sector.
- Generation of Weibull shape factor depending on user requirement (monthly, sector wise or yearly) at a required height.
- Energy calculation for different turbines.

The output will consist Annual generation, plant factor and predominant wind direction.

We selected 9 Wind Turbines from well-reputed companies. Using the program the energy production for the year 1997 for different turbines was calculated and analyzed. The outputs were as follows.

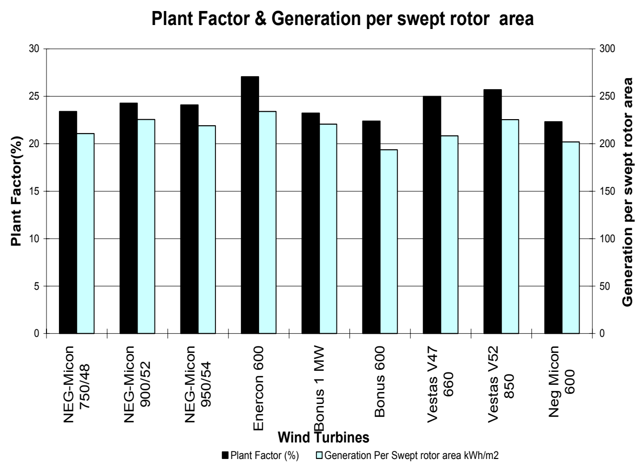

Fig. 6 Plant Factor and kWh/m2 for turbines

By considering the result and the infrastructure facilities available it was found that the best turbine to the selected site at Hambantota is the vestas V52 850 kW.

Frequency distribution at hub height (55m) is shown in the Fig 7.

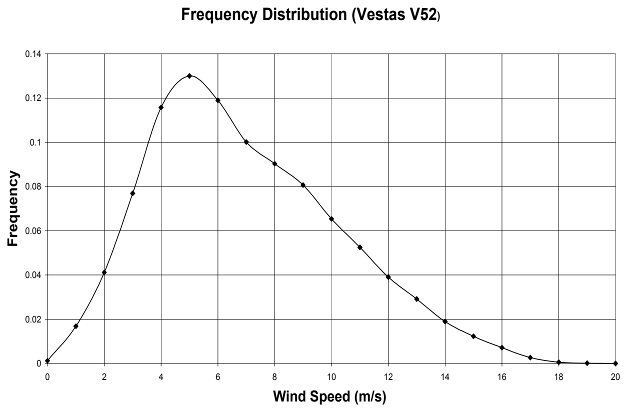

Fig. 7 Frequency distribution (Vestas V52)

Average energy production was calculated forecasting the annual generation for the 1994-2003 and taking the average of these values. This was done using the wind run data which was obtained from the meteorology department.

The frequency distribution of each year was calculated using the average wind speed and the Weibull shape factor (k_{yearly}=2.1). Average wind speed for each year was calculated using the correlation (obtained by plotting the meteorology data (1997) against CEB data which was extrapolated to the hub height of 55m) and the relevant year's meteorology data.

$$\mathbf{V_{Daily\ CEB\ at\ 55} = 1.1039 * V_{Daily\ met} + 0.6574\ (R^2 = 0.8474)} \quad (1)$$

Number of hours, during which the wind speed lies between V - 0.5 and V + 0.5, is given by "(2)" and "(3)".

$$f(V) = 1 - e^{[-\Gamma^k (1+\frac{1}{k}) * (\frac{V+0.5\Delta V}{\bar{V}})^k]} - \{1 - e^{[-\Gamma^k (1+\frac{1}{k}) * (\frac{V-0.5\Delta V}{\bar{V}})^k]}\} \quad (2)$$

No of Hours= f(v) *T (3)

Using the frequency distribution of each year and the PV curve information, projected energy production was calculated. The figure below shows the actual energy production for each year and the average energy produced when considering the 1994-2000 data. This average value (1.955 GWh/annum) was used in the Economic and financial evaluation of the wind farm at Hambantota.

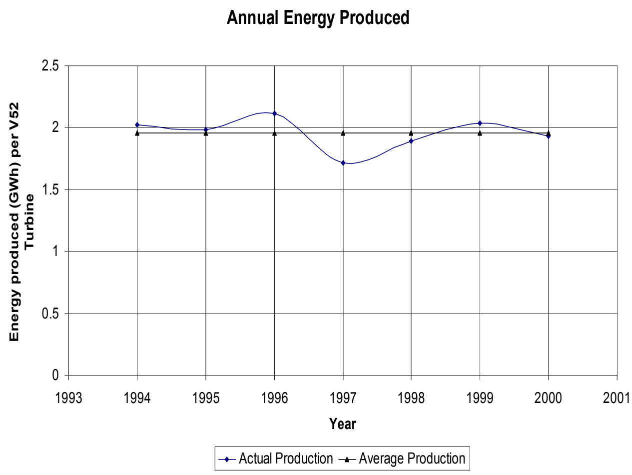

Fig. 8 Annual Energy productions

A preliminary plant layout was identified regarding important issues such as predominant wind direction (210°-240°) and land acquisition problems. And this is a plant with 60 turbines (Vestas V52 850kW WTG) delivering 51MW.

IV. Load Flow & Fault Analysis

Load flow analysis was done using the software package called Power World Simulator. Because of the complexity, some grid substations were lumped together when modelling Sri Lankan power system using the power world simulator.

According to the load flow analysis it can be seen that the maximum capacity that can be connected to the Hambantota grid without over loading any transmission line under normal operating condition is around 86MW. If the capacity of the plant exceeds this value, the two transmission lines between Balangoda grid substation and New Laxapana switchyard are going to be over loaded even under normal operating conditions.

The new wind farm is proposed to connect to the national grid through a new grid substation. According to the fault calculation, short circuit currents at the low voltage side and the high voltage sides of the proposed grid substation are 11.73kA and 4.08kA respectively. After the connection of the proposed grid substation to the Hambantota grid substation, the 3-phase short circuit current at the high voltage side (132kV) will be 4.15kA. This value is much higher than the existing value of 3.2kA.

V. Financial Evaluation for the proposed Site

Financial evaluation was carried out taking the life of the project as 20 years. Most of the important parameters used in the evaluation are shown in the table below.

The total tariff (total capacity charge) is comprised of Escalable and Non Escalable components. And to come up with a levellised tariff the total capacity charge ($/kWh) was discounted and divided by the discounted energy produced in each year over 20 years.

For the preliminary assessment the following data was taken as the base case.

TABLE 1
BASE CASE DATA

Investment cost	€1000/kW
No of 850kW turbines	60
Discount Rate	10%
Interest Rate (US$ Loan)	6%
Return On Equity	15%
Repayment period	7 Years
Forced Outage Rate	10%
Debt	70%
Equity	30%
Other costs	$5 m
Plant Factor	26%

Other costs include grid connectivity, HV transmission line cost and turbine connection cost up to the grid.

Forced outage rate include the machine down time, transmission line loss and array effect losses.

Levellised Price in the base Case is $ 0.08606. (Taken 20 years as lifetime) Total tariff for the 20 years is shown in the following figure.

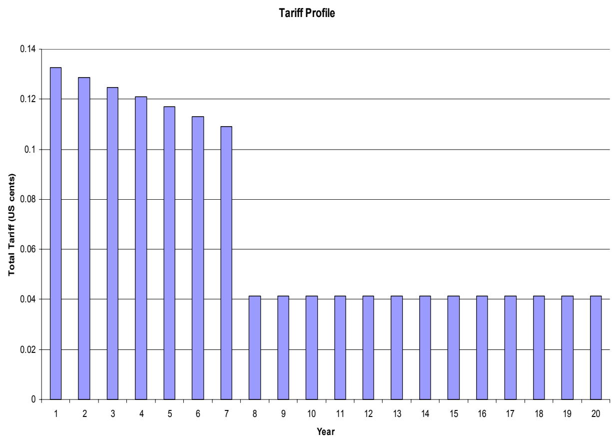

Fig. 9 Tariff Profile over 20 years

Due to the importance and reliability of some parameters they were treated on a sensitivity analysis basis, which is deviated from the base case. The parameters that have been taken in to consideration are;

- Investment Cost (€/kWh)
- Return on Investment
- Repayment Period
- Loan Interest rate
- Construction Period
- Plant factor
- No of Turbines

The outcome of the analysis is shown in the fig 10.

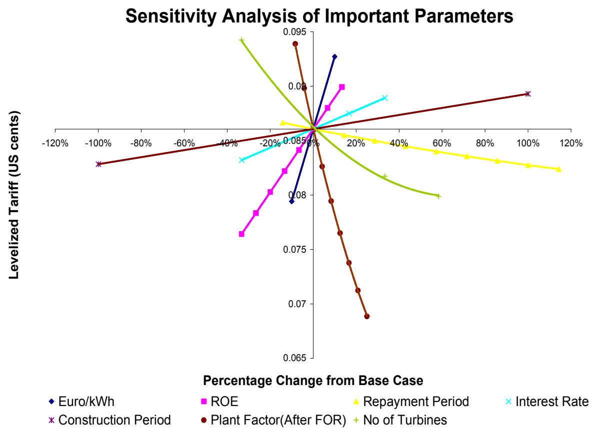

Fig. 10 Out put of the Sensitivity Analysis

By analyzing the outcome of the sensitivity analysis we can come up with the following conclusions.

- Plant factor being the most sensitiveness to the project it is critical in choosing the right site for economic viability.
- In the base case it is used 15% as the ROE, which is the normal rate of an investor (in US$ terms). If the investor is willing to have the return in two stages (small ROE in the Loan repayment period and higher ROE in the rest of the project life) keeping the IRR constant it will give an attractive price and a better Tariff in 20 years.
- Normally for an 50MW wind project it takes 2 year for project development and the construction, so it is advisable to carry out the 50MW project in two 25MW stages in parallel which one wind farm is constructed in one years time.
- Investment cost (€/kWh), Interest rate, repayment period and Number of turbines can be solely used as key decision making parameters.

VI. POWER SYSTEM STABILITY WITH WTG SYSTEM

The main objective of this part of the study is to analyse the system stability in case of putting a 50 MW Wind Turbine Generator (WTG) system on the present power system. Here a hypothetical model of the present power system and the associated WTG system was built using Matlab/Simulink software and simulations have been carried out on this model to analyse the stability of the power system during the following contingency situations.

- Tripping of the WTG system from the power system.
- A 3-Φ fault on the transmission line terminal at the grid substation where the WTG system is connected.

According to the stability criteria of the present Sri Lankan power system, the system should be stable under these contingency conditions.

A. Tripping of the WTG System

In this simulation the WTG system was tripped while it was being loaded up to about 70% of its installed capacity, which refers to an active power generation around 40 MW. In addition, referring to the characteristics of the selected wind turbine (i.e. Vestas V52 850 kW wind turbine) this level of loading corresponds to a wind speed around 11 m/s, which is much above the average wind speed (~ 7 m/s) of the selected Hambantota site. Therefore the situation considered here corresponds not to the average but to a critical case of the designed WTG system on the present power system.

According to the instant of the power system that has been considered in this simulation, the above generation loss corresponds to about 6% of the total generation of the system. The following figure illustrates the frequency variation of the system in this simulation.

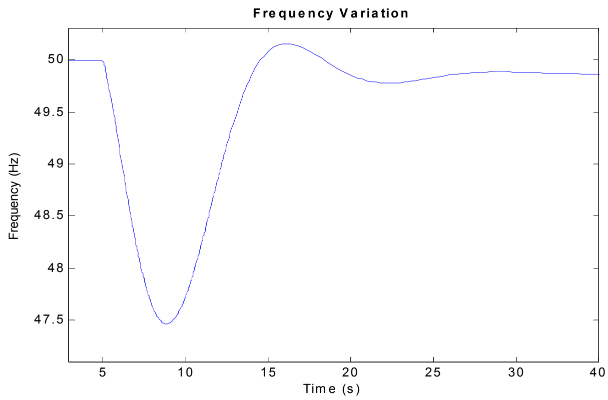

Fig.11 Frequency variation of the system during the fault

As soon as the WTG system trips from the power system, the system frequency starts to collapse to a minimum of 47.5 Hz and finally recovers back at around 49.8 Hz. Here it is important to notice that the system model that have been used to simulate this case had no load shedding scheme implemented in it and therefore the system recovered solely from its own inertia. So it's quite clear that the present power system has no severe harm whatsoever due to the tripping of this proposed WTG system from the power system during a situation similar to the mentioned above.

The voltage profile of the 132 kV bus bar at Hambantota grid substation during this simulation is shown in the Fig. 12.

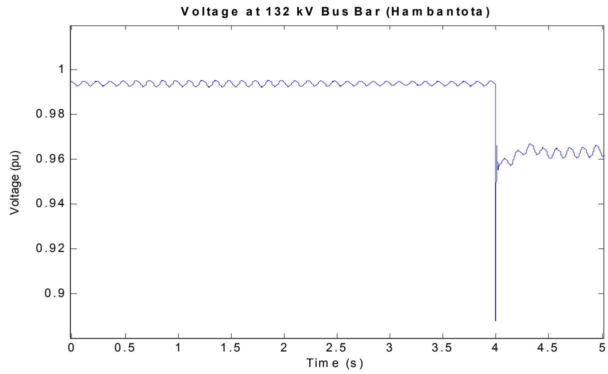

Fig. 12 Voltage variation on the 132 kV bus bar at Hambantota grid substation during the fault

Here the steady state value of the bus voltage (0.99 p.u.) suddenly falls to a value of 0.88 p.u. at the instant of tripping and again settles back around 0.96 p.u. According to the standards on the present power system, the 132 kV bus bar voltage is allowed to vary between $^{+}$/- 10% during both the normal and single contingency conditions. Therefore the above voltage drop revealed by the simulation study due to the tripping of the WTG system from the grid is acceptable and very much within the standards.

B. 3-Φ Fault on 132 kV Line Terminal

In this case a 3-Φ fault on the 132kV transmission line terminal at the Hambantota grid substation was simulated for a duration of 100 ms. The following figure depicts the fault current measurement obtained.

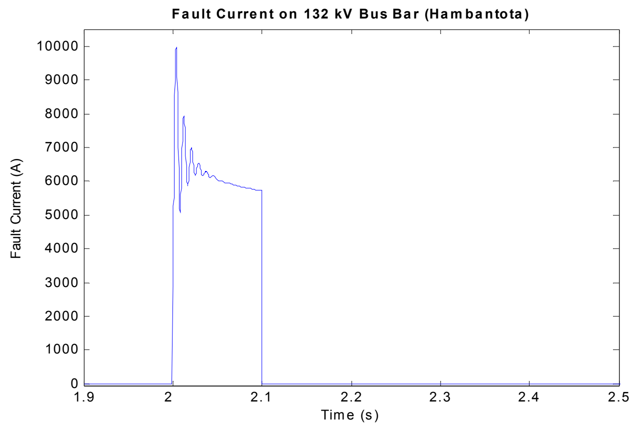

Fig. 13 Three phase fault current on the 132 kV bus bar

It reveals that the fault level of the 132kV bus bar at Hambantota grid substation is about 10 kA (maximum) even after connecting the proposed WTG system to the national grid. According to the short circuit criteria of the present Sri Lankan power system, the maximum allowable 3-Φ fault level for 132kV is 40 kA. Hence it is necessary and definitely possible to upgrade the existing fault level (3.2 kA) of the 132kV bus bar at the Hambantota grid substation in adopting this proposed WTG system. Also it was noted that the current flowing through the grid substation during the fault is very large and therefore most probably the grid substation may trip off from the network during this time by isolating the WTG system from network as well. But this mainly depends on the settings of the over current protection scheme and the other related protection schemes at the Hambantota grid substation. If the WTG system is tripped, the situation would be very much similar to the previous case. Therefore not tripping case is considered here.

The active and reactive power variation of the WTG system and the grid voltage profile obtained during the simulation are given below.

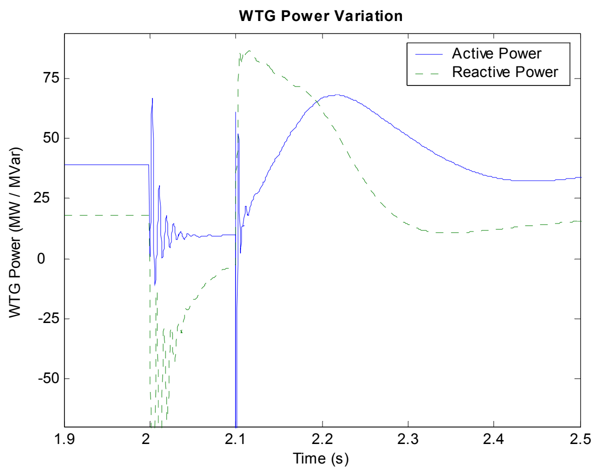

Fig. 14 Active & Reactive power variation of the WTG system

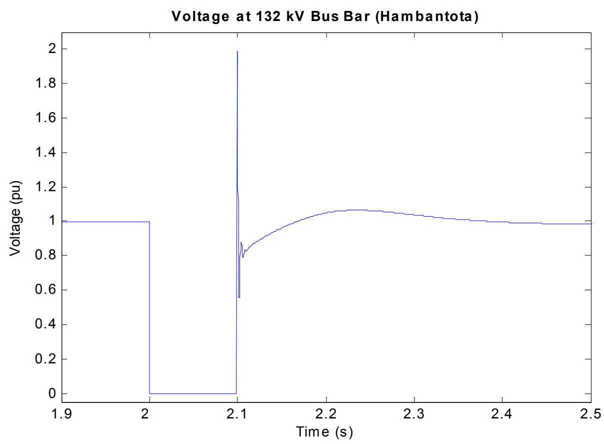

Fig. 15 Voltage profile of the 132 kV bus bar at Hambantota grid substation

Here as soon as the fault is initiated, the grid voltage collapses and therefore the WTG system is demanded to supply more and more reactive power instead of consuming it. But the ordinary induction generators which concerned in this case are unable to meet this task and therefore the reactive power contribution by the WTG system keeps reducing during the fault. Again just after the fault is cleared, the grid voltage re-establishes at 1 p.u. and the WTG power starts to resettle to its original values with oscillations. These oscillations probably overload the induction generators only for very short period of time (~ 200 ms) without imposing any serious damage on them. Therefore it is certain that this type of a contingency has no severe impact on the proposed Wind Turbine Generator system.

CONCLUSION

Analysis of the power curves of the wind turbines revealed that Vestas V-52 850KW Turbine as the most suitable turbine for the proposed site. Then a load flow analysis was carried out using the "Power World" package and found out that the maximum amount of the wind farm power to be 86MW. But due to land acquisition restrictions the wind power plant is finally limited to 51MW.

A sensitivity analysis was carried out to identify most sensitive factors related to the wind farm construction and found out that the plant factor and the Return on Equity (ROE) to be the most sensitive factors respectively. The financial evaluation also shows that the proposed project is economically viable as well.

Finally according to the "Matlab" simulations it was found that the wind power plant is stable in the power system under the above simulated cases (section VI), which was one of the basic criticism against the wind power plants. Also it can be seen

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