A Novel Control Method for Integration of Battery Energy Storage System in Microgrid for Energy Management System

Pandala Rathnakar Kumar, Rowthu Padma

Abstract: ***This paper discuss about environment and rising prices of energy, more renewable energy sources are incorporated into the power grid in the form Distributed Generation (DG) Instead of using fossil fuels, energy storage like battery or ultra-capacitors coupled with the power electronic converter systems offer fast response for frequency regulation and load changes. Recent development in Lithium-ion battery technology offers advantages like high power, longer overall life, high charge and discharge efficiency. In addition to small size, and low weight Li-ion batteries can offer high energy density and storage efficiency, which make them suited for portable devices. Battery energy storage system (BESS) is the significant factor to realize flexible control and optimal operation of active distribution networks, due to its fast power adjustment capability as well as the characteristic of supply and storage competency. So the placement sizing of BESS will directly affect the active management ability with DERs and the economic benefits of active distribution network operation.***

Keywords **:** ***BESS, Energy Management system, microgrid.***

I. INTRODUCTION

Over the years, the per capita energy consumption of the world is increasing exponentially. On the contrary, the generation of energy is not growing at the same rate. In particular, the developing economies like India, China, and Brazil, the growth of energy demand is much higher in comparison to that of developed nations. This creates a compelling need to have a robust and localized power generation with a sustainable source of energy. With todays technological advancement, it is easy and possible to have Microgrid (MG) systems with the aggregation of localized energy sources, Battery Energy Storage Systems (BESS) and loads. The MG technology has evolved over the years and is becoming more and more mature. Before the arrival of Internet of Things (IoT), MG concept was a niche technology. The electrical energy distribution and generation have been revolutionized with the latest advancement in communication technology.

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With the increased aggregation of renewable energy sources MG is poised to become an intrinsic aspect of modern power systems. This new era technology to facilitates service providers and consumers to take absolute control over Cost of Energy (COE), system reliability and energy sustainability. With the active participation of all stakeholders, MG technology will evolve rapidly to achieve excellence in all perspective.

The use of BESS is still a costly option and control and supervision strategies are compulsory for their optimal performance according to the SOC values and deep discharge constraints. The DG placing and sizing problem is to optimize the location of DGs under certain investment and scheme of working constraints in order to make distribution system benefit the most.

In view of the aforementioned advantages of the Lithium-ion batteries, a 100kVA Li-ion battery based Battery Energy Storage System (BESS) specifically meant for brown field projects are considered in this analysis. The BESS being discussed in this section is a 3-phase, 3-wire system as shown in Fig.1. Consequently, it can consume 3 balanced currents for charging or provide 3 balanced currents while discharging. Thus it can be modelled as a 3-phase current source. The main limitation of the BESS is that it is a grid-tied system and it cannot operate in absence of the main grid. This essentially calls for a Voltage Source (VS) for the BESS which will provide the reference voltage and frequency to the BESS in absence of the main grid and also provide unbalanced currents to loads.

The Fig.1 shows the architecture of a microgrid system under consideration. The Photo Voltaic (PV) source and BESS are connected in conjunction with utility grid to form a power system which in turn delivers power to different types of load. All critical loads are fed through UPS and non-critical loads are fed directly Circuit Breakers (CB) B1 and B2 serves as interlock breaker to ensure only one source acts as VS at a time. The sensing circuit of B1 detects the absence of grid voltage and will send the command to open B1 and closes B2. Similarly, the moment grid voltage restores, it opens B2 and closes B1. During grid connected mode, the main grid acts as VS and during islanded mode, UPS acts as VS and supplies reference voltage to BESS and PV inverter.

II. BESS SPECIFICATION

The Battery Energy Storage System (BESS) is connected to a low voltage network and it is able to consume and generate active and reactive power.

The BESS is installed in a network where many loads and distributed energy resources are connected. The interconnection of the BESS and the micro sources along with various loads creates a local network which is connected to the main grid by a single point (PCC). The key electrical specifications of the BESS are summarized in Table.1

Table 4.1 Technical specifications of BESS

Parameter	Values
Power	150 KVA
Input Voltage	400 V
Current	150 A
Frequency	50-60 Hz
Output Voltage	540 to 730 V DC
Efficiency	>95%

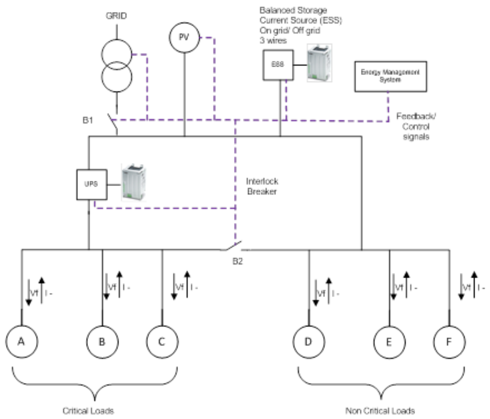

Fig. 1 Microgrid schematic diagram with BESS

A general single line diagram of the BESS under consideration is shown in Fig.2. The energy management system optimizes the managed loads on the network. Fig.3 shows the single line diagram of the network during grid connected mode of operation. During a blackout when no grid is available, the BESS can supply power to the network if a voltage source is available. A single line diagram of such an islanded network is depicted in Fig.4. The voltage source will provide voltage and frequency reference for the balanced currents to be generated by the BESS. Also, the voltage source will be responsible for feeding any unbalance in the islanded network as it is a 3- phase, 4 wire [3PH + N] system.

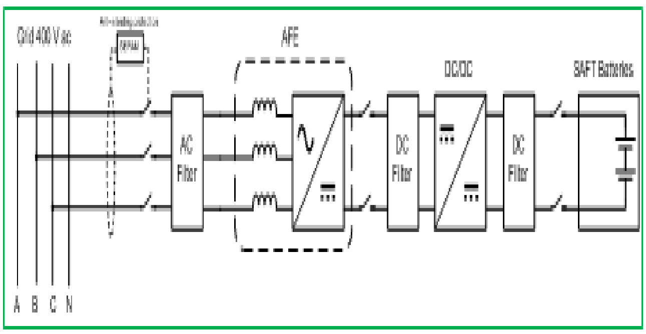

Fig. 2 Simplified block diagram of the BESS

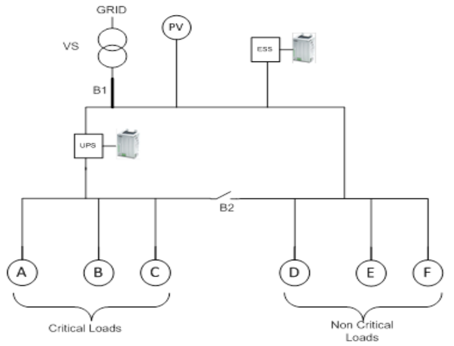

Fig. 3 Microgrid in grid connected mode of operation

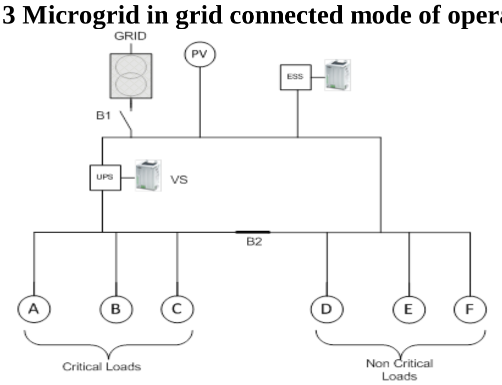

Fig. 4 Microgrid in islanded mode of operation

III. SYSTEM MODELLING

The grid is modelled as a 3-phase, 400V, and 50Hz voltage source without any source impedance. As already mentioned in the earlier section, only the priority unmanaged single and three-phase loads are connected to the network. The voltage source acting as a reference forcing function for the BESS is modelled by a 3-phase, 400V, and 50Hz programmable voltage source block without any source impedance. The BESS which essentially acts as a current source is modelled by a voltage source inverter (VSI). It is assumed that the BESS batteries are already charged completely and hence the VSI is fed by a DC source which represents battery storage block of the BESS. In order to operate the VSI as a current source, the VSI currents are controlled by hysteresis current control. The reference BESS currents (to be followed by the BESS) and actual BESS currents are compared and complementary gate pulses for two switches in an inverter leg pertaining to a particular phase are generated using the relay and Boolean logic blocks. Fig.5 shows the simulation model of reference current generation of BESS. The generic battery model that is available in Matlab Simpower system block set has been used for analysis, The accuracy of battery model affected by factors like temperature effect, internal resistance and self discharge characteristics, which are not accounted in the analysis, in general there will be a maximum of 5 percentage error between 10 to 100 percentage of SOC during charging and discharging cycles.

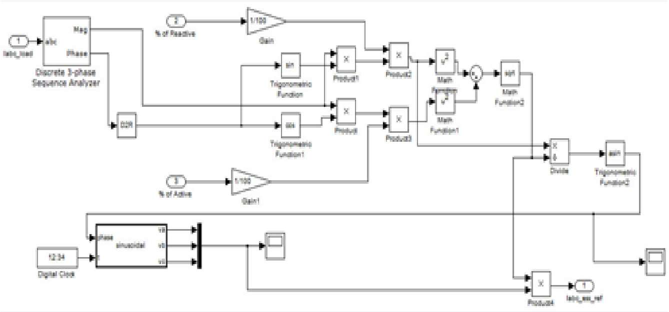

Fig. 5 Reference current generation model for BESS

The total load current in three phases indicated as Iabc load is measured using three- phase V-I measurements block and fed to the 3-phase sequence analyzer in order to obtain the magnitude and phase of the positive sequence component of the total load current. From the magnitude and phase of this balanced component, both active and reactive parts are found out. It is possible to make the BESS to feed 100 % of both active and reactive parts of the positive sequence component. Also, the BESS can feed a part of both active and reactive components, as designated by the user through the desired percentage of active or reactive components. The operation of this block can be understood by referring to the phasor diagram depicted in Fig.6

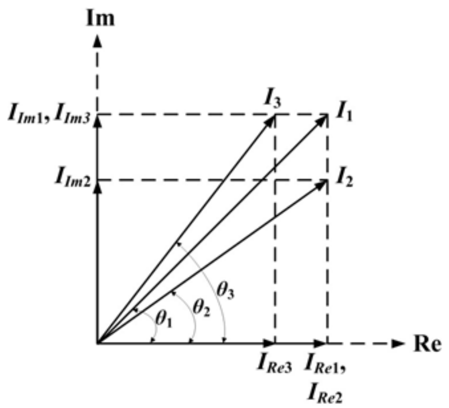

Fig. 6 Phasor diagram representation of BESS reference current generation

Let us assume that I1 is the magnitude of balanced positive sequence component of the total load current obtained from the 3-phase sequence analyzer block. If this positive sequence component is resolved across real and imaginary axes as shown in Fig. 6, it can be seen that IRe1 and IIm1 are the respective active and reactive components of I1. If the BESS is made to feed both these components at 100%, I1< θ1 will be the reference balanced current to be fed by the BESS. If the BESS is to be made to feed the total active component i.e. IRe2 = IRe1 and a part of the balanced reactive component i.e IIm2 < IIm1, then the effective BESS reference current magnitude and phase is recalculated respectively as

$$|I_2| = \sqrt{I_{Re2}^2 + I_{im2}^2} and \theta_2 = sin^{-1}\left(\frac{I_{im2}}{I_2}\right)$$

Similarly, if the BESS is to be made to feed the total reactive component, then effective

BESS reference current magnitude and phase can be calculated as

$$|I_3| = \sqrt{I_{Re3}^2 + I_{im3}^2} and \theta_3 = sin^{-1}\left(\frac{I_{im3}}{I_3}\right)$$

For the simulation case study, the percentage of balanced reactive component to be fed by the BESS is restricted to 30 percentage. Based on the desired percentage of active and reactive components, the resultant magnitude and phase of the effective balanced current to be fed by the BESS is obtained. Using this phase information and the simulation time (obtained using digital clock block); three unit sinusoidal waveforms are generated using a Matlab embedded function. The three unit sinusoidal waveforms thus generated are multiplied by magnitude of the effective balanced current to be fed by the BESS so that the three-phase reference currents for the BESS are obtained. Now, the three-phase currents fed by the VSI (representing the BESS) are to be controlled in such a way that they follow the aforementioned three phase reference currents. This is achieved by hysteresis current regulators.

IV. SIMULATION RESULTS

The execution of the simulation was divided into three parts based on the time duration: From start of execution to 0.5 s: The main grid is present during this interval and it feeds the priority unmanaged 1-phase and 3-phase loads. The grid is lost at 0.5 s by opening a three-phase circuit breaker. As already mentioned earlier, all managed loads are not considered for the simulation case study. From 0.5 s to 1.4 s: The voltage source which is essentially in a hot standby mode detects the absence of grid and connects to the network at 0.51 s. The BESS is still ramping up till 1.4 s to be able to feed the network and the voltage source is responsible for feeding the entire network for approximately 0.9 s. During this transient time period, the voltage source has to feed the entire power of the network amounting to (active + reactive + unbalance + harmonic) loads. From 1.4 s to 3.0 s: The BESS becomes ready and starts feeding the balanced part of the active (100 percentage) and reactive (30 percentage) components of the total load current, as designated by the user. During this steady-state interval, the voltage source is responsible for feeding the remaining reactive power of the network as well as any unbalance and harmonic currents.

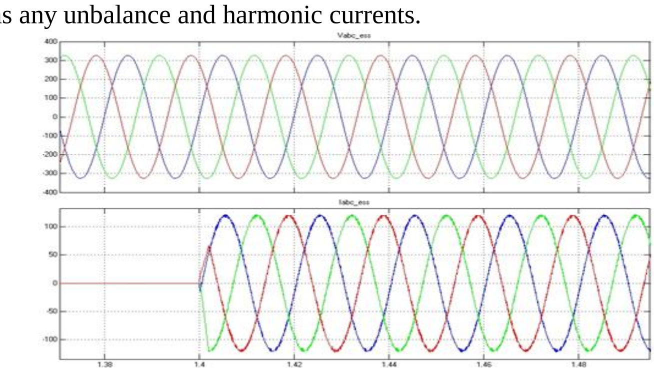

Fig. 7 Simulation results of three-phase voltage and currents supplied by the BESS for balanced load

The three-phase currents fed by the BESS during the transient period (before 1.4 s) and during the steady-state (after 1.4 s) are shown in Fig. 7 along with the three-phase voltages. It can be seen that the BESS is supplying a uniform balanced current through all three-phases after 1.4 s.

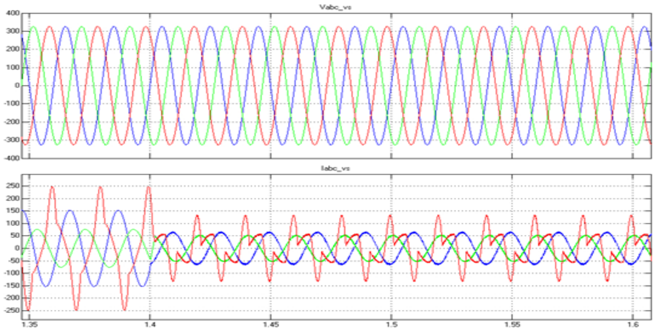

Fig. 8 Three-phase currents wave form supplied by the voltage source (UPS) for unbalanced load

The three-phase currents fed by the voltage source during the transient period (before 1.4 s) and during the steady state (after 1.4 s) are shown in Fig.8 along with the three-phase voltages. It can be seen that the voltage source is feeding the entire three-phase load currents (active+ reactive + unbalance + harmonic) during the transient (before 1.4 s). After the BESS is available at 1.4 s, it starts supplying 30 percentage of the balanced reactive component. Thus, during steady-state (after 1.4 s), the voltage source supplies less current than the earlier case and it comprises of remaining reactive component as well as unbalance and harmonic currents. Thus, the BESS is relieved from supplying any unbalance harmonic currents.

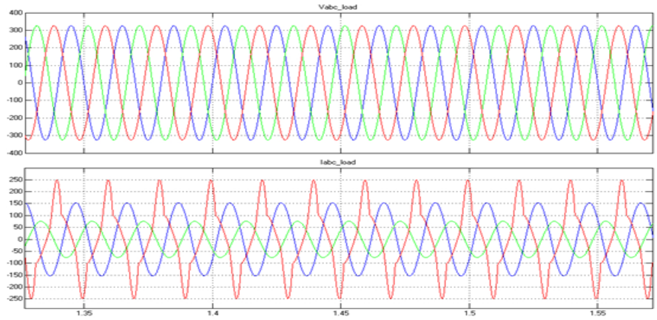

Fig. 9 Three-phase load currents and voltage waveforms for priority and unbalanced loads supplied from UPS

The total three-phase load currents (for priority unmanaged single and three-phase loads, with unbalance and nonlinear loads) are depicted in Fig. 9. It can be noted that the three phase loads continue to take the same current during transient and steady state when the BESS is functional. The power fed by the BESS and the voltage source are shown in Fig. 10 It can be inferred that the active power being fed by the voltage source during steady-state (after 1.4 s) is negligible Thus; the kVA rating of the voltage source during steady-state is dominated by the reactive power fed by it.

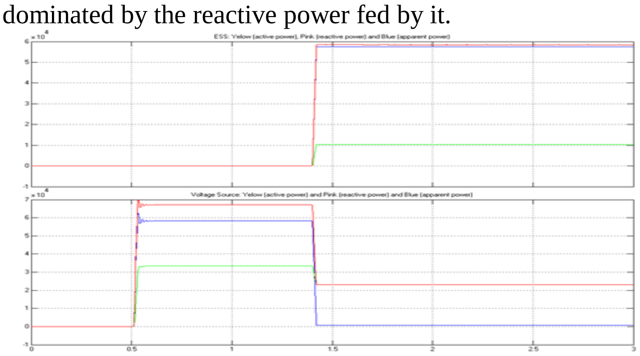

Fig. 10 Active and reactive power supplied by the BESS and the voltage source (UPS)

V. CONCLUSION

A detailed simulation and analytical study has been carried out using Matlab/ Simulink with a chosen network configuration. The BESS was modeled as a VSI operated with hysteresis current control. The algorithms for reference current generation for the BESS and active and reactive power sharing between the VS and the BESS and % current unbalance calculation were also implemented. The proposed analysis finally reveals that an uninterrupted power supply (UPS) with a 35-45% kVA size of that of the BESS and an overload capacity of 150-200% can be chosen as the Voltage Source (VS) for the BESS. Thus optimum sizing of UPS can be derived for the proposed micro grid system which will serve critical loads and also act as VS for BESS during utility grid outage. This method helps in avoiding over sizing of UPS if the connected critical loads in the network are not more than 45% of overall micro grid capacity. Also, this method proves that any stand-alone BESS can be integrated seamlessly into microgrid with DER in a cost effective manner by choosing optimum sizing of UPS.

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