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Voltage Stability of Integrated Grid with Solar & Wind Power along with LCOE: A Case Study in Bhutan

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Abstract: Renewable energy systems like solar photovoltaic and wind are increasingly used for electric power generation to offset the use of non-renewable sources of electricity and also reduce carbon emissions. Due to the intermittent nature of the resource the power generated from solar PV and wind energy conversion systems are intermittent too resulting in varying voltages and frequency. This results to an unstable grid when integrated with conventional grid, hence power converters are used to make outputs from solar and wind suitable for grid integration. Load flow analysis is used for planning and contingency analysis in power system studies, here load flow is used to access the voltage stability of grid integrated with solar PV and wind energy conversion systems. This paper discusses on voltage stability analysis using load flow simulation using MATLAB Simulink for a selected site of Bhutan's western power grid. A base case scenario without solar and wind; and integrated grid scenario with solar PV and wind is considered for voltage stability analysis. The load flow voltage and also steady state voltage shows that the voltage profile of the grid is improved with Solar PV and wind power systems. Also, a financial analysis with levelized cost of energy is attempted using Monte Carlo simulation reflecting various cost deviations. For a proposed 1.5 MW wind energy conversion systems and 1 MW solar PV, LCOE was found to be $ 70 /MWh and $ 104 /MWh.

Keywords: *Solar photovoltaic, wind energy conversion systems, Monte Carlo Simulation, MATLAB Simulink, Load flow, Voltage Stability*

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I. INTRODUCTION

Globally the anthropogenic greenhouse gas emissions have increased by 2.2 % annually in the last decade (2002-2010) of which CO_2 emissions from burning of fossil fuels and industrial processes contributing to 78%. In the same period the global temperature has increased about 1.5^0 C and prediction from climate models shows that if emissions are not regulated the temperature would rise by 2.5 to 3^0 C by 2030 itself [1]. It is suggested that decarbonizing the electric carbon grid is one of the major strategies to reduce the GHG emissions and global warming, power grids to be replaced with low carbon foot print renewable energy sources. Around the world renewable energy has seen growth rate to 8% to 9 % over the last decade but at the same time the carbon emission from energy sources have also increased to 1.3 % every year; it is pointed out that with renewables carbon emission reduction can be achieved up to 70 % [2].Among renewable energy sources solar and wind power are technologically and economically feasible renewable power sources currently available for power generation. The cost per unit of electricity generated from both the sources have been declining steadily over the years which made wind and solar competitive to nuclear, fossil based (coal) thermal power plants [3]. While most of the renewable net additions are happening in USA and Europe, developing economies like India and China are also actively contributing to renewable additions mainly with solar PV and wind energy power systems [3].

The integration of variable renewable energy sources has been increasing steadily over years of which 15% of total energy in 10 countries was generated with solar and wind in 2017, which has resulted in system stability issues like voltage stability, frequency stability, power quality issues among others [3]. Due to variable nature of the resource the generation from both the solar and wind power are not generated at constant voltage and current but varying, while the power required is at constant voltage and frequency; since all the control and protection schemes are designed based on that. System stability of integrated renewable energy grid have become important research to decarbonize the electric grid to enable variable renewables to be integrated into utility grid; energy storage schemes, pump hydro power plants which serves as reserve or back up are encouraged to facilitate swift synchronization of variable renewables with the grid.

High penetration of renewables into the power grid like solar and wind which are intermittent in nature with fluctuating output power renders the grid unstable with either low voltage or high voltage where control of power flow becomes difficult. However the use of smart electronics with reactive power control techniques improves the voltage profile successfully integrating renewables into the grid [6-7]. Renewables integrated into the grid also improves the voltage profile of the grid and stability in general. Photovoltaic systems can be used to improve the voltage sag issues in the grid and also compensate for the fault in case of contingencies which improves stability of the grid in both normal operating conditions and during contingencies [6]. The cost per unit of electricity generated has been steadily decreasing over the years since the industrial revolution of 1970s; appreciable cost reduction has occurred in solar and wind power systems from 35 cents/kWh to 3 cents/kWh today[2,9,10]. In Bhutan the power grid is dominated with renewable power, 99% of the power generated is from runoff-river scheme hydro power plants with total installed capacity of 1606 MW as of March 2019 while other forms of renewable energy are being explored [3-4]. Bhutan is a small landlocked country with a population of 0.7 million with an area of 38394 sq.km [11], with a peak load of about 350 MW. This paper aims to study the voltage stability of the solar and wind integrated grid of Bhutan for a selected site using real grid data in MATLAB Simulink environment. Also levelized cost of energy for proposed installation of solar and wind energy conversion systems is assessed using Monte Carlo Simulation.

For voltage stability analysis MATLAB Simulink software is used; it has capability of simulating power flow or load flow studies, transient stability analysis, small signal stability analysis both in time and frequency domains. In this paper voltage stability analysis of grid integrated with solar photovoltaic (SPV) and wind energy conversion systems (WECS) for a selected site in Bhutan is performed in MATLAB Simulink environment. Load flow studies are one of the popular methods used by power engineers for planning future power plants, voltage stability analysis, and also contingency analysis [12]. Load flow iterative method will be used for voltage stability; which is one of the common tools for analysis of voltage stability analysis in power system analysis [13]. Also, a levelized cost of energy is computed using Monte Carlo simulation technique considering various deviations in costs. So far there is limited study conducted on stability of solar and wind integrated electric grid of Bhutan, therefore there is a scope of such studies.

II. SITE DESCRIPTION

For voltage stability analysis of solar and wind integrated grid, a part of Bhutan's western grid is considered under the present study. The existing grid consists of two hydro power plants of Basochu upper stage with installed capacity of 24 MW and Basochu lower stage with installed capacity of 40 MW. The transmission voltages are 66kV, 132kV and 220kV respectively with Dog conductor used for 66kV, Panther conductor for 132 kV and Zebra for 220 kV. The part of existing grid considered for study covers power network of western Bhutan with Thimphu, Paro, Wangdue, Haa, Tsirang and part of Chukha. Solar and wind power systems are considered for the study; the proposed sites are Paro for solar and Wangduephodrang for wind power which are located in western Bhutan. Bhutan has good Solar and wind power potential for electricity generation, the higher altitude mountain areas and southern foothills of Himalayas present a good solar power potential with average global solar radiation of 5.5 to 6 kWh/m^2/day for average duration of about 5 to 6 hours round the year [13-[15][14]15]. Deep gorges and v shaped valleys gives rise to good wind power potential of 3rd and 4th category as per NREL's report [15]. The selected solar power site, Paro receives global solar radiation of 5.91 kWh/m^2/day with 5.83 kWh/m^2/day as beam radiation and 1.98 kWh/m^2/day as diffused solar radiation, wind power site at Wangduephodrang has wind power density of 103.75 W/m^2 at a hub height of 50m [14]. Under this study SPV system of 1 MW and WECS of 1.5 MWis considered.

III. DATA SOURCE AND METHODOLOGY

Availability of good data set in renewable energy studies of solar and wind have become very important because intermittent nature of resource which demands better control over power output; this makes renewable power expensive though the resource itself is abundantly available. An accurate grid data for future planning and contingency studies have also proved essential for power engineers involved in planning, controlling and distribution sectors. The power grid data was obtained from Bhutan Energy Data Directory report of Department of Renewable Energy, Ministry of Economic Affairs, Bhutan [16]. Transmission line parameters along with various power generating source considered are given in Table 1 and 2 respectively.

A selected part of Bhutan's western gird is modeled in MATLAB Simulink using Simpower systems library blocks, which is considered as base case without renewables. Load flow studies are then performed focusing on voltage magnitude at various nodes or buses in the grid. Solar and wind energy conversion systems are then integrated into the existing grid and then load flow studies performed for the integrated grid to accesses the improvement in bus voltages across the grid. The integration of solar and wind energy conversion systems is validated with IEEE standard 1547 Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems. In the last section a financial analysis of LCOE is performed using Monte Carlo simulation which gives per unit cost of energy when various cost deviations occur.

IV. MODELING AND SIMULATION OF INTEGRATED GRID

The power grid modeled for a selected region for a base case has synchronous generators, hydro turbine governors and IEEE type I excitation systems of MATLAB Simulink blocks representing existing hydropower plants and the rest of the grid is modeled as three phase sources connected to a slack bus. The output voltages are set in per unit system.

The parameters for the hydro turbine governors are set as; reference speed W_{ref}in pu as 1 pu and reference mechanical power P_{ref}in pu as 0.8 pu. Actual mechanical speed W_e, electrical power output P_e and speed deviations d_w in puare measured from the synchronous generator and fed back to the hydro turbine governor block as shown in Figure 1. The mechanical power output from hydro turbine governor is connected as input to the synchronous generator while gate opening terminal is terminated. Excitation System parameters are given as; desired stator terminal voltage V_{ref} in pu as 1 pu and d and q axis terminal voltage (V_d and V_q) are measured from synchronous generator and fed back into excitation system block while voltage stabilization connection is grounded since no voltage stabilizer is employed in this study. The output of the excitation system, field voltage (V_f) is further connected as input to the synchronous generator block.

The synchronous generators are modeled as salient pole with nominal power of 30MVA at a voltage of 11kV, 50Hz and the load flow parameters are set as; active power of 24MW, minimum reactive power of -2.4MVAR and maximum reactive power of 12MVAR for Bachochu upper stage hydro power plant. For lower stage nominal power of 53MVA at a voltage of 11kV, 50Hz and the load flow parameters are set as; active power of 40MW, minimum reactive power of -4MVAR and maximum reactive power of 20MVAR for Bachochu lower stage hydro power plant.The output voltage is 1 pu of the synchronous generator which is given in Figure 2.

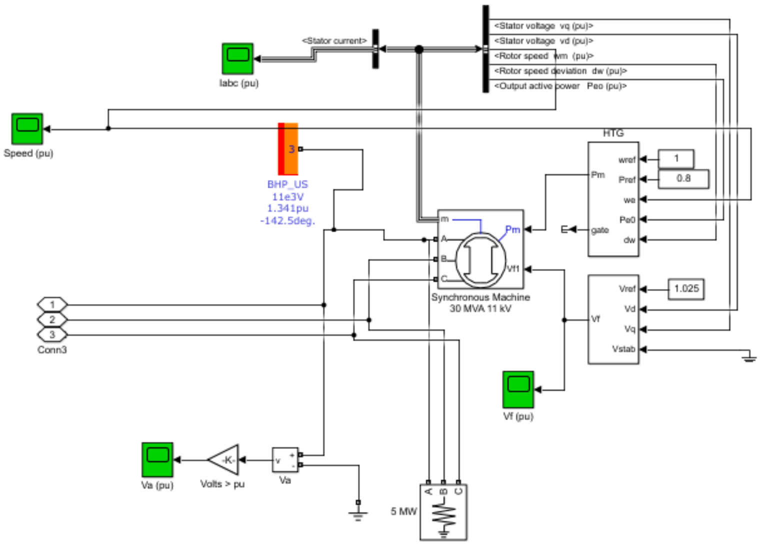

Figure 1. *MATLAB Simulink model of a hydropower plant.*

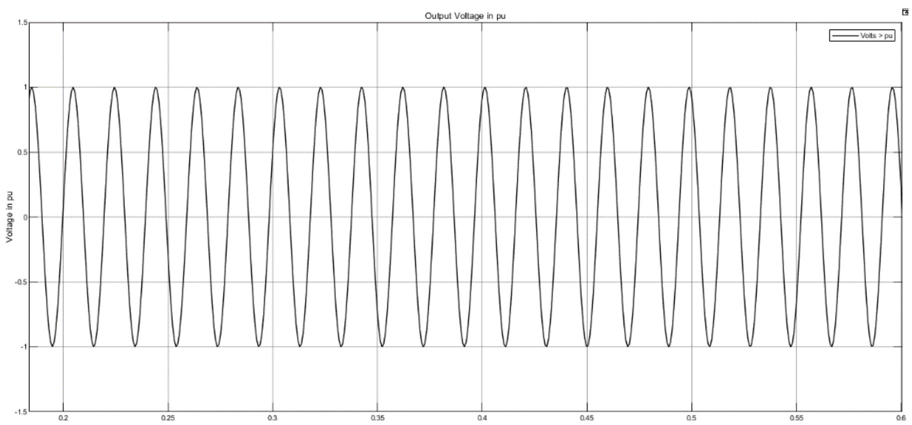

Figure 2. *Output voltage waveform from synchronous generator in pu.*

Solar power system is modeled asphotovoltaic system which generates DC power or DC voltage on modular basis. In this study, PV module of SunPower SPR-415E-WHT_D model is chosen which has maximum power of 414.8 W, open circuit voltage of 85.3V, short circuit current of 6.09 A, voltage at maximum power of 72.9V and current at maximum power of 5.69 A. An array size of 1MW is modeled under this studywith 88 modules in parallel strings and 28 (7*4) modules in series which produces DC voltage of 2400 V. Figure 3 shows the array characteristics of at a standard solar radiation of 1000 w/m^2 at 45^0 C and 25^0 C respectively. An inverter is modeled using IGBT switches in Simulink library to convert DC voltage to AC voltage of 50Hz. IGBT switches are turned ON with a gate firing pulse, which has an amplitude of 5, period of 0.02 seconds and pulse width of 25% which generates 50Hz frequency with phase delays introduced. Figure 4 shows the Simulink model of inverter with IGBT switches and Figure 5 describes the IGBT firing sequence with waveforms.

A low pass LC filter with 100mH inductance and capacitance of 40μF is modeled to reduce the harmonics produced from the inverter. A complete Simulink model of the SPV system is shown in Figure 6 with photovoltaic array, inverter and LC filter. The input solar radiation modeled as stair signal generator with maximum amplitude of 1000 w/m^{2}and minimum amplitude of 200 w/m^{2}and sample time of 0.060606 seconds to replicate the intermittent nature of solar radiation. Figure 7 describes the output AC voltage corresponding to input solar radiation. A constant temperature of 40^0 C represented by constant step signal. The SPV system generates 2280 Vdc which is further fed to a three-phase full bridge inverter which converts DC voltage into AC voltage of 1200 Vrms at 50Hz shown in Figure 8. Further the total harmonic content of 1.83% is measured across 300Ω resistive load.

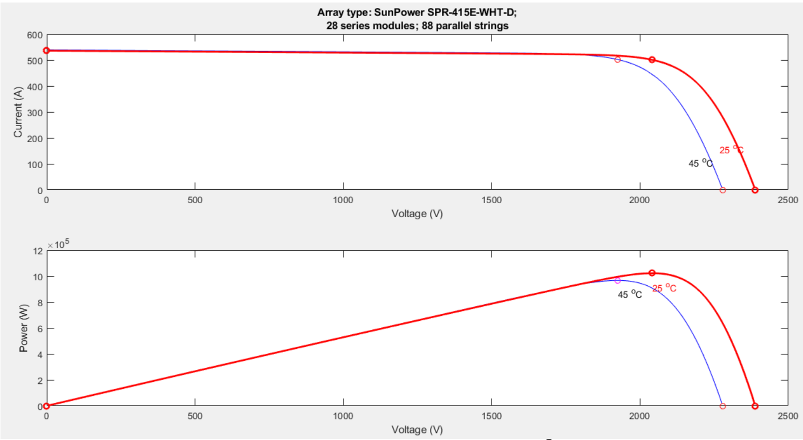

Figure 3. *SPV Array Characteristics at solar radiation of 100w/m^2 and temperature of 25^0 Cand 45^0 C.*

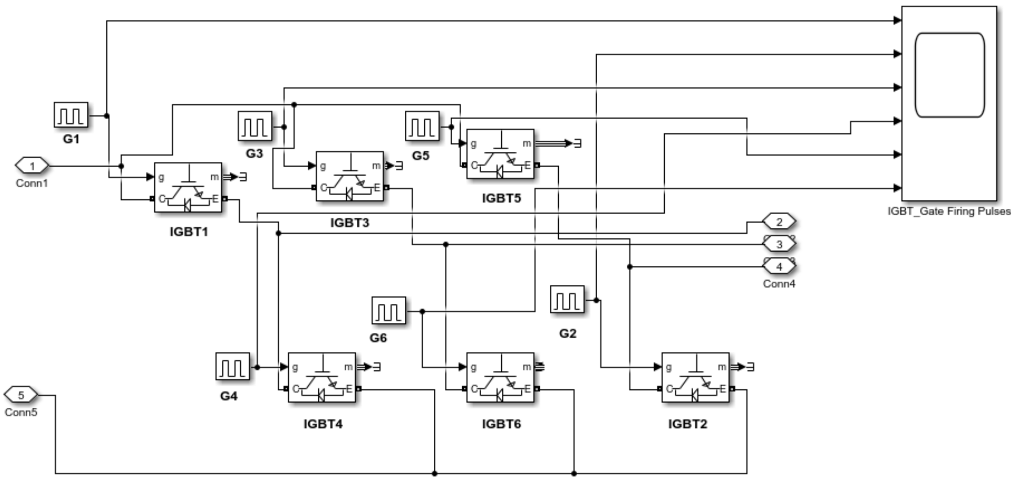

Figure 4.*Three-phase full bridge inverter with 50Hz frequency.*

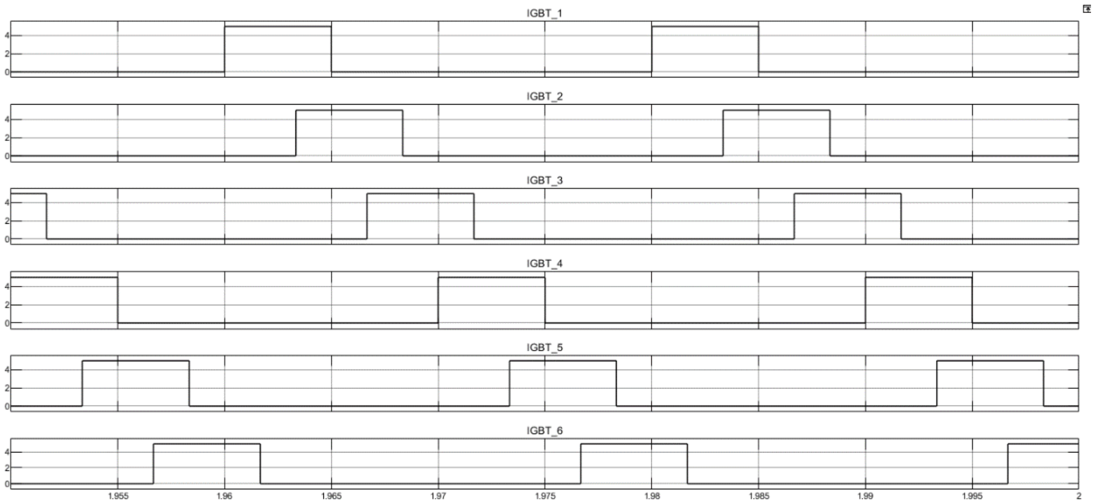

Figure 5.*Gate 1-6 firing pulse characteristics waveform.*

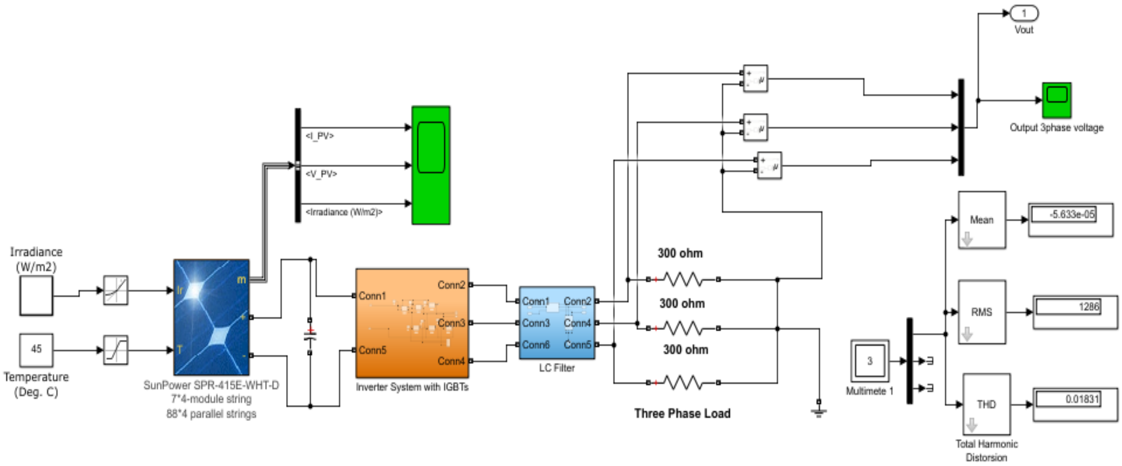

Figure 6. *SPV system with PV array and single-phase full bridge inverter.*

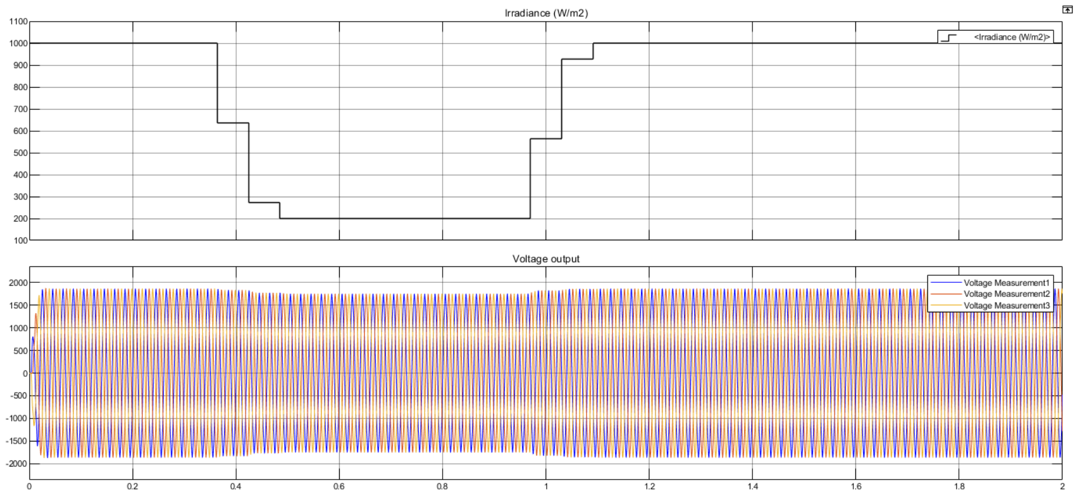

Figure 7.*Solar radiation input and output AC Voltage waveform of SPV system.*

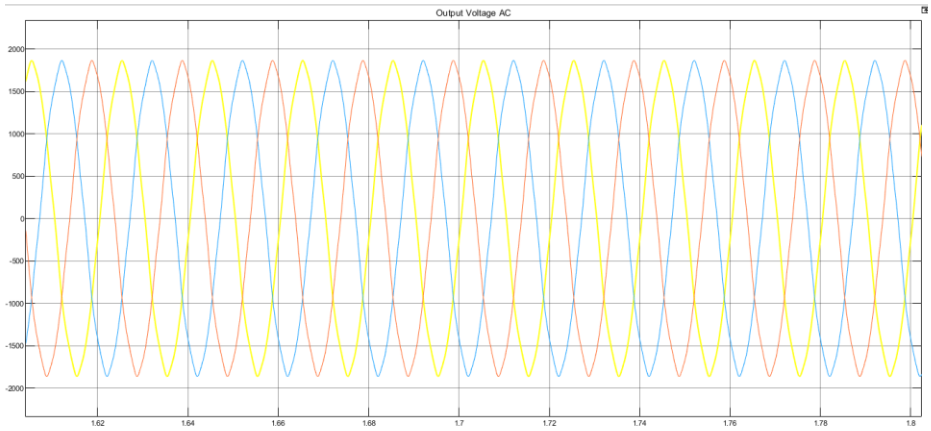

Figure 8.*AC output voltage waveforms from inverter with frequency of 50Hz.*

Wind energy conversion system is modeled with induction generators and standard wind turbine block available in Simulink. An asynchronous induction generator is chosen as generator in this study since it is widely used in WECS and cheap compared to synchronous generators. The parameters of the induction generator are set as; a nominal power of 1.666 MVA, output voltage of 480V AC at 50Hz with maximum active power of 1.5MW. A wind turbine block available in Simulink is chosen to drive the asynchronous generatorto generate an active power of 1.5 MW shown in Figure 9. The parameters of wind turbine are set as; nominal power of 1.666 MVA, base wind speed of 10 m/s, maximum power at base wind speed was set to 0.73 pu and base rotational speed to 1.2 pu, which is shown in Figure 10. Each wind turbine is modeled with maximum wind speed of 12 m/s and base wind speed of 10 m/s; which is modeled as constant signal at 0^0 pitch angle. A wind speed of 10m/s represented as constant value is fed into the wind turbine with the blade pitch angle of 0^0. The output of wind turbine which is torque (Tm) is fed as input to the synchronous generator while the asynchronous induction generator speed is fed back to the wind turbine, shown in Figure 9.

A synchronous generator is connected with the WECS operated as synchronous condenser of 400kW and a capacitor bank of 75 kW to cater to reactive power demand. WECS is modeled as 3 turbine and generator sets of 0.5 MW each with total capacity of 1.5 MW; with output voltage of 0.48kV AC, 50Hz, then it is stepped up to 11 kV AC using a transformer to be integrated with the grid, also shown in Figure 9. Figure 11 shows the input wind speed fed into wind turbine and voltage generated from the asynchronous generator at WT_Bus in per unit.

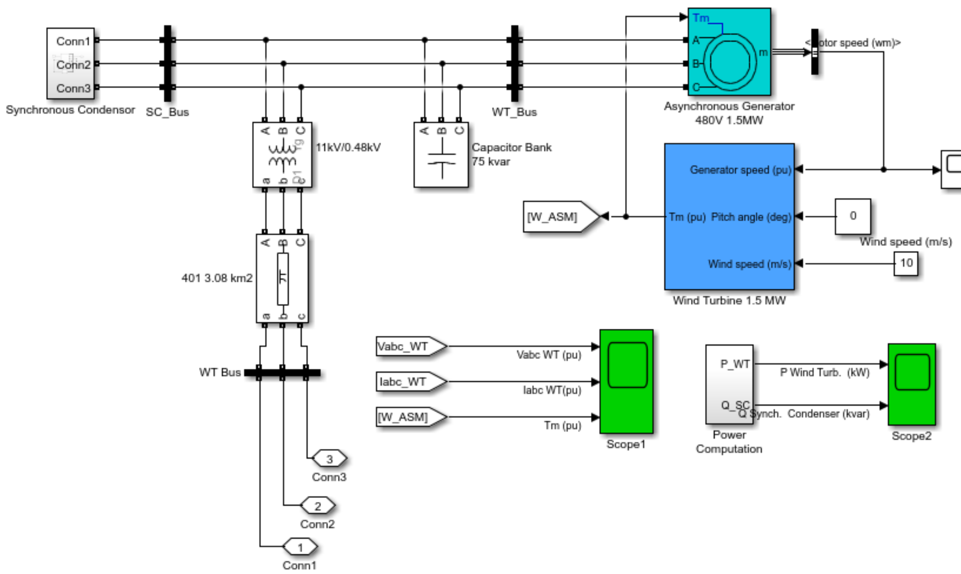

Figure 9.*MATLAB Simulink modelof wind energy conversion system.*

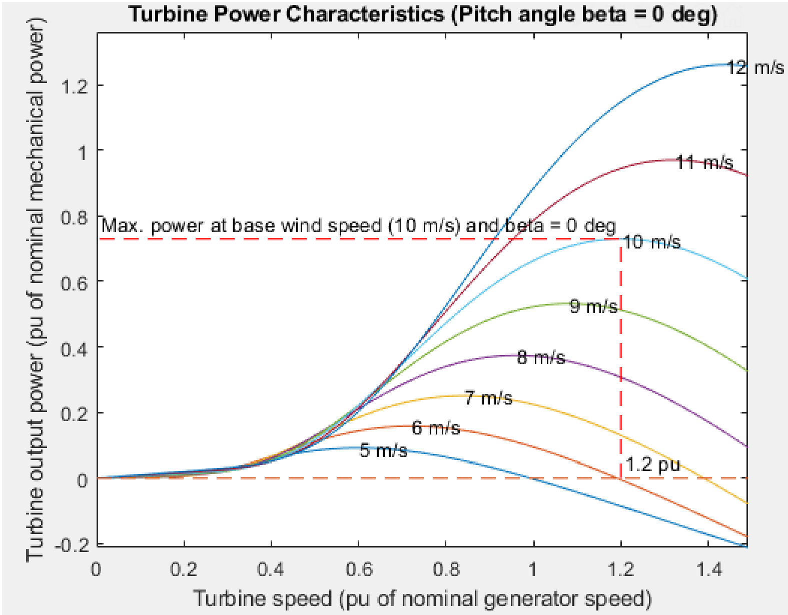

Figure 10.*Wind turbine power characteristics curve.*

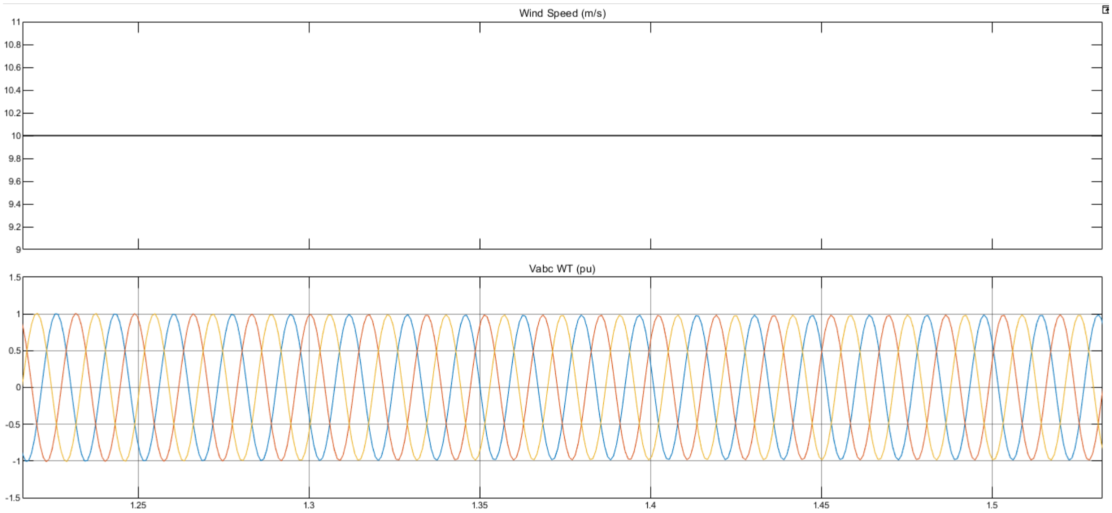

Figure 11.*1 Voltage, current output(pu) ofasynchronous generator and input wind speed to wind turbine*

The selected grid was modeled in Simulink with 64 MW of power from hydro-generators as power source in base case study. The load was modeled as constant impedance with the grid frequency set at 50Hz. A total of 14 buses with total load of 67.5 MW and 6.427 MVAR. The grid voltage level modeled includes 11kV generator buses, 66kV network with Dog conductor and 220 kV network with Zebra conductors. The conductor parameters for 66kV; whereDog conductor is used hasresistance per km of R=0.2573575Ω, impedance per kmof X=0.4165113Ωand susceptance per km of $B/2=1.38107E^{-06}\Omega$. For Zebra conductor which is used for 220 kV has resistance per kmof R=0.08Ω, impedance per km of X=0.412Ω susceptance per km of $B/2=1.40E^{-06}\Omega$. Figure 12 shows the MATLAB Simulink model of integrated grid with WECS, SPV into the existing grid.

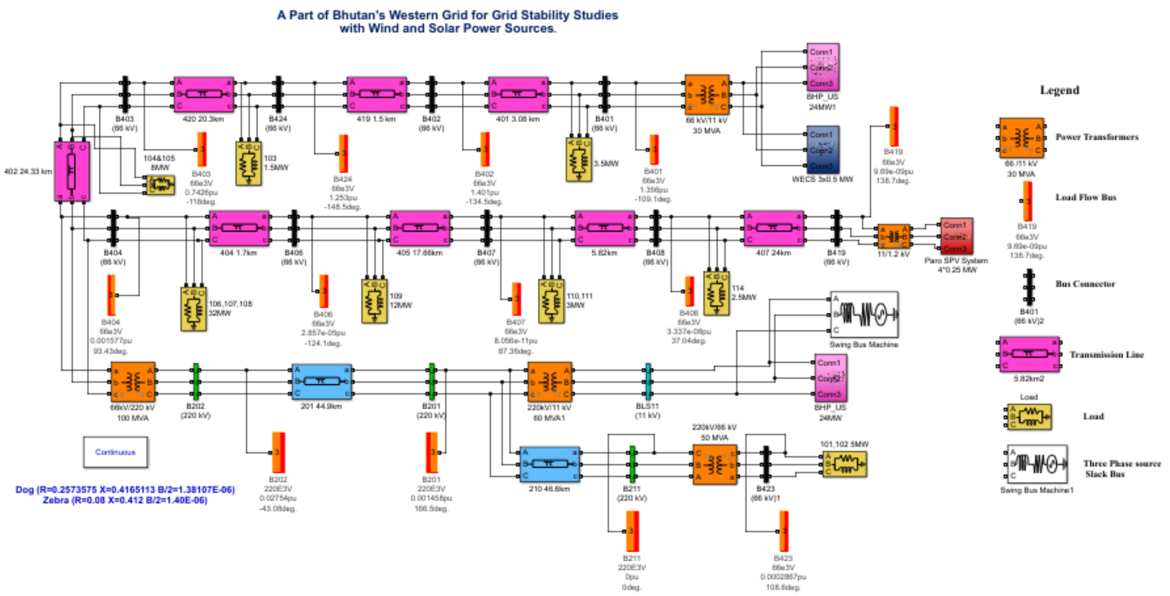

Figure 12.*Simulink Schematic model of Integrated grid with SPV and WECS.*

V. FINANCIAL MODELING AND SIMULATION

For financial analysis of the proposed systemslevelized cost of energy (LCOE) is chosen for its versatility and popularity. Renewables generally have very high capital costs compared to other sources of electricity and low running costs [3]. Monte Carlo simulation using MS Excel is employed to reflect cost variability in different cost components, life span and interest rates since normal LCOE computes only single value of LCOE. The costs considered for the Monte Carlo simulation and LCOE is derived from NREL's solar and wind energy conversion system investment guideline [17]. Monte Carlo simulation for 500 trails are performed for each varying case, where interest rates are varied from 4% to 13% for both SPV and WECS. The cost components considered for proposed system of 1.5 MW WECS and 1 MW SPV system's LCOE computation for both systems are discussed in Table 1 and Table 2.

Table 1: *LCOE parameters for WECS.*

Item	Mean	STDEV	MC simulation
	1.5		1.5
Capital	$3,000,000.00	$1,155,000.00	1629779.899
O&M	$49,500.00	$24,000.00	48410.42738
n(years)	20	2	22.93633115
i	0.06		0.06
CF	0.35	0.02	0.343474191
CRF	0.087184557		0.081385762
MWh	4599		4513.250865
LCOE($)	**67.63506652**		**40.11549805**

A capital recovery factor is calculated using equation 1

$$\boldsymbol{CRF = \frac{i(1+i)^n}{(1+i)^n - 1}} \qquad \textbf{Eq. 1}$$

Where CRF = capital recovery factor; i = interest rate and n = life span in years.

For LCOE computation, two cost components are considered the initial capital cost per kW of generated electricity which is inclusive of all other costs of converters and controllers and operation and maintenance cost in per kW.

Table 2: *LCOE parameters for Solar PV system.*

Size in MW	Mean	STDEV	MC simulation
	1		1
Capital	$2,493,000.00	$774,000.00	2409085.352
O&M	$19,000.00	$15,000.00	14429.61519
n (years)	33	9	27.29618441
i	0.06		0.06
CF	0.22	0.02	0.242961724
CRF	0.070272935		0.075359827
MWh	1927.2		2128.344699
LCOE($/MWh)	**100.7629861**		**92.0799488**

Total energy generated per year is calculated by equation 2.

$$\boldsymbol{Total\ MWh = CF * plant\ size * 8760} \qquad \textbf{Eq. 2}$$

Where CF= Plant Capacity Factor, Plant Size= Plant Size in MW.
LCOE is then calculated by using equation 3

$$\boldsymbol{LCOE = \frac{CRF*C+O}{Total\ MWh}} \qquad \textbf{Eq. 3}$$

Where LCOE= Levelized Cost of Energy($/MWh), CRF= Capital Recovery Factor, C= Initial Capital Cost, O= Operation and Maintenance Cost.

VI. RESULTS AND DISCUSSIONS

For interconnection of any electrical power sources to the existing grid or for synchronization, there are set of conditions to be fulfilled. The terminal voltage should be equal voltage magnitude, frequency, and phase angle [18]. The output from the solar and wind energy conversion systems should fulfill these criteria in order to integrate with existing grid. The existing grid operates as three phase networks, with 120^0 phase difference between any two phases and at a frequency of 50Hz with voltage levels from 11kV to 220kV. The solar and wind energy systems are connected to a 66 kV bus at Bus no 401 and 419 respectively after stepping up the generating voltages from 1200 Vrms to 66 kV in case of SPV system and from 11/66 kV in case of WECS, which is described in Figure 12. The voltage generated from SPV and WECS are with minimum magnitude of 1 pu, frequency of 50Hz and phase difference of 120^0 , as shown in Figure 8 and Figure 11. Therefore, the SPV and WECS model is suitable for integrating into an existing grid.

Further, Solar PV and WECS system are validated using IEEE standard 1547, standard for interconnection of distributed renewable sources with electric power systems and then integrated into the grid. The voltage of the renewables to be integrated must be between 0.917 to 1.05 pu, frequency between 49.5 to 50.1 Hz , the total harmonic distortion must be below 5 % [19]. Both the SPV and WECS have generated voltage of 1.0 pu, total harmonic distortion of 1.38% in case of SPV and at a frequency of 50Hz.

The base case load flow simulation was set up with two hydropower stations with total installed capacity of 64MW (Basochu upper stage 24 MW and Basochu lower stage 40 MW) with 3 phase source as swing bus with three phase short circuit ratio of 500 MVA at X/R ratio of 7. For load flow analysis the base power was set to 100 MVA, PQ tolerance to 0.01; maximum iteration 100000 at 50Hz. The swing bus and PV bus voltage magnitude were set at 1.05 pu. Similar settings were applied to load flow simulation for integrated grid with 1 MW Solar PV and 1.5 MW of Wind power. On both the occasions the load flow converged within the set criteria. Table 3 and Figure 13describes the load flow voltage comparison of base case and integrated grid.

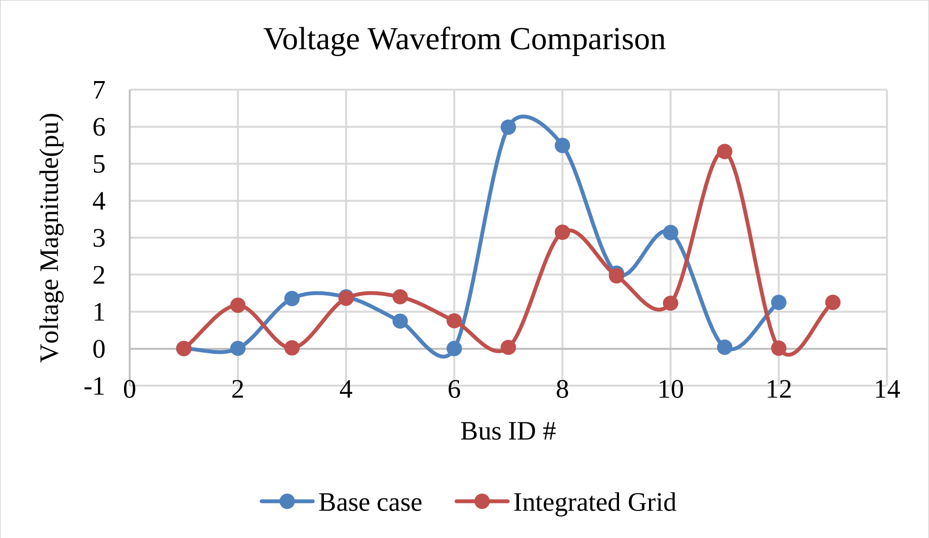

Figure 13: *Load flow voltage comparison between base case and integrated grid.*

Table 3. Load Flow Voltage Magnitude.

Bus ID #	Bus #	Base case	Integrated Grid
1	201	0.003	1.171
2	202	0.0103	0.02
3	401	1.3566	1.3599
4	402	1.4	1.3996
5	403	0.7434	0.7506
6	404	0.0043	0.033
7	406	5.987	3.146
8	407	5.491	1.969
9	408	2.036	1.225
10	419	3.139	5.326
11	423	0.0411	0.01
12	424	1.2528	1.2477

From Figure 13 and Table 3 it is observed that the load flow bus voltages without solar photovoltaic system and wind energy conversion systems at buses 201,401,403,407 and 408 are 0.003 pu, 1.3556 pu,0.7434 pu,5.491 pu and 2.036 pu respectively from base case load flow results. For the same buses the voltage magnitude with solar photovoltaic system and wind energy conversion systems atbuses 201,401,403,407 and 408 are improved to 1.171 pu, 1.3599 pu,1.3996 pu,1.969 pu and 1.225 pu respectively. This is also illustrated in Figure 13; which shows that solar photovoltaic and wind energy conversion systems may be used for improvement of voltage stability and regulate voltage.

Along with voltage stability analysis using load flow, steady state voltage analysis of the models was also performed. Similar to the voltage stability analysis using load flow analysis; the steady state analysis was carried out for the existing grid without solar photovoltaic system and wind energy conversion system. Then the steady state analysis for integrated grid with solar photovoltaic system and wind energy conversion system was performed and two voltage magnitudes were compared to check the improvement in voltage stability. For steady state analysis peak voltages at various buses were measured using steady state tool of powergui block of MATLAB Simulink at a grid frequency of 50Hz, which is described in Figure 14 and Table 4.

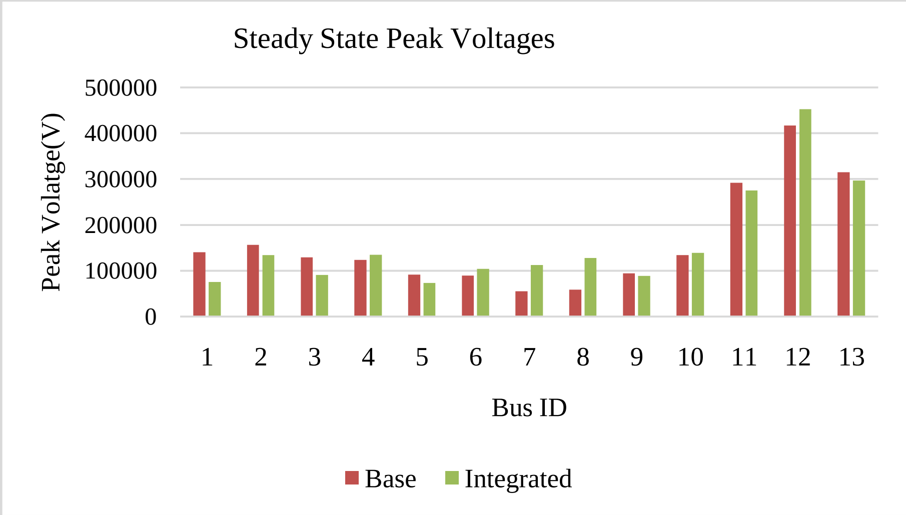

Figure 14: *Steady state peak voltage at 50Hz across various buses.*

Table 4. Load Flow Voltage Magnitude.

Steady State values of Peak Voltages			
Bus #	**Bus ID**	**Base**	**Integrated**
401	1	140532.81	75503.29
402	2	156568.29	133822.57
403	3	129095.73	90976.71
404	4	123524.7	134442.96
406	5	91538.99	73212.71
407	6	89724.19	104184.54
408	7	55050.11	112327.46
419	8	58797.4	127787.65
423	9	94282.36	88921.77
424	10	134356.5	139004.62
201	11	292016.89	275413.74
202	12	416920.9	452572.97
211	13	314936.76	297030.46

Figure 14 and Table 4 describes steady state peak voltages of grid with and without solar photovoltaic systems and wind energy conversion systems. The steady state peak voltage at buses 404, 407, 408, 419 and 424 were measured to be 123524 V, 89724 V, 55050 V, 58797 V and 134356 V respectively for grid without solar photovoltaic systems and wind energy conversion systems. These steady state peak voltages at buses 404, 407, 408, 419 and 424 improved to 134442 V, 104184 V, 112327 V, 127787 V and 139004 V respectively with introduction of solar photovoltaic systems and wind energy conversion systems; which is illustrated in Figure 14. Thus, it may be proved that the voltage profile has improved with solar and wind energy conversion systems in the grid.

Financial analysis using LCOE is done for both solar photovoltaic systems and wind energy conversion systems. The WECS systems cost derived from NREL is given as;capital cost of $3000000 per MW with a deviation of $1155000 per MW; operation and maintenance cost of $49500 per MW with a deviation of $24000 per MW and life span of 20 years with a deviation of 2 years, described in Table 1. LCOE at an interest rate of 6% without incorporating deviations is $ 67.63 per MW. Since this LCOE does not incorporate deviations, Monte Carlo Simulation technique is employed to compute over 500 trails which are then averaged for each varying interest rate. For the proposed system of 1MW solar and 1.5MW wind power plant LCOE was computed using Monte Carlo simulation, at an interest rate of varying interest rates from 4% to 13% incorporating various cost deviations.

Figure 15 shows Monte Carlo simulation of LCOE for wind energy systems over 500 trials at interest rate of 6 %, the average LCOE is estimated to be around $70 per MWh averaged over 500 trails and maximum of $ 148 per MWh. As interest rate increases the LCOE also increases giving positive correlation shown in Figure 16. It also shows the different LCOEs as interest rate is varied from 4% to 13% simulated over 500 trails. It is observed that average LCOE increaseswith interest rates as expected.

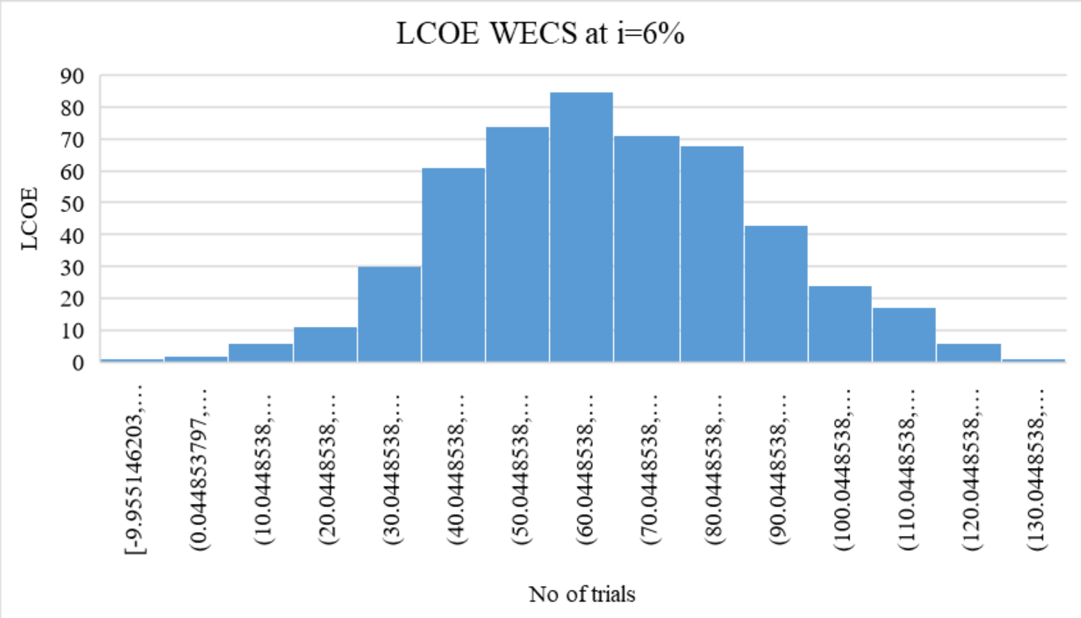

Figure 15:*Histogram of LCOE($/MWh) at i=6% with Monte Carlo Simulation.*

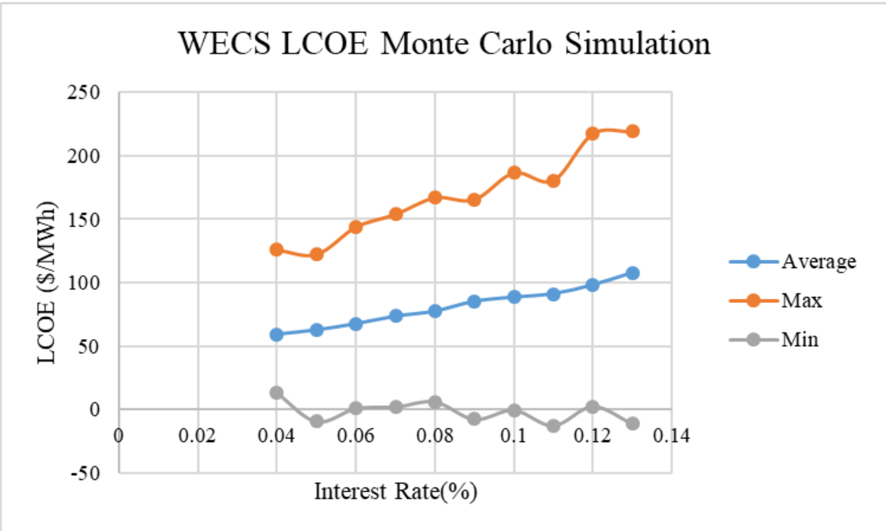

Figure 16: *Graph showing varying LCOE of WECS at different interest rates.*

Similarly, for solar photovoltaic system the NREL cost given are; capital costs of $2493000 per MW with deviation of $774000 per MW, operation and maintenance cost of $19000 per MW with deviation of $15000 per MW and life span of 33 years with deviation of 9 years. The LCOE computed without incorporating deviations is $100.76 per MW at 6 % interest rate.

The average LCOE using Monte Carlo Simulation from 500 trails at interest rate of 6 % is $104.00/- per MWh averaged over 500 trails and a maximum of $ 347.00/- per MWh shown in Figure 17 and Figure 18. LCOE using Monte Carlo Simulation with interest rates varying from 4% to 13% were performed over 500 trails and then averaged to get good LCOE whilst also noting maximum and minimum LCOE over 500 trails which is described in Figure 18. Figure 18also shows that LCOE increases with increase in interest rate from 4% to 13 % with Monte Carlo Simulation over 500 trails.

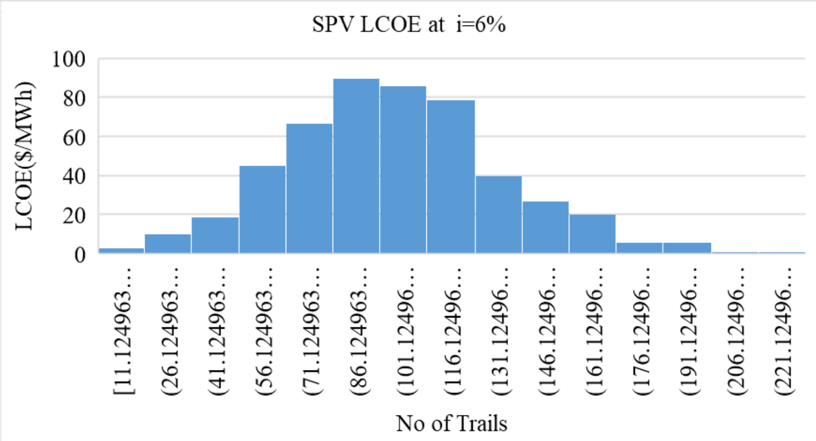

Figure 17: *Histogram of SPV LCOE at i=6% with Monte Carlo Simulation.*

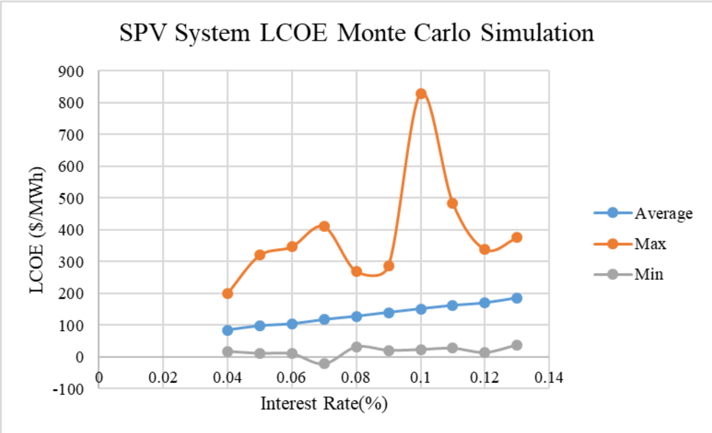

Figure 18:*Graph showing varying LCOE of solar PV system at different interest rates*.

VII. CONCLUSIONS

System stability studies with renewables integrated into the grid has become important because of increasing penetration of renewables especially solar and wind into the energy mix. Due to intermittent nature of the resource the power generation is also varying but both the solar and wind are modular in nature where by installation of power plants becomes easier. The conventional AC grid operates at a constant voltage and frequency, wind and solar systems have to generate power at constant voltage and frequency by using power converters which increases the overall cost of the system. From this study following conclusions can be drawn:

- ✓ Voltage stability improves with wind and solar power systems integrated into the grid; voltage at buses 201,401,403,407 and 408 have improved from 0.003 pu, 1.3556 pu,0.7434 pu,5.491 pu and 2.036 pu to 1.171 pu, 1.3599 pu,1.3996 pu,1.969 pu and 1.225 pu respectively with solar photovoltaic and wind energy conversion systems integrated into the grid.
- ✓ Steady state peak voltages at buses 404, 407, 408, 419 and 424 were improved from 123524 V, 89724 V, 55050 V, 58797 V and 134356 V to 134442 V, 104184 V, 112327 V, 127787 V and 139004 V respectively withsolar photovoltaic and wind energy conversion systems integrated into the grid.Thus, it may be concluded that overall voltage stability of the grid is improved with SPV and WECS.
- ✓ FurtherLCOE at 6% for WECS is averaged over 500 trails with life span of 20 years was found to be$70 per MWh. Similarly, for SPV LCOE averaged over 500 trails with life span of 33 years was found to be $104per MWh. At an interest rate of 7% LCOE of WECS and SPV was estimated at $73.53 per MWh and $117.74 per MWh respectively

The present study may be useful for future planning of wind and solar PV system to be integrated into the existing grid and making financial decisions on wind and solar PV projects. Additional research may be developed to analyze system stability by adding more renewable generators or increasing penetration of renewables into the grid. Along with load flow studies; transient stability analysis, low voltage ride through analysis using control equipment's such as STATCOMS, UPFC, or energy storage can be researched.

REFERENCES

[1]. IPCC, *Climate change 2014. Synthesis report. Versión inglés*. 2014.

[2]. IRENA (2019), *Global Energy Transformation: A Road Map to 2050*. Abu Dhabi: International Renewable Energy Agency, 2019.

[3]. REN21(2018), *Renewables 2018 Global Status Report*. Paris: REN21 Secretariat, 2018.

[4]. J. O. Petinrin and M. Shaaban, "Impact of renewable generation on voltage control in distribution systems," *Renew. Sustain. Energy Rev.*, vol. 65, pp. 770–783, 2016.

[5]. R. M. E. A. and A. M. A. Erhab Youssef, "Comparative Study of Voltage Stability Analysis for Renewable Energy Grid-Connected Systems Using PSS/E," *Proc. IEEE SoutheastCon 2015*, no. 608593, 2015.

[6]. T. Subramaniam, M. Safwan, and A. Rahman, "An Investigation on the Power System Stability of Photovoltaic Grid Integrated System," *7th Int. Conf. Control Syst. Comput. Eng.*, no. November 2017, pp. 24–26, 2018.

[7]. M. R Patel, *Wind and Solar Power Systems*, 2nd ed. New York,USA: Taylor & Francis, 2010.

[8]. B. Khan, *Non Conventional Energy Sources*, 1st ed. New Delhi: Tata McGraw Hill, 2007.

[9]. B. Department of Renewabale Energy, MoEA, "Bhutan Energy Data Directory," Thimphu, 2015.

[10]. N. S. Bureau, *Statistical Yearbook of Bhutan 2018*, October 20., no. October. Thimphu,Bhutan: National Statistical Bureau, 2018.

[11]. MoEA, "Overview of Energy Policies of Bhutan," no. May, pp. 1–12, 2009.

[12]. H. Saadat, "Power System Analysis," *Climate Change 2013 - The Physical Science Basis*. 1999.

[13]. D. Asija, P. Choudekar, K. M. Soni, and S. K. Sinha, "Power flow study and contingency status of WSCC 9 Bus test system using MATLAB," in *2015 International Conference on Recent Developments in Control, Automation and Power Engineering, RDCAPE 2015*, 2015.

[14]. N. Tenzin and R. P. Saini, "Wind and Solar Resource Potential Assessment in Bhutan," *Int. J. Eng. Advacnced Technol.*, vol. 8, no. 3, pp. 391–395, 2019.

[15]. P. Gilman, S. Cowlin, D. Heimiller, and P. Gilman, "Potential for Development of Solar and Wind Resource in Bhutan.," USA, 2009.

[16]. B. Department of Renewable Energy, MOEA, "Bhutan Energy Data Directory 2015," DRE, MoEA,Bhutan, Thimphu,Bhutan, 2015.

[17]. NREL, "Energy Analysis," *National Renewable Energy Laboratory*, 2019. [Online]. Available: https://www.nrel.gov/analysis/tech-lcoe.html.

[18]. M. G. Farret, Felix A; Simoes, *Integration of Alternative Sources of Energy*. Hoboken, New Jersey: John Wiley & Sons, 2006.

[19]. Institute of Electrical and Electronics Engineers, *IEEE Std. 1547-2018. Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*. 2018.

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