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Mitigation of Voltage Stability Problem Caused in the Hybrid Wind and Solar Outputs

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Abstract: The sun and wind-based power generation are considered to be the alternate sources of green energy where solar energy can be obtained from photovoltaic (PV) panels and wind energy from wind turbines. Due to advancements in renewable energy technology and the continuous rise in petroleum product costs, hybrid renewable energy (RE) systems are becoming more important for producing power to fulfill today's rising energy demands. This project introduces the hybrid energy system which consists of the combination of solar and wind system connected to the DC load. DC-DC buck boost converter (BBC) with controller unit is also implemented for each source. The aim of this project is to stabilize the output voltages produced by both systems using the power converter for different variations of input parameters (irradiation, temperature and wind speed). The system was simulated in MATLAB/SIMULINK (R2018a). Complete descriptions and detailed results of the simulation show the effective voltage stability of the proposed hybrid system.

Keywords: Voltage Stability Problem, Photovoltaic, Renewable Energy Technology

1. Introduction

Renewable energy (RE) is also known as clean energy of natural resources. These have been harnessed by human beings since long time for many purposes such as heating, transportation, lighting and many more. But as the time passes, these resources have slowly turned to a cheaper and dirtier energy sources which are mostly known as the non-RE resources (NRER). Two of them are fossil fuels and nuclear energy. Besides the NRER have lot of disadvantages like it can be dangerous enough to cause respiratory problems to humans due to the gas emitted such as carbon monoxide, also huge amount of fuel needed to keep the power station working therefore it is very expensive and many other disadvantages that is related to health and atmosphere another main draw-back is of their depletion with time. For this purpose, many innovations have been made in the field of electrical

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power generation by using RE. Most commonly used are solar and wind resources for the power generation. Since sunlight and wind depend on time and weather conditions, therefore output from them also varies with respect to time which is unstable. It will create more problem if they are used in combination as hybrid to be utilized to run the load. Both of these resources output is DC, which is to be converted in AC for the application of AC loads.

One of the issues in hybrid solar and wind power generation is the instability of the electric grid such as the DC voltage level of the sources, energy stockpiling and burden may not be the equivalent and should be ventured up or down for the devices to be connected in a system [1]. Therefore, the output from both photovoltaic and wind turbine will never be the same as they depend on weather conditions and times. Also, they don't match whether in the day or night. The merging of the two energies can only be done when the two voltages outputs are equal and one of the methods that can be used is by using DC-DC buck-boost converter (BBC) at both outputs to stabilize it before being merged [2]. The proposed control of BBC takes the estimations of the input voltage and the output voltage into consideration so as to decide the equal estimation of the duty cycle with the required output voltage [3]. This converter helps to increase or decrease the voltage levels so as to synchronize their outputs before being supplied to the load. This combination of these two energies is one of the solutions to resolve the energy crisis problem in developed countries. To solve this problem MATLAB was used for the simulation purpose.

2. Hybrid Solar and Wind System Design

The block diagram of the hybrid solar and wind system is as shown in Figure 1. The hybrid system consists of solar PV system, wind energy conversion system (WECS), PMSG, DC-DC converter, AC/DC Rectifier and DC load. Solar PV and wind turbine will generate power to be supplied to the load. The DC-DC converter will act as step up or step down in order to stabilize the output voltages. The PMSG will convert the mechanical output from wind turbine and convert it into electrical energy to be supplied to the load. The AC/DC rectifier will convert the AC currents produced by PMSG to DC currents.

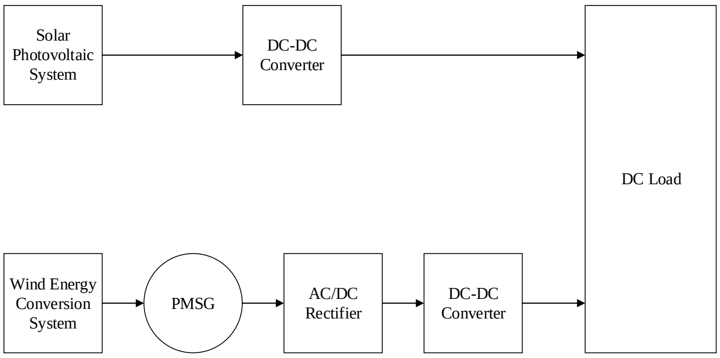

Figure 1: Block diagram of hybrid solar and wind system

2.1 Solar System

Simulink block diagram of the PV array is as shown in Figure 2. Two inputs given to the PV array are temperature and irradiance to produce outputs such as voltage, current and also diode current from the PV array. For this project, only the voltage was taken as output that need to be stabilized in the next step. The subsystem of the PV array is shown in Figure 3. The PV Array block implements a PV module array. The array is made up of strings of modules connected in parallel, with each string made up of modules connected in series. This block allows simulation of preset PV modules from the National Renewable Energy Laboratory's (NREL) System Advisor Model (2018) and the electrical parameters of the PV array [4] that are used in this project was shown in Table 1. The module PV array used in this project is SunPower SPR-305E-WHT-D.

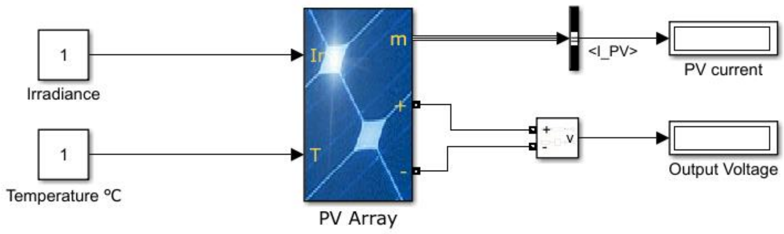

Figure 2: Simulink block diagram of the PV array

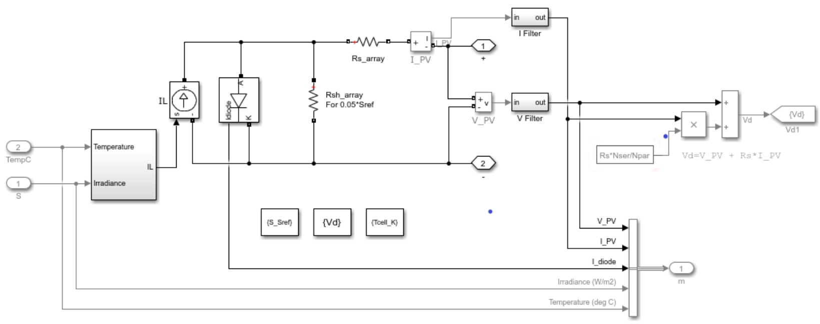

Figure 3: Subsystem of PV array

Table 1: Electrical parameters of PV array

PARAMETERS	Symbol	VALUES
Maximum Power	W	305.226
Open circuit voltage, V_{oc}	V	64.2
Voltage at maximum power point	V	54.7
Temperature coefficient of V_{oc}	% / °C	-0.27269
Cells per module (Ncell)	N_{Cell}	96
Short circuit current, I_{sc} (A)	A	5.96
Maximum current (A)	A	5.58
Temperature coefficient of I_{sc} (%/°C)	% / °C	0.061745
No. of parallel strings	-	50
No. of series-connected modules per string	-	4
Light-generated current, I_L (A)	A	6.0092
Diode saturation current, I_o (A)	A	6.3014e-12
Diode ideality factor	-	0.94504
Shunt resistance, R_{sh} (ohms)	Ω	269.5934
Series resistance, R_s (ohms)	Ω	0.37152

2.2 Windmill System

The main devices used in the windmill are wind turbine and PMSG that was modelled in MATLAB [5] is as shown in Figure 4 and the subsystem of the wind turbine was shown in Figure 5. Wind turbine will take the wind speed as the input and the output is in terms of torque applied to the generator shaft. Then the output torque was fed to the PMSG which produces three phase AC voltages. These voltages were converted to DC. The output voltages then need to be synchronized with PV system.

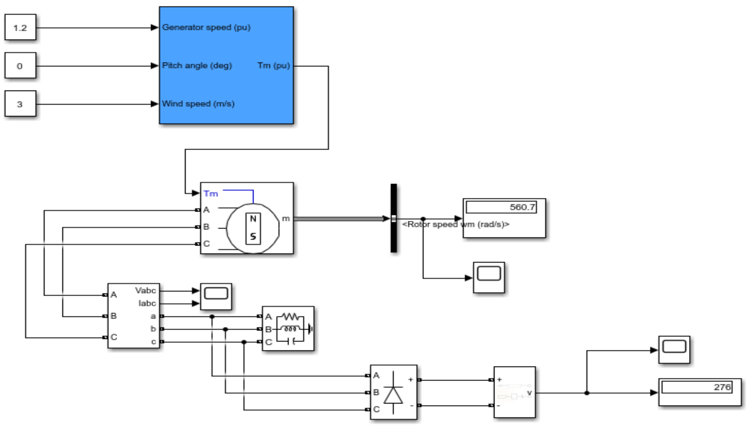

Figure 4: Wind turbine and PMSG

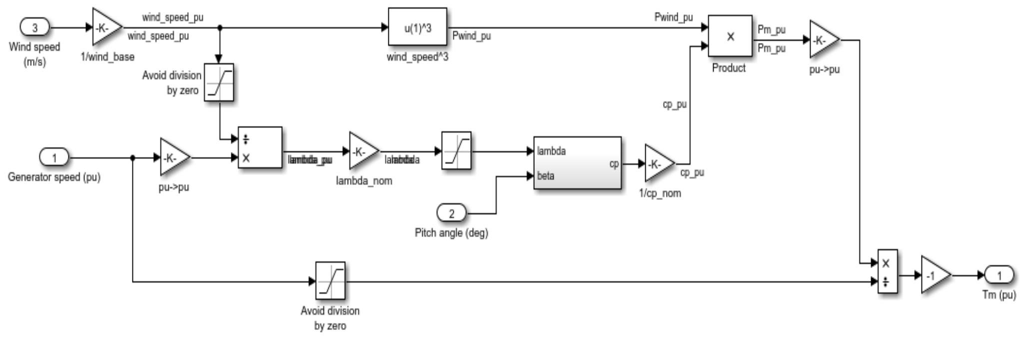

Figure 5: Subsystem of wind turbine

Table 2 shows the parameters of the wind turbine while Table 3 shows the electrical parameters of the PMSG that were used in this project. These parameters are from standard manufacturer.

Table 2: Electrical parameters of windmill

Parameters	Symbol	Values
Nominal mechanical output power	W	200
Base power of electrical generator	VA	222.22
Base wind speed	m/s	2.5
Maximum power at base wind speed	pu	0.73
Base rotational speed	pu	1.2
Pitch angle beta	deg	0

Table 3: Electrical parameters of PMSG

Parameters	Symbol	Values
Stator phase resistance, Rs	Ω	0.18
Armature inductance	H	0.000835
Flux linkage established by magnets	V.s	0.0714394
Voltage constant	V/kprm	51.8307
Torque constant	N.m/A	0.428636
Inertia	J	0.000621417
Friction factor	N.m.s	0.000303448
Pole pairs	-	4

2.3 Buck Boost Converter

Figure 6 below shows the BBC circuit designed in the Simulink. The circuit consists of two parts which are BBC and a controller. In BBC, the components used are MOSFET, inductor, capacitor, diode and resistor. The subsystem of the controller is as shown in Figure 7. The electrical parameters for the components used of BBC for PV and wind system enlisted in Table 4 while parameters for the controller [6] used are given in Table 5. The BBC operation depends on the conduction state of MOSFET and a control unit was added, which detects the level of output voltage and selects the appropriate circuit action either it needs to step up or step down the voltages.

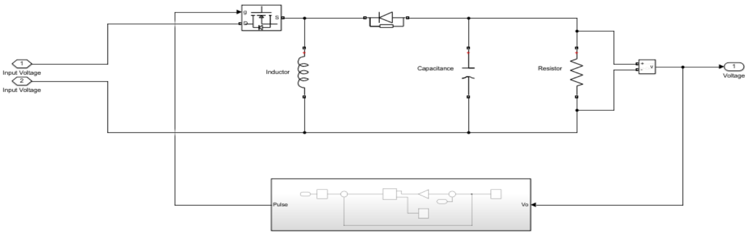

Figure 6: BBC with controller circuit in solar and wind system

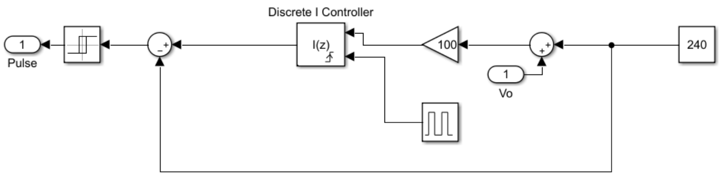

Figure 7: Subsystem of the controller circuit used in BBC

Table 4: Electrical Parameters of BBC used for PV and Wind System

Parameters	Symbol	Values
Inductor	H	4.05e-3
Capacitor	F	2e-6
Resistor	Ω	100
FET resistance, R_{on}	Ω	0.1
Internal diode inductance, L_{on}	H	0
Internal diode resistance, R_d	Ω	0.01
Internal diode forward voltage, V_f	V	0
Snubber resistance, R_s	Ω	1e5

Table 5: Electrical Parameters of Controller

Parameters	Symbol	Values
Amplitude	-	1
Period	sec	1/10000
Pulse width	-	0.1*100
Voltage reference	V	24
Gain	-	100

The DC-DC controller design is based on the reference voltage of 24 volts. Therefore, any excess voltage input to it will get bucked while vice versa if it lacks.

2.4 Hybrid Solar-Wind System

Both output voltages from solar and windmill systems are connected to produce a single output to be supplied to the load as shown in Figure 8. The capacitor is used to smooth out the fluctuating signal to make it more steady/smooth. The input parameters for irradiance, temperature and wind speed were taken from the previous research [7] collected at Seri Iskandar, Malaysia in 2018. The maximum and the highest average solar irradiance during the year 2018 are 915 W/m^2 and 298.9 W/m^2 respectively. The maximum and average temperature during this time is 32 °C and 26 °C respectively. The maximum and the average wind speed during this time are 3.2 m/s and 2.03 m/s respectively.

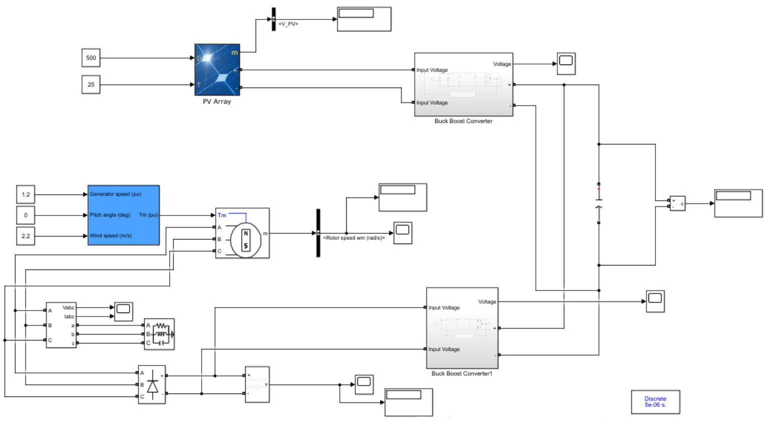

Figure 8: Hybrid solar-windmill system with BBC

3. Results of The Hybrid Solar and Wind System

The data was manipulated before using it for simulation. Three levels of data were collected i.e., minimum, average and maximum. The tool used from simulation is MATLAB/Simulink. All simulations were made for 10 sec. Initially, three inputs were used i.e., the maximum irradiance, maximum temperature and also maximum wind speed. Figure 9 and Figure 10 show value of output voltages from both systems which are 48.33V and 21.30V respectively. These outputs were then fed to the BBC, which produced the stabilized voltage of 24 volts as shown in Figure 11. The comparison of output of both the systems with and without BBC is tabulated in Table 6. It can be observed from the results that the BBC converter will step down the voltage to a lower level for the solar system because the voltage produced is greater than the reference voltage, making BBC as a Buck Converter; however, the BBC converter will act as a Boost Converter and step up the voltage for the wind system because the voltage produced is less than the reference voltage. BBC provides voltage of 24V, which is the same as the reference voltage. Later it was merged for the synchronized output.

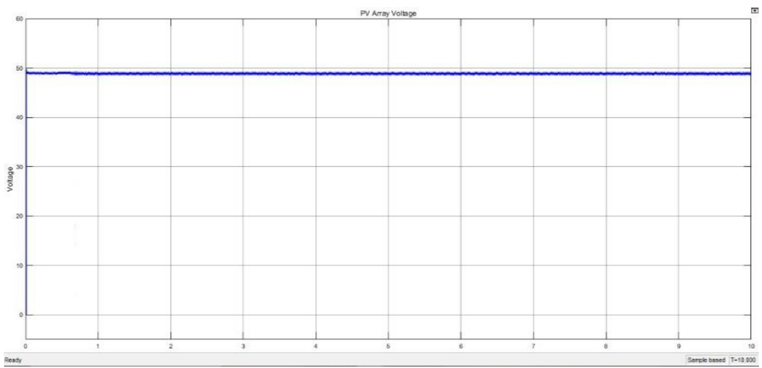

Figure 9: Voltage output for maximum value of irradiance and temperature of PV Array

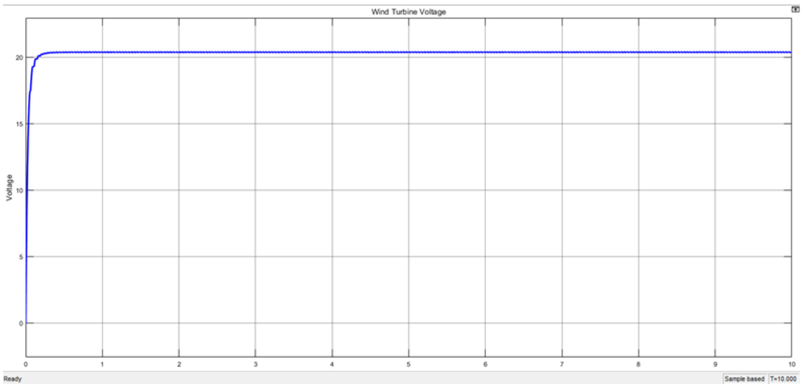

Figure 10: Voltage output for maximum value of wind speed

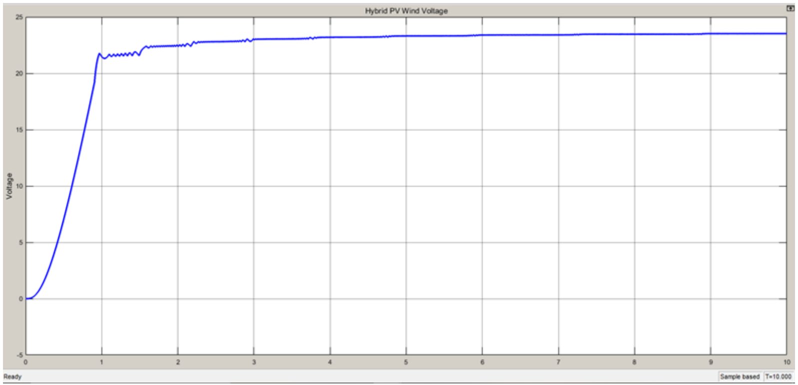

Figure 11: Voltage output of hybrid system with maximum values of input

Table 6: Voltage comparison for both systems with and without BBC with maximum value of input

Systems	Voltage Output Without BBC (V)	Voltage Output with BBC (V)	BBC Mode
Solar	48.33	24	Buck
Wind	21.30	24	Boost

Afterwards, the average value of inputs of irradiance, temperature and wind speed were being given to both systems and the results of output voltage are as shown in Figure 12 and Figure 13 respectively. The voltages produced from both solar and wind system are 28.58V and 16.45V respectively. Then, this output was fed to the BBC to provide stabilized output voltage as shown in Figure 14. For ease of the analysis, the results are summarized in Table 7. The voltage output for solar system is higher than the reference voltage, therefore, BBC will operate as a buck converter, stepping down the voltage to a lower level. For the wind system, the output voltage is below the reference voltage level thus, BBC will operate as boost converter which will step up the voltage to the voltage reference level which is 24V. Then, the outputs from both systems were combined together.

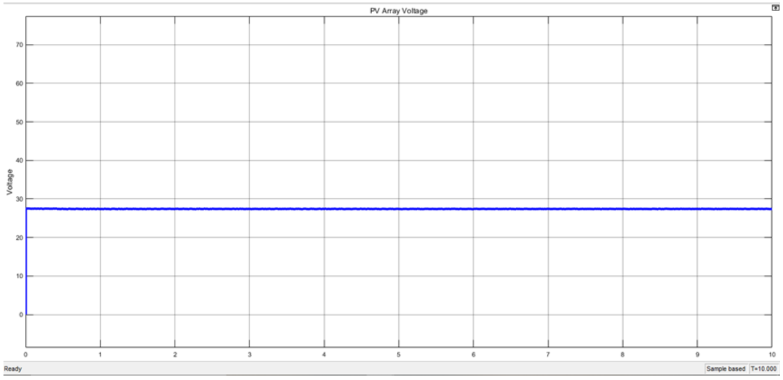

Figure 12: Voltage output for average value of irradiance and temperature of PV Array

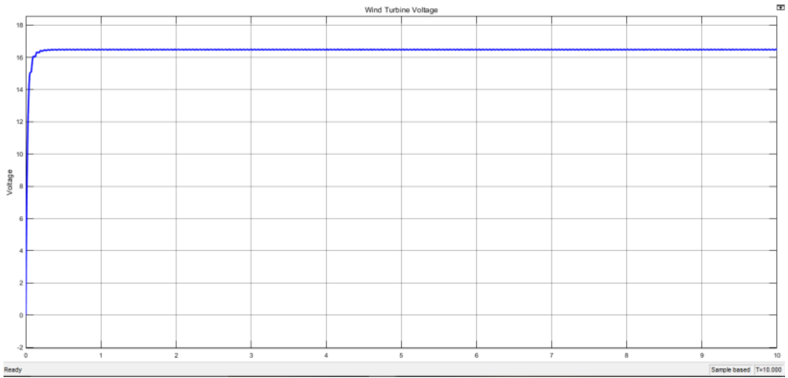

Figure 13: Voltage output for average value of wind speed

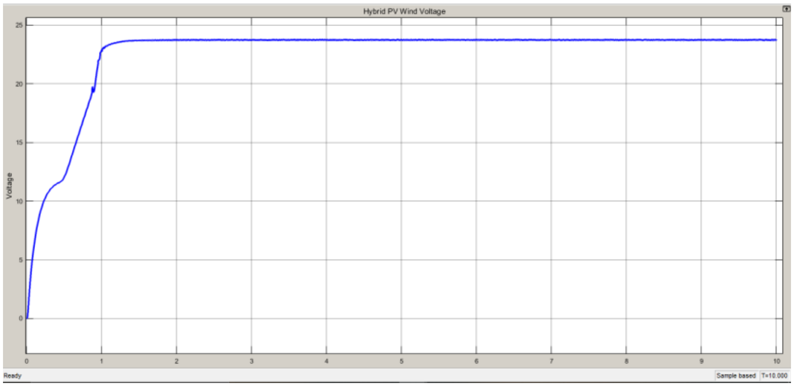

Figure 14: Voltage output of hybrid system with average values of input

Table 7: Voltage comparison for both systems with and without BBC with average value of input

Systems	Voltage Output Without BBC (V)	Voltage Output with BBC (V)	BBC Mode
Solar	28.58	24	Buck
Wind	16.45	24	Boost

4. Conclusion

As a conclusion, the design of BBC for hybrid solar-wind system was constructed to get stabilized output of 24 V. It fulfils the first objective. Simulation was conducted using MATLAB/SIMULINK (R2018a) for 10 sec. The performance of the system was evaluated in stand-alone mode with two types (maximum and average values) of wind speed, level of irradiation and temperature. As observed from the simulation, the output voltage of both solar and wind systems without implementation of BBC was not synchronized, therefore the voltage cannot be merged together to be supplied to the load. Implementation of BBC to both solar and wind systems cause the output voltages to be synchronized at a same voltage level thus enabling the output voltages from both systems to be combined together.

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