

## ANALYSIS OF STEADY STATE IMPACT OF INTEGRATED HYBRID SOLAR AND WIND SYSTEM IN A NIGERIAN SUB-GRID

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**Abstract:** *The poor condition of power supply in Nigeria has adversely affected both the social, economic and commercial activities. For the country to move forward, adequate and reliable power supply has to be made available, and for that to happen, other sources of energy have to be harnessed. This paper discusses the analysis of the impact of integrated Hybrid Photovoltaic and Wind turbine System (HPWS) in a section of the Nigerian electricity grid (Benin Transmission Station) using Electrical Transient Analysis Program (ETAP) power tool. The HPWS supplied additional generated power of 40MW at 16kV to the aforementioned section of the grid network. Major focus was on the steady state stability of the electric grid network which was modelled with specified loads. In order to effectively carry out the analysis, load flow studies were conducted using Newton-Raphson method of iteration and simulated with Electrical Transient Analysis Program (ETAP) power tool. Different case scenarios were carried out at pre-hybrid integration (Unconnected), post-hybrid integration (Connected) as well as at varying load increase of 20%, 60%, and 100%. Consequently, from the analytical simulation results, it was observed that integrating HPWS could provide adequate and reliable power supply, the optimal location of HPWS was also observed to be at the 33kV network as its result showed a better improved voltage profile with minimal Line losses in when compared to that of the 330kV and 132kV networks.*

**Keywords:** HPWS, Renewable, Grid, Hybrid

### INTRODUCTION

There is no argument that Nigeria like many other developing countries is currently faced with power supply crisis. Despite the abundance of renewable energy sources available within the country, Nigeria is still in short supply of electrical power. Only about 56% of the nation's over 150 million inhabitants have access to grid electricity while the power delivered to the remaining 44% of its population is unsteady and unreliable[1]. Therefore, there is an urgent need to harness renewable energy potentials available for reliable power supply in this country to augment the already existing electricity generation sources. Generators which are often used as an alternative source of supply by the general populace to augment the conventional power supply from the grid which are known to run only during certain hours of the day are not cost effective when operated for 24hours due to the increased cost of fueling and maintenance. Renewable energy plays a vital role in every aspect of human development, being the driving force, its role is indispensable in every aspect of social, economic, educational, military, research and political development of any nation. Hence, there is an urgent global need to harness potentials especially from renewable energy sources for reliable power supply as energy demand is constantly on the rise. All over the world, there has been a great diversion from non-renewable sources into the use of renewable source of energy due to increased global climate effect caused by some of the non-renewable sources. It is important we begin to explore the renewable energy sources. This will not only encourage proper energy mix but also increase the security and reliability of power supply. Besides, when aggressive deployment of clean, renewable energy devices is designed and installed in the Nigerian Grid network, this will not only provide the required energy to meet with our demand, but also strengthen power supply requirement as well as reduce investment demand.

The study of the effect of hybrid solar and wind penetration on the stability and reliability of power systems is of interest in many countries of the world today. Wherever renewable energy power generation is to be installed on a medium or large scale, studies on reliability and stability are carried out to predict its consequences on the network or power system in consideration.

### 1.1. Related works

A feasibility study was carried out on providing power to meet the load requirements of a typical commercial building using a hybrid solar-wind energy system by some researchers; In their study, they considered the use of a wind energy system in combination with a Photovoltaic and Diesel energy system and investigated the performance of the entire system [5]. In another publication, an impact analysis study on the integration of renewable energy into a smart power system network was executed by some researchers. A model was developed and simulated using HOMER to identify the operational characteristics of the different renewable energy sources with the existing power grid. Simulation, optimization and cost analysis of the models were performed and final recommendation was given for this study [6]. Simulation of a grid connected PV inverter integrated with a supercapacitor hybrid storage was implemented using MATLAB in another research. In the study, it was observed that the proposed system is capable of providing a better sinusoidal waveform for Power delivered to the grid via this system [7]. In a recent published document, a load flow study solution of a hybrid AC/DC distribution network using a Distributed Energy source was carried out using several scenarios where it was established that the appropriate placement point for the hybrid system must be considered so as to reduce technical losses in the network [7]. Little has been done in the area of integration of a hybrid renewable plant into a sub-grid of a developing country like Nigeria, where there is still a huge gap between Generation capacity and total installed loads which is what we will be doing in this work.

## MATERIALS AND METHODOLOGY

The following methods were adopted in the preparation of the design of this system and for this paper:

- a) Collection of modelling data from Benin Transmission Company of Nigeria used for this analysis. The network components collected from Benin transmission includes parameters of transmission Line, buses, transformers, load information and single Line diagram.
- b) Collection of solar radiation and wind speed data for Benin City used in modeling of the HPWS.
- c) Carry-out steady-state load-flow study on the grid network, first without the connection of the HPWS connected to it (pre-integration) after which we carry out another load flow study on the same grid network with the HPWS connected to it (post-integration).
- d) Modelling, Simulations and Analysis of the simulated results of the Benin electric grid network was done using Electrical Transient Analyzer Program (ETAP) power tool.

### Network Description

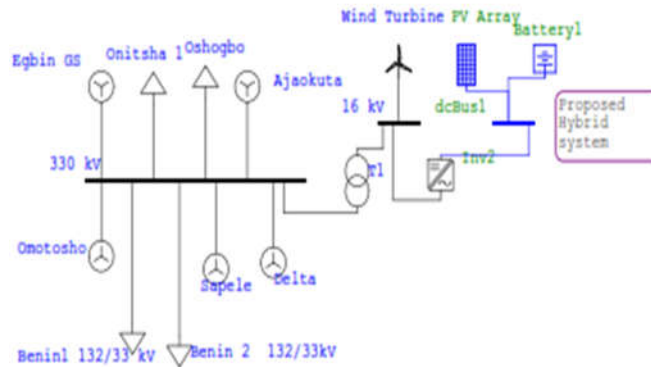
The power flow study of Benin 330kV/132kV/33kV network which is the section of the Nigerian power grid used for this research is pertinent to ascertain the state performance of the existing network for scheduled loads and generation variance. The network has the following data for 330 kV network, 12 power grid, 34 buses, 29 Branches, 4 connected loads, 7 transformers, and that of 132/33 kV network contains 5 power grid, 25 buses, 23 Branches, 9 connected loads, 5 transformers, all these were used for assessment of the impact of adding a total of 40MW of hybrid generator with (20MW from Solar generator and 20MW Wind generator) to the grid network at a generated voltage of 16 kV. The choice of generated power was based on total load demand from the existing afore-mention network. The network model is used to enable a thorough check of the network with respect to steady state stability. Details of the single Line diagram at Pre-integration (Un-connected HPWS) and Post-Integration stages (Connected-HPWS) of existing Benin 330 kV transmission network and 132/33 kV Line network which is a section of the Nigerian electrical power transmission network.

### Network Modeling Description

Power-flow analysis starts with a Single Line diagram of the proposed network drawn on ETAP and executed with the following assumptions:

- The network is a balanced three-phase system that operates in a steady state condition.
- The Single Line diagram represents a phase whose analysis adequately serves as a replica for the other phases.

The Proposed hybrid system comprises of a Wind turbine and PV array. The PV array is connected to the hybrid system through an inverter as described below;



*Fig.1.330kV post integration network diagram*

Power system solution starts with the use of one of the iterative techniques by first identifying the known and unknown variables used in the system which largely depends on the type of bus it is connected to. The buses used in this research work are classified as;

- Load Bus (PQ),
- Generator Bus (PV)
- Slack bus

The slack bus for the design system is chosen arbitrarily; a generator with the highest inertia is made a preferred choice. For this bus, only the voltage magnitude  $|V|$  and angle  $\delta$  are specified, hence the quest is to find the real power (P) and the reactive power (Q) that provides power flow balance in the network. Generator or PV bus has the bus voltage magnitude  $|V|$  and real power P, specified while Q and  $\delta$  is sought. Then, for the load or PQ buses, the real and reactive powers are specified while load flow seek to provide  $|V|$  and  $\delta$ .

## RESULTS AND DISCUSSION

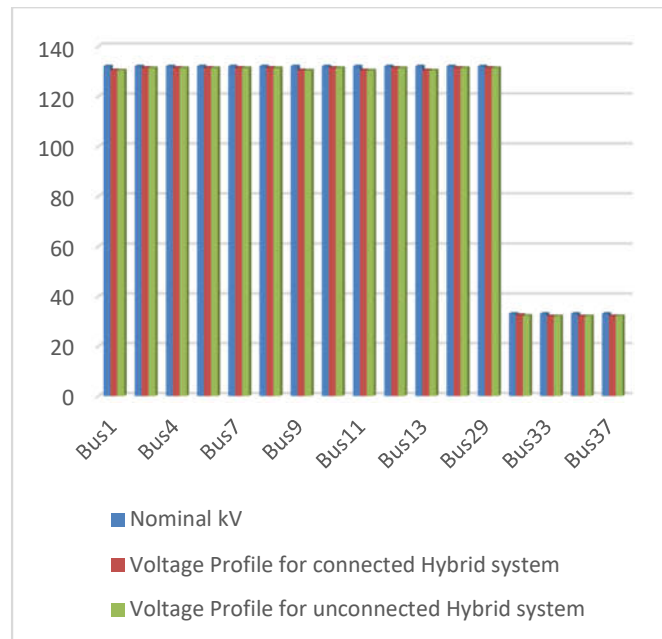
The ETAP software program was the power tool used to carry the steady state analysis of the impact of the grid-connected HPWS into the existing Nigerian grid. It was used to quickly solve the non-Linear load flow problem as well as calculate the bus voltages, branch power factors, currents, and power flows throughout the electrical system of the network in consideration. Some study assumptions for the four-scenario development carried out were put into consideration and this includes:

- The length of Lines for 330 kV were above 100 km and below for 132 kV
- Energy storage were fixed for each of two technologies of wind and solar PV.
- Static loads were fixed for each scenario.
- Energy generation only for the scenario development process.
- The model used was tested without inputting weather conditions, i.e to say an assumption that the supply from wind turbine generator and solar plant were considered constant over the year taking advantage of their complementary characteristics.

The various scenario that were used to analyze the steady state impact of HPWS on the Benin Transmission (330kV, 132kV and 33kV) Network of the Nigerian grid are stated below;

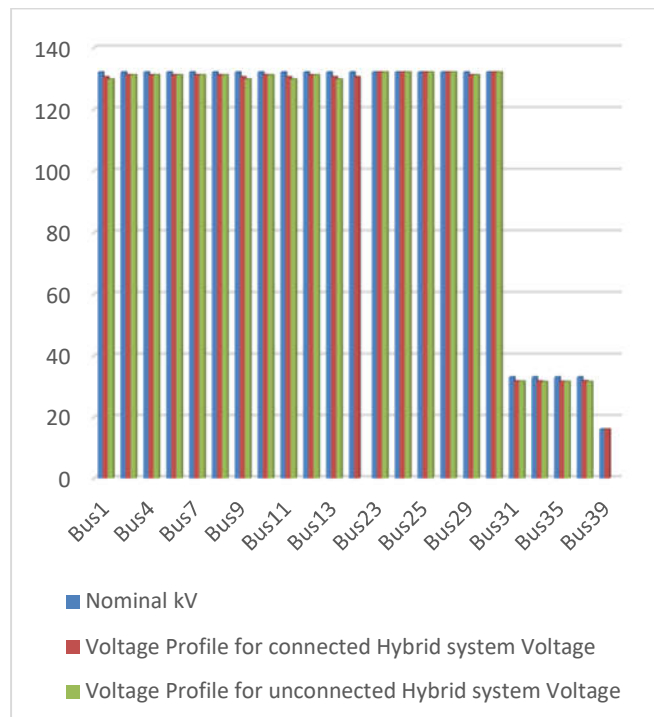
- ❖ Scenario one: Voltage profile observed at Un-connected and Connected Hybrid-Grid network.
- ❖ Scenario two: Lines losses observed at Un-connected and Connected Hybrid-Grid network.
- ❖ Scenario three: Percentage load increase of 20%, 60% and 100% at 33kV for Un-connected and Connected Hybrid-Grid network.

**Scenario One: Voltage profile observed at Unconnected and Connected Hybrid-Grid network**



*Fig.2. Voltage Profile for Un-connected and Connected Scenario at 33kV*

The chart shown above shows an improved voltage profile for buses 1, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 29, 31, 33 and 35 for the network while other buses had no significant change in magnitude because the hybrid system had no direct connection to those buses.



*Fig.3. Voltage Profile for Un-connected and Connected Scenario at 132kV*

There is a voltage improvement on buses 1, 9, 11 and 13 while others were still as they were because the hybrid system had no connection to them. There were no values for Bus 14 and 39 in the unconnected system because they were both linked to the hybrid system for evacuation of power to the grid and were not active with regards to the unconnected simulation.

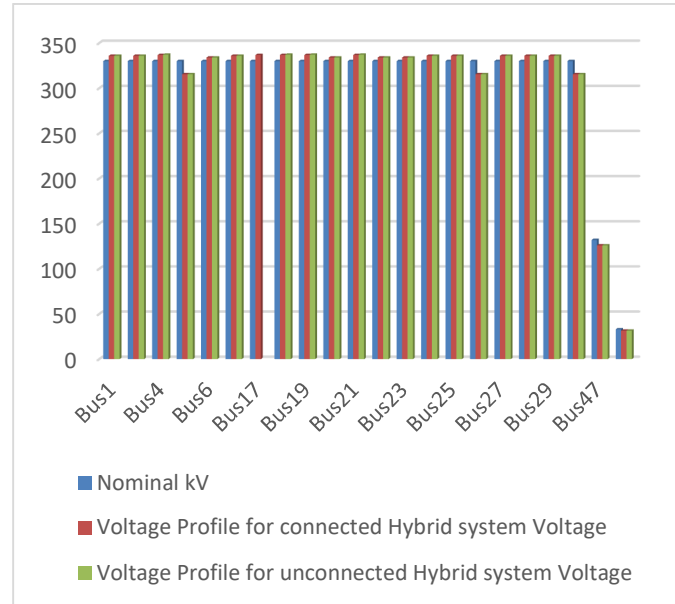


Fig.4. Voltage Profile for Un-connected and Connected Scenario at 330kV

We can see from the chart above a voltage improvement on buses 4, 18, 19 and 21, they all had same voltage magnitude because they are tied to the same infinite bus. There were no values for Bus 17 in the unconnected system because it was associated to the hybrid system for evacuation of power to the grid and was not active for the unconnected scenario.

#### 4.1. Scenario Two: Lines losses observed at Un-connected and Connected Hybrid-Grid network

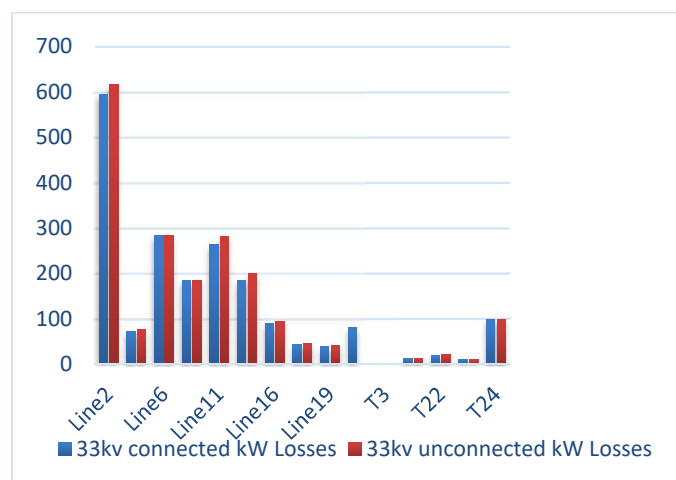


Fig.5. 33kV Line Losses for Un-Connected and Connected Scenario

As seen from above, there is a great reduction in Line losses with regards to the Hybrid system connected to the 33kV Line which could be clearly seen on the chart for Line 2, Line 4, Line 11, Line 12, Line 16, Line 17, Line 19, T21 and T22 when compared to the grid with the hybrid system un-connected, the hybrid system acts as a relief system to the already existing grid where these Lines were previously fed from in the un-connected network and also proffers reduced losses to the entire system. Also, there was no loss for T3 and Line 22 for the unconnected system because they were both linked to the hybrid system for transmission of power to the grid while for Line 6, Line 10 and T23 there was no difference noticed because the hybrid system has no connection to the buses where they were tied to.

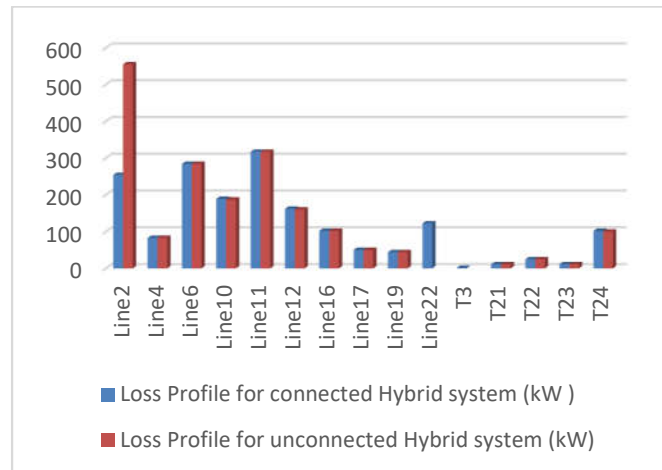


Fig.6. 132kV Line Losses for the Un-Connected and Connected Scenario

There was a significant loss reduction on Line 2 when the hybrid system was connected to the 132kV Line. While Line 10, Line 12, T21 and T24 had a little increase in its losses when compared to unconnected result from the design simulation. Also, for the other Lines no difference was noticed because the hybrid system has no connection to the buses where they were tied to.

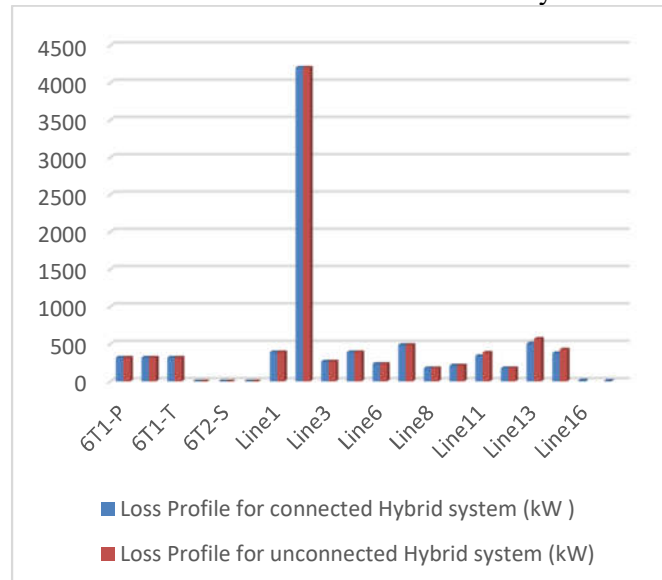


Fig.7. 330kV Line Losses for the Un-Connected and Connected Scenario

There is a little loss reduction on Line 11, 13 and 14 as compared to when the Hybrid system was unconnected to the network coming from the relief coming from the hybrid system tied to the network. There was no value for Line 16 and T4 in the unconnected system because they were both linked to the hybrid system for evacuation of power to the grid and were not active with regards to the unconnected simulation.

**4.2. Scenario Three: Percentage load increase of 20%, 60% and 100% at 33kV for Un-connected and Connected Hybrid-Grid network.**

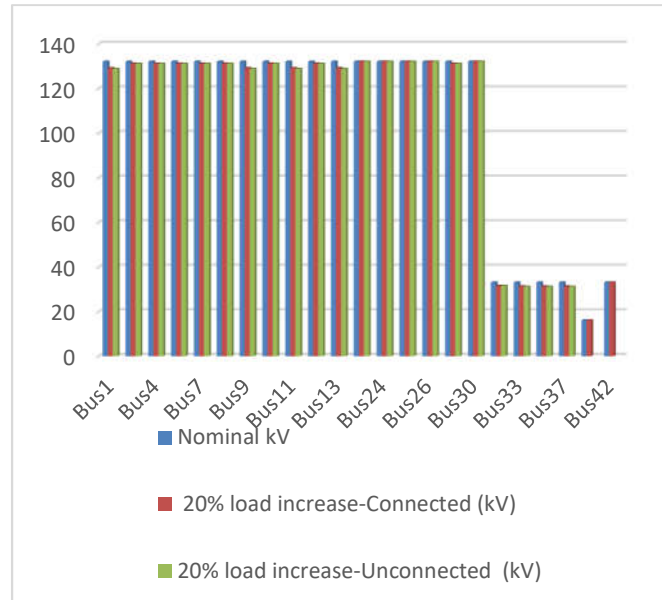


Fig.8. Chart for 20% Load Increase of 33kV Line Voltage profile

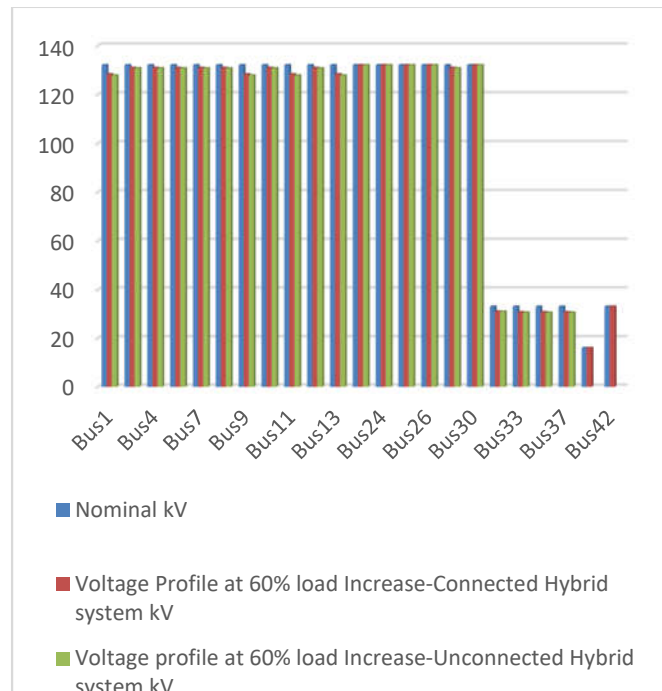
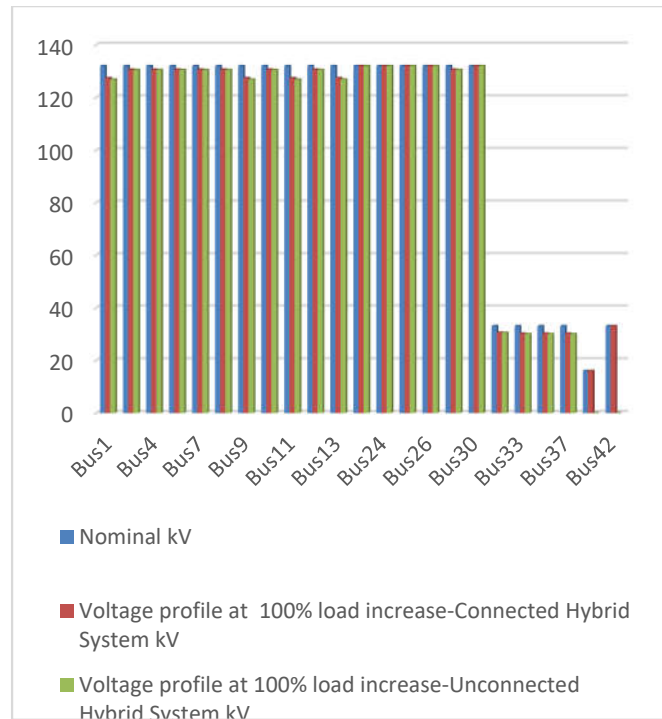


Fig.9. Chart for 60% Load Increase of 33kV Line Voltage profile



*Fig.10. Chart for 100% Load Increase of 33kV Line Voltage profile*

The various charts above show an improved voltage profile for buses 1,3,4, 6, 7, 8, 9, 10, 11, 12, 13, 29, 31, 33 and 37 while other buses had no significant change in magnitude because the hybrid system had no direct connection to those buses. There were no values for Bus 39 and 42 in the un-connected system because they were both linked to the hybrid system for transmission of power to the grid and were not active with regards to the un-connected simulation.

## 5. CONCLUSION

The results from the various scenarios of steady state analysis carried out show that the post- hybrid integrated network proffers a significant improvement on the quality of power supply and reliability on the existing Benin (330kV/132kV/33kV) network of the Nigerian grid. The connection of Hybrid Photovoltaic and Wind System (HPWS) into this section of the Nigerian grid had great impact on the grid power quality in the voltage level and also line losses of the various lines linked to the hybrid system. When the results of the scenarios were compared based on voltage level of tying the grid system, it was observed that integrating the hybrid system at 33kV close to the consumers at the distribution level will be more beneficial to the grid as compared to 330kV and 132kV transmission voltage levels, yielding the overall best result in terms of improved voltage profile and significant reduction in line losses.



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## DEFINITIONS

ETAP- Electrical Transient Analyzer Program  
HPWS- Hybrid Photovoltaic and Wind System  
kV- Kilo Volts.  
MW- Mega Watt

## APPENDIX

Table 1. 330kV loss sheet with the Hybrid generator Connected/Unconnected

No	ID	Loss Profile for connected Hybrid system (kW)	Loss Profile for unconnected Hybrid system (kW)
1	6T1-P	317	317
2	6T1-S	317	317
3	6T1-T	317	317
4	6T2-P	0	0
5	6T2-S	0	0
6	6T2-T	0	0

7	Line1	390	390
8	Line2	4204	4204
9	Line3	266	266
10	Line5	390	390
11	Line6	234	234
12	Line7	487	487
13	Line8	176	176
14	Line10	211	211
15	Line11	339	383
16	Line12	176	176
17	Line13	505	569
18	Line14	378	427
19	Line16	12.1	
20	T4	6.579	

*Table 2. 330kV voltage profile with Hybrid generator connected/unconnected*

No	BUS Bus ID	Nominal Voltage	Connected Voltage	Unconnected Voltage
1	Bus1	330	330.931	330.931
2	Bus3	330	330.931	330.931
3	Bus4	330	331.518	331.518
4	Bus5	330	327.467	327.467
5	Bus6	330	331.944	331.997
6	Bus7	330	330	330
7	Bus8	330	330.931	330.931
8	Bus17	330	331.944	331.997
9	Bus18	330	331.518	331.518
10	Bus19	330	331.518	331.518
11	Bus20	330	331.944	331.997
12	Bus21	330	331.518	331.518
13	Bus22	330	331.944	331.997
14	Bus23	330	331.944	331.997
15	Bus24	330	330.931	330.931
16	Bus25	330	330.931	330.931
17	Bus26	330	327.467	327.467
18	Bus27	330	330.931	330.931
19	Bus28	330	330.931	330.931
20	Bus29	330	330.931	330.931
21	Bus30	330	327.467	327.467
22	Bus31	330	330	330
23	Bus32	330	330	330
24	Bus33	330	327.435	327.435
25	Bus34	330	330	330
26	Bus35	330	330	330
27	Bus36	330	330	330
28	Bus37	330	330	330
29	Bus38	330	330	330
30	Bus41	330	330	330
31	Bus42	330	330	330

32	Bus43	330	330	330
33	Bus44	330	330	330
34	Bus47	132	130.865	130.865
35	Bus49	33	32.716	32.716
36	Bus 45	16	16	0
37	Bus 46	330	331.959	0

Table 3. 132kV loss sheet with the Hybrid generator Connected/Unconnected

No	ID	Type	132KV Connected kW Losses	132KV Unconnected kW Losses
1	Line2	Line	254	555
2	Line4	Line	82.854	82.854
3	Line6	Line	284	284
4	Line10	Line	191	187
No	ID	Type	132KV Connected kW Losses	132KV Unconnected kW Losses
7	Line16	Line	102	102
8	Line17	Line	50.215	50.215
9	Line19	Line	44.189	44.189
10	Line22	Line	122	0
11	T3	Transf. 2W	1.517	0
12	T21	Transf. 2W	11.186	10.957
13	T22	Transf. 2W	24.622	24.622
14	T23	Transf. 2W	11.021	11.021
15	T24	Transf. 2W	102	100

Table 4. 132kV voltage profile with Hybrid generator connected/unconnected

No	Bus ID	Nominal kV	132KV Connected Voltage	132KV Unconnected Voltage
1	Bus1	132	130.432	129.681
2	Bus3	132	131.076	131.076
3	Bus4	132	131.076	131.076
4	Bus6	132	131.076	131.076
5	Bus7	132	131.076	131.076
6	Bus8	132	131.076	131.076
7	Bus9	132	130.432	129.681
8	Bus10	132	131.076	131.076
9	Bus11	132	130.432	129.681
10	Bus12	132	131.076	131.076

No	ID	Type	33kv	33kv
			connected kW Losses	unconnected kW Losses
1	Line2	Line	595	618
2	Line4	Line	73.854	76.833
3	Line6	Line	284	284
4	Line10	Line	186	186
5	Line11	Line	264	281
6	Line12	Line	185	201
7	Line16	Line	90.898	94.564
8	Line17	Line	44.76	46.566
9	Line19	Line	39.389	40.978
10	Line22	Line	81.695	
11		Transf.		
	T3	2W	0.063	
12		Transf.		
	T21	2W	12.706	13.766
13		Transf.		
	T22	2W	20.557	21.882
14		Transf.		
	T23	2W	11.04	11.035
15		Transf.		
	T24	2W	100	100
11	Bus13	132	130.432	129.681
12	Bus14	132	130.432	0
13	Bus23	132	132	132
14	Bus24	132	132	132
15	Bus25	132	132	132
16	Bus26	132	132	132
17	Bus29	132	131.076	131.076
18	Bus30	132	132	132
19	Bus31	33	31.665	31.665
20	Bus33	33	31.676	31.493
21	Bus35	33	31.554	31.554
22	Bus37	33	31.756	31.573
23	Bus39	16	16	

Table 5. 33kV Percentage voltage profile at percentage load increase

Table 6. 33kV voltage profile with Hybrid generator connected/unconnected

No	Bus ID	Nominal kV	33kv	33kv
			connected Voltage	unconnected Voltage
1	Bus1	132	129.492	129.415
2	Bus3	132	131.192	131.162
3	Bus4	132	131.192	131.162
4	Bus6	132	131.192	131.162
5	Bus7	132	131.192	131.162
6	Bus8	132	131.192	131.162
7	Bus9	132	129.492	129.415

8	Bus10	132	131.192	131.162
9	Bus11	132	129.492	129.415
10	Bus12	132	131.192	131.162
11	Bus13	132	129.492	129.415
12	Bus23	132	132	132
13	Bus24	132	132	132
14	Bus25	132	132	132
15	Bus26	132	132	132
16	Bus29	132	131.192	131.162
17	Bus30	132	132	132
18	Bus31	33	31.693	31.686
19	Bus33	33	31.448	31.429
20	Bus35	33	31.56	31.537
21	Bus37	33	31.56	31.537
22	Bus39	16	16	
23	Bus42	33	32.999	

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