Operation and Control of DC Microgrids

Abstract

The utilization of DC microgrids in power industry has increased rapidly with the expansion in use of renewable energy sources (RES), energy storages (ESs) and DC inherent loads. DC microgrid (MG) reduces the power conversion stages, does not require frequency, phase and reactive power control in its operation making it advantageous over AC microgrids. However, the cost-effective solution to renewable intermittency, system topology and standards for reliable, stable and efficient power supply still needs examinations through research. Control strategies, for economic solution to mitigate renewable intermittency in the system with inclusion of hybrid energy storage system (HESS), interconnection of microgrids with tie-line for reliable power supply and bipolar-type DC microgrids for high quality and high efficiency power supply, is proposed, implemented and elaborated in this report.

ESs are an option to solve renewable intermittency that can increase the utilization of RES into grid, changing the undispatchable generation to dispatchable. ESs can generate profit upon charging them when local electricity price lowers and can be discharged when the price is high. Choice of energy storage ranging from short term to long term is a key factor to address the compensation of load peaks, transients and to provide autonomy to the microgrids. Unfortunately, they cannot be achieved by a single energy storage, thus the need of hybridization of ESs which have high specific energy and specific power is the solution for proper compensation of power fluctuation in autonomous microgrids. Generally, HESS with centralized control is utilized to decompose system net power and has the limitation of slow response. Conventional droop control achieve static power regulation however lacks to address frequency based autonomous power management. Frequency coordinating virtual impedance concept has been explored for the co-ordination control of an HESS in DC microgrids. Also, power decoupling methods to better attenuate the ripple power by filtration have been investigated.

Lead-acid battery and supercapacitor are used to form HESS and are connected to a common DC bus through bi-directional DC-DC converters. Battery converter can absorb low frequency power variations while the high frequency power variations can be absorbed by supercapacitor converter. Battery supplies the long-term power demand and supercapacitor responds to the short-term power fluctuations during transient process in this proposed method. For the reduction of ripple power in battery, insertion of high

order low/high pass filters for battery and supercapacitor converters instead of lower order low/high pass filters have been discussed. The effectiveness of the proposed concept is shown through simulation and experimental results.

The interconnection of DC microgrids for providing reliable power supply is particularly important in rural areas where utility grid is not available. Although, various researches are conducted in single entity, the interconnection of DC MG cluster is still novice in research. The interconnection of identical DC buses through tie-line and formation of MG clusters improves reliability of the system. To achieve power flow control through the tie- line, decentralized control approach has been proposed where the bus voltage of each MG in the MG cluster is controlled to ensure the regulation of bus voltage deviations. The use of decentralized control approach mitigates the issue of communication stress when the MG control areas are geographically distantly located. The decentralized control is accompanied by mode change based operation so that the distributed units like solar photovoltaic (PV) and energy storage system (ESS) in microgrids can adaptively adjust their operation modes depending upon the designated voltage level. By doing so, the bus voltage regulation (BVR) and power flow control is adjusted making each MG in the MG cluster autonomous. The power is generated/injected from/into MG when there is power surplus/deficit caused by supply-demand mismatch in particular MG. Tie-line power flow takes place in a MG, from another MG, due to the bus voltage decrement beyond the designated level caused by the increment in local consumption which could not be satisfied by the local generation and storages. The effectiveness of proposed decentralized control has been verified experimentally in the cluster of two microgrids.

Recently, bipolar-type DC microgrids have gained tremendous attention of researchers due to its advantages over conventional DC microgrids in terms of elevated level of quality, reliability and efficient power supply. Due to different loading in upper and lower terminals, voltage fluctuation from nominal value at respective terminals takes place and makes the system unbalanced. So, the control of parallel converters which interface distributed energy resources (DERs) and the topology of the converter along with voltage balancer play vital role in formation of efficient bipolar-type DC MG.

Although many control schemes have been proposed for bipolar-type DC microgrids, they mainly focus on coupled microgrids with central voltage balancer. This report proposes an improved droop controlled bipolar-type DC MG where the voltage balancing control is decentralized. The use of decentralized voltage balancing circuit

supersede centralized voltage balancer failure of which deteriorates the system functionality. This is realized by utilizing a converter topology to boost the input voltage and three wire system is adopted by means of voltage balancing circuit. Two battery ESs are integrated to form such system. One of the problem associated with such decentralized voltage balancing is the control conflict between two balancing circuit provided for each battery to achieve same function. Droop control is implemented to mitigate such control conflict due to two bus voltage controllers in a system and to validate the decentralized control of bipolar-type DC MG for both load sharing and voltage balancing.

The proposed control strategies for operation of DC MG incorporating rooftop PV and HESS, interconnection of two DC MG consisting of PV and ESs and bipolar-type DC MG consisting of two ESs have been verified with Piecewise linear electrical circuit simulation (PLECS) software. Experimental cases have been carried out to validate the simulation studies with laboratory scale DC microgrid(s) prototype(s) developed at Water and Energy Research Laboratory (WERL), School of Electrical and Electronic Engineering, Nanyang Technological University.