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Power Management in Micro Grid Using Energy Storage Systems Based on Battery/Ultra Capacitors

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ABSTRACT:

Renewable-energy-based micro grids are a better way of utilizing renewable power and reduce the usage of fossil fuels. Usage of energy storage becomes mandatory when such micro grids are used to supply quality power to the loads. Micro grids have two modes of operation, namely, grid-connected and islanding modes. During islanding mode, the main responsibility of the storage is to perform energy balance. During grid-connected mode, the goal is to prevent propagation of the renewable source intermittency and load fluctuations to the grid. Energy storage of a single type cannot perform all these jobs efficiently in a renewable powered Micro grid. The intermittent nature of renewable energy sources like photovoltaic (PV) demands usage of storage with high energy density. At the same time, quick fluctuation of load demands storage with high power density. This paper proposes a composite energy storage system (CESS) that contains both high energy density storage battery and high power density storage ultra capacitor to meet the aforementioned requirements. The proposed power converter configuration and the energy management scheme can actively distribute the power demand among the different energy storages. Results are presented to show the feasibility of the proposed scheme.

I. INTRODUCTION:

Due to the intermittent nature of renewable energy sources and the continuous variations of the load, storage (e.g., battery, ultra capacitor, flywheel etc.) is usually needed in a renewable powered micro grid. The renewable output power profile and the load profile are two important factors in deciding the capacity and type of the energy storage components. The PV power output profile and the load profile shows low-frequency as well as high-frequency fluctuations, which are mutually independent in nature. Hourly average variations can be considered as low frequency variation, whereas power transients, who sustain for minutes, seconds, or milliseconds, come under the high-frequency segment. To buffer out the low-frequency oscillations and to compensate for the intermittency of the renewable energy sources, energy storage with high energy density is required. To provide high-frequency component of power and also to supply or absorb the high-power transients, energy storage with high power density is required. Fig.1.2 shows the energy density and power density profiles of different energy storages, whereas a general theory of Ragone plot is provided. It is to be noted that, the load profile and renewable source profile strictly decides the desired location of the optimum energy storage on the Ragone chart and this location will be different for different micro grids.

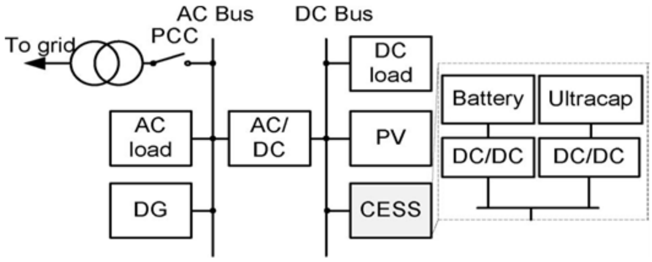

Fig 1: Block diagram showing CESS interface with the dc grid.

In micro grids, where power levels are in the range of a few megawatts, battery, ultra capacitor, and flywheel are the more suitable options. Battery and ultra capacitor are considered as high energy density storage and high power density storage, respectively, and their combination is a very promising option to realize the

CESS system. Ultra capacitor–battery hybrid energy storage performs better than battery-alone energy storage for a stand-alone PV system. Battery–ultra capacitor hybrid storage has the virtues of both high energy density and high power density, and also, such system increases battery life. Battery–ultra capacitor hybrid achieves power and life extension of battery. This exploits the potential of battery and ultra capacitor as a CESS, as shown in Fig.1.

MICROGRIDS:

Distributed generation located close to demand delivers electricity with minimal losses. This power may therefore have a higher value than power coming from large, central conventional generators through the traditional utility transmission and distribution infrastructure. With the use of renewable distributed generation, the dependency on fossil fuels and on their price can be minimized. This step will also lead to a significant reduction of carbon dioxide emissions, which is required in several government programs. If, in addition, distributed generation and consumption in a certain area are integrated into one system. The importance and quantification of these benefits has been recognized, although these are yet to be incorporated within the technical, commercial. A microgrid is a regionally limited energy system of distributed energy resources, consumers and optionally storage. It optimizes one or many of the following:

Power quality and reliability, sustainability and economic benefits and it may continuously run in off-grid- or on-grid mode, as well as in dual mode by changing the grid connection status. According to this definition, a microgrid maximizes the benefits of distributed generators and solves the above-mentioned disadvantage, also utilizing distributed generation during utility power system outages.In grid-connected mode, the microgrid operator can take economic decisions – such as to sell or buy energy depending on on-site generation capability, its cost, and the current prices on the energy market. In case of a utility power system outage, the point-of-common-coupling breaker will automatically open, and own generators will continue to supply power to loads within the microgrid. The idea of microgrids is not new. In the very beginning of rural electrification, several microgrid structures had been installed. Later, the economical benefits of an interconnected utility grid with large power plants led to today’s power system structures. Today, there are several industrial sites worldwide with on-site generation and islanding capability. The main reason for these constellations usually is the requirement for process optimization in a certain industrial site. For example, huge amounts of steam are required for chemical processes. In this case the process owner can decide to install its own steam turbine-based generation, which will increase power supply reliability and reduce the cost of energy.

The generators in such an industrial sites usually cover exactly the demands of the site, generally to avoid possible generation and demand imbalance in case of islanding. This “classical microgrid” will be separated from the utility grid in case of a disturbance outside the microgrid, and its own generators will continue to supply the process load. The grid connection is a backup solution for the case that one or more on-site generators have to be disconnected, for example due to a fault or for maintenance purposes. The related investments can be justified through the calculation of economical losses caused by utility power system outages and energy cost reduction by the use of the steam, which is created for the chemical process anyway. Other on-site generation systems can achieve a high degree of efficiency through the application of combined heat and power (CHP) or combined cooling and heating power (CCHP) systems, if the heating and cooling can be reasonably used for own processes.

Power System Disturbances:

Power systems face hundreds of disturbances every day, mainly caused by natural incidents such as lightning and arc flashes on rainy days.

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The majority of disturbances is usually eliminated by protection devices that only separate the affected power system component for a limited period of time – for example a transmission line segment until an arc has disappeared. If a power system meets certain reliability and security requirements, nearly none of these disturbances will lead to significant power outages. In every country of the world, today's customers expect a reliable and secure power supply. However, an interconnected power system with long transmission and distribution lines will always be prone to disturbances. Unfortunately, there are always some exceptional situations, in which a single disturbance causes Cascading outages, eventually leading to blackouts. It is generally expensive and requires a rather long time scale to increase the reliability and security of a large power system. As mentioned above, a power system is subject to several disturbances every day, and it can cope with these disturbances without any power supply interruption on the customer's side. In addition to natural disturbances, there are – intentionally or unintentionally – man-made disturbances.

II. BIDIRECTIONAL DC–DC CONVERTERS

In principle, bidirectional power transfer between two unipolar DC voltage sources may be established with two unidirectional DC–DC converters C1

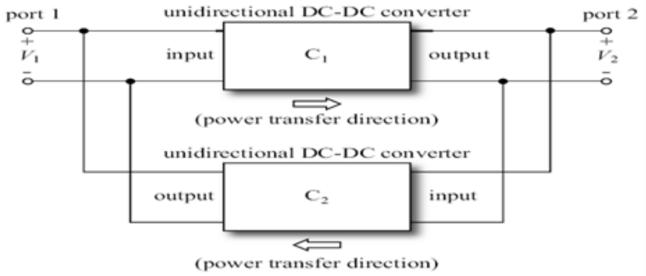

Figure 2: Principle construction of a bidirectional DC–DC converter using two unidirectional DC–DC converters

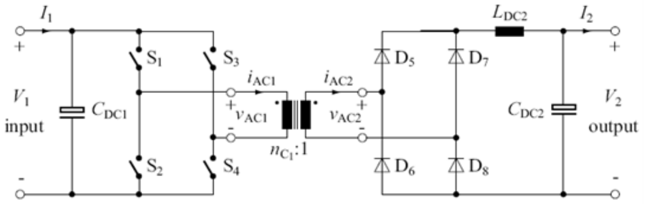

Fig 3: Unidirectional full bridge DC–DC converter with output inductor LDC2.

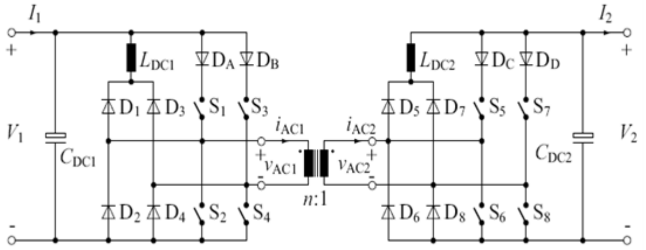

Fig 4: Bidirectional full bridge DC–DC converter topology

Bidirectional full bridge DC–DC converter topology, constructed from two unidirectional full bridge DC–DC converters C1 and C2 according to Figure 2 and Figure 3; the diodes DA, DB, DC, and DD are required in order to avoid reverse blocking voltages on S1 . . . S8 and C2 according to Figure 1. There, C1 is used to transfer power from port 1 to port 2 (forward direction, forward operating mode) and C2 is needed to transfer power in the opposite direction (backward direction, backward operating mode). In order to illustrate an example of a practical converter realization including galvanic isolation, full bridge DC–DC converters with high frequency (HF) transformers and output inductors are employed for C1 and C2 (Figure 3)

Dual Active Bridge Dc–Dc Converter:

The Single-phase Dual Active Bridge (DAB) converter contains two voltage sourced full bridge circuits or half bridge circuits (or even push-pull circuits) and a HF transformer. The reactive network simply consists of an inductor L connected in series to the HF transformer; hence, the DAB directly utilizes the transformer stray inductance. Due to the symmetric circuit structure, the DAB readily allows for bidirectional power transfer.

The main advantage of the DAB are the low number of passive components, the evenly shared currents in the switches, and its soft switching properties.4 With the DAB converter topology, high power density is feasible. However, the waveforms of the transformer currents $i_{AC1}(t)$ and $i_{AC2}(t)$ highly depend on the actual operating point (i.e. V1, V2, and the output power P_{out}; cf.); for certain operating points, very high transformer RMS currents result. Moreover, high maximum capacitor RMS currents I_{CDC1} and I_{CDC2} occur.

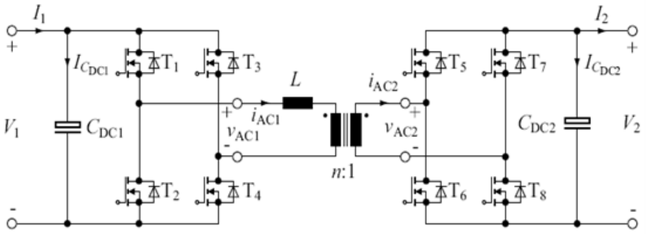

Fig 5: Dual Active Bridge (DAB) converter topology

Particularly high transformer and capacitor RMS currents result if the conventional modulation scheme – the so-called phase shift modulation – is employed. Comparatively small VA ratings of the LV side switches, a low VA rating of the HF transformer, and a low total value of the magnetic energy storage capability already result for the DAB when operated with the conventional modulation scheme. Moreover, the DAB contains the lowest number of inductors. Expectedly, the total VA ratings and the required magnetic energy storage capability can even be reduced with the use of the efficiency optimal modulation scheme. However, the very large LV side RMS capacitor currents ($\leq$ 244A or $\leq$ 125A, depending on the modulation scheme) present a considerable challenge regarding the practical realization of the DC capacitor CDC2. The actual DAB employs full bridge circuits on the HV side and on the LV side. Within the regarded DC–AC converter topologies (full bridge, half bridge, and push-pull), the full bridge circuits allow for the best converter utilization due to the following reasons.

- The advantage of the half bridge is the lower amount of required switches (reduced hardware effort regarding gate drivers). For the half bridge, the switch RMS current ratings are twice the RMS current ratings of the switches used for the full bridge. Thus, similar total VA ratings result for the switches of the half bridge and the switches of the full bridge. However, the magnitude of the half bridge AC voltage is half of the magnitude of the full bridge AC voltage. This presents a serious disadvantage with respect to the LV side circuitry: if a half bridge is employed on the LV side, transformer RMS currents of up to 590A and switch RMS currents of up to 420A occur (DAB, phase shift modulation).

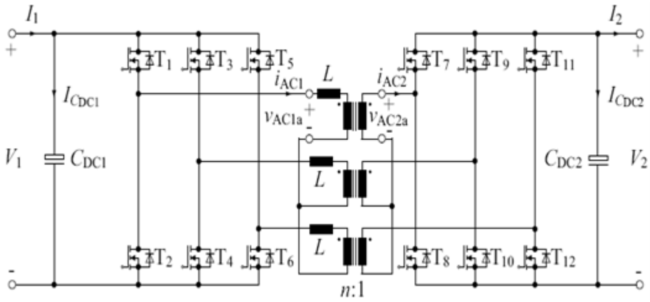

Fig 6: Three-phase Dual Active Bridge (DAB) converter topology

A disadvantage of the three-phase DAB is the high number of active components needed: 12 semiconductor switches and, accordingly, 12 gate drivers (6 high-side gate drivers) are required. Moreover, high conduction and switching losses result for certain operating points if the converter is operated within wide voltage and power ranges, due to the restrictions regarding the employed modulation scheme.

Steady-State Operation of the Dual Active Bridge

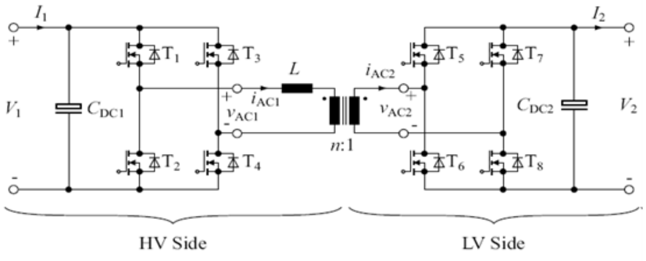

Fig 7: Dual Active Bridge (DAB) converter topology

III. PROPOSED CONTROL STRATEGY OF DABS FOR ENERGY MANAGEMENT OF THE CESS SYSTEM

The CESS system consists of both high energy density and high power density storage. Battery is selected here as a high energy density storage. Due to intermittent nature of the renewable energy sources, the battery needs to source or sink energy for a long period of time. Therefore, battery capacity has to be high, which can be achieved by connecting multiple battery banks. Connecting too many batteries in series reduces the volumetric efficiency of the battery bank. For interfacing ultra capacitor with dc bus, one has to consider that the terminal voltage of ultra capacitor is less (around 28–45 V), while the dc bus is regulated at high voltage (around 800 V for connecting an inverter interfacing a 415-V 3-phase 4-wire system). The ultra capacitor needs to supply or absorb high current for a short duration of time. Considering these requirements, the modular power converter structure adopted for interfacing battery and ultra capacitor to the dc bus.

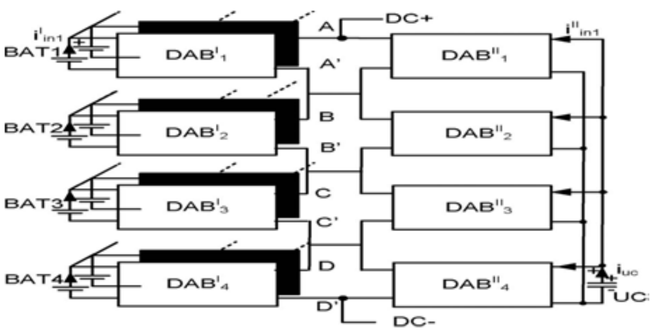

Fig 8: Topology of the proposed interleaved DAB-based CESS

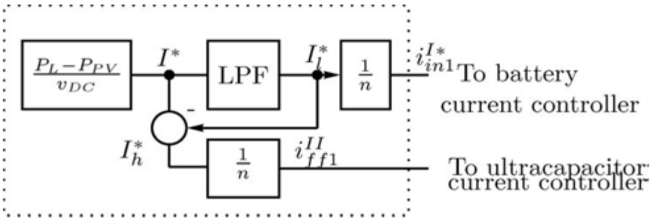

Fig 9: Energy management strategy for case I

IV. SIMULATION RESULTS:

Dynamic response for a step change in current demand from the CESS system (Case I)

In this case, the circuit consists of three phase voltage source in series with RC branch (415v, 50Hz, star connection) is connected to three phase VI measurement block. three phase VI measurement block, it measures the voltage and current, when connected in series with three phase to ground voltage and line currents, whose lines are connected to universal bridge(it implements of bridges selected power electronic devices series RC snubber circuit are connected in parallel with each devices)Timer generates a signal changing at specified times, connected to breaker and to RL dc load. In CESS, there are total eight DAB, in each DAB, there are two batteries are connected to converters. In converters, there are four IGBT/Diode switch on each of linear transformer.

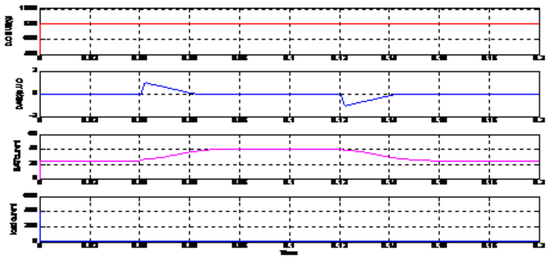

Fig 10: Dynamic response for a step change in current demand from the CESS System (Case I) Dynamic response of converter currents when one battery current Reference is made zero (Case II)

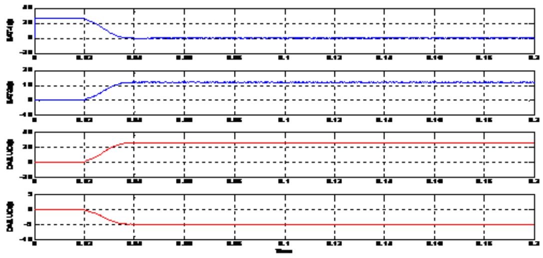

Fig 11: Dynamic response of converter currents when one battery current reference is made zero (Case II).

Ultra capacitor charging scheme (Case III)

In this case, the circuit consists of three phase voltage source in series with RC branch (415v, 50Hz, star connection) is connected to three phase VI measurement block. three phase VI measurement block, it measures the voltage and current, when connected in series with three phase to ground voltage and line currents, whose lines are connected to universal bridge(it implements of bridges selected power electronic devices series RC snubber circuit are connected in parallel with each devices)

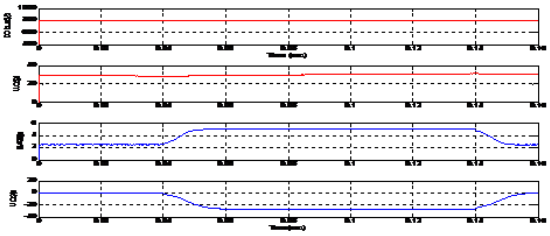

Fig. 6.3 Ultra capacitor charging scheme (Case III)

Fig 6.3, the ultra-capacitor SOC control is also an important requirement of the energy management scheme. The ultracapacitor SOC can be easily estimated from its terminal voltage. The energy management scheme has to maintain the ultracapacitor SOC within a band. If the ultracapacitor voltage falls below the lower band, then the energy management scheme generates appropriate current references for the battery and ultra-capacitor.

V. CONCLUSION:

Renewable-energy-based micro grids are a better way of utilizing renewable power and reduce the usage of fossil fuels. Usage of energy storage becomes mandatory when such micro grids are used to supply quality power to the loads. Micro grids have two modes of operation, namely, grid-connected and islanding modes. During islanding mode, the main responsibility of the storage is to perform energy balance. During grid-connected mode, the goal is to prevent propagation of the renewable source intermittency and load fluctuations to the grid. This CESS interfaces battery as a high energy density storage, and ultra capacitor as high power density storage to the dc bus. The dc–dc converter structure is formed using DAB modules whose terminals are connected in series or parallel depending on feasibility. The proposed modular dc–dc converter topology along with its energy management scheme can flexibly share the power between different batteries and ultra capacitor.

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