

Review of Various Power Conversion Converters for Battery Energy Storage Systems

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ABSTRACT: As the demand for safe and reliable electricity increases, our infrastructure continues to evolve and innovate in order to accommodate such growth. The benefits of energy storage can span power generation, through transmission and distribution, and all the way to users. An energy storage system is indispensable for compensation of the active-power fluctuation; it can mitigate the disturbance and maintain the stability of voltage and frequency. Power conversion system (PCS), as an interface between storage system and public grid, plays an great role in achieving the power transfer between storage system and public grid. This paper summarize the various research based on power conversion converter for battery energy storage systems current topologies and the control strategies commonly used in engineering under different working situations and requirements, and analyze their differences and characters, which will helps in choosing the PCS structures and control strategies.

KEYWORDS: Power, Conversion, converter, Energy, battery, Storage.

I. INTRODUCTION

Battery energy storage system (BESS) has been used for some decades in isolated areas, especially in order to supply energy or meet some service demand. There has been a revolution in electricity generation. Today, solar and wind electricity generation, among other alternatives, account for a significant part of the electric power generation matrix all around the world. However, in this scenario of high level of renewable energy, BESS plays a key role in the efforts to combine a sustainable energy source with a reliable dispatched load and mitigates the impacts of the intermittent sources. Therefore, the installation of BESS has increased throughout the world in recent years. Despite their benefits, the implementation of such systems faces considerable challenges.

Energy storage system consists of two parts, storage facility and PCS. PCS, the interface between storage facility and micro grid (utility grid), operates the function of transferring and swapping energy between the storage system and the micro-grid bidirectional. The structure and control strategy are significant for the stability, efficiency and performance of the PCS. This paper summarizes the commonly used topology structures, and analyses their differences and characters. Then the control strategy is presented and summarized.

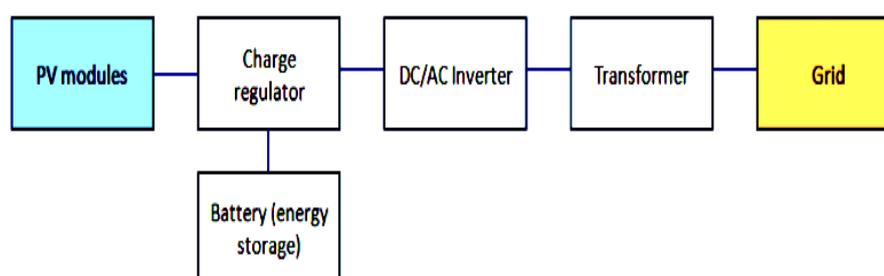


Figure 1: Block diagram of battery energy storage system

With the rapid development of global economy, the global electricity consumption surges which give rise to the serious power supply shortage. Renewable energy sources such as wind turbine generators and photovoltaic provide a new way to resolve the problem. However, the distributed power such as photovoltaic power and wind power are intermittent and produce fluctuating active power. Interconnecting these intermittent sources to the utility grid at a large scale may affect the voltage and frequency control of the grid, and may lead to severe power quality issues. Therefore, Energy storage system is very important for the micro-grid, it can store the excess power from the grid when the power supply is greater than the power consumption. On the other hand, it releases the shortage of power to the grid when the generation system produces a smaller power. The energy storage system brings a significant enhancement in power quality, stability and reliability to the grid. Therefore, the energy storage system is more and more widely used in distributed generation system and micro grid..

II. RELATED WORK

O. Kwon et al., [1] proposes a bidirectional grid-connected single-power-conversion converter with low-input battery voltage. The proposed bidirectional converter consists of a bidirectional dc-dc converter and an unfolding bridge, and the power conversion stage only corresponds to a bidirectional dc-dc converter. The bidirectional dc-dc converter can perform bidirectional power conversion between the low input battery voltage and a rectified sine wave due to its step-up/down voltage regulation functions. The unfolding bridge unfolds the rectified sine wave into the grid voltage and provides a current path to the grid. The study also proposes a control algorithm to regulate the grid current through a single power-processing stage. The control algorithm is comprised of a feed-forward nominal voltage compensator and a repetitive control scheme. The feed-forward nominal voltage compensator presets the operating point to lighten the burden of the grid current control, and the repetitive controller provides precise control of the grid current. Thus, the proposed bidirectional grid-connected single-power-conversion converter results in high power quality and high efficiency. Experimental results based on a 250-W prototype module are conducted to evaluate the performance of the converter and to verify the analysis.

A. Jahan et al., [4] presents highlights the concern, inspects the consequences of reactive power compensation and optimization on system security and power characteristics, and suggests synchronized active and reactive power distribution at the grid to diminish this instability. Also a wind energy system is connected parallel to the PV system to increase the system's reliability. Additionally, an expansive control system with the reactive power compensation algorithm (RPCA) is suggested to acquire intense voltage regulation and competent power distribution.

Y. Jeong et al., [5] This work presents a high-efficiency bidirectional grid-tied converter using single power conversion with high-quality grid current and a control system for it. The proposed converter is composed of a bidirectional flyback dc-dc converter and an unfolding bridge circuit. By adjusting the PWM signal of the flyback, the proposed converter performs bidirectional power conversion between the grid and energy storage device in only one step. The control system consists of a feed-forward controller, a linear feedback controller with a low-pass filter, and a repetitive controller. The development of the proposed control system considers the inherent dynamic characteristics of the converter, thus overcoming the constraints on designing feedback control gains originating in right-half-plane zero and LC filter dynamics. Therefore, the control system ensures desired reference tracking and disturbance rejection performances while satisfying stability requirements. In conclusion, the proposed converter can achieve high conversion efficiency through a single power conversion, and its control system makes the implementation of the single power conversion in the proposed converter feasible. The theoretical analysis for the proposed converter and its control system is described. Finally, experimental results using a 250 W prototype are represented to confirm the validity of the proposed converter and its control system.

M. A. Hernandez Navas et al., [6] This work presents a wind power generation system (WPGS) with battery energy storage system (BESS) based on the Z-source inverter (ZSI) with simple boost control. Wind turbines using the squirrel cage induction generator (SCIG) are widely accepted due to their robustness, simplicity, light weight and low cost. The SCIG is connected to the power grid through voltage source converters VSC, and the WPGS is reinforced by the BESS in order to keep grid power balance. The BESS has a battery bank, which is integrated with the system through a bidirectional DC-DC converter (buck-boost). Moreover, the ZSI is an alternative power conversion topology that can both (buck-boost) the input voltage using passive components. The operation of ZSI is analysed, and the active and reactive power decoupling method is proposed for a double closed-loop control system, which ensures the stability in voltage capacitor of ZSI. Also, the traditional sine pulse width modulation technique is modified to achieve the shoot through characteristic of ZSI. The proposed system has high performance, minimal component count, increased efficiency and reduced cost. Simulation results verify the efficacy of the proposed control strategies.



M. Pahlevani et al., [7] This work presents a new dc-bus voltage control technique for single-phase bidirectional ac/dc converters. The proposed controller is able to significantly improve the transient response of the dc-bus voltage control loop and provide a robust and reliable closed-loop control system. In the proposed approach, the dc value of the dc-bus voltage is precisely estimated through a specific adaptive filter. The structure of the proposed filter provides a very fast and robust estimation for the dc value of the dc-bus voltage. In particular, the proposed dc-extraction technique is able to precisely estimate the dc value in presence of double-frequency ripple mounted on top of the dc-bus voltage in single-phase ac/dc converters. Simulation and experimental results demonstrate the superior performance of the proposed closed-loop control system compared to the conventional ones.

W. Cha et al., [8] A single power-conversion LED backlight driving system with high power factor control is proposed. The proposed converter is composed of a full-bridge diode rectifier and a quasi-resonant flyback converter. The proposed converter provides a simple structure, a low cost, and high power factor of 0.988 by using the novel control algorithm without the PFC circuit. To achieve good controllability, the novel control algorithm is transformed by adding a nominal value predetermined to relax its control burden. Detailed analysis and experimental results for a 90-W prototype are discussed.

. Table 1: Summery of Literature Survey

| Sr No. | Author Name | Publish Detail | Proposed Work | Outcome |
|--------|-----------------|-----------------|--|--|
| 1 | O. Kwon | IEEE April 2018 | bidirectional grid-connected single-power-conversion converter | 250-W prototype module are conducted to evaluate the performance |
| 2 | Y. Jeong | IEEE Nov 2017 | presents a high-efficiency bidirectional grid-tied converter | 250 W prototype are represented to confirm the validity |
| 3 | M. A. Hernandez | IEEE Sep 2016 | Presents a wind power generation system | high performance, minimal component count, increased efficiency |
| 4 | M. Pahlevani | IEEE Aug 2015 | New dc-bus voltage control technique | superior performance of the proposed closed-loop control system |
| 5 | W. Cha | IEEE May 2014 | single power-conversion LED backlight driving system | 90-W prototype are discussed |

III. VARIOUS POWER CONVERSION CONVERTERS

A. Topologies and Control Strategies of PCS

The storage facility in this paper is referred to storage battery units. PCS is a power electronic converter in nature used to regulate the power transfer between the storage facility and micro-grid. Figure below show the structure of the whole energy storage system.

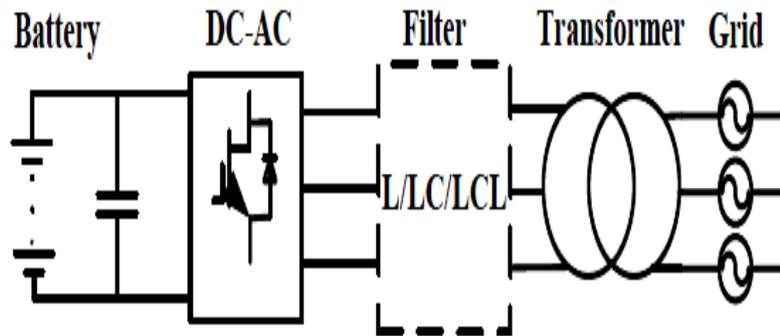


Figure 2: Topology of single-stage power conversion system

Structure of energy storage power conversion system PCS has many topological structures, the commonly used structures such as single-stage PCS, two-stage PCS and cascaded PCS will be presented.

B. Single-stage PCS

Figure shows the single-stage PCS topology. From the figure we can conclude that the PCS is essentially a bidirectional dc-ac converter. This converter can not only absorb superfluous energy from the grid and store the power in battery units, but also release energy stored in the battery banks to the grid and convert the dc voltage to ac voltage connected to the grid in order to keep the balance of the grid. Moreover, a filter could be installed in the output side of the battery unit to filter out the harmonics and mitigate the ripple in the currents injected into the grid. Battery DC-AC Filter Transformer Grid L/LC/LCL Fig. Topology of single-stage power conversion system The prominent advantages of single stage PCS are the simple circuit structure, relatively simple control method, and less switch quantity which means less losses. However, the disadvantage is also obvious, the operation dc voltage of the battery units is limited; lack of flexibility of system capacity configuration and current-levelling ability of the battery units is poor, which effectively affect the battery lifetime. For the single-stage PCS, there two aims for the control strategy. One is ensuring the balance of the active power in the grid, the other one is maintaining the voltage and frequency stability of the grid when unpredictable events occur and supporting the critical load connected to the grid. Currently, the commonly used control strategies include PQ control, V/f control and constant current control.

C. Two-stage PCS

Figure shows the two-stage PCS topology. This PCS consist of two converters: bidirectional dc-ac converter and bidirectional dc-dc converter. The dc-dc converter is mainly used for boosting or bucking the dc voltage and provide a stable dc voltage. Dc-ac converter work in the state of rectification mode when the battery units release power and convert the ac voltage of the grid to dc voltage. This dc voltage will be regulated by the dc-dc converter and stored in the battery. When the battery release energy, the output dc voltage of the battery units is boosted by dc-dc converter and provide suitable input dc voltage to dc-ac converter. At last output a appropriate ac voltage required by utility grid. L/LC/LCL Battery DC-DC DC-AC Filter Transformer Grid .

In the practical application, bidirectional dc-dc converter is categorized by isolated dc-dc converter and non-isolated converter. The difference between the two kinds of converters is whether there is a high frequency isolation transformer. introduced in detail the traditional non-isolated dc-dc converters such as bidirectional dc-dc converter, bidirectional Boost/Buck converters, bidirectional Cuk converters and bidirectional converters. They all evolved by basic unidirectional converter. presented a novel converter combined interleaving technology with the non-isolated dc-dc converters so as to lower inductance designing requirements and reduce the voltage and current stress on the switches. The isolated converter mainly includes flyback-typed converter, forward-typed converter push-pull-typed converter and bridge-typed converter.

The advantages of Two-stage PCS are as follow: the operating voltage rang of the battery unit is relatively higher than the single-stage PCS; the charging current ripple is small and the harmonic component is relatively simple; the second order harmonic component of the charging current in the single-phase or three-phase asymmetric system can be inhibited by dc-dc converter; this structure 263 has a high degree flexibility in cells allocation of battery units. However, the drawbacks of this structure consist in the large number of switches which brings more losses and reduce the efficiency of PCS.

For the two-stage PCS, dc-dc converter is used to control charging/discharging current for the battery units, thus a current-loop is adopted to achieve a constant charging/discharging current. While the DC-AC converter is intended to sustain the intermediate dc voltage stability and achieve the goal of the unity power factor operation. A double-loop control scheme consisting of an outer voltage loop and an inner current loop is commonly adopted. The inner current loop is to control the current injected to grid according to the command signal so as to achieving unity power factor operation. While the outer voltage loop is designed to maintain the dc-link voltage and produce command current signal to the inner loop.

Harmonic voltage of the reactor could be detected quickly by means of a fast harmonic voltage detection algorithm, and corresponding harmonic voltage is produced to compensate the effect of the grid voltage harmonic by this repetitive control so as to decrease the grid current total harmonic distortion. However this method cannot realize zero static error of current tracking. To solve this problem Reference [7] presented a repetitive scheme with voltage feed-forward combined the PI control with the PR control. PI realized the zero static error tracking of the grid-connected current, while PR realized the effective suppression of the selective harmonics, so as to improved the quality of the grid-connected current. C.

D. Cascade multilevel PCS

H-bridge converter is increasingly widely used in practical application. To reduce the batteries nominal voltage, the number of series connected storage cells can be distributed in a number of converter cells making use of the cascaded H-bridge converter. This cascaded H-bridge structure allows direct connection to a medium-voltage grid with less voltage/current harmonics without bring any increase in voltage rating to individual switching devices[8]. Moreover, as the structure of each converter cells is same, that will facilitates the modularization designing and packing. Topology of the cascaded multilevel PCS. BMS Battery units Battery units Battery units Battery units Grid Fig.6 Topology of Cascaded H-bridge Converter Cascaded H-bridge converter has many advantages. Firstly, multilevel output could upgrade the current quality injected to the grid. Secondly, cascaded structure reduce the voltage in each 264 converter cells and bring a reduction to switch losses, and have a equivalent switching frequency under the fundamental switching frequency operating condition. Moreover, it also has a easy and flexible extension capability because of the modular packing of the converter. In recent years, there are few researches on control strategy of cascaded H-bridge PCS. Power conversion is converting electric energy from one form to another such as converting between AC and DC; or changing the voltage or frequency; or some combination of these. A power converter is an electrical or electro-mechanical device for converting electrical energy. This could be as simple as a transformer to change the voltage of AC power, but also includes far more complex systems. The term can also refer to a class of electrical machinery that is used to convert one frequency of alternating current into another frequency.

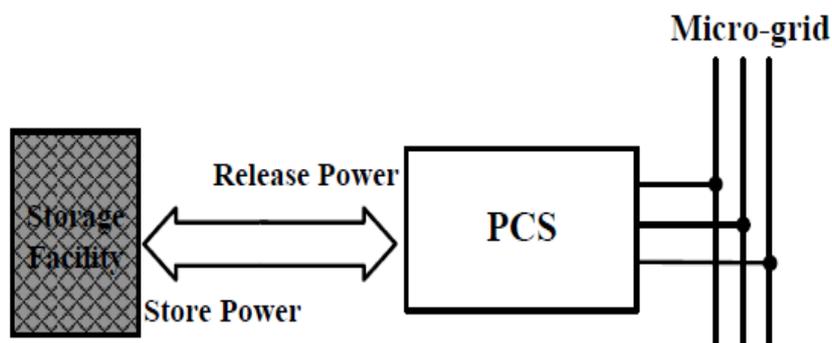


Figure 3: Structure of energy storage power conversion system

The block diagram of a power electronic converter is shown in figure above. It consist of an electrical energy source, power electronic circuit, a control circuit and an electric load. This converter changes one form of electrical energy to other form of electrical energy.

The power electronic circuit consists of both power part and control part. Power part transfers the energy from source to load and it consists of power electronic switches (SCR or TRIAC), transformers, electric choke, capacitors, fuses and sometimes resistors.

The control circuit or block regulates the elements in the power part of the converter. This block is built with a complex low power electronic circuit that consists of either analog or digital circuit assembly. Power electronic converters

perform various basic power conversion functions. This converter is a single power conversion stage that can perform any of the functions in AC and DC power conversion systems.

Depending on the type of function performed, power electronic converters are categorized into following types.

- AC to DC = Rectifier: It converts AC to unipolar (DC) current
- DC to AC = Inverter: It converts DC to AC of desired frequency and voltage
- DC to DC = Chopper: It converts constant to variable DC or variable DC to constant DC
- AC to AC = Cycloconverter, Matrix converter: It converts AC of desired frequency and/or desired voltage magnitude from a line AC supply.

These types of power electronic converters may be found in a wide variety of applications such as switch mode power supplies (SMPS), electrical machine control, energy storage systems, lighting drives, active power filters, power generation and distribution, renewable energy conversion, flexible AC transmission and embedded technology.

IV. CONCLUSION

With the continuous progress of batter technology and power electronics technology, the structure of the PCS will be revised and improved. In the current practical application, single-stage PCS will be commonly and extensively used in the small and medium power application considering the efficiency and cost. While in high power application, the modular cascaded H-bridge PCS is the most suitable choice. The new structure develops towards a direction of less losses, higher reliability, higher efficient cost and higher degree of modularity. Moreover, as the control strategy is becoming more and more mature, PCS could flexibly adopt different control strategies according to different working modes or control targets.

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