I J C T A, 9(14) 2016, pp. 6519-6529

Stability Analysis of Hybrid Power System with BESS

Kruti Gupta[*] and Kamal Kant Sharma[*]

ABSTRACT

In this study, the transient stability analysis is done on hybrid system and is subjected to different types of unsymmetrical faults. It is found that critical fault clearing time is greatly reduced in hybrid system with BESS as compared to SMIB system thus ensuring safe operating margin of hybrid system and to remain it in stable state. The reliability and continuity of power is also improved. A Lithium ion battery cell is used in conjunction with hybrid system consisting of wind farm and mini/micro hydro plant integrated via power electronic interface. It is seen that BESS helps in improving load leveling by charging when demand is less than generation and by discharging in vice-versa case.

Keywords: Battery Energy Storage System (BESS), Distributed Generation (DG), Renewable Energy Sources (RES), Lithium ion battery etc.

I. INTRODUCTION

Due to the intermittent nature of renewable energy sources (RES), energy storage devices are extensively used in hybrid power systems to fulfill load requirements, thereby reducing adverse effects of Distributed Generation (DG) on grid and helps improving transient stability of system. The selection of storage device is made on basis of its features and characteristics.

Batteries are extensively used now-a-days in every research field as it incorporates both technical and economical advantages. Research is also being carried out on the type of material used in battery for wide range of operation. Lead acid and Li-ion batteries are gaining more importance due to their high power densities, energy capabilities, their life cycle cost and low maintenance. On the contrary, they are having high capital costs which are the reason for their restricted use.

The main purpose of energy storage device is to meet periodically increasing power demand. Various kinds of long term and short term energy storage devices are available now due to technical progress which has potential applications in all sectors of power industry and also in technical and economical development. A lot of research study is carried out by various institutes in the field of RES and their implementation in power systems [1].

Selecting a better energy source for hybrid system is not a big problem, but the problem lies in extracting and storing the energy for future use. As almost all natural sources are weather dependent and are intermittent in nature, they are economically infeasible causing power quality problems. Some of the commonly used energy storage systems (ESS) are super capacitor, flywheel, SMES, flow battery, rechargeable battery etc.

In our study, we focus on hybrid power system consisting of 9 MW wind farm and SMIB system with 3-ö synchronous generator rated 100 MVA, 13.8 kV connected to 200 MVA, 25 kV network through “-Y 110 MVA transformer. This hybrid power system is used in conjunction with BESS integrated via power

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electronic interface to store extra amount of energy during peak hours and stability analysis is studied in detail [25].

II. LITERATURE SURVEY

Batteries are of various types and all of them work under similar conditions such as low energy capacity vs. size and poor performance in cold conditions. Battery capacity derating is a major problem as its effective capacity value decreases with time depending on certain factors like temperature, battery improper handling etc. Proper storage and work condition helps in slowing down battery ageing process and charge-discharge control [2]. The influence on battery life cycle should also be carefully examined. Major features considered for selecting battery are reliability, cost, efficiency, durability, portability, life expectancy, maintenance etc [3].

The composition of mathematical model of battery behavior with its implementation in virtual simulation environment is studied and capacity of battery to supply expected load can be evaluated [2].

A model of BESS is developed in MATLAB environment using PSB toolbox. The performance of model is tested under varying load conditions. A control algorithm of BESS to provide load balancing & reduce harmonics in supply currents & terminal voltage is proposed. It is found to be flexible & is tested for PQ improvement for linear and non-linear loads. BESS provides more benefits in terms of improved voltage, energy management & protection from interruptions [4].

The integration of storage device with DG provides greater flexibility, reliability and also influences stability of grid. Wind energy is modeled as both fixed and variable speed wind energy farms whereas battery and ultra capacitor is modeled as storage with suitable power electronic interface. The transient stability is analyzed based on certain factors such as generator rotor speed deviation, rotor angle and terminal voltage of DG. The impact on transient stability is system specific and depends on location and type of fault [5].

Flywheel energy-storage systems (FESSs) which are suitable for improving the quality of electric power delivered by wind generators & for helping these generators to contribute to ancillary services. [6].

A control scheme for FC generation to improve transient stability and damping performance of micro grids is proposed which has numerous benefits to distribution system due to the use of UC and fast adjustment of power electronic conditioning system. Real power modulation technique is used for controlling FC generator for improving stability and power swing damping of micro grids [7]. Most of the basic features of UC in order to use it effectively in various test systems such as description of double layer capacitors, their typical applications, determination of appropriate size for suitable application, specifications, performance characteristics, packaging, various design considerations, mechanical integration and interconnecting methods, safety information and product quality are given in [9].

An innovative control strategy for voltage-regulated DC hybrid power source which employs polymer electrolyte membrane fuel cell (PEMFC) as main energy source and super capacitors as auxiliary power source for DG system has been proposed in [8]. The dynamic behavior of integrated DG consisting of WT, SOFC and MT under variable load profile is studied which reduces cost of power generation and level of pollution reduces fuel consumption. Also, MT is used efficiently to meet peak demand of system by utilizing its standby capacity, quick startup capability and easy controllability in [10].

The basic principle of hybrid compressed air and super capacitors energy storage (CASCES) system, flowchart of MEPT algorithm by quadratic interpolation (QI) and perturbation observation (PO) techniques are studied in [11].

The transient stability of system with DG and storage device such as battery and UC is studied on account of its different types, location of faults and varying penetration levels of SG. The storage device had positive impact on transient stability. The economic analysis includes the cost of system with different DG configurations with and without storage devices and all are compared using HOMER software. UC and biomass technology need to be more economical to be cost effective for increased benefits [12].

Hybrid EV requires efficient storage medium and advances in field of double layer electrolytic capacitor technology have opened a new era. This paper reviews some applications of UC and provides guidelines for sizing UC for minimal mass in HEV. New Jeol UC has much less mass reduction. The rating of interface is influences by choice of operating current and voltage of UC.[13]

III. MATHEMATICAL MODELING OF LITHIUM ION BATTERY

(A) Construction of Lithium Ion Battery

A typical battery cell consists of cathode, anode and separator (Fig. 1). This apparatus is immersed in electrolytic medium consisting of lithium salt. Porous cathode (made of graphite) is connected to negative potential of battery and anode (made of metal oxide) is connected to positive potential of battery. The separator (behaving as insulator) can be either solid or liquid with high concentration of lithium ions preventing flow of electrons but ions can pass through electrolytic solution. The lithium ions on the surface of cathode will undergo chemical reaction during discharging and thus, electrons accumulate to negative potential of battery. On the other hand, positive ions coming from electrolytic solution will diffuse to metal oxide anode particles. The direction of flow of ions and electrons is reversed during charging process of battery [14].

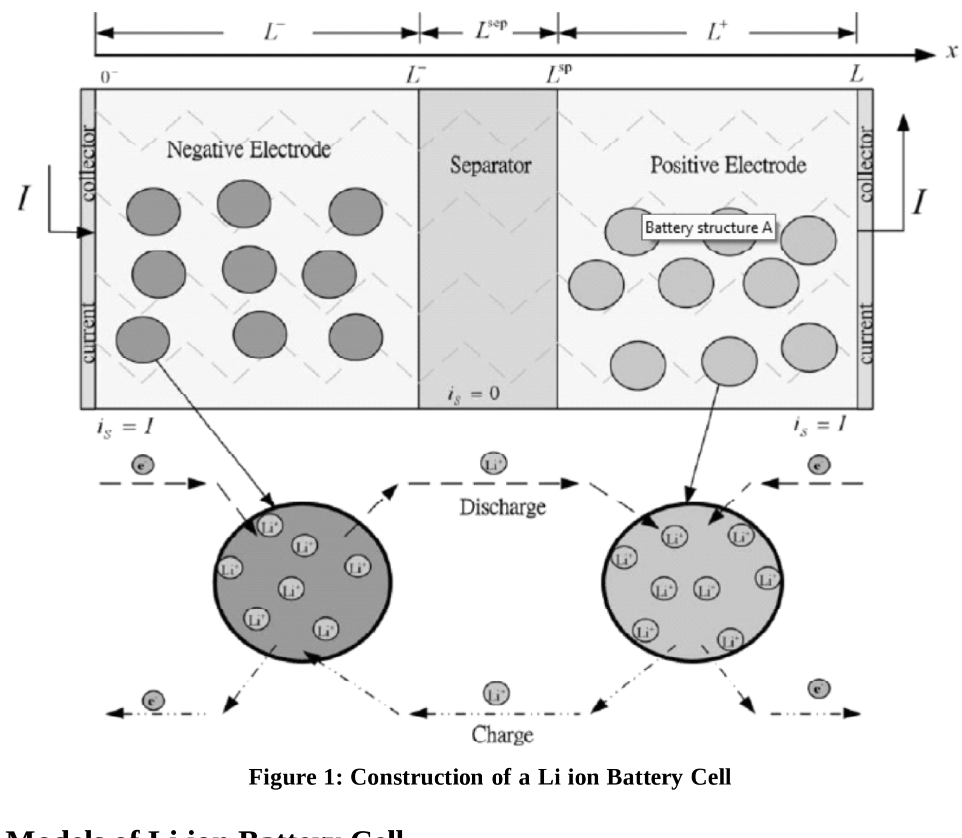

Figure 1: Construction of a Li ion Battery Cell

(B) Different Models of Li ion Battery Cell

Most of the existing models for simulation of Li ion battery cell are divided into three categories viz. Experimental, Electrochemical and Electrical [15-18].

The experimental and electrochemical modeling does not simulate battery dynamics properly. However, specially developed electric circuit based models can be used for accurate prediction of charge and discharge of batteries by taking SOC into account. Some electrical models such as IR, OTC, TTC, DP and PNGV models are discussed in [15]

(C) Electrical Modeling of Li ion Battery Cell

The equivalent circuit diagram (Fig. 2) of internal resistance (IR) model as in [15, 19] is shown below:

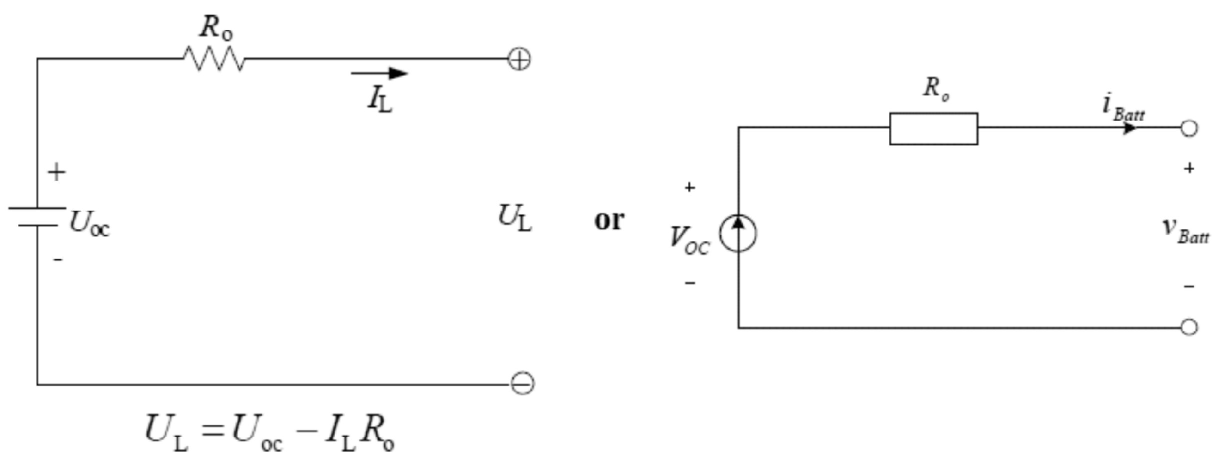

Figure 2: IR Equivalent Model of Li ion Battery Cell

The general equation which is used to represent electrical model of Li ion battery is given below [2]:

$$V = E_0 - K\frac{Q}{Q-it}it - K\frac{Q}{Q-it}i - R.i + C \tag{1}$$

Where, V is battery potential in V

E_0 is battery constant voltage in V

K is polarization resistance in Ω

Q is battery capacity in Ah

it is actual battery charge in Ah

A is exponential zone amplitude in V

B is exponential zone time constant inverse Ah^{-1}

R is battery internal resistance in Ω

i is actual battery current in A

C is exponential voltage in V

All these parameters can be readily obtained from manufacturer's datasheet. However, the values of K, A and B should be calculated from discharge curve of battery.

The equations are as follows [2]:

$$A = V_{full} - V_{\exp}$$
$$B = \frac{3}{Q_{\exp}} \tag{2}$$

To calculate E_0, the following equation must be used:

$$E_0 = V_{full} + K + R.i - A \tag{3}$$

Due to different nature of chemical materials used in different type of batteries, equations for simulation of these batteries also differ. For Li-ion battery,

$$V = E_0 - K\frac{Q}{Q-it}it - K\frac{Q}{Q-it}i - R.i + C$$

for discharge cycle (4)

where, $$C = A.e^{(-B.it)}$$ (5)

$$V = E_0 - K\frac{Q}{Q-it}it - K\frac{Q}{it-0.1Q}i - R.i + C$$

for charge cycle (6)

where, $$C = Ae^{(-B.it)}$$ (7)

(D) Power Electronic Interface

In our research study, three phase full controlled bridge rectifier is used as power electronic interface. The controlling of conduction interval of each SCR controls DC output voltage and is said to be operated in rectifier mode. This is known as phase control and thus, converters are named as phase controlled converters. The polarity reversal of DC output voltage is possible due to SCR blocking voltage in either direction. Thus, they can fed power from DC side to AC supply and is said to be operated in inverter mode. Line commutated converters are described as commutating of SCR in converter circuit via supply voltage under rectifier mode. Now a days, three phase full controlled bridge rectifier is replaced by high power IGBT based VSC connected to DC link in medium to moderate power lines. However, the basic B phase bridge converter block is used in very high power lines [20].

IV. SYSTEM UNDER CONSIDERATION

Two SMIB systems with 9 MW wind farm comprising of six 1.5 MW wind turbines connected to 575 V distribution system exporting power to 25 kV grid via 30 km feeder and 3-ö SG rated 100 MVA, 13.8 kV, 112.5 rpm connected to a 200 MVA, 25 kV network via delta-Wye 110 MVA transformer are connected in hybrid mode feeding combined load of 80 MW on power system [21-23].

For improving the performance of hybrid system comprising of wind and mini/micro hydro plant, an energy storage such as Li-ion battery is used. Li-ion battery will be charged for storing extra amount of electrical energy when generation is more than demand and for discharging purpose when demand is more than generation [24]. A hybrid system with battery storage device is shown in Fig. 3 and detailed Simulink diagram of hybrid system with BESS is shown in Fig. 4.

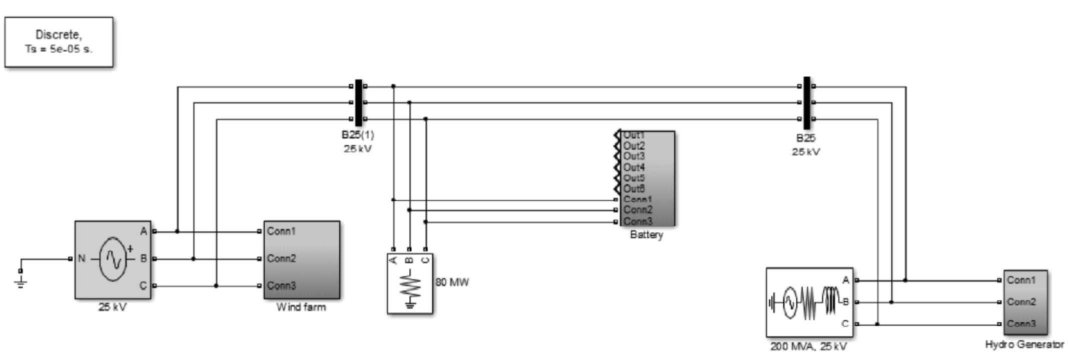

Figure 3: Hybrid System with BESS

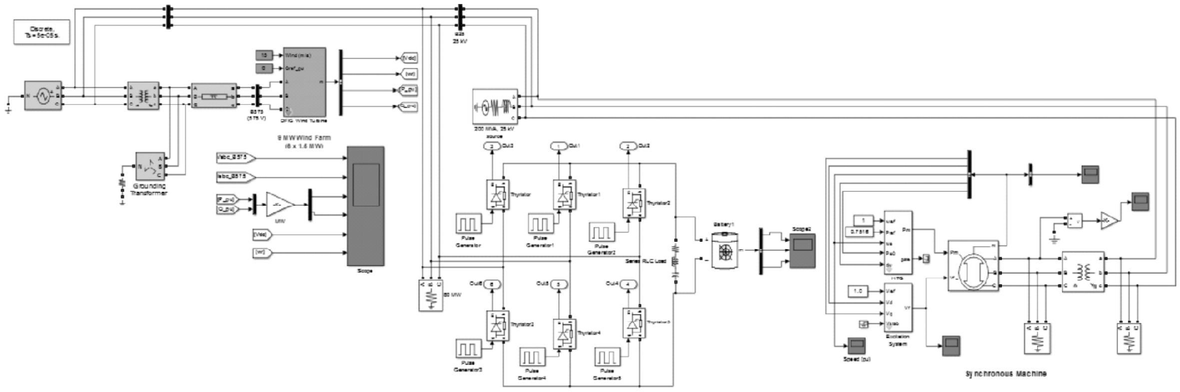

Figure 4: Detailed Simulink Diagram of Hybrid System with BESS

As battery is connected to three phase line, a suitable power electronic interface is required to convert three phase AC to DC supply where battery can be connected for charging and discharging. The phase delay in gate firing pulse which is given to all the thyristors in upper group and lower group is given by

$$\frac{30 + a}{360} * 0.02 \text{ in seconds} \tag{8}$$

where, a is firing angle for ωt=0˚ having a delay of 60˚

In this research study, we are taking firing angle a = 0˚. Thus for all thyristors, phase delay would be 30˚, 90˚, 150˚, 210˚, 270˚ and 330˚.

V. TECHNICAL ANALYSIS OF HYBRID POWER SYSTEM USING BESS

The analysis of transient stability is studied by implementing unsymmetrical faults like L-G, LL-G and LLL-G to hybrid system with BESS. The three phase fault is applied to hybrid system with battery storage device shown in Fig. 5.

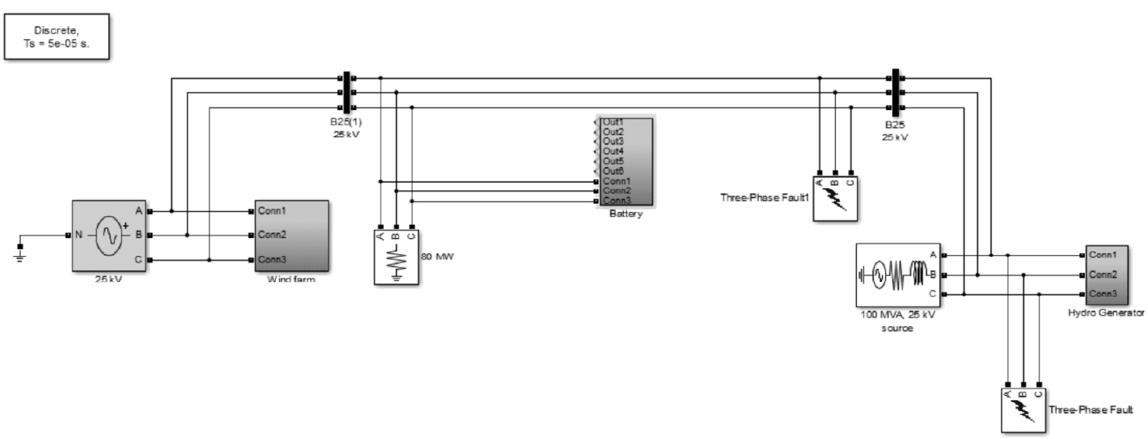

Figure 5: Hybrid System with BESS showing Faults

A 3-ϕ fault is applied at 0.03 s and it gets cleared at 0.05 s. Unsymmetrical faults L-G, LL-G and LLL-G fault are applied on the system and stability analysis is done.

(A) L-G Fault on Hybrid Power System with BESS

The DFIG-WT initially generates 9 MW of wind power and the turbine speed is found to be 1.2 pu of generator synchronous speed. The DC voltage at POI is governed at 1150 V and reactive power is fixed at 0 MVAR. The wind speed is maintained constant at 15 m/s or 1.2 pu.

In Fig. 6, L-G fault is applied at 0.25 s and gets cleared at 0.45 s. The fault gets cleared within 12 cycles and oscillations in current at 575 V bus can also be observed during the fault. The active power increases by approximately 5 MW at 0.25 s and 0.45 s and the reactive power decreases to about 90 MVAR during the fault. The DC voltage at POI is regulated at 30 kV and wind speed decreases to zero during the fault.

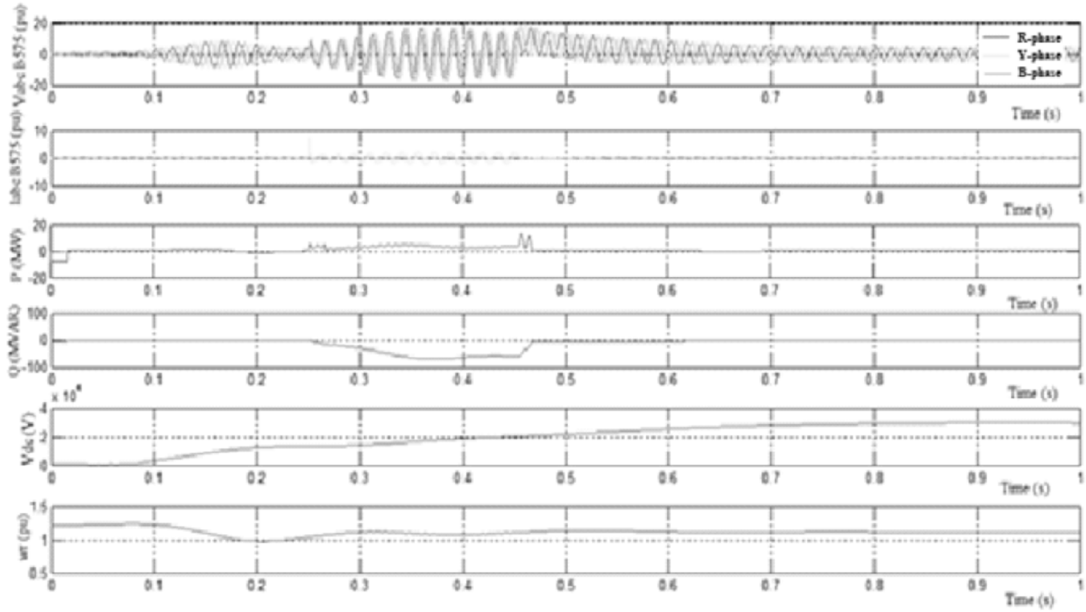

Figure 6: L-G Fault Applied to Hybrid Power System with BESS

(B) LL-G Fault on Hybrid Power System with BESS

In Fig. 7, LL-G fault is applied at 0.25 s and gets cleared at 0.45 s. The fault gets cleared within 12 cycles but the amplitude of oscillations is less as compared to L-G fault. The oscillations in current at 575 V bus can also be observed during the fault. The active power increases by approximately 25 MW at 0.25 s and the reactive power increases to about 100 MVAR. The DC voltage at POI is regulated at 21 kV and wind speed decreases to zero during the fault.

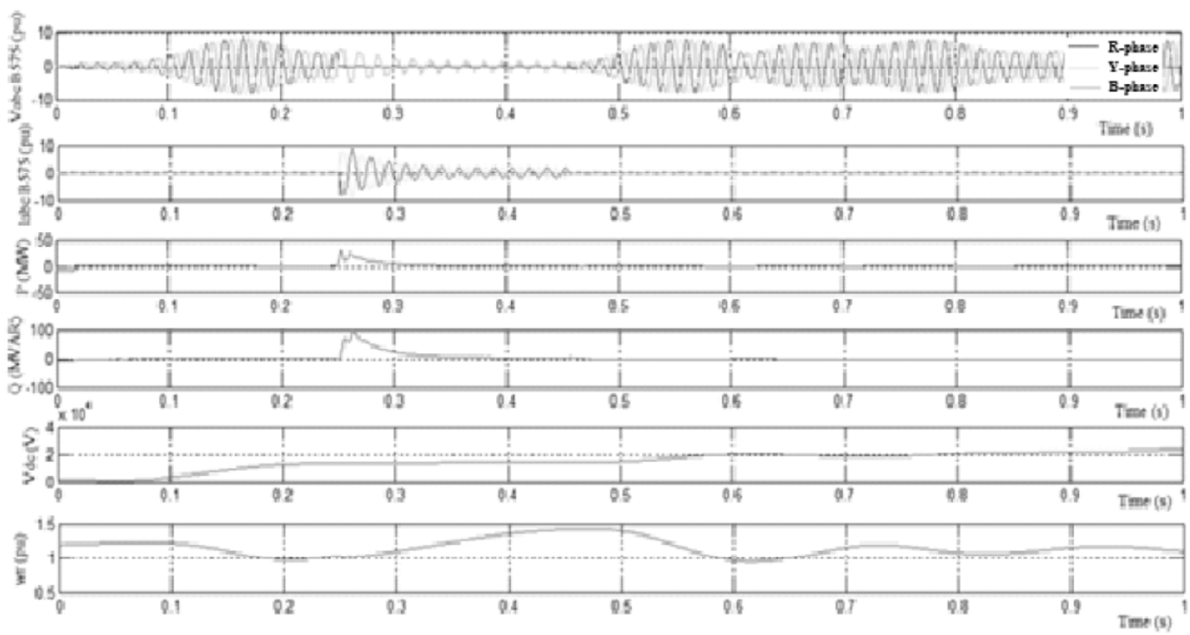

Figure 7: LL-G Fault Applied to Hybrid Power System with BESS

(C) LLL-G Fault on Hybrid Power System with BESS

In Fig. 8, LLL-G fault is applied at 0.25 s and gets cleared at 0.45 s. The fault gets cleared within 12 cycles but the amplitude of oscillations is very much less as compared to L-G and LL-G faults. The oscillations in current at 575 V bus can also be observed during the fault. The active power increases by approximately 50 MW at 0.25 s and the reactive power increases to about 100 MVAR. The DC voltage at POI is regulated at 21 kV and wind speed decreases to zero during the fault and is maintained at 1.2 pu thereafter.

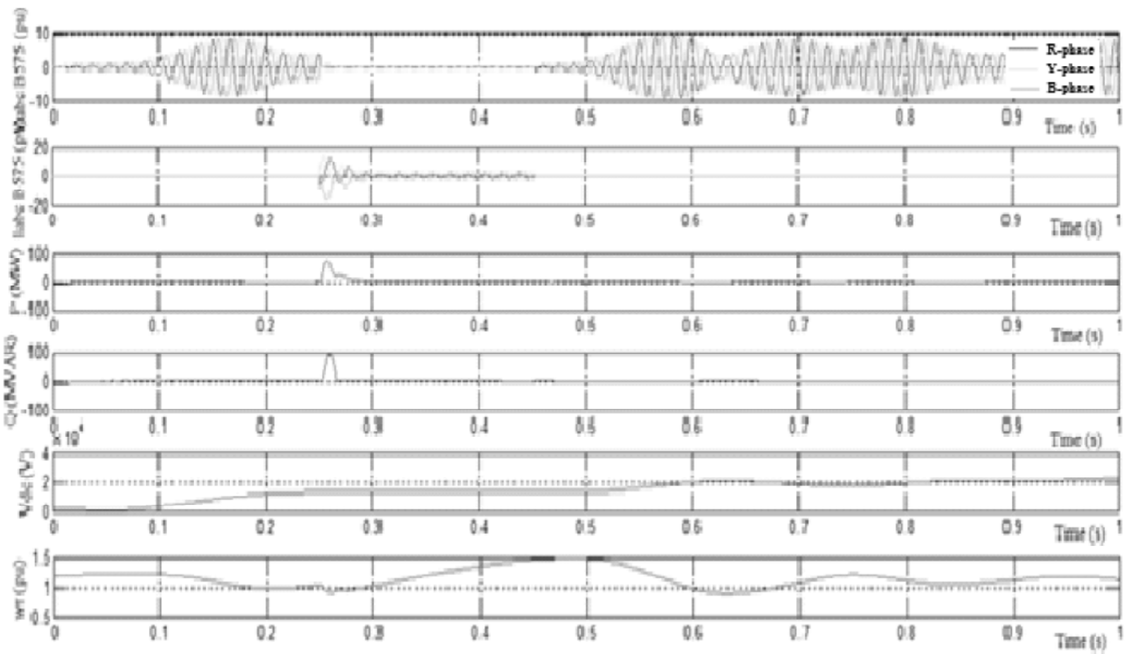

Figure 8: LLL-G Fault Applied to Hybrid Power System with BESS

(D) Effect of Grid Fault on Mini/Micro Hydro Plant

The machine active power initialization is done at 75 MW and terminal voltage is governed at 13.8 kV. The machine reactive power, mechanical power and field voltage requested to supply electrical power is calculated by Machine initialization block and is given by: Q = 21.9 MVAR, P_{mec} = 79.6 MW (0.7955 pu), E_f = 1.2907 pu. The simulation is done in steady state with HTG and excitation system connected to synchronous machine. In HTG block, the initial mechanical power P_{mec} is set at 0.7516 (150.32 MW) by Machine initialization tool. In excitation block, the initial terminal voltage and field voltage is set at 1 pu and 1.29071 pu respectively.

In Fig. 9, grid fault is applied at 0.25 s and gets cleared at 0.45 s. When the simulation is started, the terminal voltage is 1 pu at starting and decreases to about 0.5 pu during fault and returns back to nominal value soon after the fault is restored. The fast restoration of fault is because of excitation system output whose magnitude reaches 11.5 pu during fault. At the same time, the speed of SG increases up to 1.05 pu and oscillates at 1 pu due to governor action. The speed of SG takes more time to be stabilized as compared to excitation system due to the fact that rate of valve opening/closing in governor system is limited only to 0.1 pu/s.

(E) Effect of Grid Fault on BESS

Fig. 10 shows grid fault applied to battery storage device. The total load connected to the system is 95 MW and the total generated power by hybrid system with wind and mini/micro hydro plant is 84 MW. As the demand is more than generation, battery charges and is also seen from above voltage waveforms. The voltage increases and current decreases maintaining constant state of charge (SOC) at 30%.

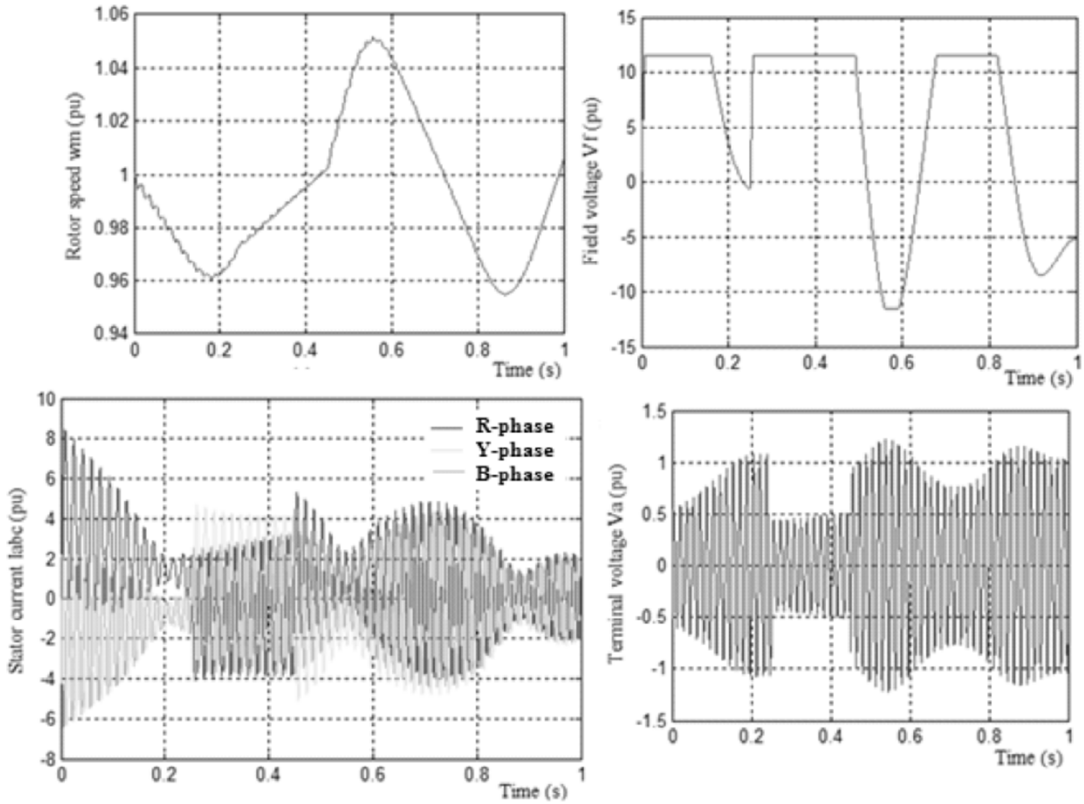

Figure 9: Effect of Grid Fault on Mini/Micro Hydro Plant

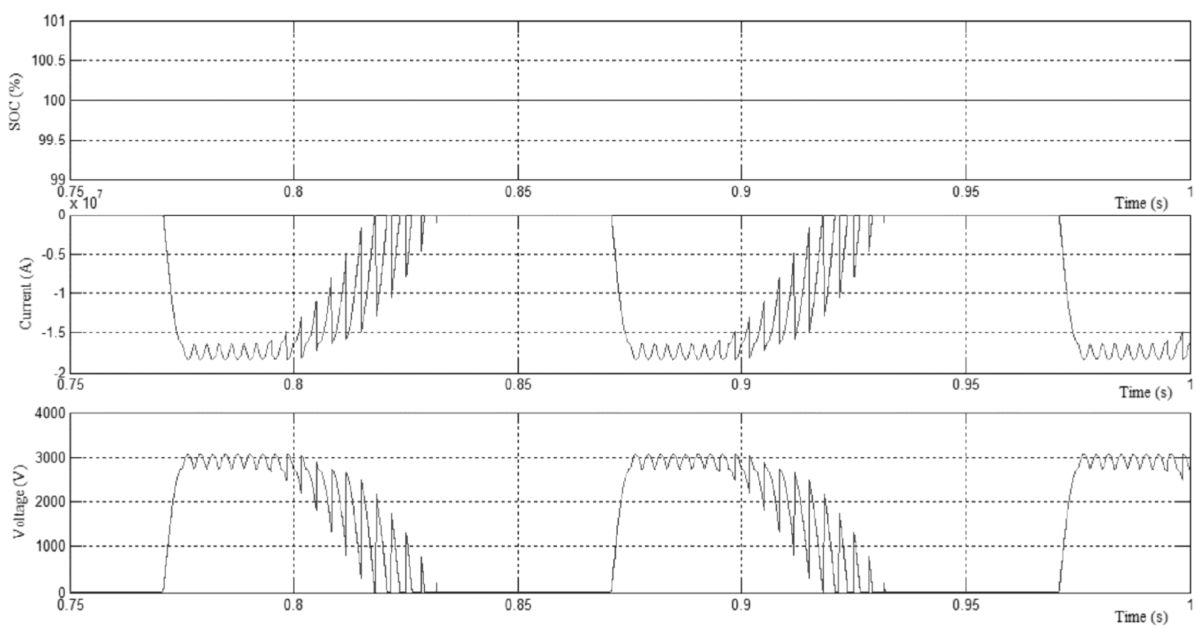

Figure 10: Effect of Grid Fault on BESS

VI. CONCLUSION

The two standalone systems viz. 9 MW wind farm and mini/micro hydro plant are connected in hybrid mode and modeled using Simulink of Sim Power Systems Toolbox of MATLAB software. The detailed transient stability analysis is done by fault insertion via fault breaker in hybrid system. It is found that distortion decreases as compared to two standalone system connected to SMIB. Further, storage device such as Li-ion battery is connected to hybrid system and again transient stability analysis is analyzed. The results showed that critical fault clearing time decreases and thus, the system would remain stable for the most severe fault. It is also shown that when demand is more than generation, the battery will charge and when demand is less than generation, the battery will discharge. This is called load leveling and it improves the efficiency of overall system.

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