

Increased Wind Power Generation in Sri Lanka: A Case Study

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Abstract

Sri Lanka has a significantly large wind resource, as proven in many studies. The Central Province has the best wind capability compared with other provinces. In this study Ambewela, Hare Park, Ratninda and Naula sites are identified as suitable locations for wind power extraction in the Central Province. The 21MW wind power plants (WPP) for Ambewela, Hare Park & Ratninda sites and 4MW WPP for Naula are decided. Nuwara Eliya, Badulla, Ukuwela and Naula 132/33kV grid substations are identified as suitable interconnection points for the above selected sites, respectively. After detailed analysis of wind resource in the area Gamesa G97; 2MW & Leitwind LTW77; 1MW wind turbines are selected as most suitable for the Central Province. The WPPs were modeled in the Sri Lankan Power System using Power System Simulation for Engineers (PSS/E) software to conduct the load flow analyses, single contingency analyses, fault level calculations, PV & QV analyses and dynamic studies. By analyzing the results of above studies, minor system improvements and long term improvements for better wind absorption into the Sri Lankan power system have been identified. Minor system improvements includes adding reactive power resources at identified locations, minor improvements to existing transmission lines and increasing the reserve margin of the power system. Major system improvements were identified using the PSS/E software to represent the real situation of the power system and make improvements in the planning procedure and criteria, conduct comprehensive voltage stability study and implement under voltage load shedding scheme. Further proposed introduce higher voltage backbone system or major improvements of existing 220kV backbone system, introduce more active and reactive power sources in suitable locations, implement group frequency controlling method, introducing new generation and bulk energy storage options such as Pumped storage power plants which enhance the wind absorption limits in the power system.

Keywords:

Candidate sites, wind turbines, interconnection points, systems studies, system improvements, pumped storage power plants

Introduction

Sri Lanka has large wind resources which proven in many studies. Wind is recognized as the one leading renewable source to generate electricity because wind is an infinite primary energy source and the low environmental impact, wind is known as a main clean source to generate electricity.

In order to integrate large amounts of wind power successfully, a number of issues need to be addressed. Among them, this paper discusses the initial site screening process for wind power plants, selecting wind turbines, selecting the interconnection points and the interconnection study, to identify the required transmission network reinforcement.

The site screening process mainly involves initial screening of wind resources and land suitability. The most essential factor in selecting a wind energy site is the wind resource itself. The wind resource in Sri Lanka mainly varies according to exposure to the monsoon winds. Factors that would exclude a site from consideration include national parks, wildlife sanctuaries or other areas where development is prohibited, migration routes of migratory bird species, areas with high concentrations of rare or endangered birds, some military areas, culturally sensitive areas (historic, religious or archaeological sites) and urban areas. In addition, sites will be subjected to an initial screening for transportation and transmission access.

The selection of wind turbine involves matching wind turbine parameters with the site characteristics such as wind speed, frequency of each

wind speed, wind direction, site conditions...etc.

Wind as a power generation source has specific characteristics, which include variability, geographical distribution and its behavior in the power system. These raise challenges for the integration of large amounts of wind power into electricity grids and selecting the interconnection points is the first challenge. When selecting interconnection points, available interconnection points (grid substations), capacities of the existing grid substations, possibilities of having new grid substations, line routes and lengths has been considered. Then the selected interconnection points has been verified by system studies such as load flow analysis, single contingency analysis, fault level calculations, PV & QV analyses and dynamic studies.

Methodology and Results

The Table 1 shows the electricity generation targets which envisaged with coal and NCRE resources according to the Government of Sri Lanka policies.

Table 1- Electricity Generation Targets [4]

Year	Electrical Energy Supplied to the Grid as a Share of the Total			
	Conventional hydroelectric	Maximum from oil	Coal	Minimum from NCRE
2015	28%	8%	54%	10%

The Long Term Transmission Development Plan for 2008-2016 describes the maximum demand for the year 2015 as 3500 MW. So 5% and 10% of the system maximum demand for year 2015 is 175 MW and 350MW, respectively. Using information in the report on Wind and Solar Resource Atlas of Sri Lanka and Maldives prepared by National Renewable Energy Laboratory, USA the most suitable provinces for wind power connection and their proportional contribution to meet a national target of 5% or 10% of the peak demand are illustrated as Table 2.

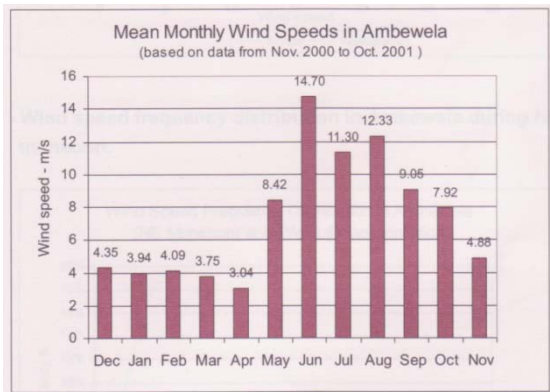
Table 2 - The Contribution of Wind Capacity from the Most Suitable Provinces [6]

Province	Good-Excellent Potential MW	Wind Capacity (10% Demand)	Wind Capacity (5% Demand)
Central	7,550	134	67
North Western	1100	20	10
Northern	4,950	88	44
Sabaragamuwa	2,200	39	20
Uva	3850	69	34
	19,650	350	175

The paper analyzes and discusses the challenges, procedure for power system improvements to absorb almost 67 MW wind resource from Central Province. The 67 MW satisfies a 5% target from wind from Central province. The reasons for selecting only wind resources to fulfil the 5% target of Non Conventional Renewable Energy by 2015 are wind power generation is the available economical NCRE energy option, it has the best tariff in Sri Lanka, the low environmental impact, wind is known as a main clean source to generate electricity.

In this paper, the Central Province was selected as the candidate siting area because of the good wind potential and the availability of measured wind data in the area under "Wind Energy Resource Assessment Puttalam and Central Regions of Sri Lanka", which was conducted by the Ceylon Electricity Board. This study had selected three wind data monitoring stations in the Central Province (Rantinda, Hare Park and Ambewela). The detailed data analysis is given for the Ambewela site. So in this paper, Ambewela wind data is considered common for all locations in the Central Province. The wind mast in Ambewela is situated in the cattle farm of the National Livestock Development Board and its elevation is about 1800 above MSL. The overall wind pattern in Ambewela follows the general monsoon wind climate in Sri Lanka, which is characterized by South West Monsoon (SWM) (May~September) and North East Monsoon (NEM) (December~February) (Figure 1). The annual average wind speed in Ambewela is 7.31m/s at the measuring height of 40m [5].

Figure 1 - Mean Monthly Wind Speeds in Ambewela [5]



Source: Wind Energy Resource Assessment Puttalam and Central Regions of Sri Lanka

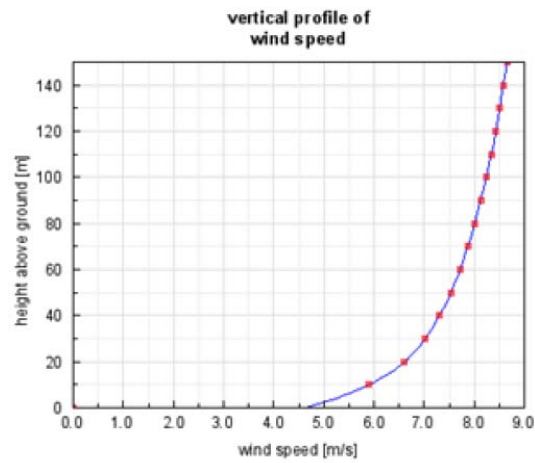
Wind turbine selection was done using web based software in the “The Swiss Wind Power Data Website”. The web site is mandated by the Federal Department of the Environment, Transport, Energy and Communications, Swiss Federal Office of Energy (SFOE), Switzerland. This software consists of calculators to obtain the wind profile, weibull distribution, air density and wind power for turbines. The wind profile calculator enables an estimate for the vertical wind speed profile, i.e. the increase of wind speed with height above ground. On the ground, the wind is strongly affected by obstacles and surface roughness. High above the ground in the undisturbed air layers of the geotropic wind (at approx. 5 km above ground) the wind is no longer influenced by the surface. Between these two extremes, wind speed changes with height. This phenomenon is called vertical wind shear.

$$v_2 = v_1 \frac{\ln\left(\frac{h_2}{z_0}\right)}{\ln\left(\frac{h_1}{z_0}\right)}$$

The reference wind speed v_1 is measured at height h_1 . v_2 is the wind speed at height h_2 . z_0 is the roughness length. The suitable roughness length for the Ambewela site is 0.03 which describe the land type of ‘open agricultural land without fences and hedges; may be some far apart buildings and very gentle hills’. When the height above ground, wind speed and roughness length are defined, the software calculates the wind speed at different elevations. The re-

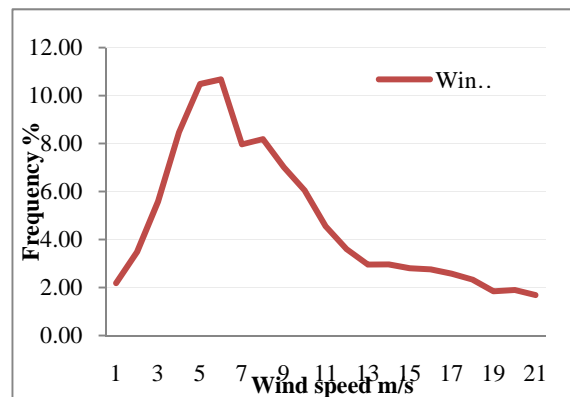
sult obtained for the Ambewela site is given in Figure 2.

Figure 2 - Vertical Profile of Wind Speed in Obtained from Web Based Software [19]



This web based tool can be used to approximate a wind speed distribution with a Weibull function. The obtained Weibull parameters may subsequently be used in the power calculator to estimate the power production of a wind turbine. The Figure 3 shows the Weibull wind speed distribution for the Ambewala site.

Figure 3 - Measured Wind Speed Distribution Data for Whole Year



Air density decreases with increasing altitude and thus the production of a wind turbine decreases. Air density can be calculated either from the altitude or from measurements of temperature and air pressure. In this paper, air density was obtained using the measured values and air density is 0.999 kg/m³.

With the power calculator in this web based software, it was possible to estimate the power output for a site for different turbine types.

A turbine availability of 100% was assumed (no losses due to down time, transformer losses, park effects, etc.). For the power calculator, either we can estimate the Weibull distribution for the site with Weibull calculator or the power calculator approximates a distribution for the mean wind speed that is entered. In this paper, the following parameters of the Weibull distribution were used for power calculations. Weibull scale factor $A=7.87$ and Weibull shape factor $(k) = 1.48$ (Figure 7). The power calculator in "The Swiss Wind Power Data Website" has data for more than 45 wind turbines. So using the web based software, it was possible to calculate annual energy output, plant factor and hours at full capacity. Further it produces the power distribution curve of each wind turbine when it is subjected to the site parameters (Figure 8).

The following Table 3 shows the selected best wind turbines from the 45 different wind turbines.

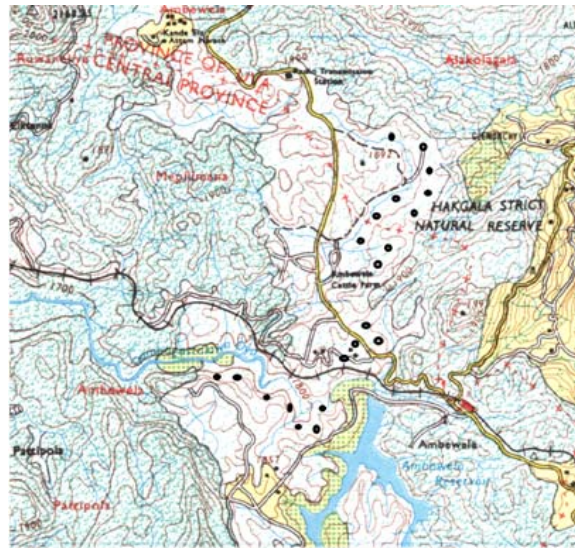
Table 3 - Summary of the Best Wind Turbines

Model	Capa. (kW)	Power Prod. (kWh/y)	Capa. Factor	Hours at Full Load Per Year	Energy Output kWh/kW
Leit-wind LTW77	1000	3,109,414	35.5	3107	3109
VestasV100	1800	5,306,819	33.6	2946	2948
Gamesa G97	2000	5,707,164	32.6	2852	2854
VestasV90	1800	5,001,970	31.7	2777	2779
VestasV112	3000	8,190,553	31.1	2728	2730

According to the Table 3, Gamesa G97 can be selected for the 2MW turbine and Leitwind LTW77 can be selected for the 1MW turbine. [20,21].

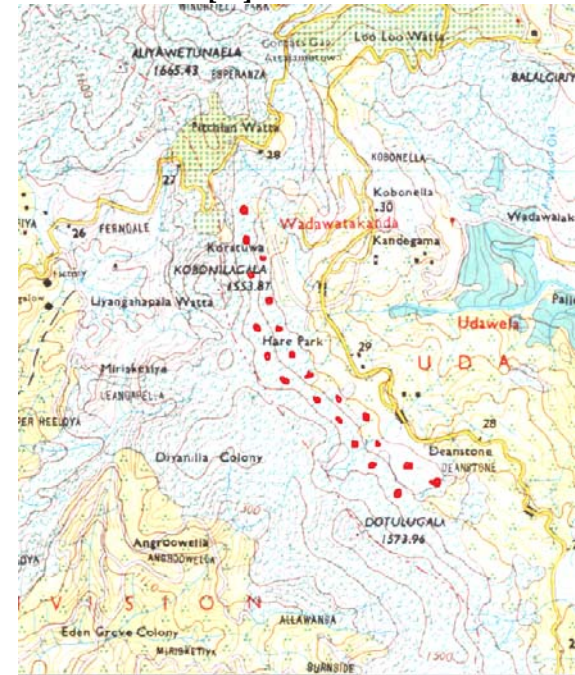
Considering the possible transmission network constraints and site constraints, only 21 MW of wind capacity was considered for each site at Ambewela, Hare Park, Rantinda, and 4 MW for the Naula site. Then the considered total wind capacity will be 67MW. The Figure 4~6 shows the geographical positioning of the Wind plants.

Figure 4 - Map of Ambewela and its Wind Plant Locations [22]



*The black colour dots show the locations for proposed 11 wind power plants.

Figure 5 - Map of Hare Park and its Wind Plant Locations [22]



*The red colour dots show the possible locations for wind power plants.

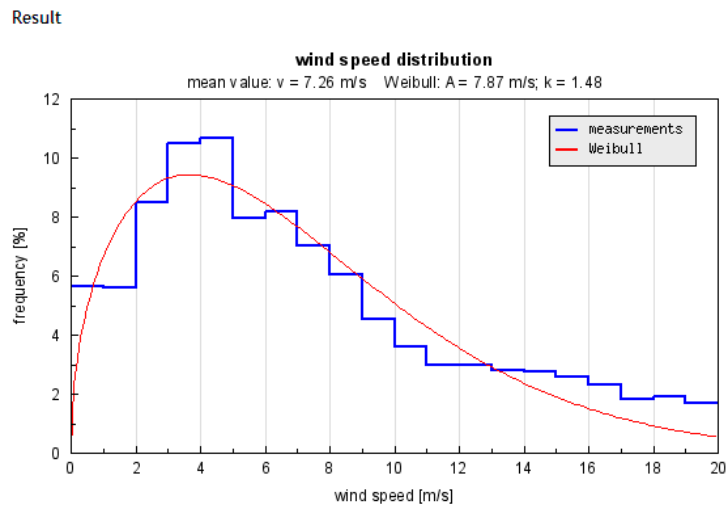
Figure 6 - Map of Rantninda and its Wind Plant Locations [22]



*The red colour dots show the possible locations for wind power plants

Figure 7 - Weibull Wind Speed Distribution Data for the whole Year [19]

Class	Frequency in %
0 - 1 m/s	5.66
1 - 2 m/s	5.58
2 - 3 m/s	8.48
3 - 4 m/s	10.48
4 - 5 m/s	10.67
5 - 6 m/s	7.97
6 - 7 m/s	8.18
7 - 8 m/s	7.01
8 - 9 m/s	6.03
9 - 10 m/s	4.54
10 - 11 m/s	3.59
11 - 12 m/s	2.96
12 - 13 m/s	2.96
13 - 14 m/s	2.80
14 - 15 m/s	2.76
15 - 16 m/s	2.57
16 - 17 m/s	2.33
17 - 18 m/s	1.84
18 - 19 m/s	1.90
19 - 20 m/s	1.68
Sum	99.99



The measured data and Weibull distribution matches with Weibull shape factor $k \sim 1.48$.

Figure 8 - Result from Power Calculator with Turbine Dewind D8/80-2MW at Ambewela Site [19]

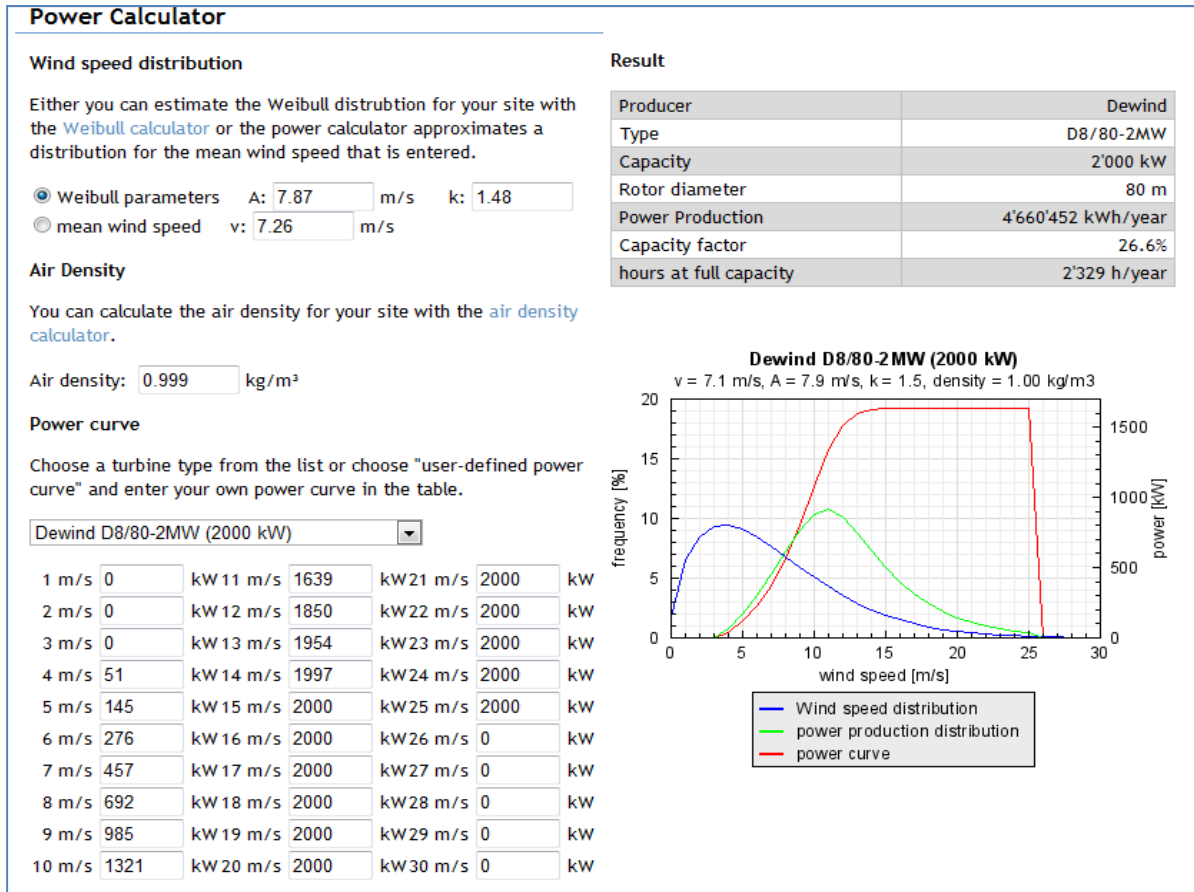
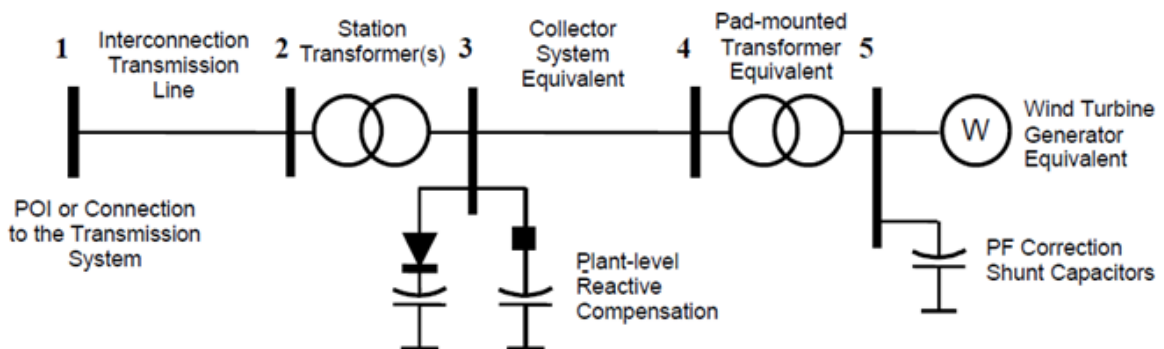


Figure 9 - Single Turbine Representation for a WPP (Muljadi, April, 2010) [9, 15, 16, 18]



Possible Interconnection Points in Central Province - Grid Substations

Kiribathkubura, Ukuwela, NuwaraEliya, Wimalasurendra, Pallekele, Naula and Badulla grid substations (GSs) are possible interconnecting points for wind power plants. The most suitable GS for interconnection was selected considering the distance to the GS from each wind plant site. The GS was selected to reduce the length of the interconnection line. Since Sri Lanka is a small, populated country, getting the right of way for new medium voltage transmission lines is more difficult than increasing the capacity of an existing GS. Further, construction of new medium voltage transmission lines and new GS is more expensive than the first option. So the closest GSs to the wind sites were selected. The Ambewela wind plant is proposed to be connected to the Nuwareliya GS, the Hare Park wind plant is proposed to connect to Badulla GS, the Ratninda wind plant is proposed to connect to Ukuwela GS, and the Naula wind plant is proposed to connect to Naula GS.

System Studies for Interconnection

The wind power plants modeled into the Sri Lankan power system using PSS/E software. The Figure 9 shows the single turbine representations for wind power plants.

PSS/E Load Flow Setup

A wind turbine generator in load flow is treated as a conventional machine and specified on the existing generator record of the Power Flow Raw Data File. At the end of this data record there are two additional data for wind control mode and power factor. During the study the wind turbine was operated in fixed power factor mode with a power factor range in the interval from 0.98 capacitive to 0.96 inductive and was measured on the 690 V generator side and with 100% of rated active power.

Transmission Planning Criteria

Transmission planning criteria in Sri Lanka has been developed to ensure the quality and reliability of the power supply. Under voltage criteria, it defines the allowable voltage variation at any bus bar at every time. In the 220kV system, it is +5% under normal operation and -

10% +5% under single contingency condition. In the 132kV system, it is +10% under normal operation and single contingency condition.

Under thermal criteria, the loading of any transmission equipment should not exceed their rated thermal loading values for steady state conditions. And for single contingency conditions it should not exceed 120% of their rated thermal loading values.

Under security criteria, it discuss the N-1 contingency situation i.e. outage of any one equipment of the transmission system at a time. So system should maintain its voltage & thermal criteria under single contingency too.

The stability criteria ensure the system stability during & after system disturbance such as three-phase fault, loss of generation, load rejection etc.,. Three phase short circuit criteria ensures the protection of transmission equipment against short circuit fault currents.

The generator dispatching criteria allows generation schedule for transmission planning process in merit order and should not require regular operation of out-of-merit generation to prevent an unacceptable voltage profile or loading condition in the event of an outage of any transmission circuit. So all the system studies were conducted satisfying the above described transmission planning criteria [7].

Transmission System Studies

In the typical daily load curve of Sri Lanka, the night peak occurs around at 19.30. The day-peak occurs around at 11.00 and the low load condition occurs around at 03.00. The power flow and single contingency analysis were done for all three load scenarios. In general, detailed system studies were performed under hydro maximum and thermal maximum generation dispatch scenarios. The day-time or night-time operation of Sri Lankan power system can be categorized by its main power supply. For example if a higher percentage of day peak demand is supplied by thermal sources, it is called TMDP. If a higher percentage of day peak demand is supplied by hydropower sources, it is called HMDP. However for this study, only thermal maximum generation dispatch scenario

was considered. It is because the ultimate objective of this study is to explore opportunities in replacing the thermal generation with wind power generation.

System studies were conducted covering the total behavior of the load curve during the night peak time, day peak time and low load condition. Accordingly, six scenarios were considered for studies namely, Thermal Maximum Night peak (TMNP), Thermal Maximum Day peak (TMDP), Thermal Maximum Low Load condition (TMLL), all with and without the proposed wind power plant (WPP) connection.

Simulation results were analyzed according to the Ceylon Electricity Board's Transmission Planning Criteria. Table 4 describes the results of power flow and single contingency analysis.

There were no thermal or voltage violations observed under normal operation in the TMNP without WPP case. Then, each WPP was considered to be separately connected to the system one at a time and the power flow studies were re-run. There were no violations observed. In single contingency analysis, two scenarios were considered. The first scenario was year 2015 TMNP case without wind and the second scenario was the year 2015 TMNP case with 67 MW of wind. In the first scenario, there were no thermal violations but there were voltage violations on most of the southern and eastern area bus bars. In the second scenario, there were no thermal violations but still there were voltage violations. However, the voltage profile has improved due to WPP connections.

In TMDP without WPP case, Kotugoda GS transformer was overloaded to 121% and there were no voltage violations observed in normal operation. In single contingency analysis in the same case, there were a few thermal violations but no voltage violations were observed. In TMDP, with 67 MW WPP, there were no violations observed in normal operation. However, there were a few thermal violations observed in the single contingency study. The magnitude of overloading is higher in TMDP with 67 MW WPP case. In the TMLL case, there were no violations observed in both normal and single contingency analysis.

The maximum three phase short circuit current was calculated using PSS/E software for each bus bar in the power system for year 2015. The calculated future maximum three phase short circuit current with WPP for each bus bar does not exceed the existing or proposed switchgear capacity. Table 5 shows the maximum three phase short circuit current for WPP connected bus bars.

The Figure 10 shows PV curves on a few bus bars when opening the Kotmale-Kiridiwela 220 kV line. The curves show the voltage profiles of each bus bar when 2000 MW power is transferred from the 220 kV systems to the rest of the system. For safe operation, the voltage should be in the vicinity of 95% of the nominal voltage [14]. However, most lines exceed that limit during very lower power transfer levels can be seen. The bottom of the QV curves, in addition to identifying the stability limit, defines the minimum reactive power requirement for stable operation. Hence, the QV curve can be used to examine the type and size of compensation needed to provide voltage stability.

*There were voltage violations on most southern and eastern area bus bars. Although there were voltage violations, the case with wind power plants has an improved voltage profile compared with the case without wind power plants.

**When Polpitiya~Sithawaka one 132kV line was out, thermal violations can be observed in the remaining line. Further when Chilaw~Madampe one 132kV line was out, thermal violations can be observed in the remaining line. The magnitude of overloading was higher in TMDP with 67 MW WPP case.

Table 4 - Summary of the Power Flow Results

Case	Normal Operation		Single Contingency	
	Thermal Violations	Voltage Viola.	Thermal Violations	Voltage Violations
TMNP without WPP	No	No	No	*
TMNP with 21MW WPP @ N'Eliya GSS	No	No		
TMNP with 21MW WPP @ Badulla GSS	No	No		
TMNP with 21MW WPP @ Ukuwela GSS	No	No		
TMNP with 4MW WPP @ Naula GSS	No	No		
TMNP with 67MW WPP	No	No	No	*
TMDP without WPP	Ko-tugoda -New transformer overloads by 121%	No	**	No
TMDP with 67MW WPP	No	No	**	No
TMLL without WPP	No	No	No	No
TMLL with 67MW WPP	No	No	No	No

The normal transient system stability analysis was carried out under the specific pre-identified transient system disturbances and two switching sequences as given below [7].

Successful Re-closing:

t=0 Fault occurs
t=120ms, fault cleared & circuit tripped
t=620ms, circuit re-closed

Unsuccessful Re-closing:

t=0 Fault occurs
t=120ms, circuit tripped
t=620ms, circuit re-closed with fault
t=740ms circuit tripped

Table 5 - Maximum Three Phase Short Circuit Currents

Grid Substation/ Power Station	Voltage (kV)	Maximum Three Phase Short Circuit Current (kA)
Wind-Badulla	0.690	20.8
	33	12.5
Wind-Naula	0.690	21.6
	33	4.5
Wind-Nuwareliya	0.690	20.7
	33	12.2
Wind-Ukuwela	0.690	20.0
	33	10.2
	33	12.2
Wind-Ukuwela	0.690	20.0
	33	10.2

The WT3 PSS^{TME} wind turbine stability model was developed to simulate performance of a wind turbine employing a doubly fed induction generator (DFIG) with active control by a power converter connected to the rotor terminals. This wind turbine is referred to as Type 3 in the classification of the Western Electricity Coordinating Council Wind Generator Modeling Group (WECC WGMG).

Figures 11 to 15 show that WPPs are not stable with system disturbances due its inherent features. If the wind power generation contributes a higher percentage of the country's installed generation capacity, it will adversely affect the overall system stability and reliability. If the system has PSPPs installed, then through a control mechanism, PSPPs can connect to the system in a sever disturbance. That will prevent blackouts and improve system stability and reliability.

Figure 10 - PV Curves on Kilinochchi, Chunnakam, Polonnaruwa & Naula 132kV Bus Bar (BB) and 0.575kV wind connected BB when the Kotmale-Kiridiwela 220kV line is open

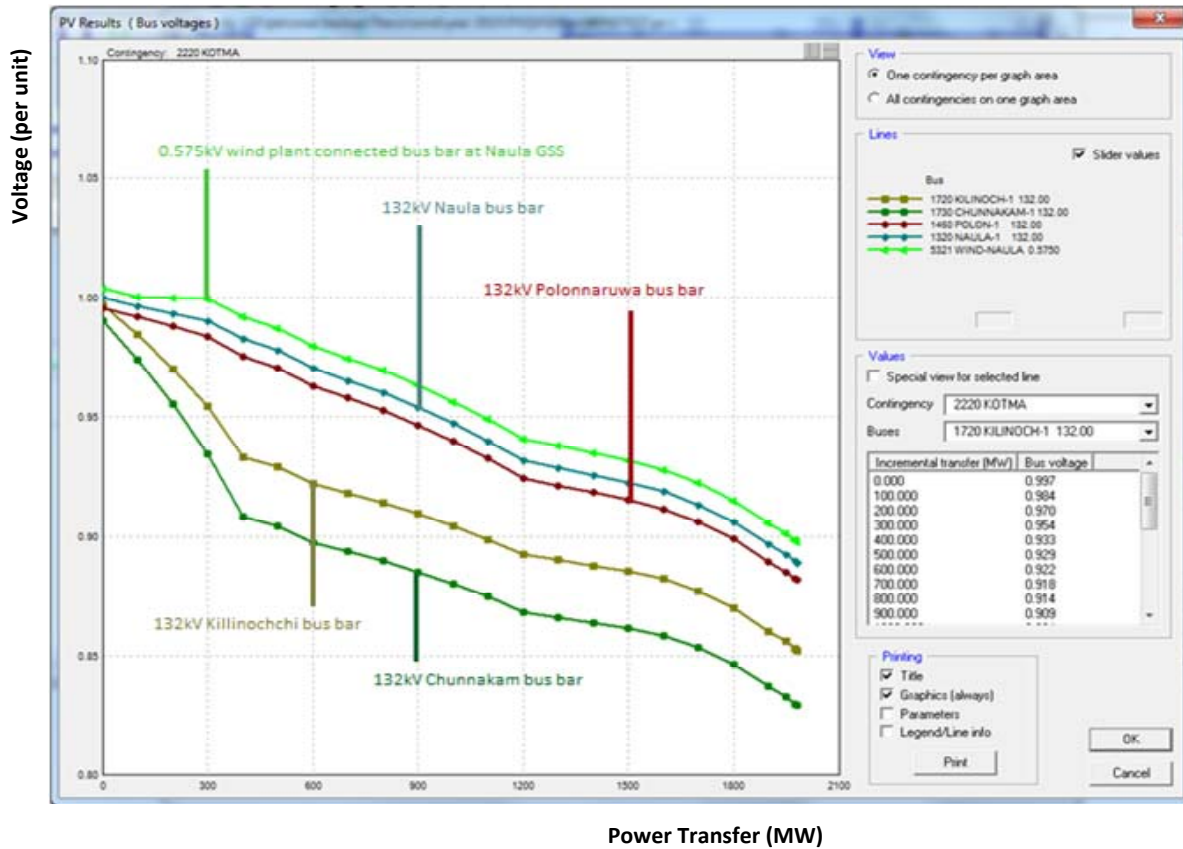


Figure 11 - Power Flow Variation of 220kV Kelanitissa BB, 132kV Polpitiya BB, 132kV KHD BB, 132kV Kukule BB and 0.575kV Wind PT BB when one Trincomalee Coal Power Plant Trips

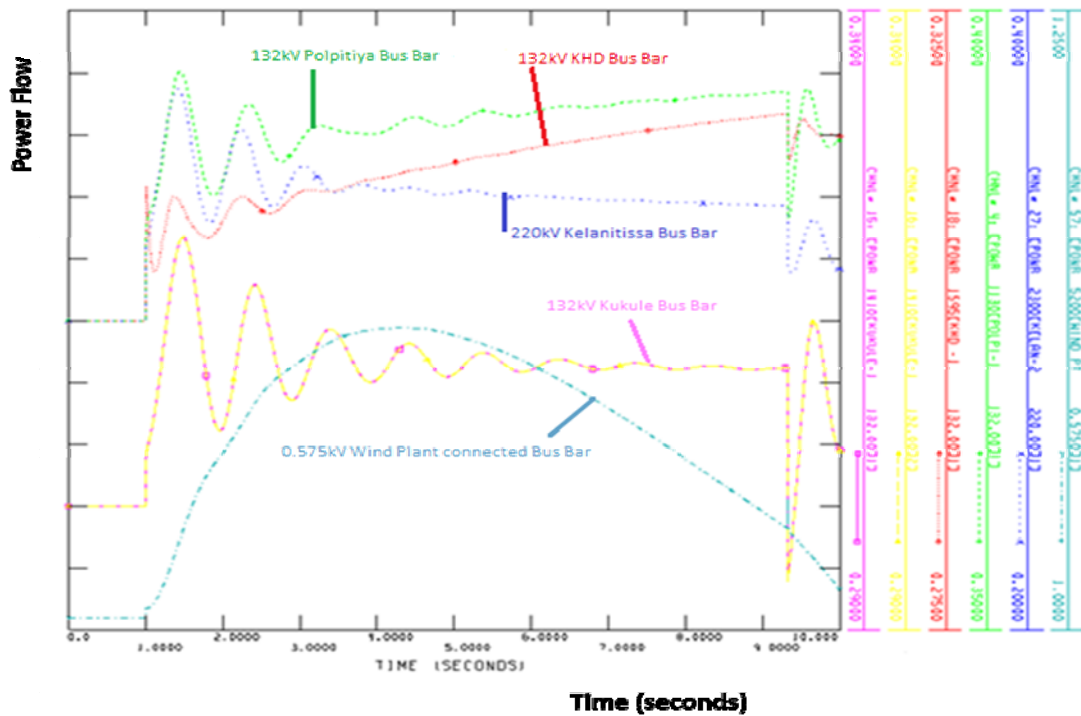


Figure 12 - Voltage Variation of 132kV Chunnakum BB, 132kV Kilinochchi BB, 132kV Galle BB, 132kV Ampara BB, 132kV New Laxapana BB and 33kV Wind Collector when one Trincomalee Coal Power Plant Trips

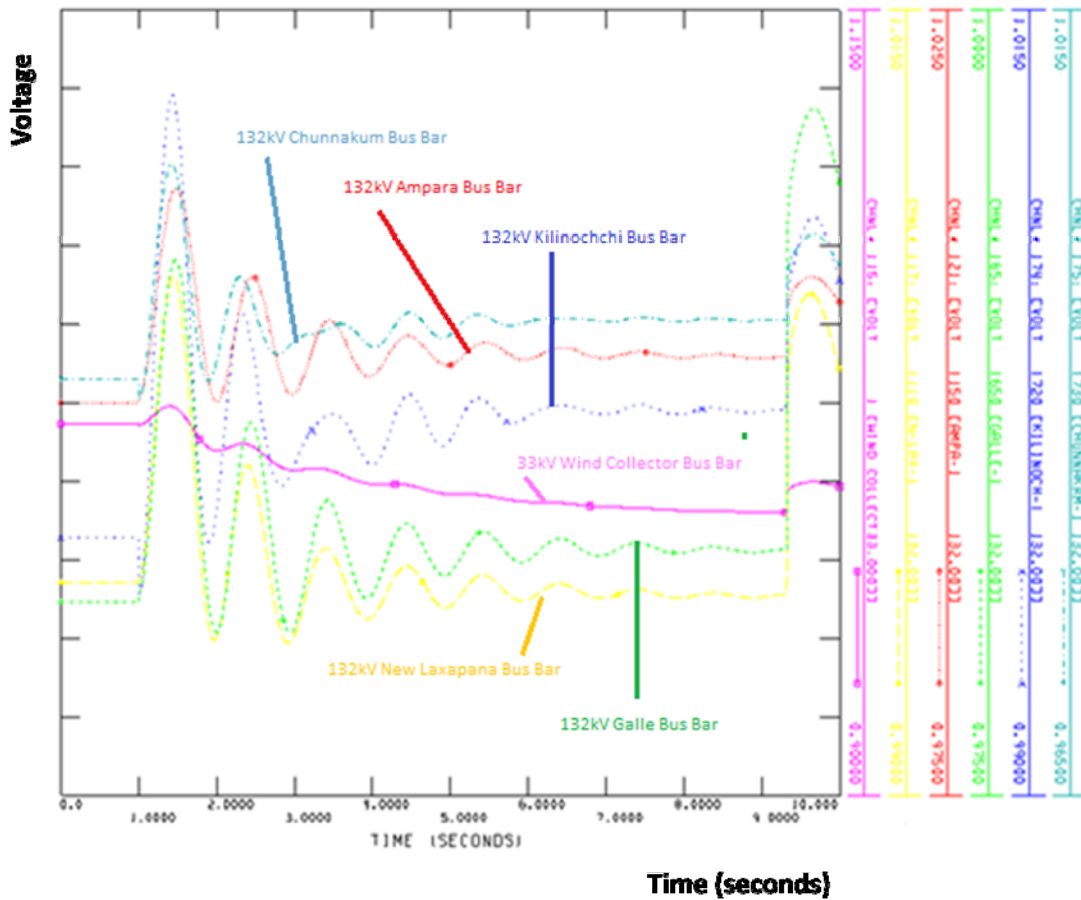


Figure 13 - Angle Variation of 132kV Kurunagala, 132kV Samanalawewa , 0.575kV Wind PT , 132kV KHD, 132kV Kukule and 132kV Laxapana when one Trincomalee Coal Power Plant trips

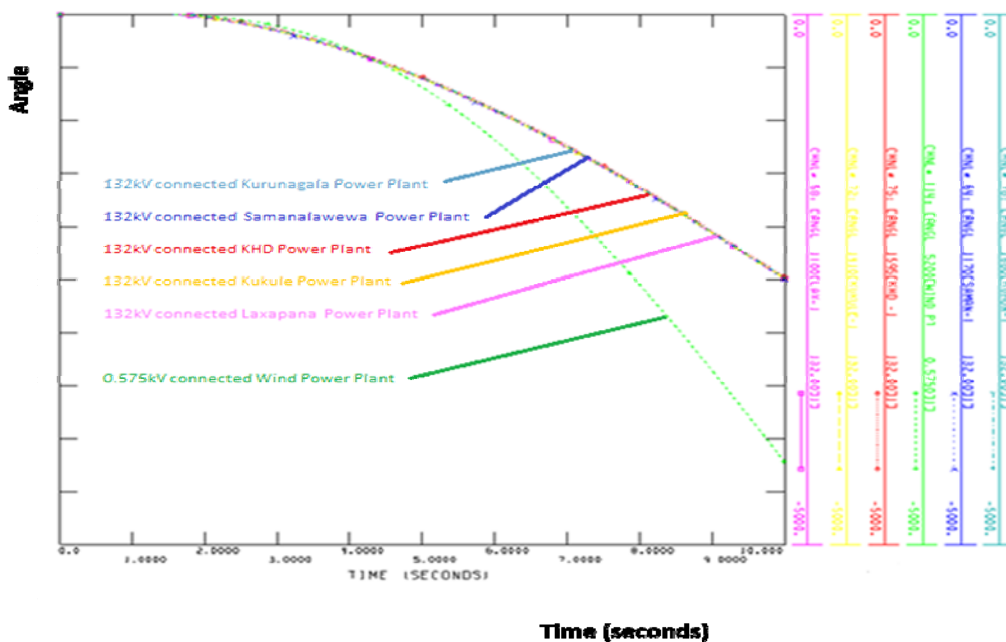


Figure 14 - Angle Variation when there is a Three Phase Short Circuit Fault on one of the 220kV Overhead Lines between Kotmale -Victoria. Successful re-closing is Assumed. Angle Variation of **Kerawalapitiya Power Plant (PP)**, **Kotmale PP** and **wind PP** with respect to the Victoria PP are observed

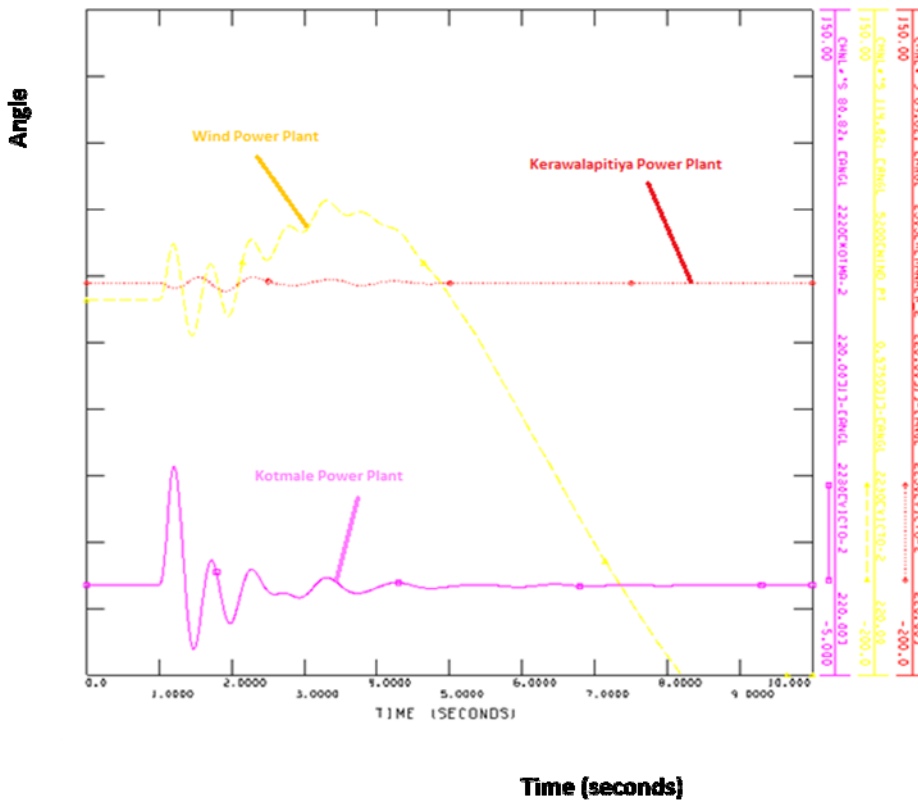
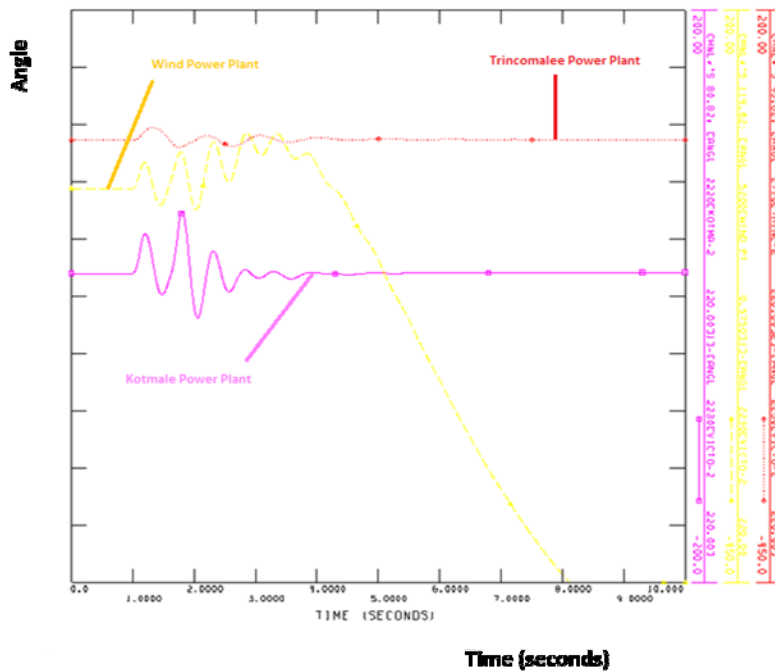


Figure 15: Angle Variation when there is a three Phase Short Circuit Fault on One of the 220kV Overhead Line between Kotmale - Victoria. Unsuccessful re-closing is Assumed. Angle Variation of **Trincomalee Power Plant (PP)**, **Kotmale PP** and **wind PP** with Respect to the Victoria PP are observed.



Results and Conclusions

Gamesa G97, 2MW and Leitwind LTW77, 1 MW are the best wind turbines for the Central Province. Ambewela, Ratninda, Hare Park and Naula sites were selected to consider wind plant developments. Further 21 MW of WPP are proposed for Ambewela, Ratninda & Hare Park and a 4 MW WPP for Naula. Grid inter-connection points for the WPP were selected as Nuwaraeliya GS, Ukuwela GS, Badulla GS and Naula GS, respectively, for the selected sites. In conclusion, the proposed system improvement was divided into two categories. They are minor system improvements to solve the readily visible system problems and major system improvements to solve the hidden problems in the real power system, the power system modeling and transmission planning criteria.

Minor system improvements were introduced to the year 2015 system and verified for their improved results. The proposed minor system improvements are adding static var compensators in a few places, changing line arrangements, upgrades to existing lines and increasing the reverse margin to cater to system transients. They are described as follows.

- Install the Static Var Compensators (SVC) in Ampara and Baddegama 132kV bus bars to improve the undervoltage situation in the areas around those bus bars.
Ampara SVC (+50MVar/-10 MVar)
Baddegama SVC (+100MVar/-20 MVar)
- Change the present line arrangement of Athurugiriya-Kosgama, Athurugiriya- Seethawaka, Seethawaka-Polpitiya and Polpitiya-Kosgama 132kV transmission lines to double circuit of Athurugiriya-Kosgama and double circuit of Polpitiya-Seethawaka
- New Chilaw~Madampe 132 kV line is a 17 km long Lynx line which has been designed to operate at 55°C. So the tower sizes are small. The New Chilaw~Madampe 132 kV line overloading can be solved by upgrading the line to Lynx, with 75°C operating temperature.
- Provide voltage support to radial long transmission line ends such as Killinochi, Chunnakum, Puttalam, Naula and Polonnaruwa. All these lines are lightly loaded, too. By analysing the load forecast for each GS, and the PV and

QV diagrams, the capacity of reactive power support equipment at each location were decided.

Chinnakum SVC (+20MVar/-4 MVar)
Killinochi SVC (+10MVar/-2 MVar)
Puttalam SVC (+25MVar/-5 MVar)
Polonnaruwa SVC (+10MVar/-2 MVar)
Naula SVC (+10MVar/-2 MVar)

All the above SVCs should operate to control the voltage at each bus bar.

- To absorb more wind power into the power system, it is necessary to increase the reserve margin of the power system.

The suggested major system improvements in the future for more and improved wind integration with system stability are as follows;

- The power system modeling has to be redone using proper models to reflect the actual case including loads, generators, transmission lines, transformers, switched shunts, etc.
- A comprehensive voltage stability study has to be conducted to identify the voltage problems in the power system and mitigation methods.
- Implement under voltage load shedding scheme.
- The transmission expansion planning process should be in two stages as;
 1. Bottom to Top
 2. Top to Bottom

That means if we prepare 10 year horizon transmission plan; the planning process should start from present year and proceed to 10th future year to identify the systems minimum requirements to satisfy the transmission planning criteria. Then considering the all the comprehensive studies such as

1. Rotor Angle Stability Study
2. Frequency Stability Study
3. Voltage Stability Study

The 10th future year power system should strengthen to cater the any type of disturbance

in the power system. The result of this type of process can be major differences in the power system, such as

1. Introducing new high voltage level to the system. For example 400kV backbone system or major improvements in existing backbone system (220kV) to increase power transfer capability & voltage stability.
2. Introducing new reactive power sources into the system
3. New generators in different locations or changing the planned future generation sites to a newer locations
4. Introducing Group of generators to frequency controlling rather than one generator to do the work.
5. Introducing new generation options to the power system such as Pumped Storage Power Plants. The Pumped Storage Power Plants will allow absorbing more wind power into the system. The pre feasibility level study has done for the Pumped Storage Power Plants for Sri Lanka. [1, 2, 3, 8, 11, 12, 13]
6. To absorb more wind power into the power system, it is necessary to increase the reserve margin of the power system or introduce bulk energy storage such as Pumped Storage Power Plant. [1, 2, 3, 8, 11, 12, 13]

References

- [1] E M T G Jayathilake, and M.T.A.P. Wickramarathna, *Predicting the Possible Capacity of Pumped Storage Power Plant for Sri Lanka by Forecasting Load Curve Shape*, SLEMA Journal Volume 14 No.2 September 2011.
- [2] M T A P Wickramarathna, *Planning of Pumped Storage Power Plants for Power Generation in Sri Lanka*, SLEMA Journal Volume 14 No.2 September 2011.
- [3] M T A P Wickramarathna, *Reconnaissance study of pumped storage power plants for peaking power generation in Sri Lanka*, Conference HYDRO 2011, 'Practical Solutions for a Sustainable Future', Prague, Czech Republic.
- [4] Ministry of Power & Energy, Government of Sri Lanka, *National Energy Policy and strategies of Sri Lanka*.
- [5] K S Fernando (RMA Pvt. Ltd), P L G Kariyawasam (CEB), A M A Alwis (CEB), *Wind Energy Resource Assessment Puttalam and Central Regions of Sri Lanka*.
- [6] D Elliott, M. Schwartz, G Scott, S Haymes, D Heimiller, R. George, *National Renewable Energy Laboratory, USA, Wind Energy Resource Atlas of Sri Lanka and the Maldives*.
- [7] *Long Term Transmission Development Plan 2008-2016 Prepared by Ceylon Electricity Board*.
- [8] E M T G Jayathilake, M T A P Wickramarathna, *Study on Pumped Storage Power Plants and Optimization for Peaking Power Generation in Sri Lanka, Volume I, Forecasting Load Curve Shape & Predicting the Possible Capacity of Pumped Storage Power Plant, April 2009*.
- [9] Muljadi, E., *WECC Wind Generator Development. National Renewable Energy Laboratory (April, 2010)*.
- [10] PSS^{TME} 31.0, *Online Documentation*. (2007, December).
- [11] M T A P Wickramarathna, *Study on Pumped Storage Power Plants and Optimization for Peaking Power Generation in Sri Lanka, Volume II, Site Selection and Basic Design Configurations, June 2009*.
- [12] M T A P Wickramarathna, *Study on Pumped Storage Power Plants and Optimization for Peaking Power Generation in Sri Lanka, Volume III, Economic Evaluation for Selected Pumped Storage Power Plants, July 2009*.
- [13] M T A P Wickramarathna, *Study on Pumped Storage Power Plants and Optimization for Peaking Power Generation in Sri Lanka, Volume IV, Interconnection of Kiriketi Pumped Storage Power Plant, October 2009*.
- [14] M. Behnke BEW Engineering, A. Ellis Public Service Company of New Mexico, Y. Kazachkov Siemens PTI, T. McCoy Global Energy Concepts, E. Muljadi National Renewable Energy Laboratory, W. Price and J. Sanchez-Gasca GE Energy, *Development and Validation of WECC Variable Speed Wind Turbine Dynamic Models for Grid Integration Studies*.
- [15] WECC Wind Generator Development, Eduard Muljadi, National Renewable Energy Laboratory.
- [16] Eduard Muljadi National Renewable Energy Laboratory Abraham Ellis Public Service Company of New Mexico, *Validation of Wind Power Plant Dynamic Models, Preprint*.
- [17] Nicholas W. Miller William W. Price Juan J. Sanchez-Gasca *Dynamic Modeling of GE 1.5 and 3.6 Wind Turbine-Generators Prepared October 27, 2003 Version 3.0*.

- [18] *Dynamic Modeling Guide DRAFT Prepared by WECC Renewable Energy Modeling Task Force November 2010.*
- [19] *"The Swiss Wind Power Data Website". The web site is mandate by Federal Department of the Environment, Transport, Energy and Communications, Swiss Federal Office of Energy (SFOE), Switzerland.*
- [20] *New Gamesa G9X-2.0 MW, Husum, September 23, 2010.*
- [21] *LEIT Wind, Technical Data LTW77.*
- [22] *1:50, 000 map published by Sri Lanka Survey Department.*

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