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Simulation of Isolated Wind Diesel System with Battery Storage under Sudden Load Variations

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ABSTRACT: In this Wind Diesel Hybrid System (WDHS), the Diesel Generator (DG) and Wind Turbine Generator (WTG) both supplies power to the consumer loads. The power, frequency and voltage fluctuations of system are occurred under sudden load variations i.e; sudden decreasing of load or sudden increase of load. Under sudden decreasing of load The problem of reverse power condition of diesel generator occurred for active power balance between the system components, because the speed governor cannot control the system frequency during reverse power condition of diesel generator which leads to power, frequency and voltage fluctuations. The sudden increasing of load also causes power, frequency and voltage fluctuations for active power balance in the system. These fluctuations are controlled with the help of both Battery Energy Storage System (BESS) and changing the wind generator output by varying wind speed with help of step signal. The BESS operations are controlled by Active Power Regulator (APR). Under normal load condition, the speed governor controls the system frequency and Active power regulator (APR) does not give any control signal to the BESS and there is no BESS operations are performed. A major important for the theoretical study of hybrid system is the availability of models, which can be used to study the behaviour of hybrid system and software environment. Therefore, the wind diesel hybrid system model will be presented. The system will consist of Diesel Generator (DG), Wind Turbine Generator (WTG), consumer load, BESS, APR. All these models are designed and tested through the MATLAB-SIMULINK software and observed the variations in system variables in the graphs for both sudden decreasing and increasing of consumer loads.

KEYWORDS: Wind Diesel Hybrid System (WDHS), Battery Energy Storage Systems (BESS), Active power regulator (APR), Diesel generator (DG), Wind Turbine Generator (WTG).

I.INTRODUCTION

In wind-diesel hybrid system both wind turbine generator (WTG) and diesel generator (DG) supplies power to the consumer load, To reduce fuel consumption and operating costs of the system the wind turbine generator contributes maximum power [1] based on wind energy availability the WDHS systems are classified as low, medium and high penetration [4] based on WDHS system classification there are three operating modes namely 1.Diesel only (DO), 2. Wind Diesel (WD), and 3.Wind only (WO) modes. Wherein DO mode only DG supplies power to load, in WD mode both DG and WTG supplies power to load and in WO mode WTG alone supplies power to load [8]. The DO to WD mode transition with no BESS is simulated in [6] the WDHS system with sudden disconnection of WTGS and loads with no BESS is simulated in [3].The DG with clutch mechanism in high penetration WDHS is simulated in [5], [2]. The dump load (DL) is used in medium penetration WDHS for active power balance in the system when DG power levels varying from zero value to its maximum range in [7].With BESS the reverse power condition of DG under sudden load decrements controlled in medium penetration WDHS there by system performance is improved [9].

II.WIND DIESEL HYBRID SYSTEM

The layout of Wind Diesel system is shown in figure (1) and it contains of wind system, diesel system, Battery Energy Storage Systems (BESS) and Active power regulator (APR).

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1. Wind system: this system contains both wind turbine and Induction Generator (IG). Where fixed speed wind turbine is considered here and it does not required any pitch or yaw control and it takes wind energy as input and gives mechanical energy as output and the output can be changed by changing wind speed with the help of step signal i.e.; the output can be increased with positive step signal under sudden load increasing condition and decreased with negative step signal under sudden load decreasing condition. The squirrel cage IG is used here and it works on induction principle and it is mechanically coupled to wind turbine with the help of shaft and it takes input from wind turbine and gives electrical energy as output which directly connected to the system busbar.

2. Diesel system: it contains Diesel engine, DG, Excitation system and Speed governor. Where diesel engine mechanically coupled to DG with the help of shaft and it takes diesel as input and gives mechanical energy as output and this output given to DG, here synchronous generator is used as DG and it outputs electrical energy which directly connected to the system busbar. The DG frequency oscillations occur due to sudden system load changes which can be controlled with the help of DG Speed governor and the DG terminal voltage is controlled with the help of Excitation system under sudden load variations.

3. Active power regulator (APR): Under sudden load varying condition the DG takes reverse power for making active power balance in the system which may cause frequency variations in the system. the APR compares both actual and nominal system frequency continuously. If any frequency error occurs it gives a reference signal which is used to generate the PWM generator input reference signal and the PWM outputs the gate pulses which are given to the converter circuit and further battery operations start to reduce this error.

4. Battery Energy Storage Systems (BESS): it consists of three phase transformer, converter circuit, filter and battery where the three phase transformer step-down the system voltage and given to the converter circuit, based on gate pulses reference received from PWM generator the convertor acts as rectifier under sudden load decreasing condition or inverter under sudden load increment condition, the ripples at converter output is reduced with the help of the LC-filter and the battery consumes energy under sudden load decreasing condition or delivers energy under sudden load increment condition there by active power balanced in the system and then system performance is improved.

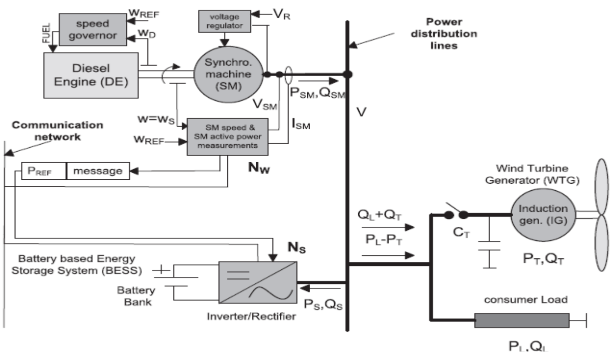

Fig.1.WDHS layout

III.REVERSE POWER CONDITION AND ACTIVE POWER REGULATOR (APR)

This negative power taken by DG is called reverse power. The causes for reverse power condition: 1.Sudden load decrement, 2.The WTG power is greater than the reduced load. The DG takes negative power under sudden load decrement to maintain active power balance between the system components, which may leads to system unstability because the DG speed governor cannot control the system frequency under this condition. In this reverse power condition the fluctuations occurred in the system frequency and voltage and which may leads to mechanical damage of system components. The active power balance equations are given as:

Under Normal condition:

$P_D + P_W = P_L$……………………………………..(1)

Under Reverse power condition:

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$P_W \gg P_L$……………………………………………(2)
$P_D + P_W \neq P_L$……………………………………..(3)
Where P_D = DG active power
P_W = WTG active power
P_L = consumed active power by load

The APR maintains active power balance under reverse power condition, by providing a control signal (P_{REF}) to BESS by measuring frequency error(e_f). The APR contains proportional and derivative controllers where the proportional controller controls the battery operations based on the frequency error(e_f), the derivative controller improves the system speed response and stability.The term P_{INV} in equation (4) prevents the DG reverse power and steady state frequency error. The K_P, K_D values are given in the appendix. The APR simulation schematic is shown in below figure (2).

$P_{REF} = K_P e_f + K_D \frac{de_f}{dt} + P_{INV}$…………………… (4)
Where frequency error(e_f)=$f_{actual} - f_{nominal}$.
f_{actual} = Actual system frequency
$f_{nominal}$ = Nominal system frequency

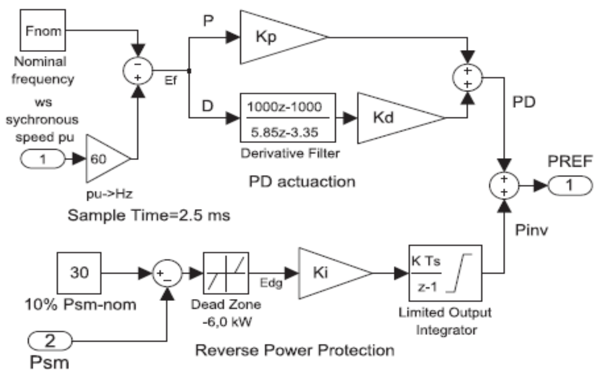

Fig.2.APR Simulation schematic

IV.BATTERY ENERGY STORAGE SYSTEM (BESS)

In the BESS the main components are converter and battery. Based on the signal received from APR the converter acts as rectifier or inverter i.e.; 1. If$P_{REF} > 0$ the the converter acts as rectifier with the help of gate pulse received from PWM generator and the battery consumes power from the system which indicates that the system load was decreased and this may cause DG reverse power condition. 2. If$P_{REF} < 0$ the the converter acts as inverter and battery supplies power to the system which indicates that the system load was increased. The active power balance of the system with battery as shown in equation (5). The 240v Ni-Cd battery model has taken from [10]. The model contains a variable controlled voltage source V in series with a constant internal resistance R. The V value calculated from the equation (6) and the state of charge (SOC) of battery indicates that whether battery is charging or not if SOC is 100% the battery is fully charged and empty when SOC is zero value its equation is in (7) and its Simulink schematic as shown in Figure(3)

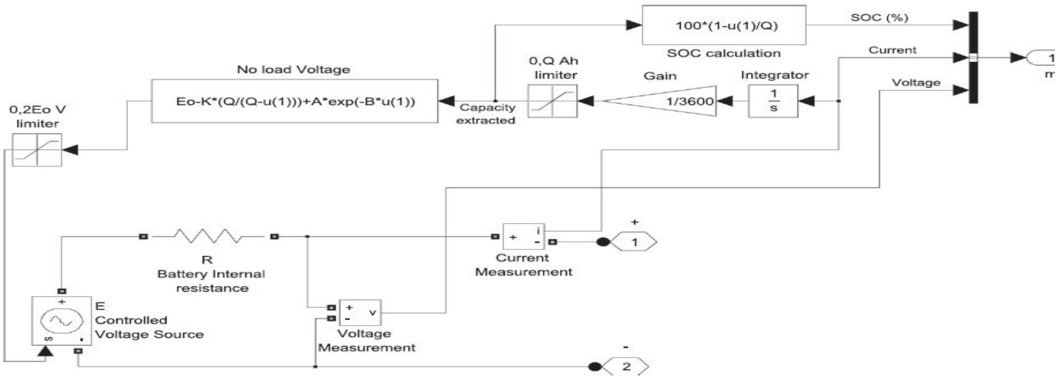

Fig.3.Battery Simulation schematic

$P_D + P_W = P_L + P_b$……………………………………… *(5)*

Where P_b =battery consumed/delivered power.

Here P_b value is "positive" when it consumes power and it's value "negative" when delivers power.

V=V_O- (K(Q/(Q-Q')))+Aexp(-BQ')……………….(6)

WhereV_O, K, A, B are constants its values given in the appendix.

Q (Ah) = maximum theoretical capacity of battery.

Q' (Ah) = actual capacity of battery.

SOC = 100(1-(Q/Q'))……………………………… (7)

Here SOC value is "positive" when battery charging and its value "negative" when discharging.

V. SIMULATION AND RESULTS

The model of WDHS with BESS is developed in MATLAB-SIMULINK in two different modes:

1. Sudden load **decreasing** mode and its complete model is shown in fig. 4

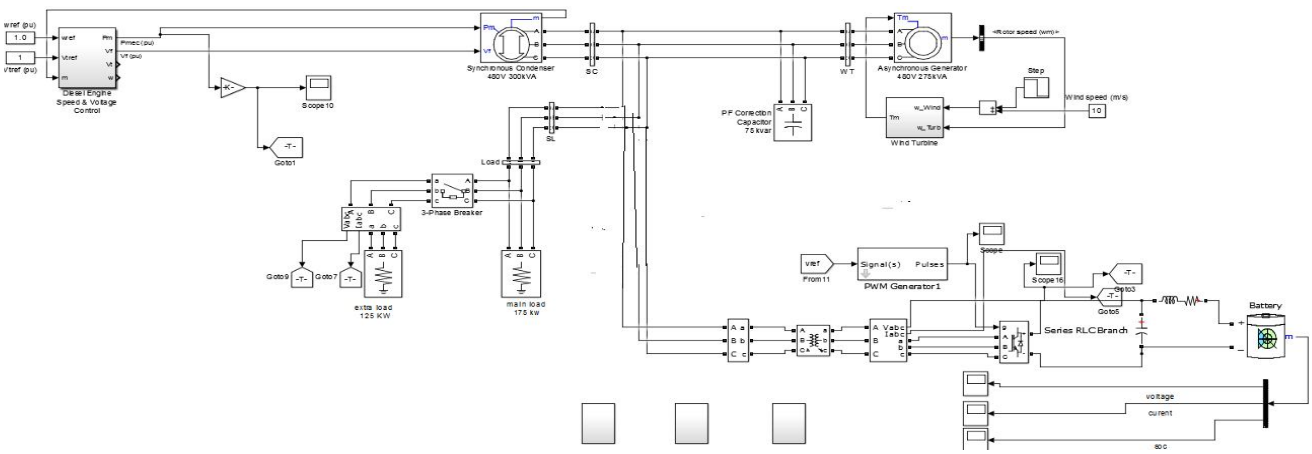

Fig.4 The complete simulation model of WDHS with BESS under sudden load decreasing mode

In this mode initially the total load is 300kw and it is suddenly decreased to 175 kw at t=0.2s with the help of circuit breaker which leads to reverse power condition of DG and system performance deproved. To control this problem, the BESS operation is started at t=0.2s and then continued upto t=8.2s after that the **negative** wind step is given to control the system performance. In this section graphs for the following variables are shown: the active powers for consumer load and BESS (Fig. 4.1), the active powers for the WTG and DG (Fig. 4.2), the battery voltage–current–SOC (Fig.

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4.3), frequency per unit (Fig. 4.4) and the RMS voltage per unit (Fig. 4.5) the active powers for WTG and DG are considered positive if produced and for the load and BESS positive if consumed.

In the fig. 4.1, it shows the graph of time Vs Consumed (+) active powers by the BESS and load.where at t=0.2s the load is suddenly decreased from 300KW to 175KW, after load reduction the battery consumes active power upto t=8.2s which is considered as positive and then the battery stops active power consumption.

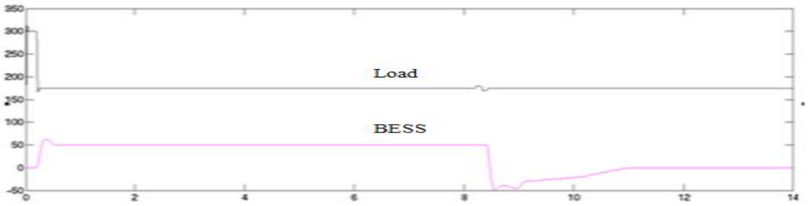

Fig. 4.1 Time (sec) **Vs** Consumed (+) active powers (KW) by the BESS and load

In the fig. 4.2, it shows the graph of time Vs the active powers for the WTG and DG.where at t=0.2s the both WTG and DG powers are disturbed due to sudden load decrement at t=0.2s and comes to normal position with the help of BESS operation at t=0.2s and negative wind step at t=8.2s.

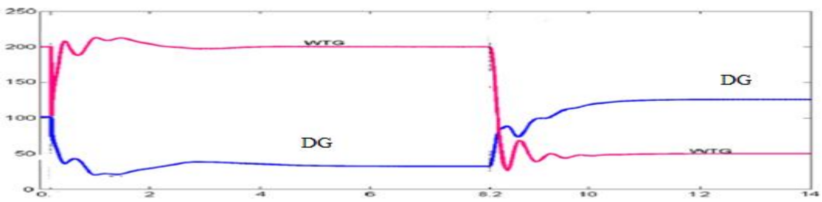

Fig. 4.2 Time (sec) **Vs** the active powers (KW) for the WTG and DG.

In the fig.4.3, it shows the graph of time Vs the battery voltage–current–SOC. in this both battery voltage, soc are constant where soc is positive when battery charging and battery current waveform follows its active power consumption.

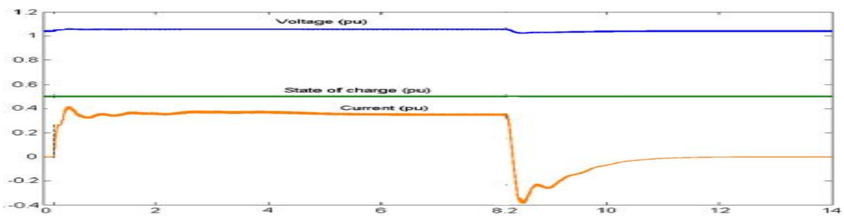

Fig.4.3 Time (sec) **Vs** the battery voltage–current–SOC.per unit

In the fig. 4.4, it shows the graph of time Vs frequency per unit. In this the frequency variations under sudden load decrement condition with BESS and negative wind step is observed.

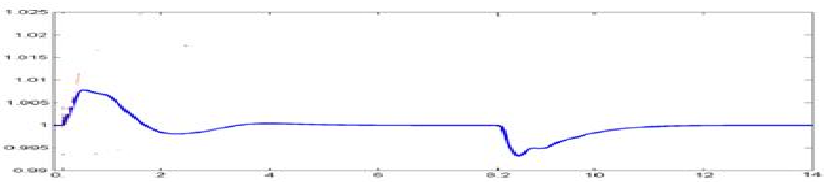

Fig.4.4 Time (sec) **Vs** frequency per unit.

In the fig. 4.5, it shows the graph of time Vs the RMS voltage per unit. In this the voltage variations under sudden load condition with BESS and negative wind step is observed.

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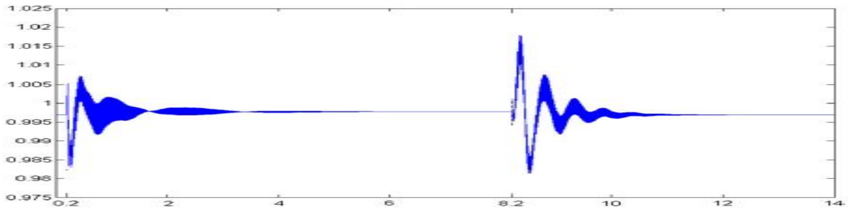

Fig. 4.5 Time (sec) **Vs** the RMS voltage per unit.

2. Sudden load **increasing** mode and its complete model is shown in fig. 5

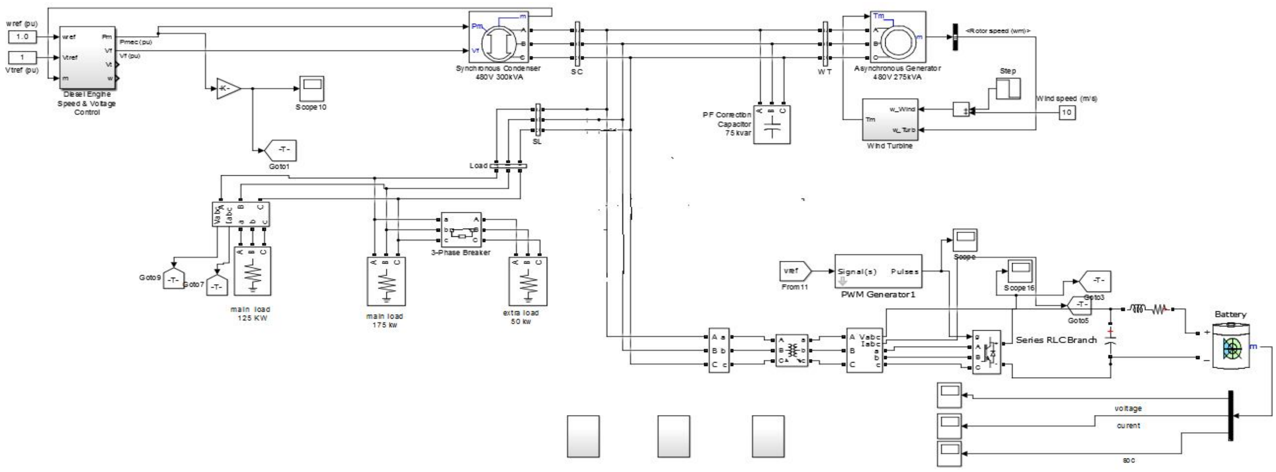

Fig.5 The complete simulation model of WDHS with BESS under sudden load increasing mode

In this mode initially the total load is 300kw and it is suddenly increased to 350 kw at t=0.2s with the help of circuit breaker which leads to reduction of system performance. To control this problem, the BESS operation is started at t=0.2s and then continued up to t=8.2s after that the **positive** wind step is given to control the system performance. In this section graphs for the following variables are shown: the active powers for consumer load and BESS (Fig. 5.1), the active powers for the WTG and DG (Fig. 5.2), the battery voltage–current–SOC (Fig. 5.3), frequency per unit (Fig.5.4) and the RMS voltage per unit (Fig. 5.5) the active powers for WTG and DG are considered positive if produced and for the load and BESS negative if delivered.

In the fig.5.1, it shows the graph of time Vs active powers of BESS and load.where at t=0.2s the load is suddenly increased from 300KW to 350KW, after load increment the battery delivers active power upto t=8.2s which is considered as negative and then the battery stops active power delivered.

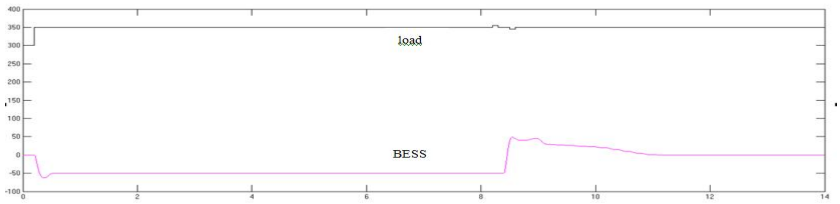

Fig.5.1 Time (sec) **Vs** active powers (KW) by the BESS and load

In the fig.5.2, it shows the graph of time Vs the active powers for the WTG and DG.where at t=0.2s the both WTG and DG powers are disturbed due to sudden load increment at t=0.2s and comes to normal position with the help of BESS operation at t=0.2s and positive wind step at t=8.2s.

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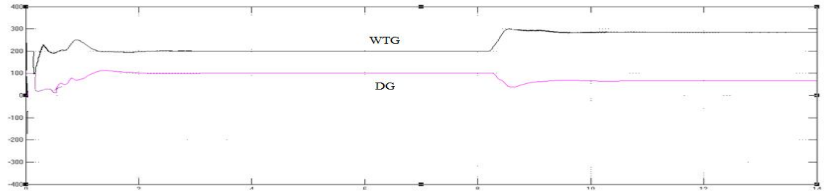

Fig.5.2 Time (sec) **Vs** the active powers (KW) for the WTG and DG.

In the fig.5.3, it shows the graph of time Vs the battery voltage–current–SOC. in this both battery voltage, soc are constant where soc is negative when battery discharging and battery current waveform follows its active power delivered.

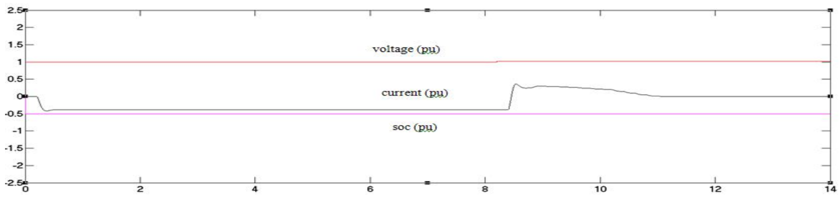

Fig.5.3 Time (sec) **Vs** the battery voltage–current–SOC.per unit

In the fig.5.4, it shows the graph of time Vs frequency per unit. In this the frequency variations under sudden load increment condition with BESS and positive wind step is observed.

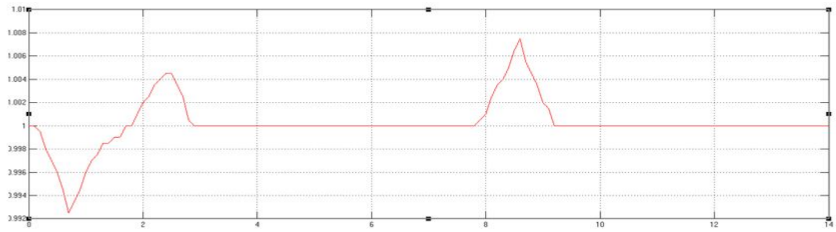

Fig.5.4 Time (sec) **Vs** frequency per unit.

In the fig.5.5, it shows the graph of time Vs the RMS voltage per unit. In this the voltage variations under sudden load increment condition with BESS and positive wind step is observed.

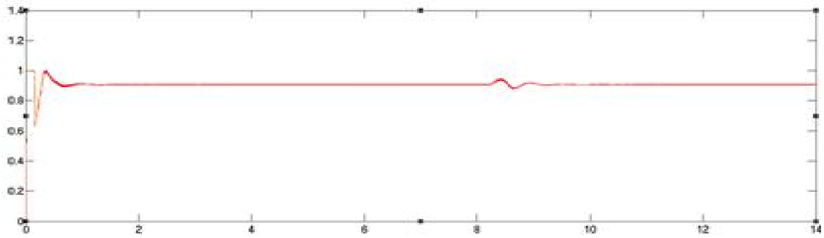

Fig.5.5 Time (sec) **Vs** the RMS voltage per unit.

VI.CONCLUSION

In this paper The MATLAB-SIMULINK models of WDHS with BESS under sudden load variations and wind speed changes is presented. mainly under sudden load decreasing mode, the problem of reverse power condition of DG occurs to maintain active power balance between system components, which leads to power, frequency and voltage fluctuations in the system because the speed governor of DG cannot control system frequency under DG reverse power condition. In the similar way the power, frequency and voltage fluctuations occurs in sudden load increasing mode for

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International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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active power balance in the system. These system fluctuations are effectively controlled and then the performance of system is improved under sudden load variations with the help of APR, BESS and by changing wind speed.

Appendix A

Parameters of Isolated Power System
Nominal frequency = 60 Hz
Rated voltage (rms, phase to phase) = 480 V
Diesel Generator (DG)
Synchronous machine rated power, PSM-NOM = 300 kVA
Wind Turbine Generator (WTG)
WTG rated power, PT-NOM = 275 kVA
Active Power Regulator (APR)
Proportional gain, KP = 125 kW/Hz
Derivative gain KD = 12.5 kW s/Hz
Reverse Power Activation Threshold = 60 kW
Reverse Power Deactivation Threshold = 66 kW
Battery
Battery rated voltage = 240 V
Battery rated Capacity = 390.625 Ah
Battery voltage model parameters:
v0 = 256.95 V; K = 3.7501 V; Q = 410.16 Ah; A = 28.80 V; B = 0.0384 (Ah^{-1}).
Internal Resistance = 0.0154 Ohm
Filter Capacity, C = 8 mF
Filter Inductance, L = 2.5 µH
Transformer Rated voltage primary/secondary (rms, phase to phase)= 480/120 V

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