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Research Article

Investigation of Hybrid Renewable Energy Source and Hybrid Energy Storage System

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Abstract

There are many renewable energy sources in nature today. The most commonly used of these are solar, wave, wind and flow energy. The weakest aspect of these renewable energy sources in nature is that the amount of energy produced depends on the nature conditions. The power generation capacities of these energy sources depending on the weather conditions in order to more stable them are necessary to combine. By combining more than one renewable energy source, a hybrid power generation system is created. Hybrid energy storage units are added to this hybrid power generation system to ensure persistence of energy. In this study, sea flow energy and offshore wind energy are combined and a hybrid power generation system has been created. In addition, a hybrid energy storage unit consisting of a battery and ultracapacitor has been created in order to ensure the persistence of the energy produced. All two hybrid units were simulated using MATLAB/Simulink program. By integrating these systems with each other, their dynamic behaviors were investigated under possible working conditions. The results of the simulation show that the hybrid energy storage unit supports the wind and sea flow energy.

Keywords: Hybrid Energy Storage; Hybrid Power Generation; Power Converters; Renewable Energy Sources

Highlights

1. The instability of renewable energy sources has been eliminated by establishing a hybrid power system.
2. A hybrid energy storage system has been created by using battery and ultracapacitor which have complementary features.
3. Hybrid energy storage system has been shown to prevent voltage and power fluctuation.
4. The possible working conditions results of the simulated hybrid power generation and hybrid energy storage system are given.

Introduction

Several countries around the world are undertaking many works and goals on large-power renewable energy source (RES) and also energy storage systems. Another disadvantage of RES such as wind, wave and solar energy as well as installation and investment costs is that the power they produce is discontinuous, variable and unstable. The generated energy can be intermittent in seconds, minutes. It may even last longer due to seasonal changes. These unsteady behaviors can reveal several important problems such as voltage sag and frequency change on a grid. In order to eliminate this effect, renewable energy resource installations were carried out geographically to different regions [1-2]. The most convenient way to correct this unstable and discontinuous output characteristic of renewable energy sources (RES) is the use of energy storage systems. By means of different algorithms developed, it is possible to control the flow of energy and transfer the energy between the systems. Storage units have enabled the efficient use of the RES's by eliminating these negative effects. These demands in RES, by increasing the efficiency energy storage units in recently technology, have become an exciting subject in the implementation fields [2].

For floating platform applications, there are different axis wind turbines, and the vertical axis wing design studies have been carried out recently. A concept with a nominal capacity of 5MW was created with the Darrieus type wind turbine developed by Cranfield University and Norwegian University of Science and Technology. The dynamic behavior of the designed turbine has been investigated and performance and improvement studies have been carried out [3]. Furthermore, it is necessary to develop specific design criteria for heavy operating conditions (fluctuation, swing, wobble) of vertical axis wind turbines located in sea/ocean environment [4-5]. An overview of round and semi-submersible motion responses is presented, illustrating the interaction of aerodynamic and hydrodynamic charges on the movement of the platform by simulating various environmental conditions [5]. As a result of these studies, even though floating support structures can adequately support vertical-axis wind turbines, the vertical axis wind turbines, especially in wavy weather conditions, have to be redesigned in order to prevent them because they are subjected to excessive tensile stress [6-7].

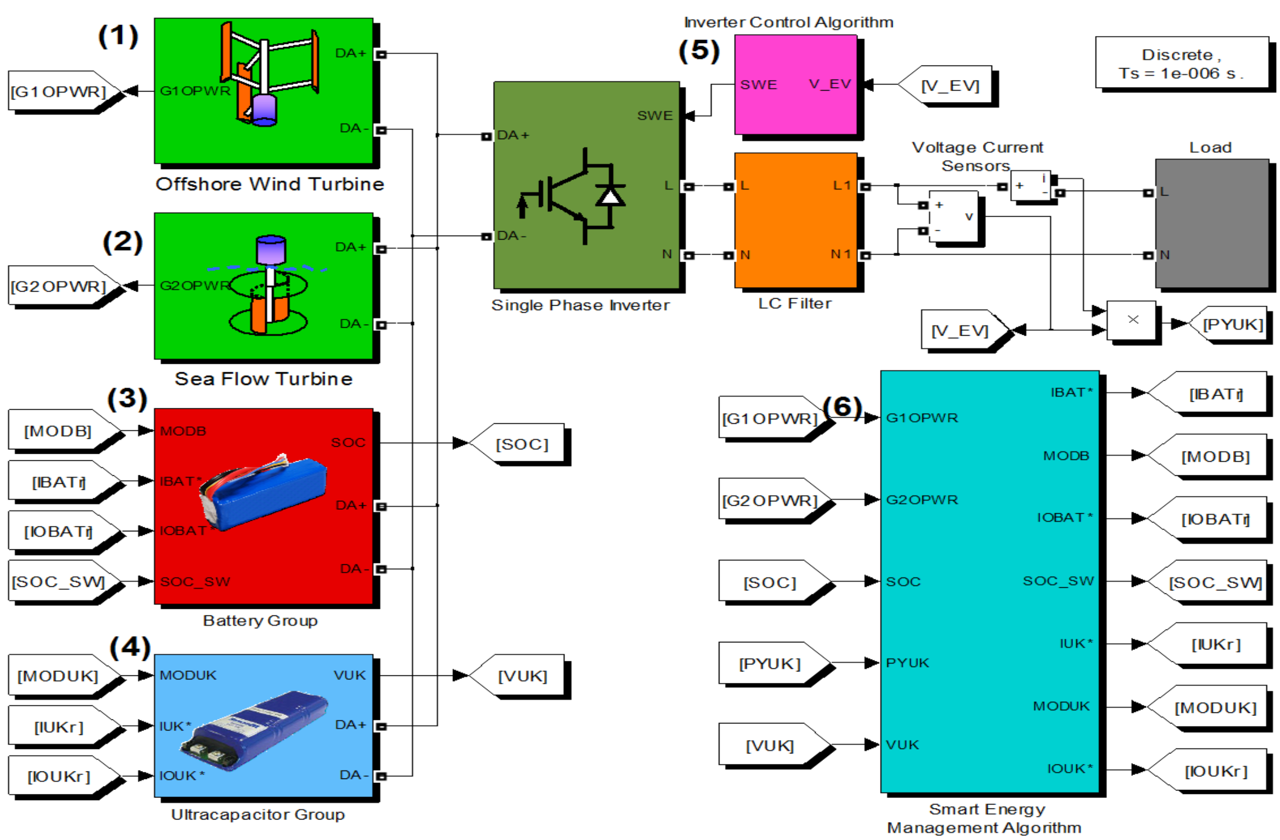
Hybrid power generation systems (HPGS) are created by using renewable energy sources together. Thus, the persistence of energy is ensured by providing power generation in different time periods. The purpose of the hybrid energy storage system (HESS) is to create a system with complementary features by combining the power and energy density, life cycle, response time of energy storage system technologies with different characteristics [8-10]. In other words, high power density energy storage units have a fast response rate, but high energy density energy storage units have a slow response rate. Therefore, it has been useful to synergistically hybridize by combining the functional advantages of different energy storage system technologies. This new technology, especially in the fields of renewable energy and electric transport sector, continues to be researched by many researchers. In the electric transport sector, it has been shown that battery-powered vehicles can hybridize with the ultracapacitor by forming a hybrid energy storage unit [11-13]. In the field of grid integration in renewable energy applications, the most commonly hybrid energy storage system is used battery and ultracapacitor with solar energy systems [14-15]. The use of a hybrid energy storage system is thought to be a convenient solution for various applications in the future. However, further research and development is being done to demonstrate their feasibility and improve their functionality [16- 17].

In this study has created hybrid energy production system model from offshore wind and current energies and hybrid energy storage system consisting of battery and ultracapacitor. Thus, by integrating hybrid systems with each other, smart energy management algorithm will meet the need on the demand side and produce high quality electricity. A complementary source was created for RES using a hybrid energy storage system. In addition, it has been shown that in the system are prevented by voltage and power fluctuations thanks to the hybrid energy storage system. With the ultracapacitor in the hybrid energy storage system, the demands of the sudden loads are met continuously. In this way, the system model will help in the analysis of the system dynamic behaviors before the actual production phase.

Hybrid Renewable Energy Source and Hybrid Energy Storage System Simulation Study

(Figure 1) shows the MATLAB/Simulink block diagram of the hybrid renewable energy source and hybrid energy storage system. In this study, with the offshore wind generator Block (1), sea flow generator Block (2), battery group Block (3), ultra capacitor group Block (4), inverter controller Block (5), smart energy management algorithm Block (6) the system is simulated. The HPGS and HESS are combined with a direct current (DC) bus. In this renewable power generation system, the smart energy management algorithm reads all the power parameters and controls the system according to the possible working conditions.

Figure (1): HPGS and HESS MATLAB/Simulink block diagram



Mechanical energy produced from wind and sea flow energy is transferred to the generators with the help of reducers. In the hybrid power generation system, a 48V 1kW permanent magnet generator is simulated separately. In the hybrid energy storage unit, 48V 20Ah lithium-ion battery and 48V 38.6F ultra capacitor were simulated in the battery group and system analyzes were performed. The system parameters in the HPGS and HESS simulation are detailed in (Table 1).

Table (1): HPGS and HESS simulation parameters

Parameters		**Value**
Wind and sea flow generator	Nominal Rated Power (PG)	1kW
	Nominal RPM	800 rpm
	Line/Line RMS Open Voltage (VOC)	68,3V
	Maximum Current (IGM)	20A
	Efficiency	%92
Battery Group (Lithium-ion)	Battery Voltage (VBAT)	48V
	Battery Current Capacity (CBAT)	20Ah
	Battery Power Capacity	960Wh
Ultracapacitor Group	Ultracapacitor Voltage (VUK)	48V
	Ultracapacitor Capacity (CUK)	38,6F
	Ultracapacitor Power Capacity	12,6Wh
Load Group	Resistive Load	6-10-20Ω, Single Phase
Simulation sample time		1e-6 s

Hpgs and Hess Simulation Study

Wind and Flow Energy System Block Diagram

MATLAB/Simulink block diagram of wind generator, DC/DC boost converter and proportional integral (PI) DC bus voltage control algorithm is given in (Figure 2). PI DC bus voltage control algorithm controls the 48V to 400V with the DC/DC boost circuit. The voltage produced by the wind generator varies depending on the wind speed. The DC/DC boost converter circuit keeps the output voltage constant at 400V against changes in the input voltage.

Battery Energy Storage Block Diagram

The battery group with the HESS unit is connected to the DC bus *via* a bidirectional DC/DC converter. The battery energy storage unit uses 4 pieces 6 cell 22,2V, 10Ah lithium-ion batteries. Batteries are connected as 2 series and 2 parallel groups in order to obtain energy capacity obtained from the battery group is 960Wh. (Figure 3) shows the battery group, the bidirectional DC/DC converter and 48V in the battery group. Thus, the total control algorithm of MATLAB/Simulink simulation model.

Figure (2): Wind and sea flow generator and control algorithm block diagram

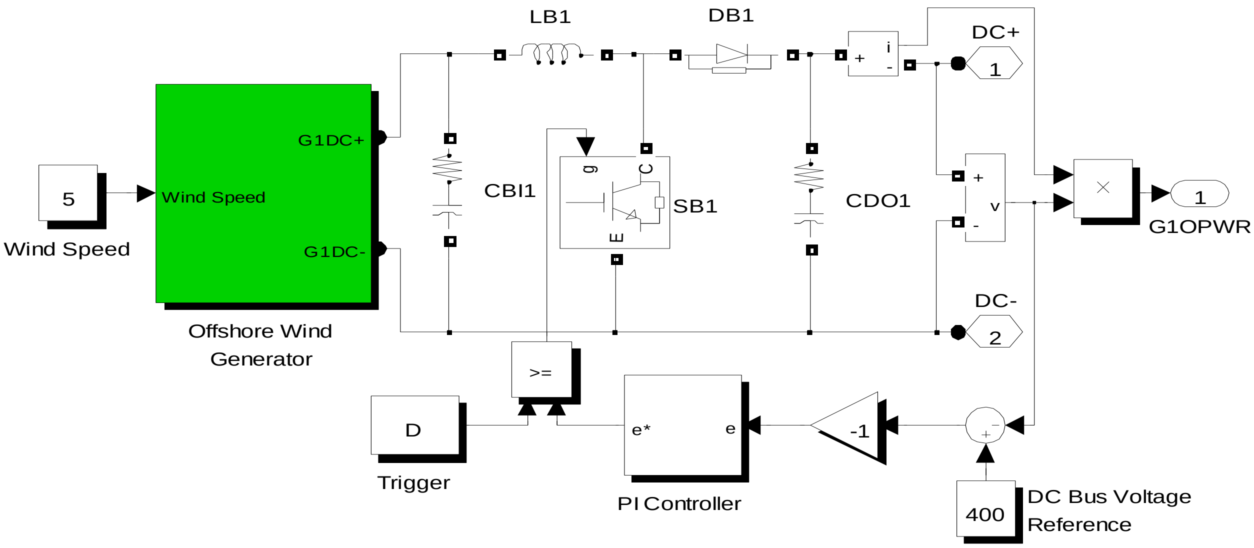
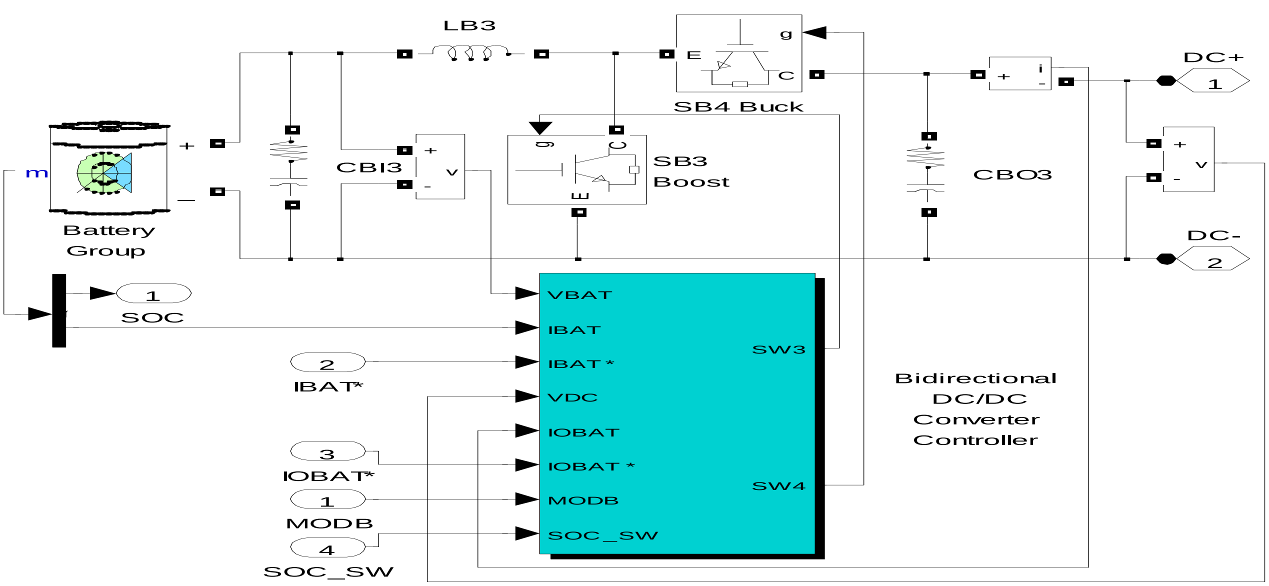


Figure (3): Battery group, bidirectional DC/DC converter and controller block diagram

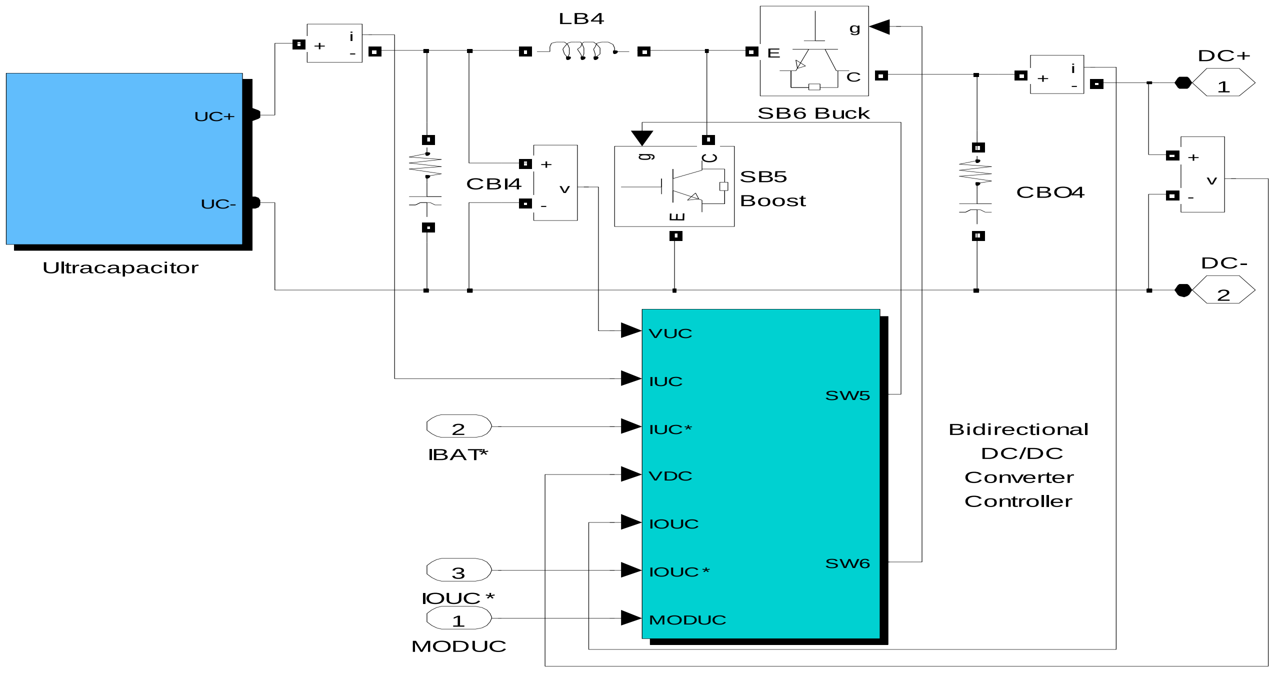


Ultracapacitor Energy Storage Block Diagram

In (Figure 4), an ultracapacitor group, bidirectional DC/DC converter control unit MATLAB/Simulink simulation model is given. As in the battery group, DC/DC bidirectional converter structure is used in order to ensure the charge/discharge of the group of ultracapacitor. 3 pieces 16V 58F ultracapacitor modules were used to obtain

48V voltage. The total energy capacity obtained from the ultracapacitor group is 12.6Wh. The ultracapacitor group is connected to the DC bus *via* a bidirectional DC/DC converter.

Figure (4): Ultracapacitor group, bidirectional DC/DC converter and controller block diagram



Hpgs And Hess Simulation Study Results

Possible working conditions of HPGS and HESS, wind and sea flow speed values are given in (Table 2). In Condition 6 is PTOT<PLOAD; the possible working condition with high state of charge of PBAT and PUC is examined and the power diagram of this condition is given in (Figure 5). In this condition, in case of sudden load demand, it was investigated that the ultracapacitor group was prevented from fluctuation of the DC bus in support of the battery group. The reaction of the smart energy management algorithm to the rapidly changing dynamic behavior of the system is shown in Figures 11, 13 and 15, respectively.

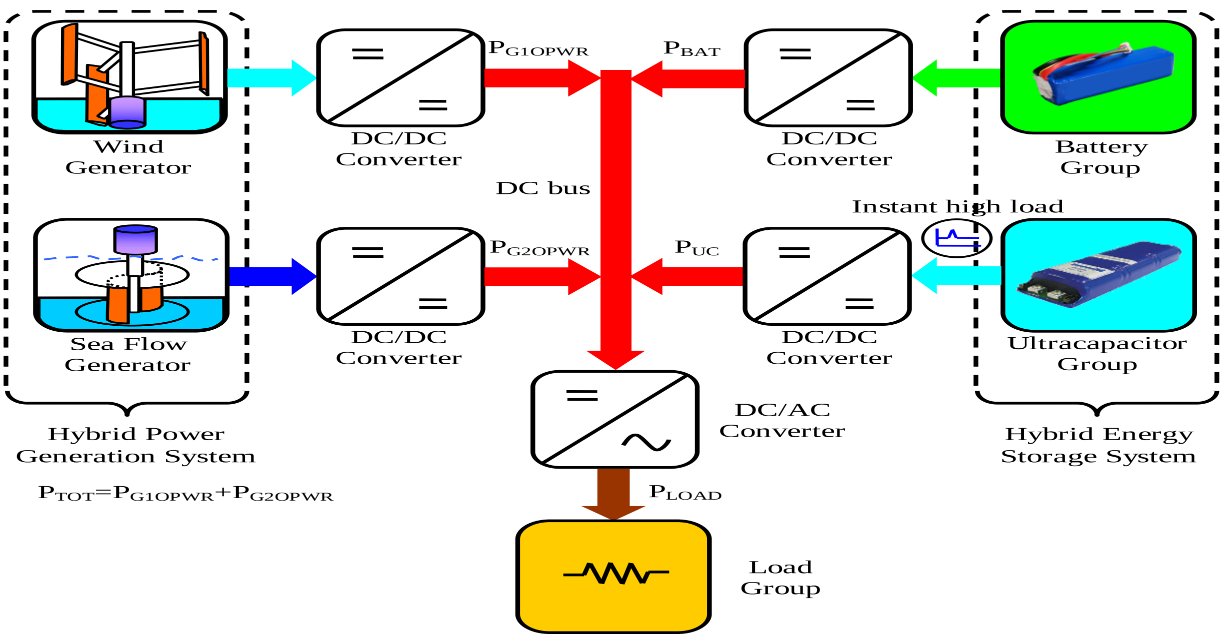
Investigation of Condition 6 and Simulation Results

In (Figure 6), HPGS reducer conversion ratios and power generation values are given for Condition 6. In this study, the conversion ratios of the reducers were determined according to the wind and sea flows measured in Istanbul Bosphorus. In Condition 6, the wind turbine rotates at a wind speed of 6.39 m/s. Reduction ratio of the reducer connected to the wind turbine was chosen as 10 times. In this case, the generator produces 500W power at 580 RPM. In Condition 6, the sea flow is stationary and does not provide a flow of energy to the system.

Table (2): HPGS and HESS possible working conditions

Cases	P_{TOT}/P_{LOAD} Compare	Battery (SOC)	Ultracapacitor (VUC)	Wind Speed (m/s)	Flow Speed (m/s)
1	$P_{TOT} \approx P_{LOAD}$	Low	Low	7,71	1,28
2	$P_{TOT} \approx P_{LOAD}$	High	High	8,81	1,06
3	$P_{TOT} > P_{LOAD}$	Low	Low	7,71	1,28
4	$P_{TOT} > P_{LOAD}$	High	High	6,39	0,80
5	$P_{TOT} < P_{LOAD}$	Low	Low	6,39	0
6	$P_{TOT} < P_{LOAD}$	High	High	6,39	0
7	$P_{TOT}=0$	Low	Low	0	0
8	$P_{TOT}=0$	High	High	0	0
9	$P_{LOAD}=0$	Low	Low	4,85	0,99

Figure (5): Power diagram for Conditions 6 of system



(Figure 7) shows the DC/DC boost circuit output current graph connected to the wind generator. The offshore wind generator generates 500W of electrical energy at a speed of 6.39 m/s. The generator output approximately 1.3A current is generated. 500W power is generated from the generator and shown in detail in (Figure 8). The power generated by the generator is transferred to the DC bus *via* the DC/DC boost converter. Since no power is generated from the flow generator, the DC/DC boost converter included here is inactive.

Figure (6): When the $P_{TOT}<P_{LOAD}$; HPGS reducer conversion ratios and power generation values

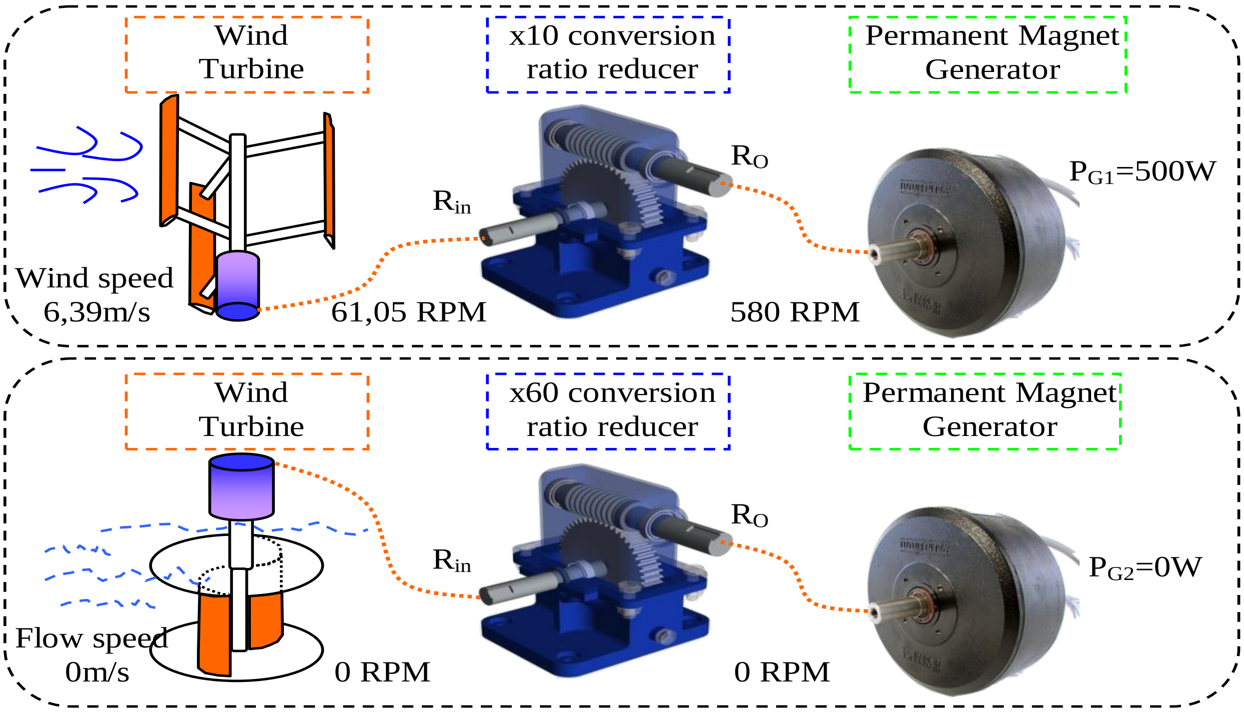


Figure (7): Offshore wind generator circuit output current for Condition 6

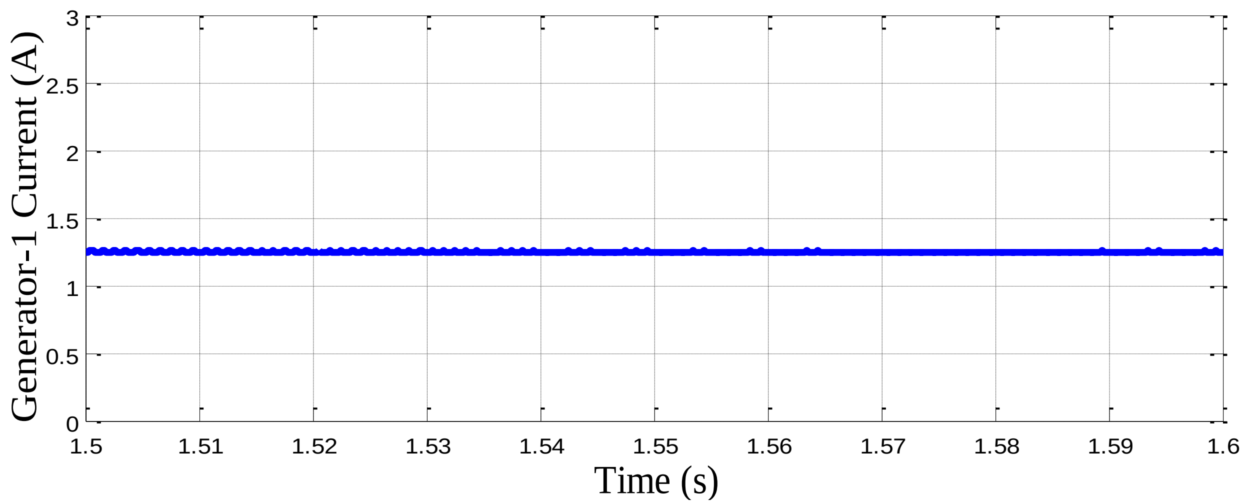
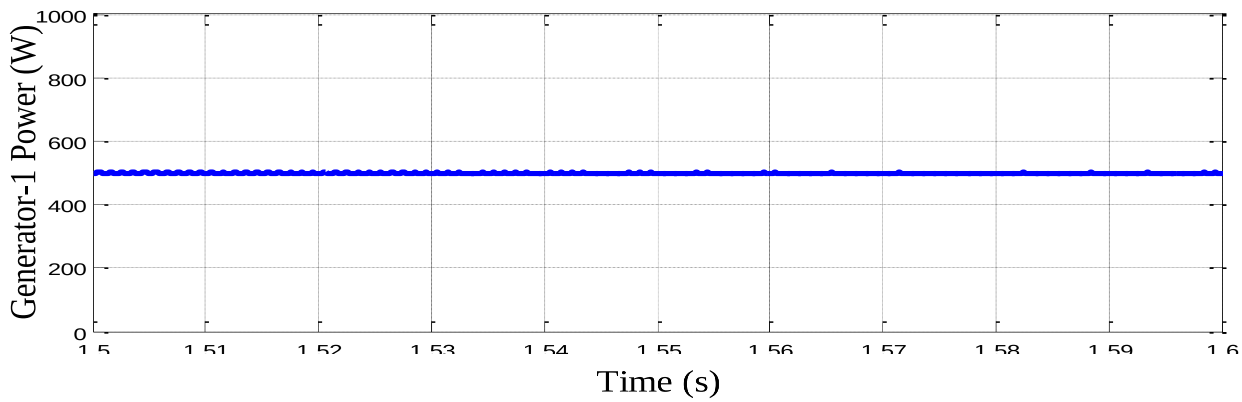


Figure (8): Offshore wind generator circuit output power for Condition 6



In Condition 6, 500W is produced from the offshore wind generator and the load demanded by the load group is 800W. The difference power PDIFF is calculated as -300W by the smart energy management algorithm. If the difference is negative, this means that the battery group in the system is activated. The power flow through the DC bus is provided to the system by calculating the reference current value that should be discharged by the battery group. In (Figure 13), during the operation of the system, a load demand of 1000W is suddenly activated in 1.5s. Smart energy management algorithm detects this sudden load demand and activates the ultracapacitor group. The reference current value of the ultracapacitor group to be discharged is calculated and sent to the bidirectional DC/DC converter circuit. The ultracapacitor group is then disengaged to meet the load from the battery group for a long period of time and the entire power is supplied by the battery group. Thanks to the smart energy management algorithm and the ultracapacitor, the battery group is prevented from having deep discharge and the life cycle of the battery group is extended.

In (Figure 9), the current graph of the battery group in the case of a sudden load change operation condition is given in detail. The battery group is discharged in 1.5s according to the current value calculated by smart energy management algorithm. In (Figure 13), the battery group state of charge is given in detail, and it is seen that it has decreased since the level of 90%. In (Figure 11), the current graph of the ultracapacitor group is given. Ultracapacitor group is activated by the DC/DC boost converter as soon as the load is switched on and prevents voltage and power fluctuations in the system.
In case of sudden load demand in the system, this power requirement is met by the ultracapacitor group and is discharged at the calculated 20A current value for Condition 6. (Figure 12) shows the voltage graph of ultracapacitor group which is discharged during the sudden load demand. Because of the low power energy density which is the structural feature of the ultracapacitor group, the voltage value at the terminal decreases very rapidly.

In (Figure 13), the current change graph of the load group in the system is given for Condition 6. Load group first demands 800W power, 1000W additional power is activated in 1.5s, and a total of 1800W power is demanded. The voltage graph of the inverter and load group is given in Figure 14. The inverter outputs 230V RMS voltage and 50Hz frequency. The power change graph demanded by the load group is given in Figure 15. Although the load group requires a sudden load from the inverter, there is no voltage fluctuation in the inverter output.

Figure (9): Battery group input current for Condition 6

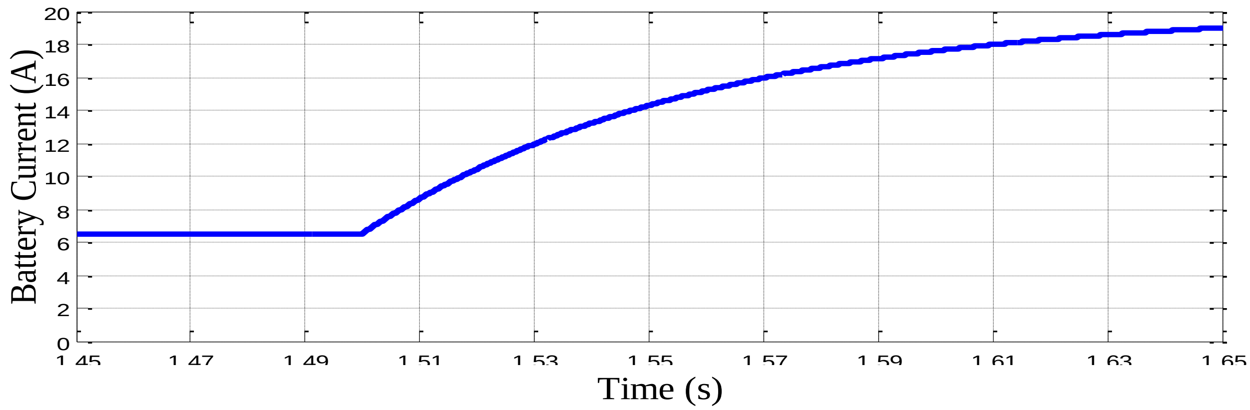


Figure (10): Battery group SOC for Condition 6

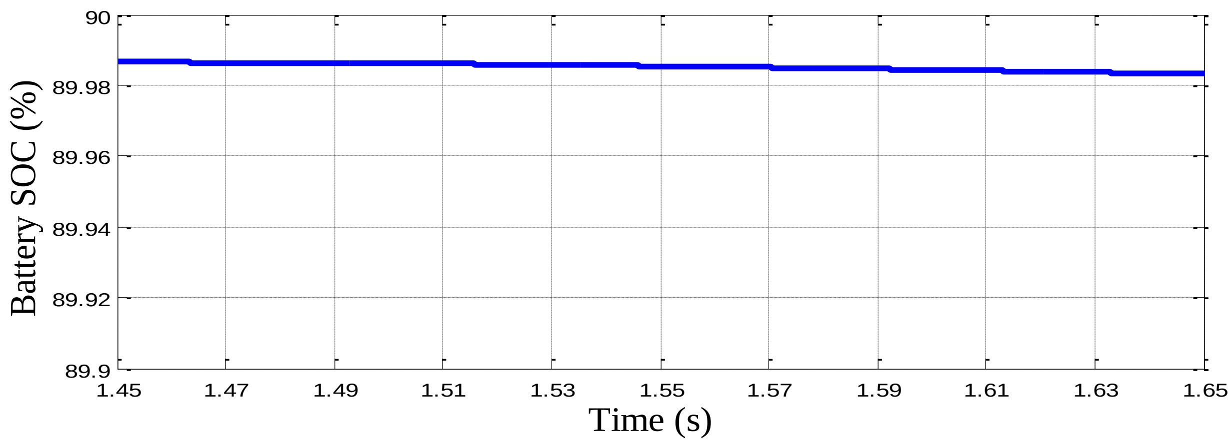


Figure (11): Ultracapacitor group input current for Condition 6

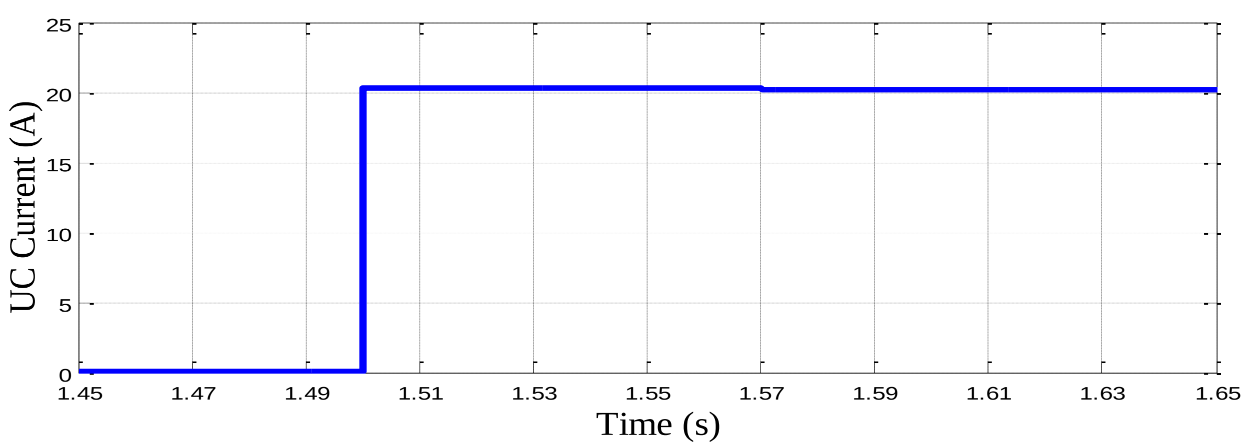


Figure (12): Ultracapacitor group voltage for Condition 6

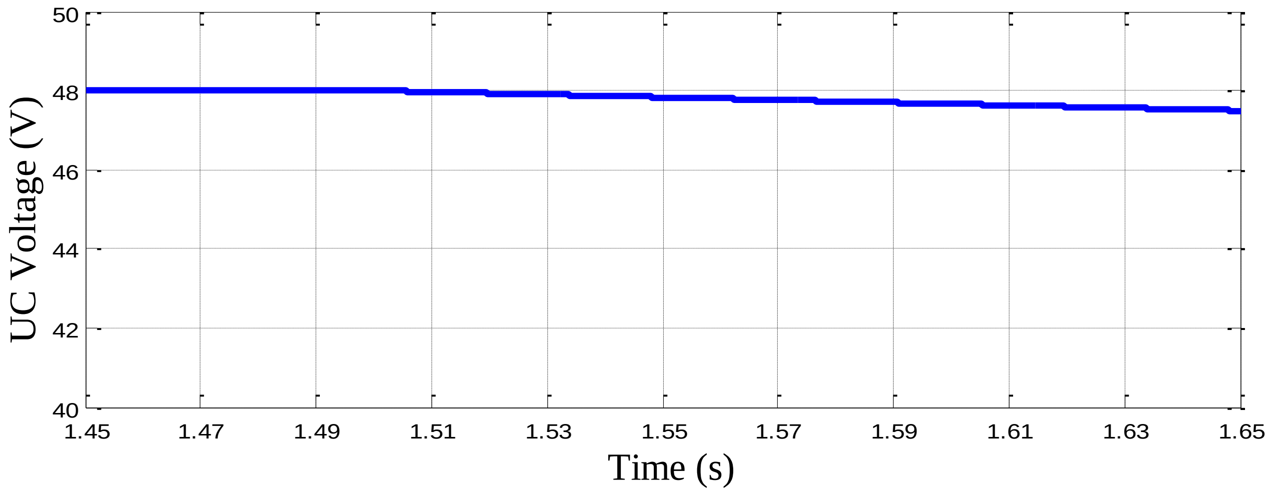


Figure (13): Load and inverter current for Condition 6

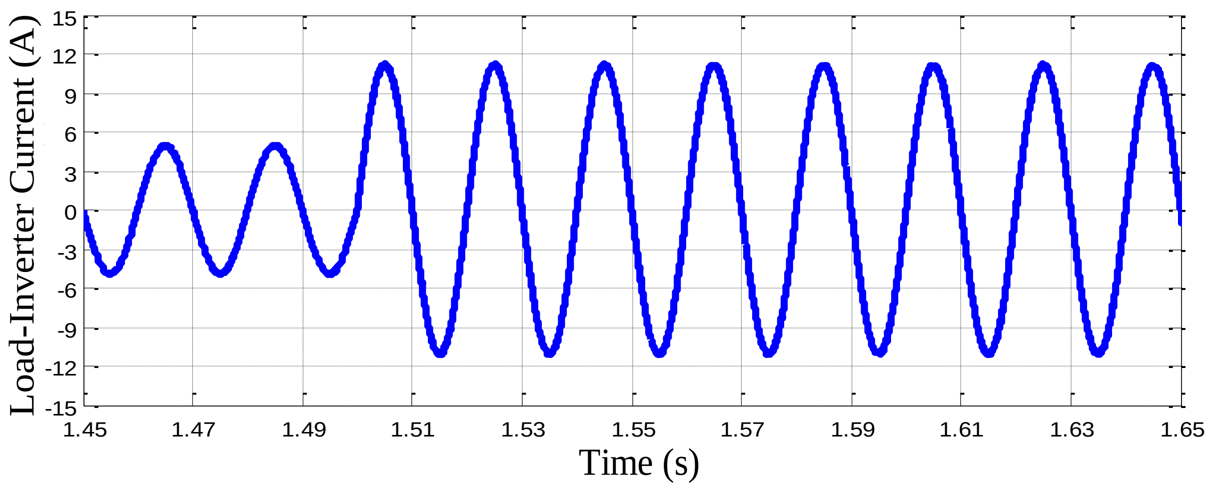


Figure (14): Load and inverter voltage for Condition 6

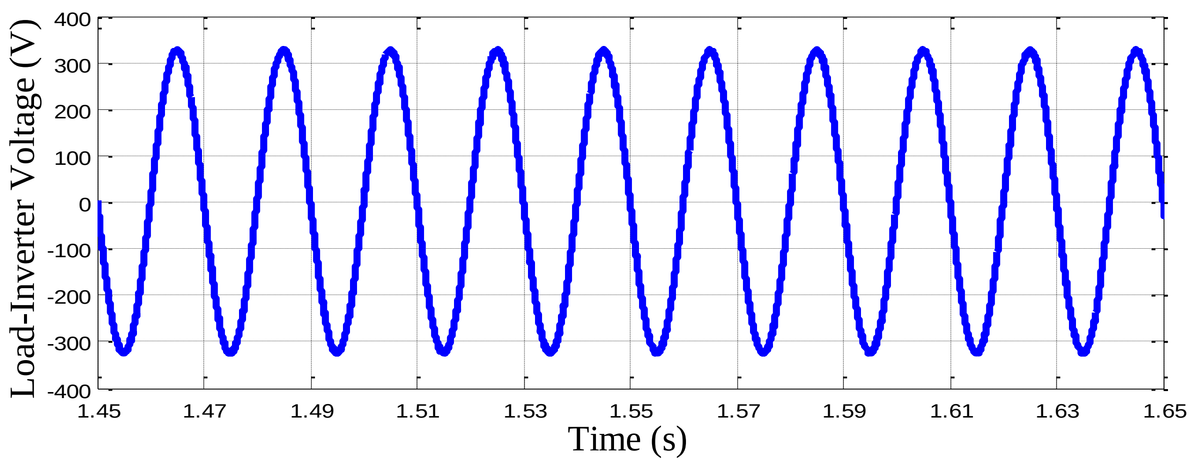
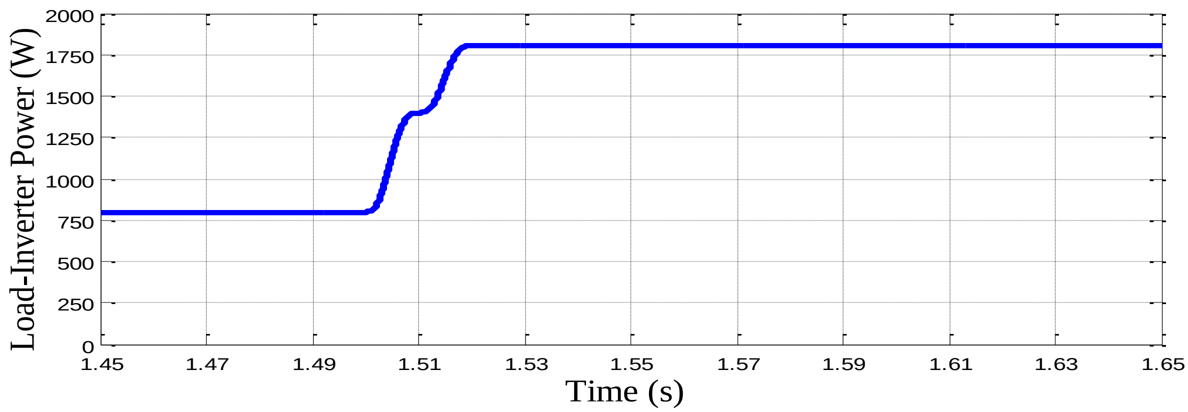


Figure (15): Load and inverter power for Condition 6



Investigation of Condition 3 and Simulation Results

In Condition 3 is $P_{TOT}>P_{LOAD}$; the possible working condition with low state of charge of P_{BAT} and P_{UC} is examined and the group. The power produced by HPGS is high, and the HESS is charged by the smart energy management algorithm because of the low state of charge of battery and the ultracapacitor group. The smart energy management algorithm calculates the difference power and gives the current values to be charged by the battery and the ultracapacitor. Thus, the system quickly evaluates dynamic behaviors and ensures stable operation of HPGS and HESS.

power diagram of this condition is given in (Figure 2) In this case, the possible working condition results are examined in which the power value generated from HPGS is higher than the power group demanded by the load (Figure 17) presents the simulation parameter values of offshore wind and flow systems. The 7,71m/s wind speed from the offshore wind turbine is transferred to the generator by the reducer and 750W electrical power is obtained by the generator. The 1.28m/s flow speed from the flow turbine is transferred to the generator by the reducer and 750W electric power value is produced.

Figure (16): Power diagram for Condition 3

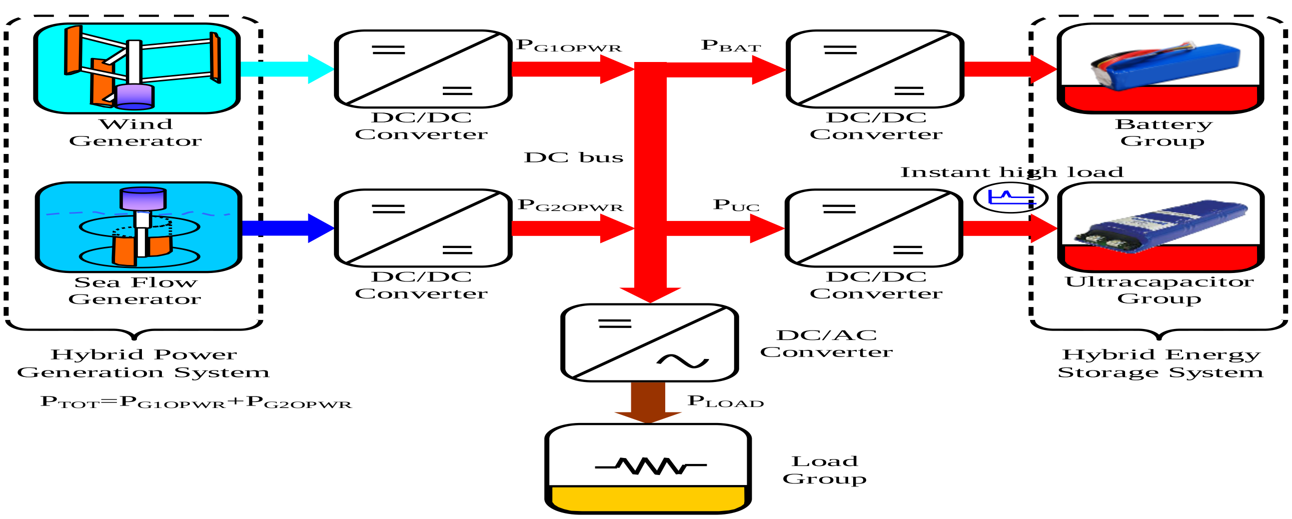


Figure (17): When the $P_{TOT}>P_{LOAD}$; HPGS reducer conversion ratios and power generation values

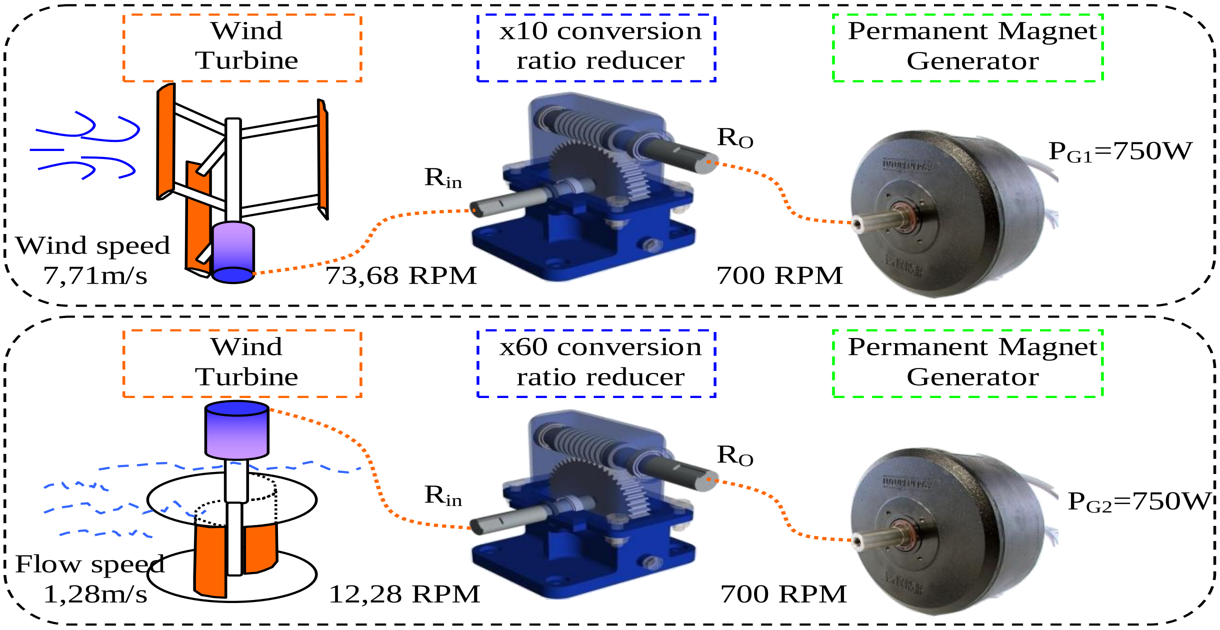


Figure (18): Offshore wind generator circuit output current for Condition 3

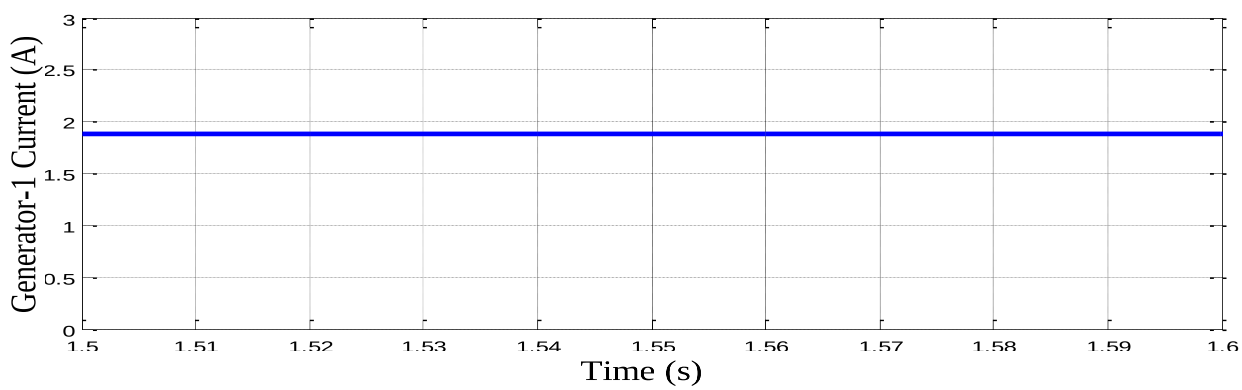


Figure (19): Offshore wind generator circuit output power for Condition 3

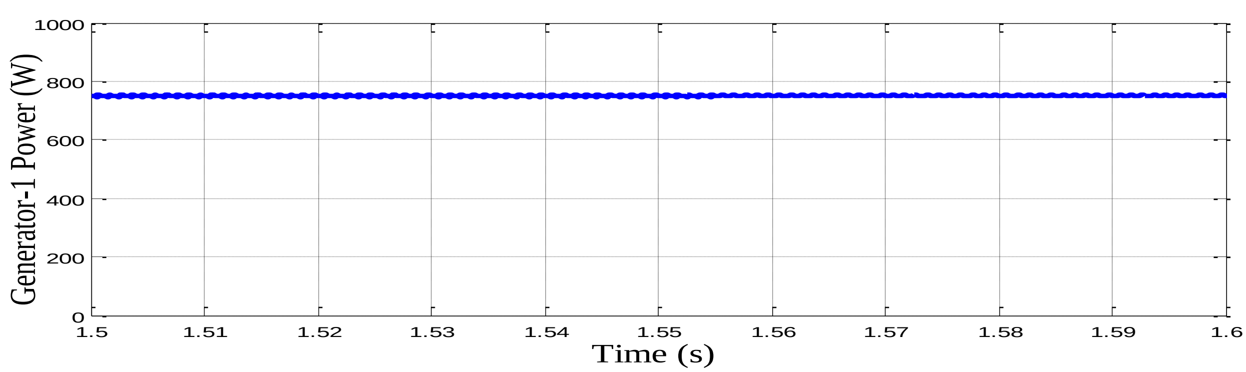


Figure (20): Sea flow generator circuit output current for Condition 3

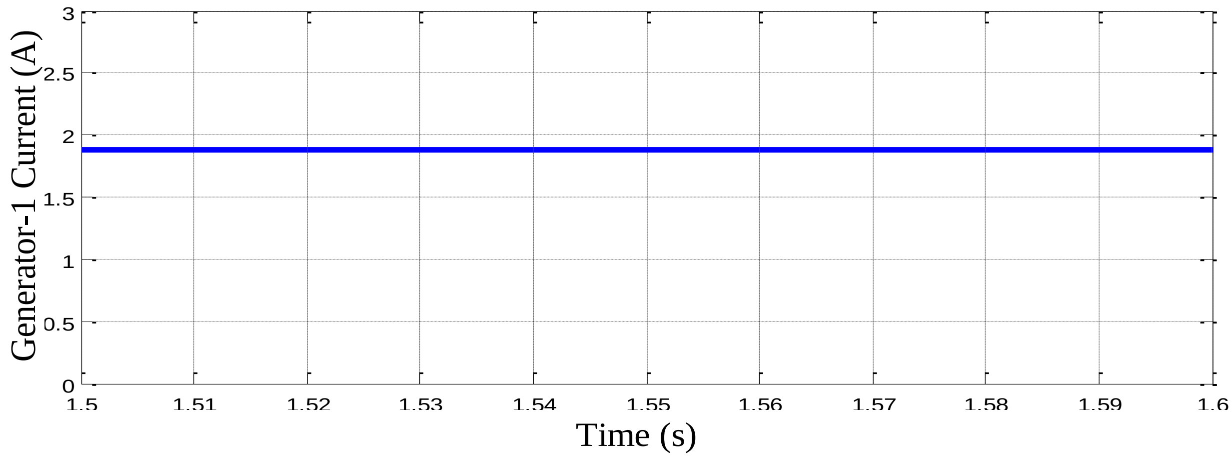
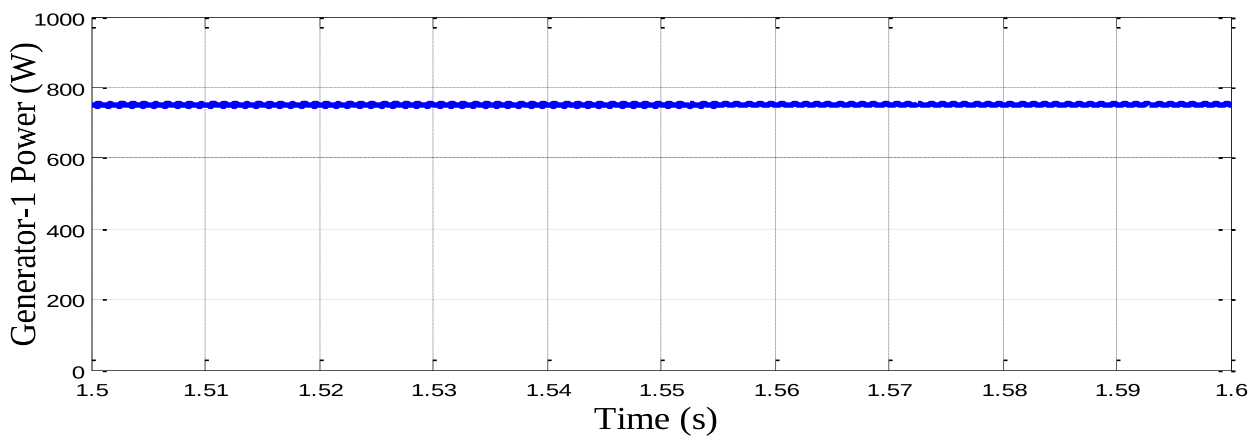


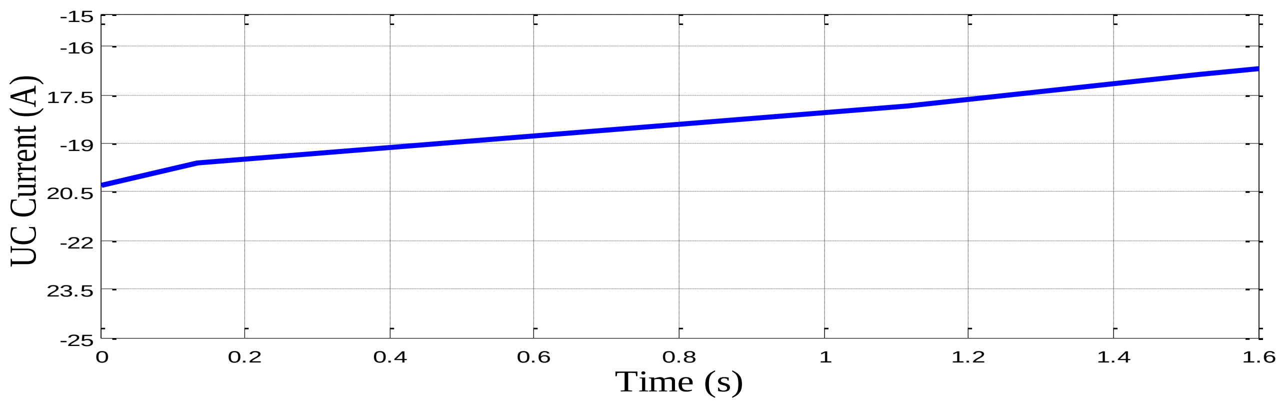
Figure (21): Sea flow generator circuit output power for Condition 3



(Figure 18) shows the output current of the offshore wind output circuit. HPGS and HESS DC bus voltage is 400V. The power produced from this generator is shown in (Figure 19) as 750W. (Figure 20) shows the flow generator output circuit current and the power value 750W produced by this generator in Figure 21. The total power P_{TOT} produced by HPGS is 1500W.

As the power value produced in Condition 6 is more than the load demand power, the power difference P_{DIFF} between the load and produced power is calculated as 1000W by the smart energy management algorithm. This power difference P_{DIFF} value is used to charge the battery and the ultracapacitor group. The situation which is empty the ultracapacitor group is examined. As mentioned in the smart energy management algorithm, since the initial charge current of an empty group of ultracapacitor is very high, it is limited to 20A by the controller to avoid voltage fluctuation to the DC bus. The charge current of the ultracapacitor group is shown in (Figure 22) and is shown to be fast charging in the graph. It is also shown in (Figure 23) that the voltage of the ultracapacitor group increases rapidly.

Figure (22): Ultracapacitor group input current for Condition 3



The smart energy management algorithm calculates the current to be charged by the battery group and transmits this reference current to the bidirectional DC/DC converter. (Figure 24) shows the charging current value at the input of the battery group. The battery group SOC information is shown in detail in (Figure 22). In the SOC information graph, the scale is given at values close to 30%. Since the battery group has a high energy density, a small part of in 1 second it is observed.

Figure (23): Ultracapacitor group voltage for Condition 3

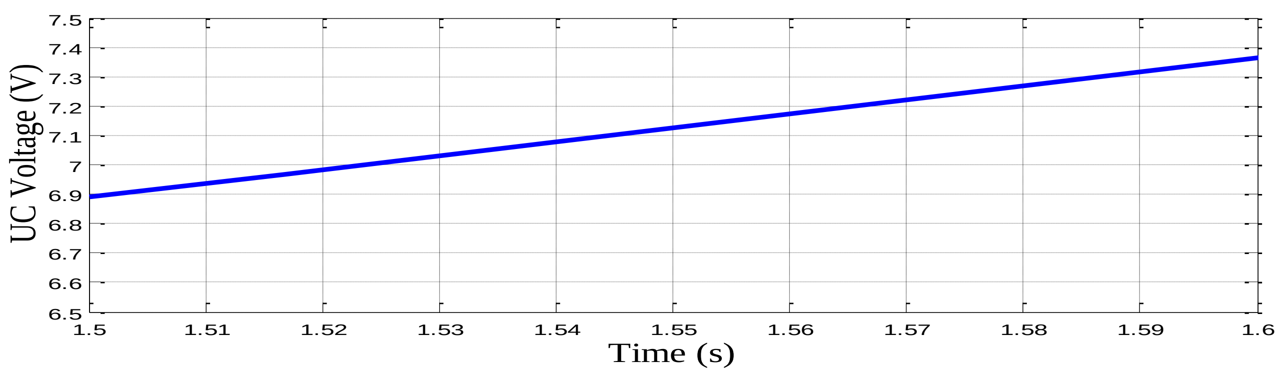


Figure (24): Battery group input current for Condition 3

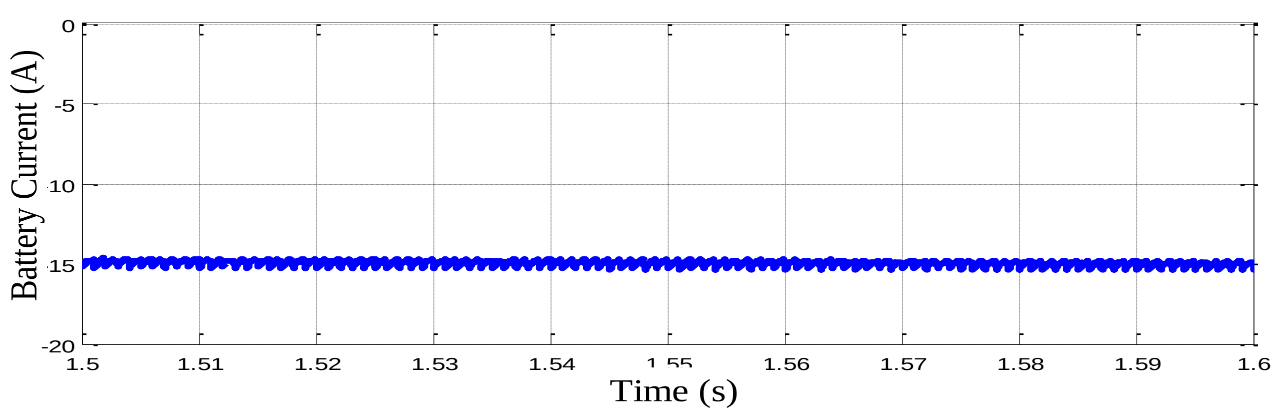
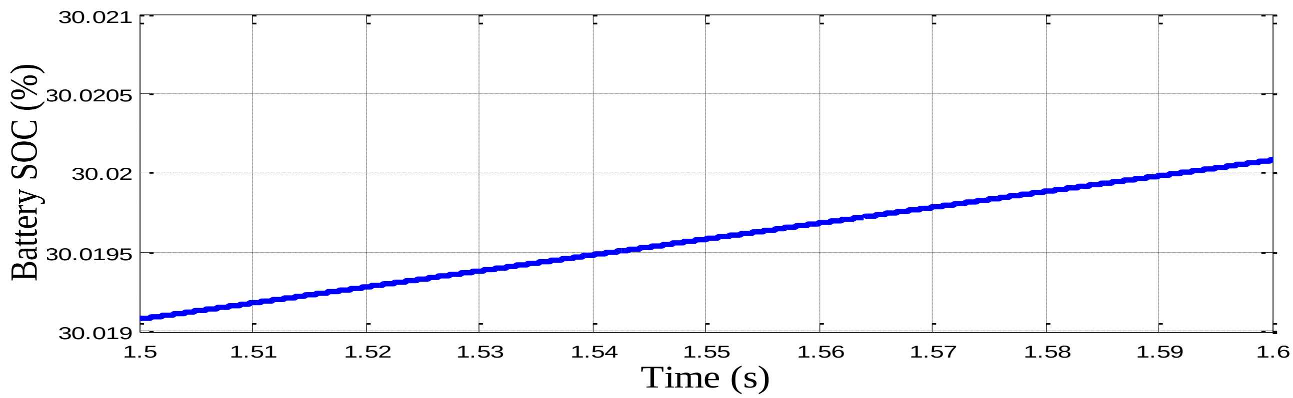


Figure (25): Battery group SOC for Condition 3



In Condition 3, the power value demanded by the load is much lower than the power value and is 500W. The load and inverter output current graph is given in (Figure 26) and the power value is given in (Figure 27).

Figure (26): Load and inverter current for Condition 3

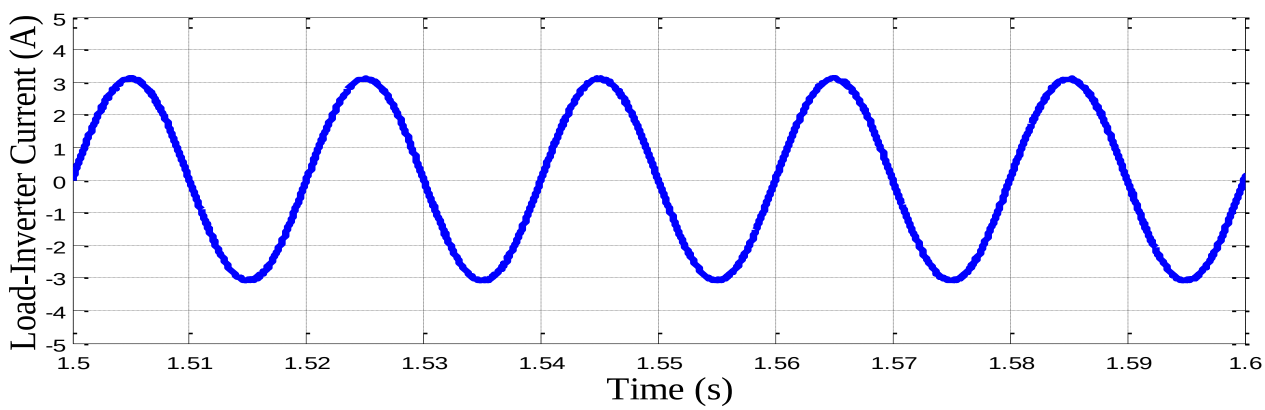
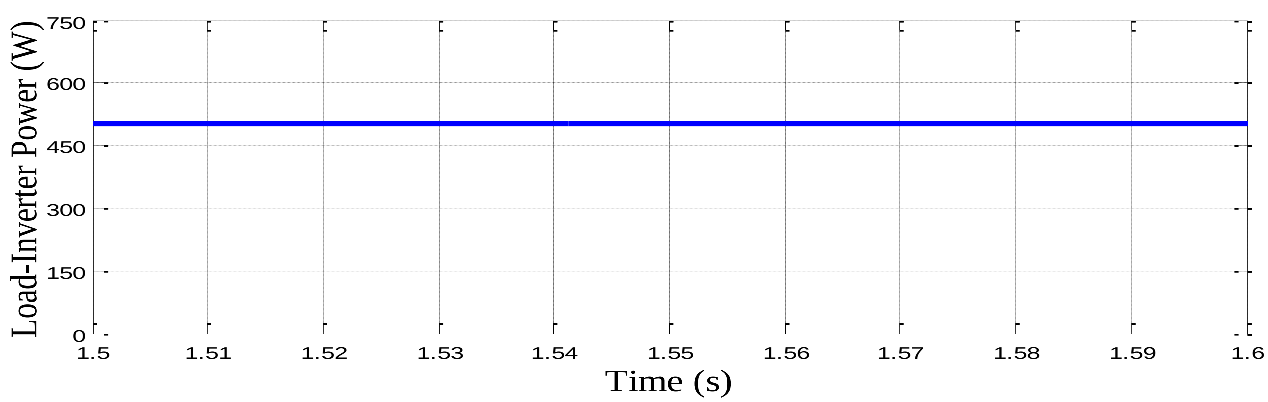


Figure (27): Load and inverter power for Condition 3



Conclusion

In this study, simulation of wind and sea flow energy and each unit of energy storage system are made by MATLAB/Simulink program. The wind and the sea flow energy unit and energy storage unit primarily provide the power demanded by the load. Thus, quality and continuous energy transfer is realized. It has been determined that all units are controlled by smart energy management algorithm and by reacting rapidly to sudden load changes of the system, voltage and power fluctuation are prevented. Due to their complementary features, the ultracapacitor energy storage unit provide sudden power demand, battery energy storage unit provide continuous power demand. In addition, with the results obtained in the simulation studies, it was seen that the ultracapacitor prevented the voltage sag both in the DC bus and the load side. By utilizing the continuity of energy with the battery and ultracapacitor hybrid energy storage system, it was ensured that RES was used more effectively. With HESS consisting of a battery and an ultracapacitor, it is envisaged that the batteries will maximize their life cycle and storage capacity and minimize the charge/discharge cycle.

Acknowledgments

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