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Research Article

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Dynamic Operation of a High Penetration Wind-Diesel System with Battery Energy Storage

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Abstract This paper demonstrates the model of grid connected hybrid generation system consists of doubly fed induction generator (DFIG) based wind energy conversion system, diesel generator (DG), and battery energy storage system(BESS). The performance of the presented system is evaluated through different simulation cases using MATLAB/SIMULINK program. The power and voltages waveforms at different points of the system are presented and analysed during normal and abnormal conditions. This study is shown that hybrid system is supplying power to grid equal to 1.5MW approximately and after disturbance the system returns work again in the same efficiency.

Keywords double fed induction generator, diesel generator, nickel-cadmium battery, renewable energy, active power

1. Introduction

The renewable energy (RE) is clean energy that have a very low environmental impact compared to the conventional energy sources. RE sources never run out, on the other hand conventional energy sources are finite and one day will be depleted. Wind is considered as renewable energy source, when wind energy is used to generate electrical power, which is coupled with diesel generators to increase the reliability of the system and allows for the cost of diesel fuel to be offset [1]. Diesel generators can be used as a back-up, when wind energy source fail to meet the required power and when the battery charge depleted for better reliability and economy. Hybrid system provide several benefits for the user such as improve reliability, energy serves, reduce emissions and pollution, provide continuous power supply, increase operational life and reduce cost [2].

Several papers have been published on the subject of wind-diesel hybrid system, WDHS dynamic simulation. In [3] a high Penetration-WDHS with battery energy storage system is simulated in three operation modes: Diesel only, wind Diesel and wind only. In another work [4] aWDHS with a BESS is molded but the battery is simulated as a simple constant voltage source. In [5] a small hybrid power system consists of wind turbine and diesel in addition to energy capacitor system, which can smooth the output power flow.

In the present paper, a hybrid system connected to the grid consists of DFIG wind turbine, diesel generator and battery storage is simulated. Additionally, a dynamic operation of a hybrid system during normal operation and under up normal condition.

2. System Description

The high penetration wind diesel hybrid system (WDHS) connected to grid is shown in figure 1 consists of wind turbine generator (WTG), DG and BESS.

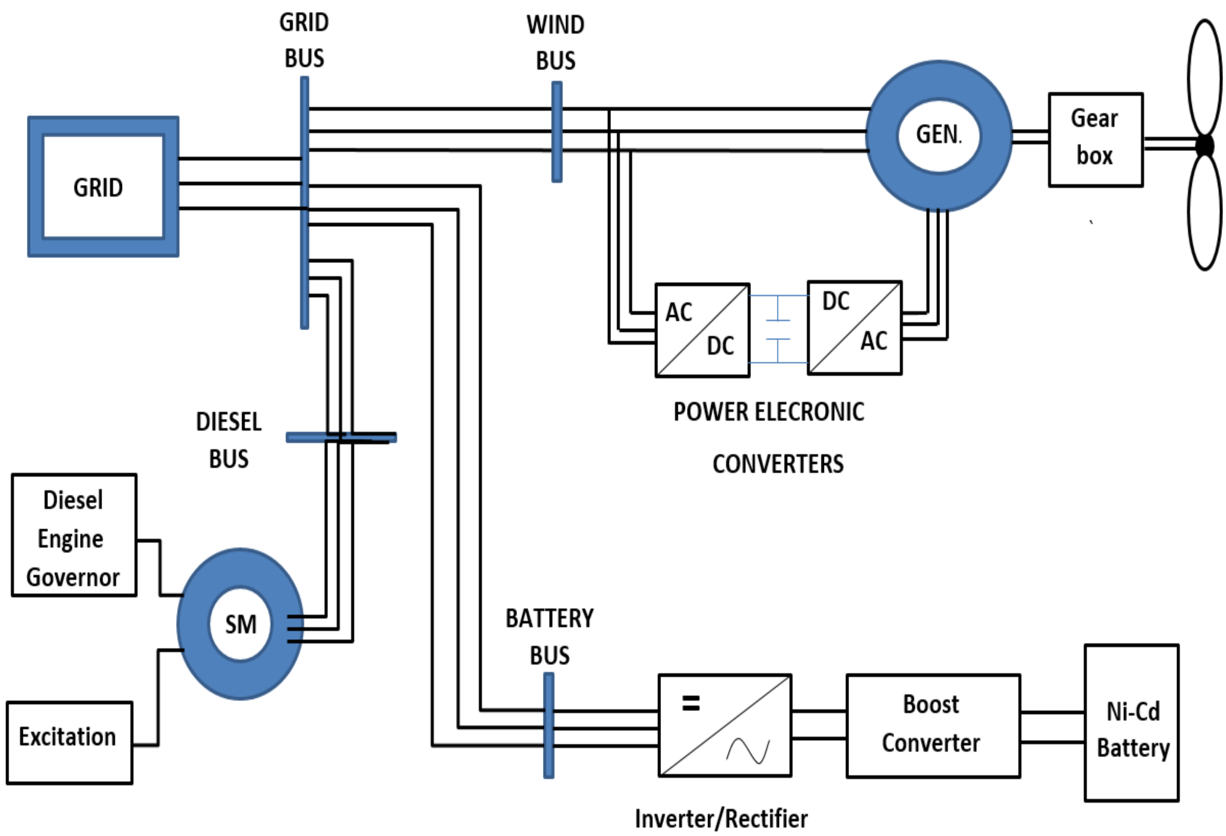


Figure 1: schematic diagram of the grid connected hybrid system

The DG contains of a synchronous machine(SM), diesel engine governor (DEG) and excitation. The mechanical power is provided from DEG to synchronous machine. The governor is necessary to make the diesel engine runs at constant speed [2].

The WTG consists of a WT is driving double fed induction generator with an AC/DC/AC converter. The AC/DC converter connected to rotor winding is called rotor side converter (RSC) and another DC/AC converter is called grid side converter. Active power is produced from WTG, which depends on the cube of the wind speed and other factors. The induction generator consumes reactive power so a capacitor bank has been added to compensate the power factor [6].The BESS includes a battery bank, boost converter to increase DC battery voltage from 240V to 400V and power converter which mediator between the battery bank and the grid [7].

3. Simulation schematic

The MATLAB Simulink model of the hybrid system connected to grid of figure 1 is shown in figure 2.The Next, some of the components are described such as the induction generator, synchronous machine, transformer, battery, etc. are blocks which related to simpowe systems library [8].

The SM has a related power of 600KVA. The mechanical parts of the diesel engine governor and the excitation are modeled by using emergency diesel generator and asynchronous motor, which from MATLAB examples [9]. The shaft speed of the SM in per unit values and reference speed equal to 1 per unit are the input of diesel engine governor and the mechanical power is the output of this block. The terminal voltage and current and field current of SM are inputs of excitation block and field voltage is output of the block.

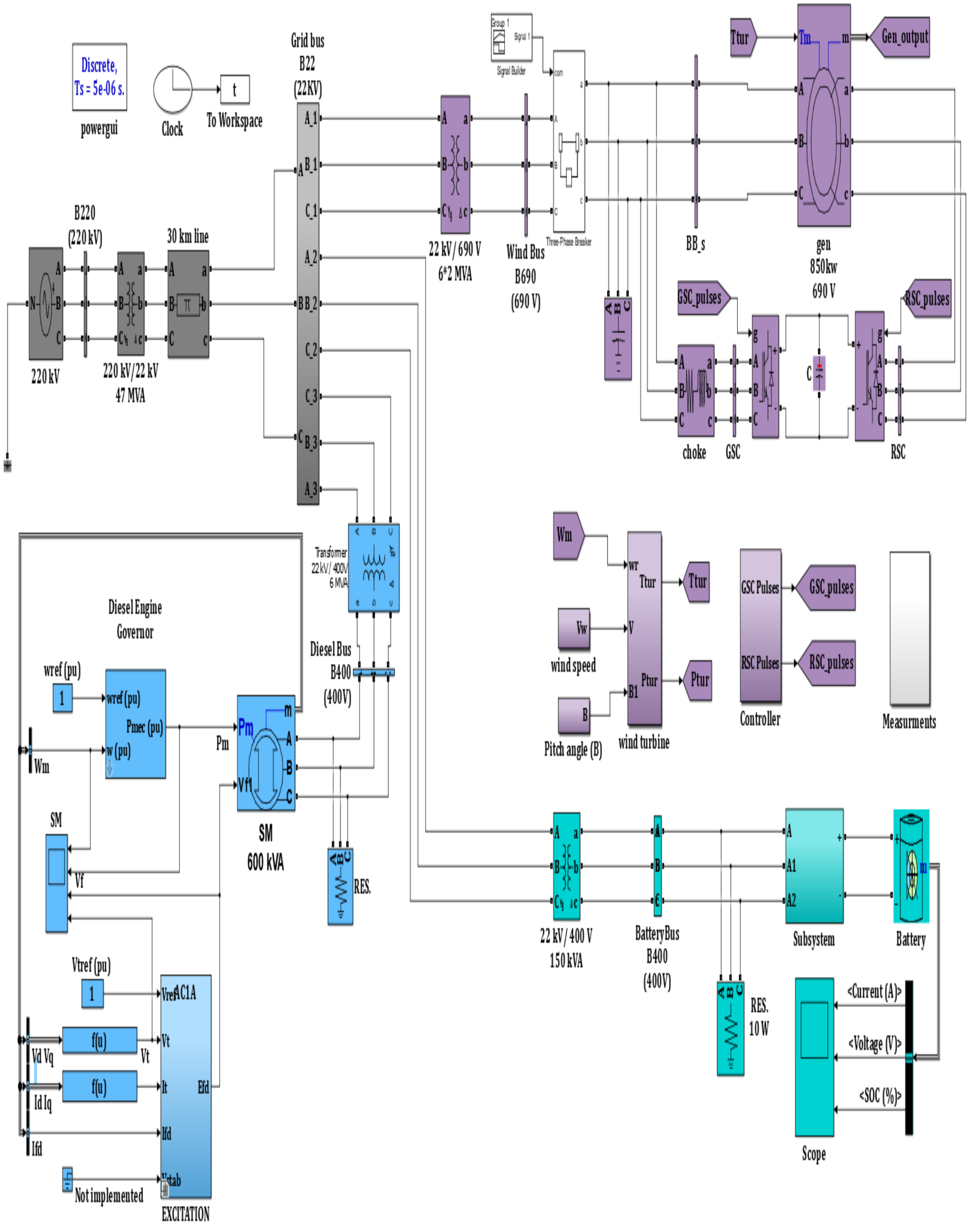


Figure 2: Simulink model diagram of hybrid system connected to grid

The double fed induction generator consists of induction generator (850KW), the wind turbine block shows in figure 3, which defines the mechanical torque applied to the induction generator as a function of wind speed.

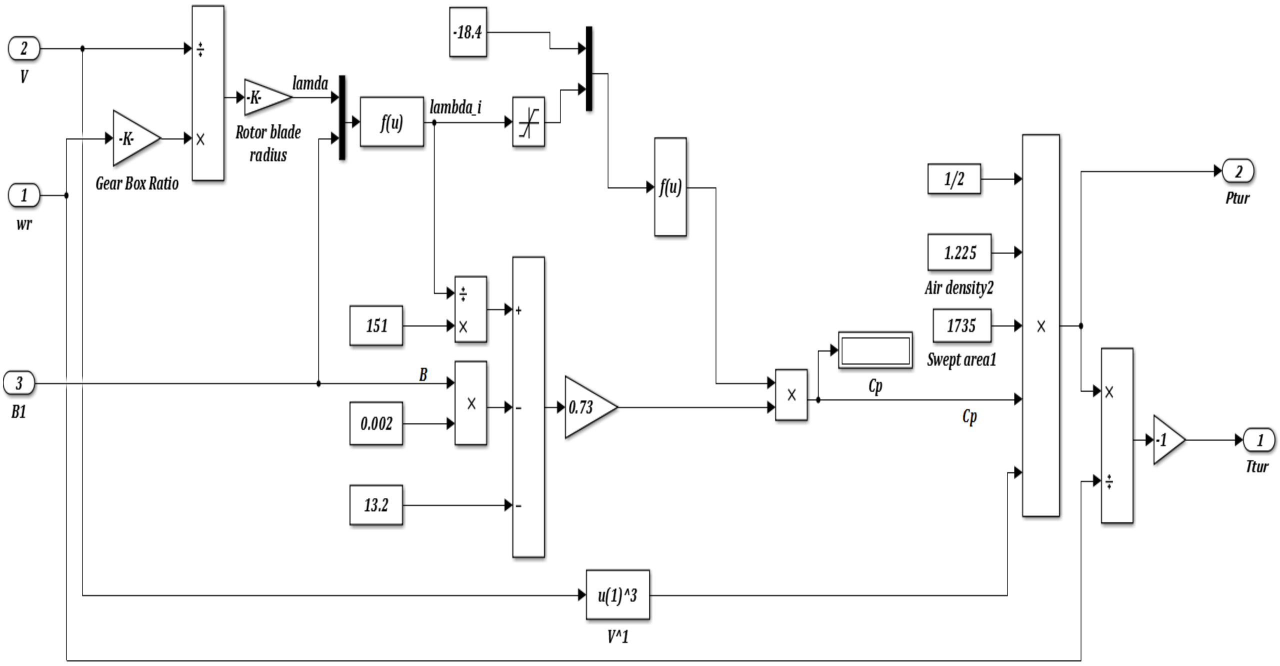


Figure 3: Simulink model of a wind turbine sub system

The converter includes two different converters, the rotor side converter and grid side converter and they both are controlled independently [10]. The rotor side converter provides active and reactive power control of the machine while the grid-side converter controls the dc link voltage which are shown in figures 4 and 5 [11].

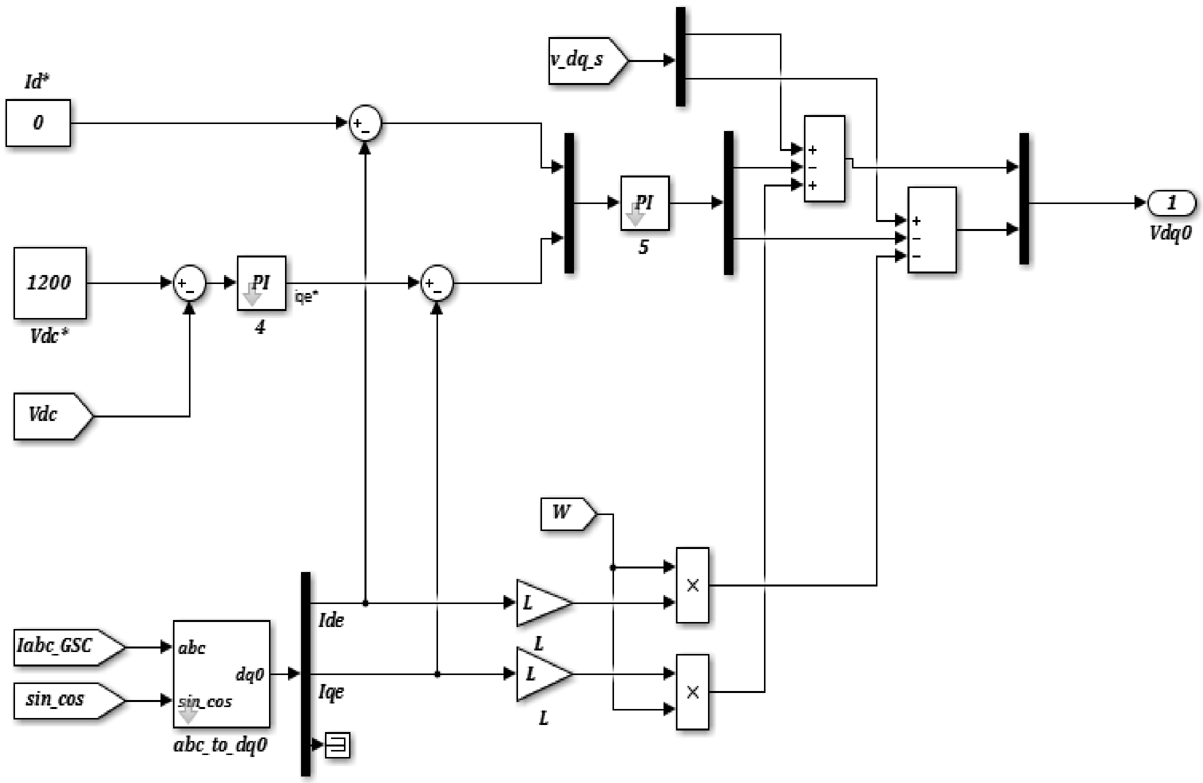


Figure 4: Simulink model of grid side converter controller

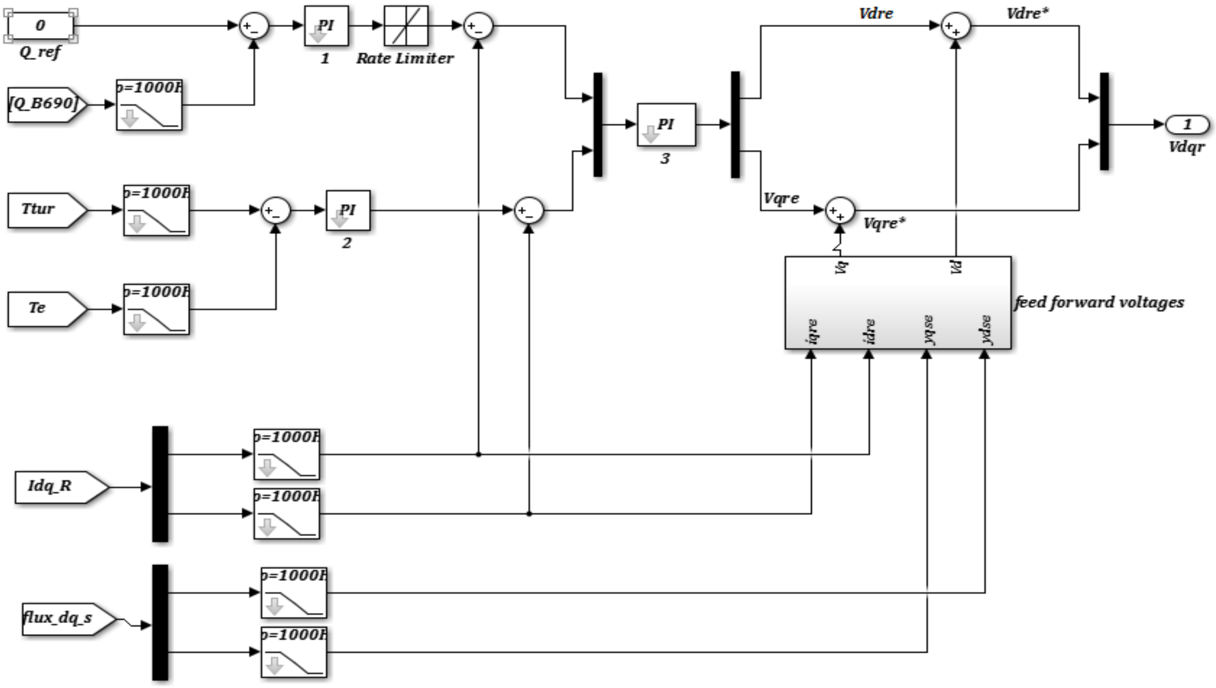


Figure 5: Simulink model of rotor side converter controller

The BESS IS Based on a Nickel-Cadmium (Ni-Cd) battery bank, boost converter, L- filter and a three phase bidirectional controlled converter of rated power 150 KW are shown in figure 6. The 240V Ni-Cd battery model [6]. The energy stored in the battery is 93.75KWH, which is get from a storage energy need of 15 min for the 150 KW inverter rated power. A capacity equal to 390.625 Amp-hr. (93.75KWH/240V=390.625Ah). Connecting the battery to the DC side of power converter through boost converter, which increase battery voltage from 240V DC TO 400V DC. L-filter has been used for smoothing the battery current [12].

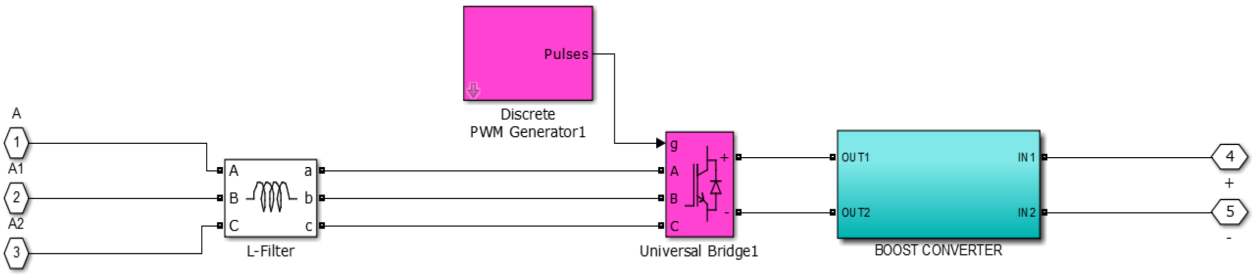


Figure 6: Simulink model of battery subsystem

4. Results and discussions

This section, the simulation has been executed to study the dynamic operation of the hybrid power system under normal operation and disconnecting wind system.

4.1. Case Study (1):

In case of normal operation, the active power for the grid bus, diesel bus, wind bus and battery bus are plotted in KW show in figure 7, which presents the active powers are being in negative sign when the power are transmitted to the grid from hybrid system.

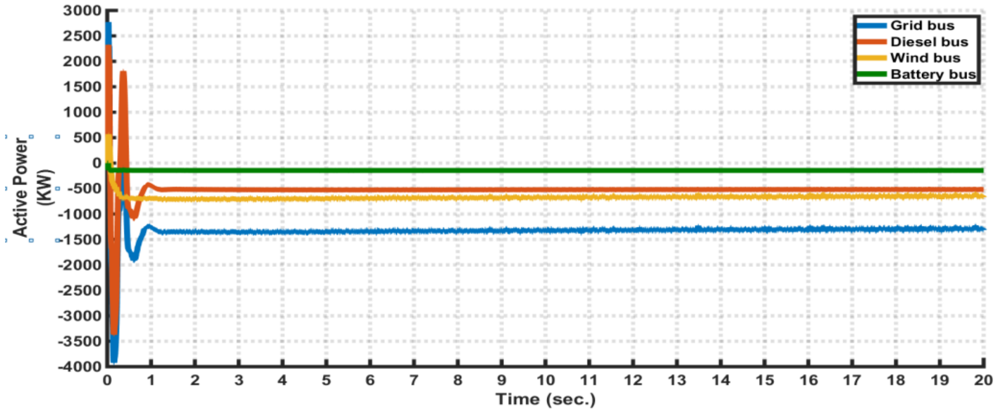


Figure 7: Active power under normal condition

The values of steady state active power, over shoot and settling time at variant buses are elaborated in table 1.

Table 1: Results under normal operation

	Wind bus	Diesel bus	Battery bus
Active power (KW)	-660	-520	-144
Over shoot (%OS) % from steady state value of active power	1.14	4.42	1.04
Settling time (sec.)	0.6	1.05	0.055

Under normal operation figures 8(a), 9(a), 10(a) and 11(a) show the transient three phase voltages at grid bus, wind bus, diesel bus and battery bus respectively. Steady state 3-phase voltages at grid bus, wind bus, diesel bus and battery bus are shown in figures 8(b), 9(b), 10(b) and 11(b) respectively, which are roughly similar to sinusoidal wave with high ripple. It is clear that the effective value for voltages at grid bus is18 KV, wind bus is 562.7 V, diesel bus is 327.5 V and battery bus is 326.2 V

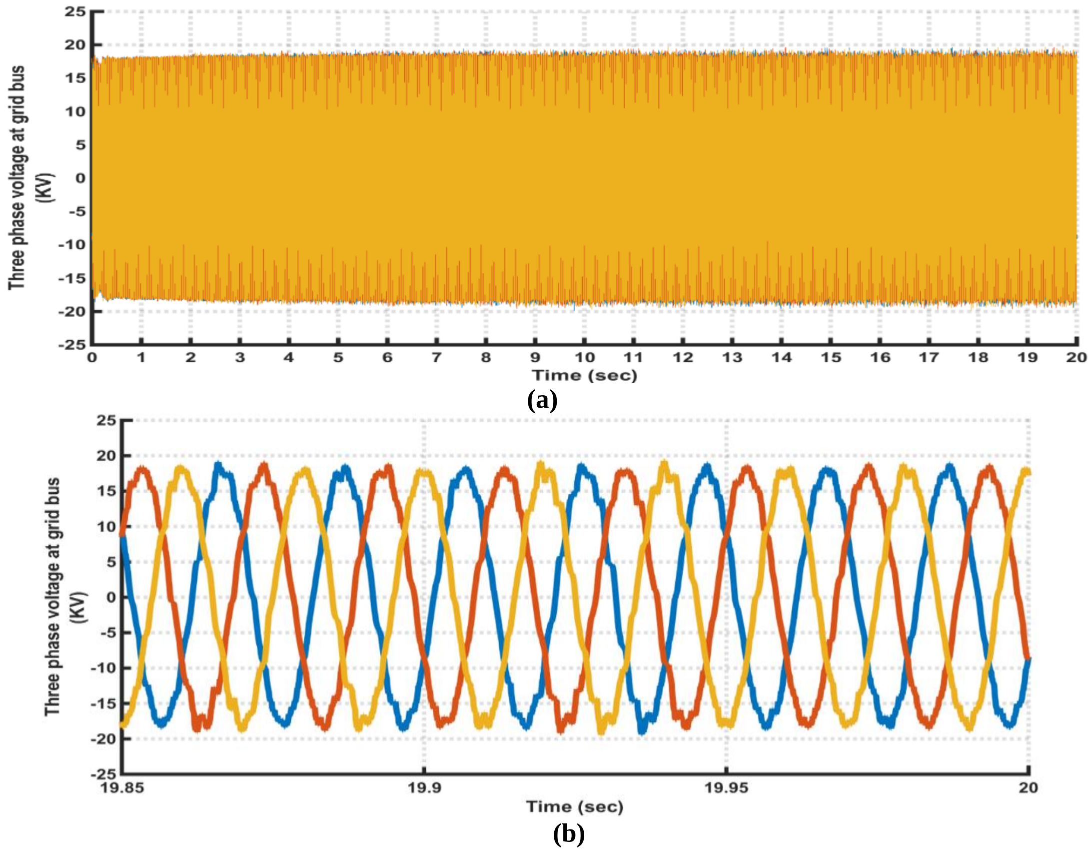
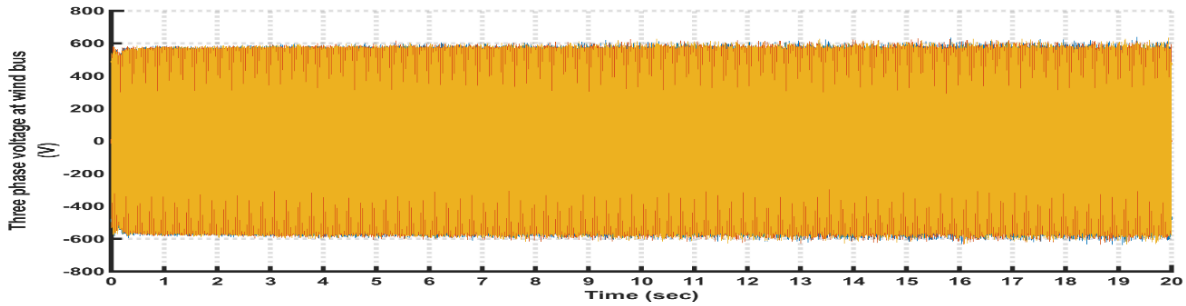


Figure 8: Transient and steady state voltage at grid bus under normal operation

(a) 3-phase voltage at transient (b) 3-phase voltage at steady state



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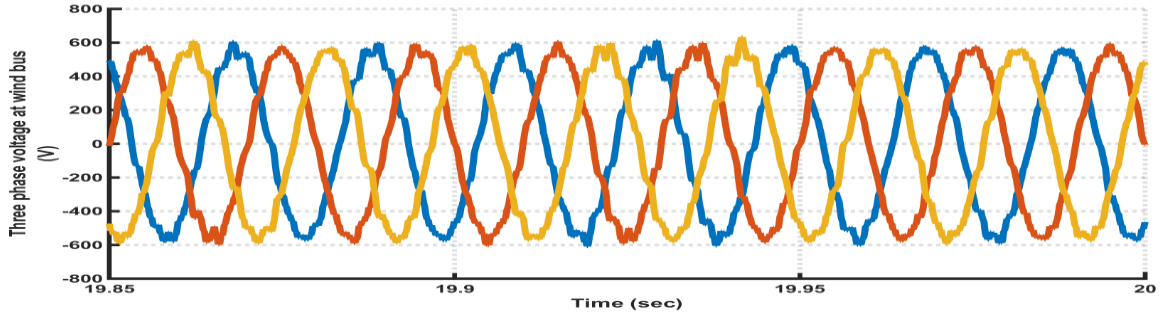
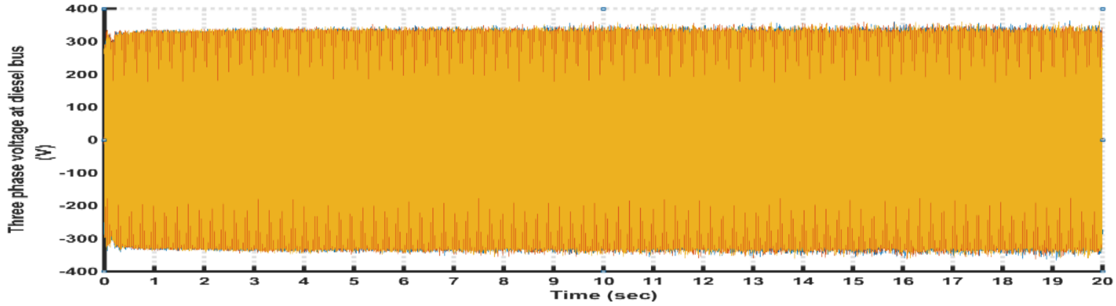


(b)

Figure 9: Transient and steady state voltage at wind bus under normal operation

(a) 3-phase voltage at transient *(b) 3-phase voltage at steady state*



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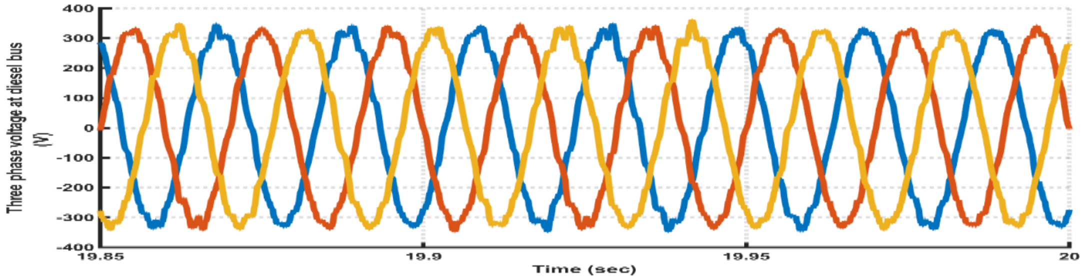
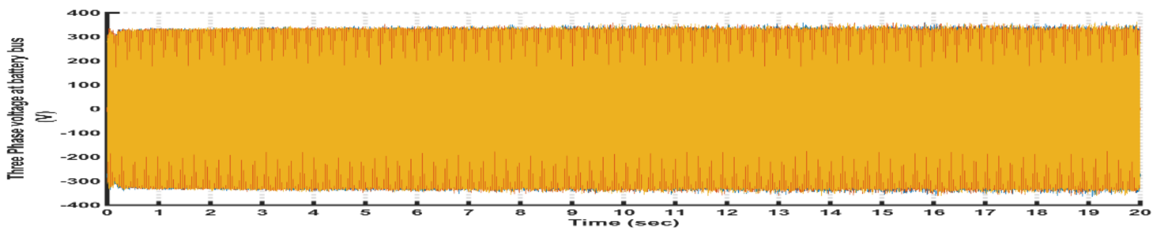


(b)

Figure 10: Transient and steady state voltage at diesel bus under normal operation

(a) 3-phase voltage at transient *(b) 3-phase voltage at steady state*



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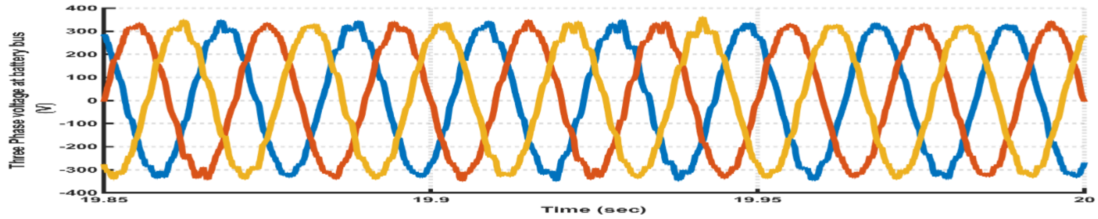


(b)

Figure 11: Transient and steady state voltage at battery bus under normal operation
(a) 3-phase voltage at transient (b) 3-phase voltage at steady state

4.2. Case Study (2)

In this case study, disconnecting wind system is applied in t=6 sec. by opening the three phase breaker 3PB shown in figure 2 and reconnected at t=10 sec. Active power at grid bus, wind bus, diesel bus and battery bus are shown in figure 12.The table 2 shows the value of steady state value of active power at before, during and after disturbance. It is noticed that system is operating normally after the disturbance.

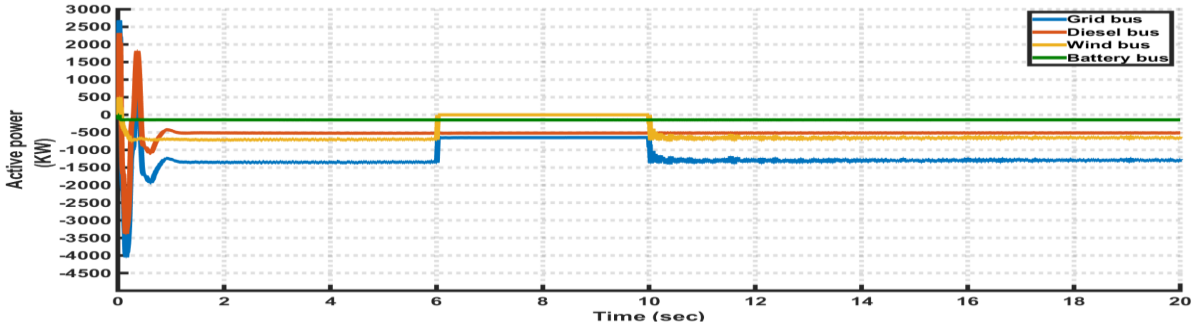
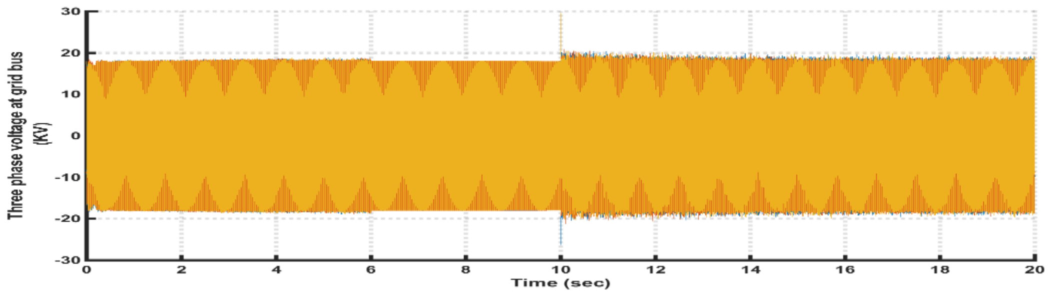


Figure 12: Active power under disconnecting wind system condition

Table 2: Results under case of disconnecting wind system

	Before Disturbance	During Disturbance	After Disturbance
Active power at wind bus (KW)	-660	0	-660
Active power at diesel bus (KW)	-520	-520	-520
Active power at battery bus (KW)	-144	-144	-144
Active power at grid bus (KW)	-1324	-664	-1324



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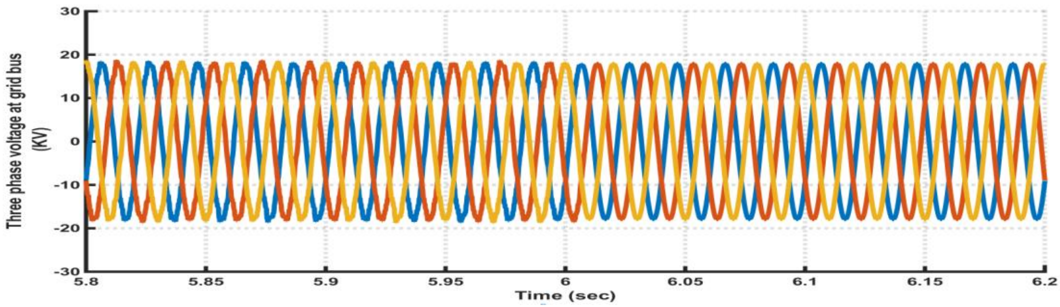

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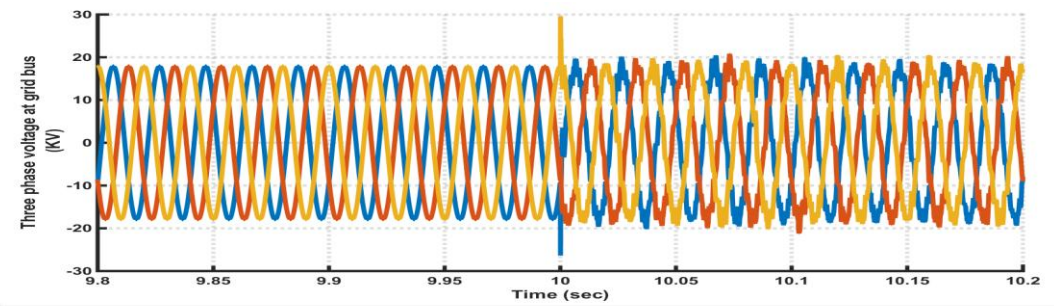
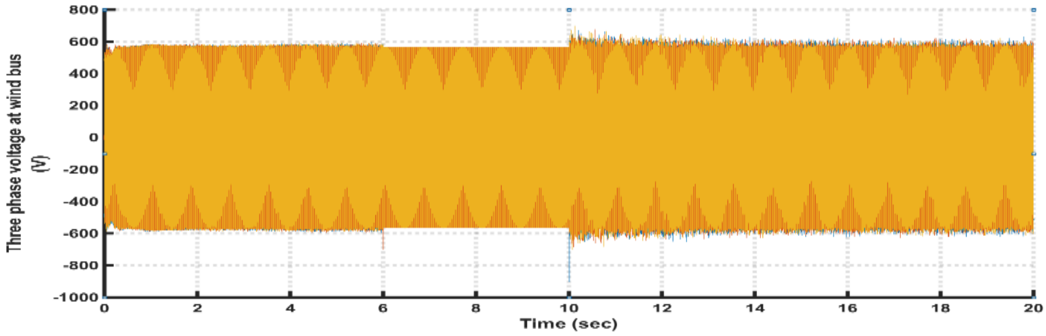


(c)

Figure 13: three phase voltage at grid bus under disconnecting wind system condition
(a) Transient and steady state 3-phase voltage, (b) 3-phase voltage before and during disturbance.
(c) 3-phase voltage during and after disturbance

Figure 13 shows the three phase voltage at grid bus under disconnecting wind condition from time 6 to 10 seconds. It is clarified that voltage stays at the same steady state value and the grid voltage after disturbance has over shoot with value of 28KV reaches the steady state again at t=10.001 seconds.

The three phase voltage at wind bus in case of disconnecting wind system is shown in figure 14. It is noticed that the value of voltage remains constant at steady state but with high ripple after disturbance.



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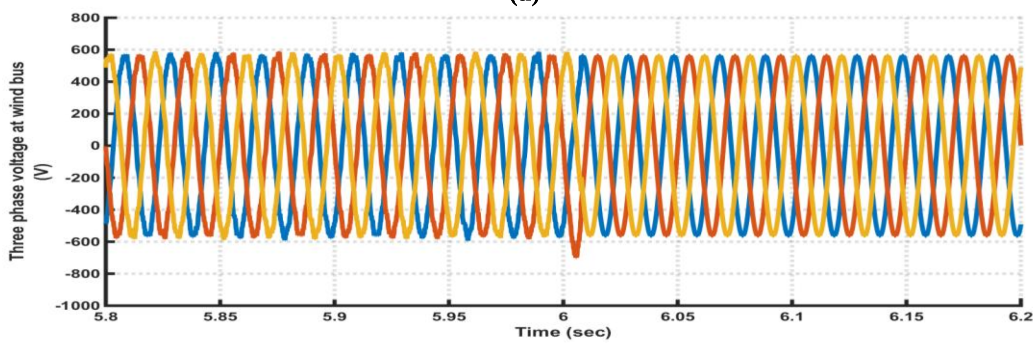

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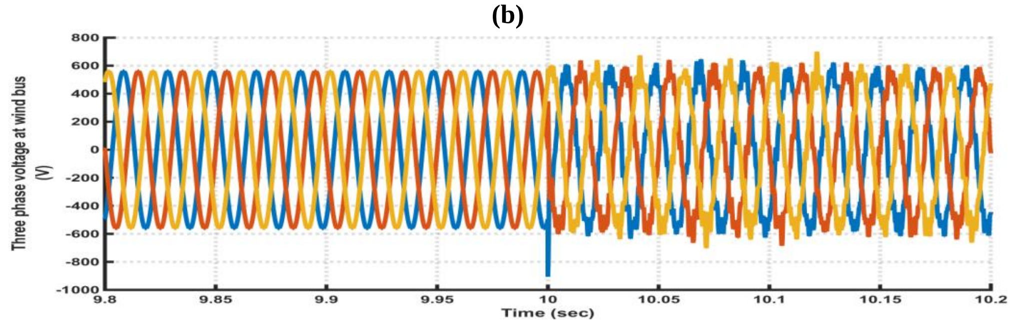
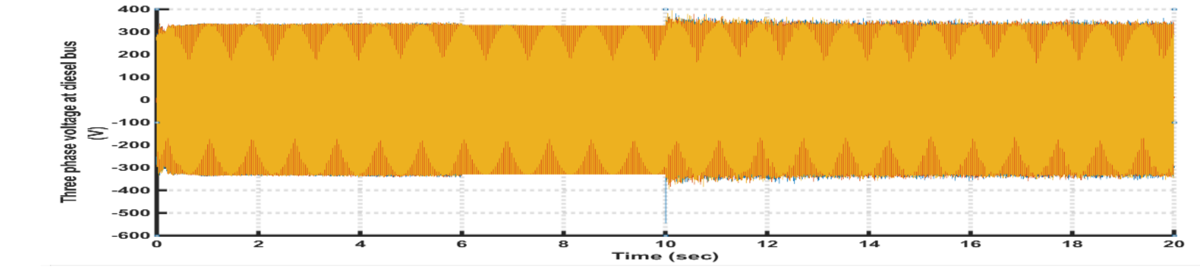


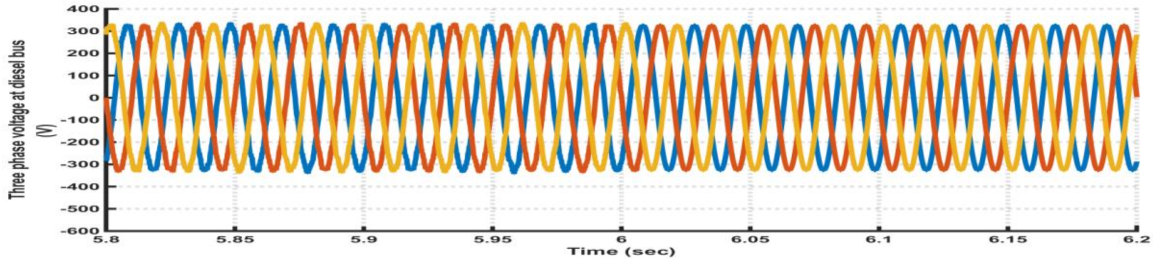
(c)

Figure 14: Three phase voltage at wind bus under disconnecting wind system condition
(a) Transient and steady state 3-phase voltage, (b) 3-phase voltage before and during disturbance.
(c) 3-phase voltage during and after disturbance

The three phase voltage at diesel bus and battery bus under case of disconnecting wind system is displayed in figure 15 and figure 16 respectively. It is presented that after disturbance system reach steady state again at t=13.5 sec with some ripple.



(a)



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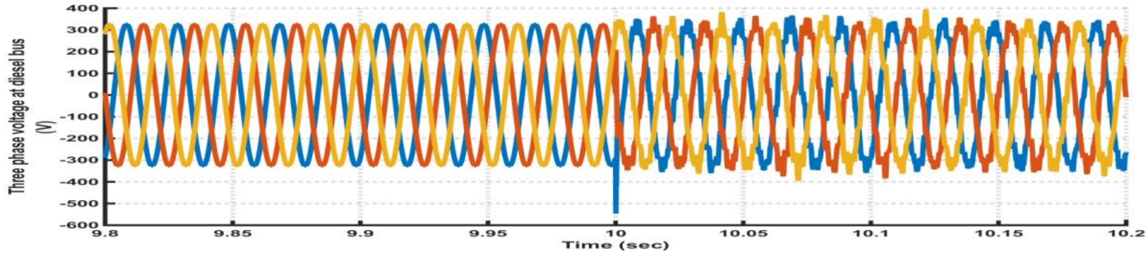
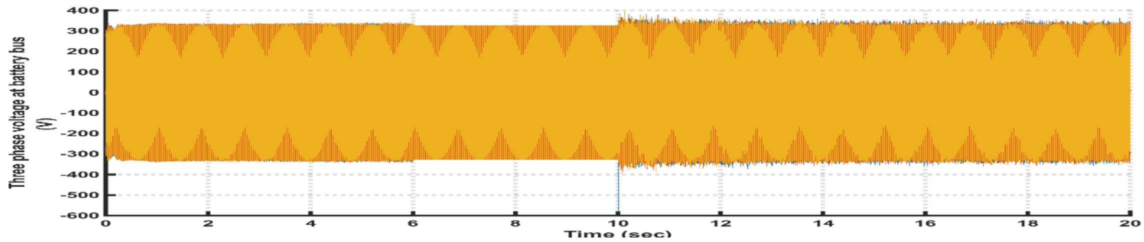


(c)

Figure 15: three phase voltage at diesel bus under disconnecting wind system condition (a)Transient and steady state 3-phase voltage. (b)3-phase voltage before and during disturbance. (c)3-phase voltage during and after disturbance.



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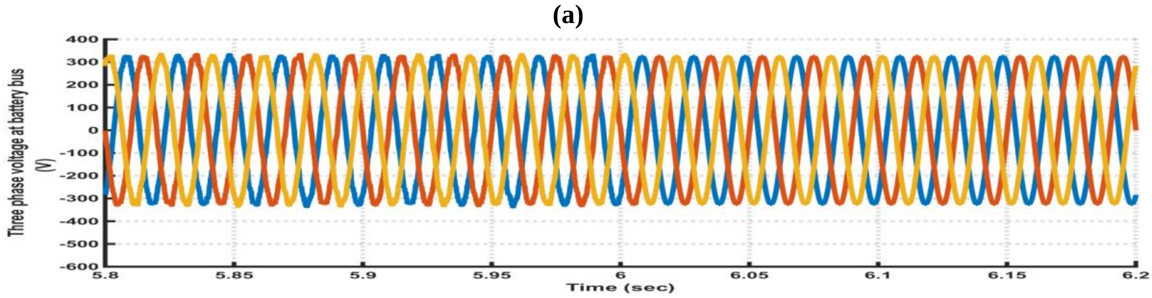

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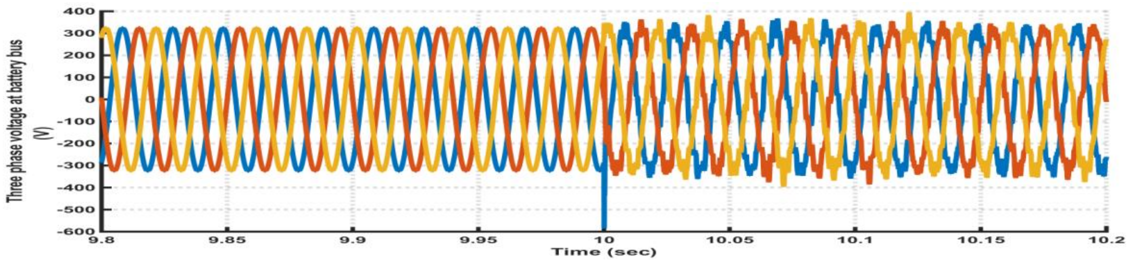

(c)

Figure 16: three phase voltage at battery bus under disconnecting wind system condition (a)Transient and steady state 3-phase voltage. (b)3-phase voltage before and during disturbance. (c)3-phase voltage during and after disturbance.

5. Conclusion

The models for all wind-diesel with battery storage system components have been presented. The first study case covers the normal operation of proposed system connected to grid which demonstrates the active power at wind bus (-660KW), diesel bus (-520KW) and battery bus (-144KW). This active power have a negative sign, thus hybrid system is supplying power to grid equal to 1.5MW approximately. Transient three phase voltages at all buses are similar to sinusoidal wave with ripple. It is clear that, the effective value for voltages at wind bus is 562.7 V, diesel bus is 327.5 V and battery bus is 326.2 V. In the second study case, the simulation has been executed to study the dynamic operation of the hybrid power system under disconnecting wind system at time equal to6 sec and it is reconnected at time equal to 10 sec. It is noticed that after disturbance the system is operating normally, the value of voltage at wind bus remains constant at steady state (562.7V) but with high ripple and the three phase voltages at diesel bus and battery bus reach steady state value again at time equal to 13.5 sec with some ripple.

APPENDIX (A)

Parameters system:

Nominal frequency= 50Hz. Grid voltage (line to line) = 220KV

Wind turbine parameters:

Diameter=47m Swept area=1735m^2

Rotational speed: variable 14.6 rpm-30.8rpm gear box ratio= 1:58

Number of blades=3 air density=1.225kg/m^3 cut-in wind speed=3m/s

stop wind speed= 23m/s

Asynchronous machine:

Rated power=850Kw Voltage (line to line) =690V

PI controller 1: $K_{P=}5$ K_i=0.1 reference reactive power=0

PI controller 2: $K_{P=}2$ K_i=2

PI controller 3: K_p= 0.1 K_i=10

PI controller 4: K_p=0.02 K_i=0.2 reference DC voltage=1200

PI controller 5: K_p=2 K_i=50

Synchronous machine:

Rated power=600KVA Voltage (line to line) =400V

Battery:

Battery rated voltage=240 V Battery capacity= 390.625 Ah

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