Voltage fluctuation issue for grid connected hybrid wind and solar energy sources: A case study on integrating Poonakary (Pooneryn) Wind Solar Hybrid Energy Park

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Abstract: This research investigates the issue of voltage fluctuations arising from the integration of a massive hybrid wind and solar energy park into Sri Lanka's electricity grid. It primarily concentrates on the Poonakary (Pooneryn) Wind Solar Hybrid Energy Park, connected to the Kilinochchi grid by a 35 km long 132 kV transmission line. The purpose of this study is to understand what happens as far as voltage stability when connecting a large hybrid wind-solar system into a power grid in Sri Lanka. The research will employ extensive simulation work under different network conditions to evaluate how voltage has been fluctuating and its conformity to grid code specifications. This study helps in optimizing energy park design and operation, as well as transmission infrastructure while ensuring reliability of the grid and preventing economic losses associated with it by identifying likely disturbances in voltage levels. The study will conclude with recommendations aimed at addressing voltage fluctuations in subsequent renewable energy integration projects in Sri Lanka.

Keywords: - Voltage fluctuation, Grid stability, Hybrid wind and solar energy, Poonakary, Pooneryn, Kilinochchi, Sri Lanka, power quality.

Introduction

The demand for energy has increased globally and to ensure that this demand is met sustainably renewable sources of energy is Essential. Following this global trend, Sri Lanka has also planned for a strategic plan to improve the stability of the grid by integrating the renewable resources for generation and increasing the strength of the infrastructure to absorb renewable energy capacity. Poonakary Wind Solar Hybrid Energy Park that form the core of this initiative is expected to play a huge role in the power mix of the country. Nevertheless, the growing- fast and massive adoption of distributed renewable energy systems such as wind and solar energy has problems including voltage fluctuations that affect the stability of power system.

The Poonakary Wind Solar Hybrid Energy Park is a mega-scale project divided into two phases being located in the northern most part of Sri Lanka. The first eliminated tackles wind power generation while the second further case which is still under construction deals with solar power generation with an overall target capacity of 400MW. Because of this ambitious plan of generating a good portion of electricity from renewable energy sources, a 35 km, 132 kV transmission line is currently being developed to link the energy park to the Kilinochchi grid substation.

Though a feasibility study has been conducted in relation to the project, a detailed study on voltage fluctuations as a result of the connection of the Poonakary energy park to the Kilinochchi grid has not been made. This research intends to addresses this gap through the simulation and analysis of the voltage fluctuation under different grid conditions.

Literature Review

Since 1990 the functioning of the Jaffna peninsula is in an isolated manner within the previously existing power system of Sri Lanka. Firstly, a 132KV transmission line of double circuit with distance of approximately 10.5 km will be laid.

Connected to the national grid through Jaffna Peninsula whose main transmission line is coming up from Anuradhapura to Chunnakam. At that time, only Chunnakam grid benefited from 15 MW diesel power plant. Nevertheless, the development here was slowed due to the influence of the civil war, which caused some faults in both the Killinochchi grid as well as the Chunnakam transmission line. As a result, the Jaffna Medium Voltage network became isolated from the rest [1]. However, the proceeding uses of islanded operation, although solving the certain challenges that come with its implementation have also brought about its own problems in a developing country such as Sri Lanka. It is for this reason that a number of power networks have had their sizes reduced through this approach complications. For instance, problems like high generation costs, and environment unfriendly gases have deservedly earned the comedian due to the excessive dependency new [2] issues have arisen such as emissions, and machine replacement costs on thermal generation methods [3].

These challenges were noted, and thus Ceylon Electricity Board (CEB) attempted to open the link and bring the peninsula of Jaffna back into the Sri Lankan transmission system. This planning decision is a significant attempt to improve the system's overall availability and efficiency of power outputs. It must be noted that constant confrontation with competitors triggers adverse outcomes that are characteristic of isolated operation, thereby minimizing the negative effects that arise in this regard [1].

This interconnection is intended to consolidate the existing joint that has been established in the interconnection of the systems as well as pass through power to the north. In order to optimize the several factors like power reliability and quality have to be maintained. This aspect has to be resolved during planning phase in order to get proper connectivity. According to this interconnection, the load center (Northern Sri Lanka) is shifted far away from the generation (Central Sri Lanka) [1]. As a result, following the connection, the use of lengthy AC transmission lines (approximately 224 km long) may pose several technical issues in terms of system reliability, stability, and power quality. To meet these issues, reactive power compensation is considered as a viable alternative.

The identified Kilinochchi node is situated closer to the northern part of Sri Lanka, whereas the majority of electricity demand in Sri Lanka and power generation locates closer to the central area of the country. This implies that the amount of renewable energy electricity that may be embedded to the area presently served by the existing 132kV network may be restricted. Headed by the 132kV line from Vavuniya in the South and from the Chunnakam Grid substation in Jaffna in the North. In its way, many 33kV feeder, distributes the electricity within the region with generously holding Kilinochchi Substation [4]. At the Kilinochchi substation there is no more space for a new entry bay available. Thus, opening the existing 132 kV overhead line, at appropriate places, for new renews' generation to be linked up of the western Pooneryn area, the connecting solution to the new substation therefore will be a new switching substation.

Thus, any addition that is established in the Kilinochchi region relative to the generation of power would have the investment expenditures include those to be done at 132kV and above. The SC power at the present moment ranges within 563-519 MVA in this voltage level. The long-term investment plan of CEB has been effectively implemented to cover all the areas of investments. Contains the increase of the length of the 220kV network especially stretching up from Vavuniya substation to another newly established N-Collector substation on the outskirts of the city toward the north Kilinochchi. Out of developing this new substation, the strength of the grid will be greatly improved. Also improved and guaranteeing a more reliable 132 kV system [5]. The existence of wind power generation as a component of the power supply system presents some technical disturbances that can affect the power quality. Some of the challenges include voltage flicker, voltage fluctuation (over and under voltage), voltage swell and voltage surge. Rhythmic change, musing, abrupt change of voltage, exchanging and varying of both active and reactive types of power [6]. Addressing out of these critical factors is crucial in order to achieve the harmonization of wind power and achieve the stability and reliability of the whole electrical system maintaining for a long time [7]. By carefully bearing all these factors in mind and counteracting them, it is possible to create a more effective and long-term clean energy transition while maintaining the reliability of the power grid as well as the power quality standards. Variable wind speed produce in fluctuating power output from wind turbines, which is leading to voltage fluctuations at the common coupling point [8]. These voltage fluctuations can give rise to flicker in the electrical system. Typically, flicker comprises periodic voltage fluctuations with frequencies of less than about 30-35 Hz and is characterized by its small amplitude [9].

What we are hoping to study is the voltage fluctuation problem that occurs at the grid connection point when wind solar hybrid system connected to a grid substation [10]. For that, we should have knowledge about the transmission system of Sri Lanka, grid code, and permitted voltages in the three important stages of power system, namely the generation stage, the transmission stage and the distribution stage [5].

Table 1: Allowable voltages related to common couplings

Common coupling between	Allowable voltage regulation (%)
Generation to Transmission	+/- 6
Transmission and Distribution	+/- 10
Distribution to End Consumers	+/- 2

Methodology

In our research endeavor, being research and analytical approach, the systematic method of research was adopted when considering the voltage fluctuation problems that are bound to happen when integrating the Poonakary Wind Solar Hybrid Energy Park with the Kilinochchi grid. Thus, data collection and analysis coupled with modeling and simulation were employed as the research method of the current work.

Firstly, a literature review of the voltage issues such as voltage dips, voltage swell, voltage flicker and voltage harmonics in the Poonaryn location, the effects that the problems may have on the people and environment surrounding the area were done. At the same time, the structure of the power grid has been examined in detail to diagnose the possible presence of the influence of renewable energy sources in the power grid. Accurate data which refers to the coordination between Poonaryn wind solar hybrid energy park and the Kilinochchi grid substation was successfully collected with an adequate planning for modeling and simulation.

Therefore, a system diagram that depicted all the components coupled with the parameter of the power system in this particular instance was created applying the EMTDC/PSCAD simulation software. More dynamic analyses were then performed on varying operating scenarios for the purpose of understanding voltage fluctuations. The collected data was processed using EMTDC/PSCAD and MATLAB to obtain the behaviors, tendencies and the intensity of the voltage fluctuations in the electrical circuit. For this purpose, it was quite advantageous, especially because of the updated capabilities of MATLAB in data analyses and graphics.

To enhance objectiveness and reliability of the results further constant modification of the simulation model was done through the addition of new factors and tuning the parameters of the model. Furthermore, the outcomes-obtained from the simulation were compared with real life data easily available in the literature to check the validity of the model.

In this regard, adopting the structured methodology in the research, the research aimed at presenting the series of identified voltage fluctuation issues related with the incorporation of the Poonakary Wind Solar Hybrid Energy Park.

Calculations

Calculating Maximum and Minimum Voltage Limits.

Voltage Regulation for common coupling between Transmission and Distribution is ±10%.

Actual Voltage = Per-Unit Voltage×Base Voltage

Assuming 132 kV as 1 per-unit (pu).

$$Minimum V_{\min} = 0.9 \times 132\,\mathrm{kV} = 118.8\,\mathrm{kV}$$

$$Maximum V_{\max} = 1.1 \times 132\,\mathrm{kV} = 145.2\,\mathrm{kV}$$

According to these calculations, the maximum and minimum voltage variations at the common coupling point are 118.8 kV (0.9 pu) and 145.2 kV (1.1 pu), respectively.

Required data for simulations:

The Kilinochchi to Poonakary transmission line to be constructed is a medium-voltage transmission line.

Table 2: Transmission line parameters

Transmission line length	45km
Type of conductor	ZEBRA 2X400mm2
Operating voltage	132kV
First phase wind Capacity	100MW
Positive Impedance	0.0380 + 0.3060j W/km
Zero Impedance	0.30196 + 1.07744j W/km
Mutual Impedance	0.26575 + 0.66775j W/km

Calculating the Resistance and Reactance of the cable: Maximum Three Phase Fault Level:
For 132kV = 3.7 kA
For 33kV = 8.2 kA
Considering the Thevenin voltage = 132 kV
Thevenin impedance

$$= \frac{\text{Thevenin voltage}}{\text{Maximum Three Phase Fault Level}}$$

R is resistance and X is reactance.
If X/R = 5j
X = 5R

According to the calculation, we can obtain below values:

Table 3: Values obtained from the calculation

Thevenin impedance (Z)	35.68 Ω
Resistance (R)	6.997 Ω
Reactance (X)	34.98 Ω

Results & Discussion

We have drawn the PSCAD diagrams and conducted simulations for the following scenarios:

1. Poonakary wind phase,
2. Poonakary hybrid wind and solar phase,
3. Simulation with applied faults.

Based on these observations, the outputs, results, and discussions are presented here.

First Phase - Wind 100MW Simulation outputs without changing average wind speed (7.8m/s)

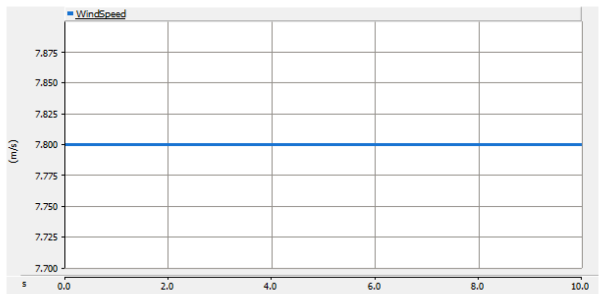


Figure 1: Wind speed

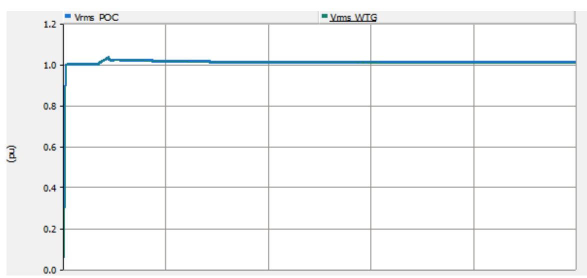
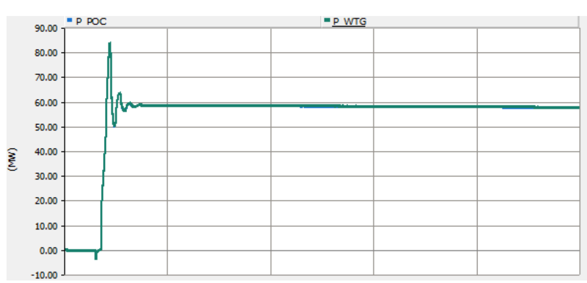


Figure 2: Voltage variation without changing the wind speed



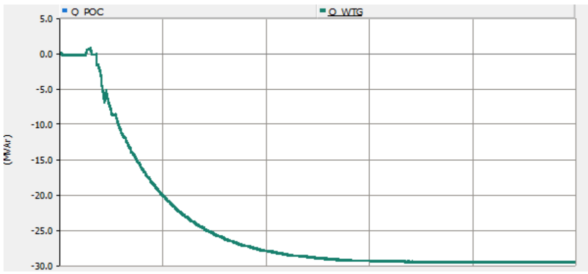


Figure 3: Active Power and Reactive Power variation of wind phase

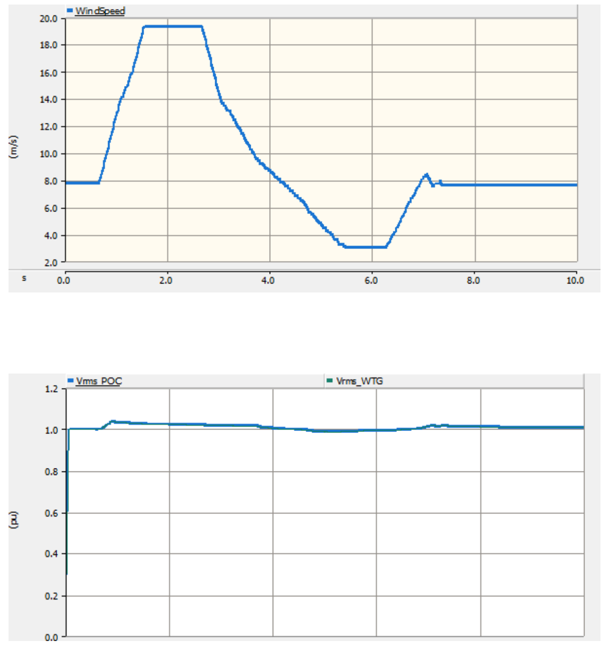


Figure 4: Wind speed and the voltage variation

V_{rms} POC is the RMS voltage at the Point of Connection to the Grid where the wind turbine generator (WTG) attaches. Vrms WTG represents the RMS voltage produced by the wind turbine blades independently. In a first step, it can be observed that the Vrms values of both channels slowly increase, suggesting an increase of voltage levels. Afterward, they reach a definite value; which indicates a steady state of working of the system under test.

Active power is defined as the power that really transfer and used to produce work while reactive power is the power that gets stored in the system and then delivered at a later time. The variation of active and reactive power can be due to load changes, generation changes, and/or system impedance changes. In case of a wind turbine, the active power that can be produced solely depend with the wind speed while the reactive power will correspond with the power factor of the wind turbine. This is a measure of the utilization of power and a low power factor results in higher loss in the power system.

Simulation outputs when changing wind speed

Even with wind speeds varying between 3 to 20 m/s, the maximum voltage reached 1.03 pu and the minimum was 0.98 pu. Since the acceptable voltage range is 0.9 pu to 1.1 pu, we can conclude that the voltage fluctuation during the wind phase remains within acceptable limits.

Second Phase - Solar 150MW connected to the existing grid

Simulation outputs without changing average wind speed (7.8m/s) and considering STC (1000W/m2, 25°C) for Solar part

Voltage variation of wind side:

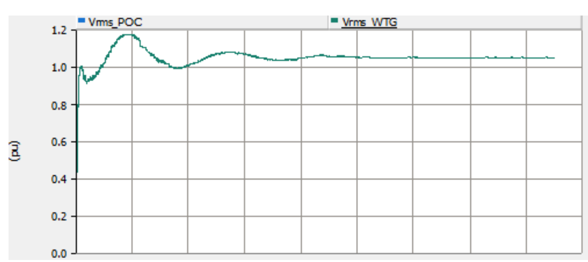


Figure 5: Voltage variation of wind side

Voltage variation of solar side:

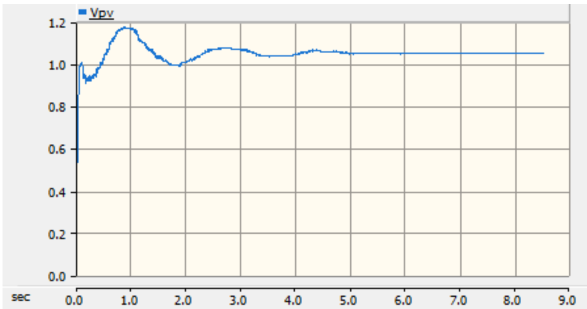


Figure 6: Voltage variation of Solar side

When considering the hybrid wind and solar simulation, the wind side shows voltage variations with a maximum of 1.16 pu and a minimum of 0.93 pu, where the upper limit is exceeded.
In the solar part, the maximum and minimum voltages are 1.17 pu and 0.92 pu, respectively. Since the required voltage range is 0.9 pu to 1.1 pu, we can conclude that voltage fluctuations in this phase also exceed the acceptable limit.

Simulation outputs when changing the wind speed and solar irradiation

Voltage variation of wind side:

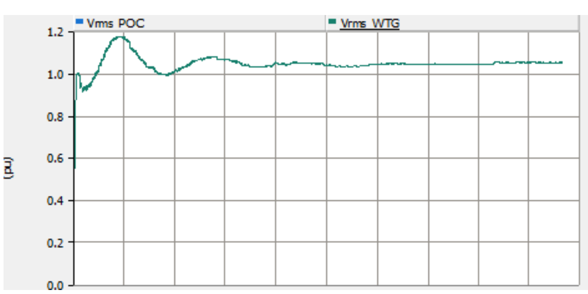


Figure 7: Voltage variation of wind side

Voltage variation of solar side

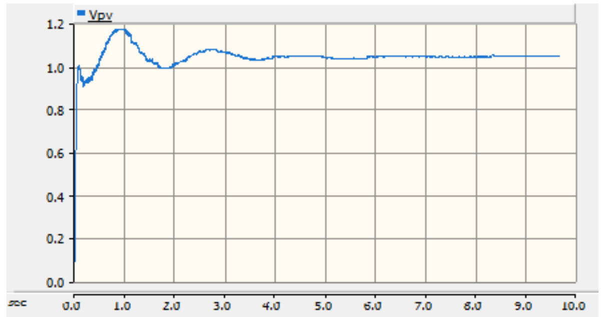


Figure 8: Voltage variation of solar side

When considering the hybrid wind and solar simulation with varing wind speed ans solar irradiation, the wind side shows voltage variations with a maximum of 1.16 pu and a minimum of 0.94 pu, where the upper limit is exceeded.
In the solar part, the maximum and minimum voltages are 1.17 pu and 0.92 pu, respectively. Since the required voltage range is 0.9 pu to 1.1 pu, we can conclude that voltage fluctuations in this phase also exceed the acceptable limit.
According to the calculations and observations that we have found, the maximum voltage which coupling points can bear is 145.2kV and minimum voltage is 118.8kV. If the voltage fluctuates with in that limits it is good for the power system stability. If exceeds this limit, we have to get necessary actions for reduce this voltage fluctuation or need to connect renewable energy park which have suitable capacity. According to the simulation outputs we have received, the voltage seems to be in appropriate limit. The SCR ratio related calculation we did earlier, the maximum renewable energy capacity that can connect to the coupling points for 132kV infrastructure is 166MW and capacity for 220kV infrastructure is 400MW. Further, we can use voltage stabilizers,

surge protectors, SVCs and STATCOM for maintain voltage stability and improve the overall performance of the power system

Conclusions

Some of the problems associated with the large-scale renewable energy technologies particularly the wind and/or solar energy include voltage fluctuations when integrated to the conventional utility power systems, for instance the Poonakary Wind Solar Hybrid Energy Park. Several challenges were identified and it was suggested that this research aims to explicate such challenges, owing to the role that 'greater details' plays for simulation and analysis. Hence, with the use of EMTDC/PSCAD software and the data analysis, all the interconnection between the energy park and the Kilinochchi grid were modelled.

For the evaluation of the simulation results, where it was possible, the data obtained were correlated with actual data. Therefore, the findings of the current study can provide useful measures of voltage fluctuation characteristics concerning the integral of the Poonakary energy park. From these ideas, the successful solutions concerning the planning and functioning of the grid, which do decrease the probability of the voltage instability and become the way to success in integration of renewables into the power system of Sri Lanka, can be derived.

In future possibly there will be concentrated efforts to manage the controlling of voltage and increasing the stability of the grid using the energy storage devices that are present in the system.

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