Method to Balance Grid Voltage Condition Injecting Three-Phase Currents by Controlling Three-Phase CSC

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Abstract— A topology for an interface of DC grid with an AC grid using single stage bidirectional Current-Source Converter (CSC) has been reported in the literature. Under a balanced-grid voltage condition, the DC-link inductor current can be regulated over a wide range (zero to rated value), while the AC-side current has low harmonic distortion. However, unbalanced grid voltages result in second-harmonic pulsation in the current and power on the DC side of the converter. In addition, the AC-side currents will be unbalanced due to the presence of a negative sequence component. This would result in undesired tripping of the converter if one of the phase currents exceeded its rated value. Various control loop structures for the operation of voltage-source converter under unbalanced grid voltage conditions has been reported in the literature. However, use of similar control loop structures for CSC may lead to unstable operation. In this paper, a control scheme to inject balanced three-phase currents into the AC grid under an unbalanced grid voltage condition. The stability of the proposed control scheme is studied using a small signal model of the converter. The performance of the proposed control scheme is studied MATLAB/Simulink and validation by experiments.

Key words: Controlling Three-Phase CSC, Injecting Three-Phase Currents

I. INTRODUCTION

Film capacitor-based Voltage Source Converter (VSC) has lower energy density, higher cost, and/or employs additional active ripple reduction circuits. Further, VSC requires an additional DC–DC boost converter to interface a low-voltage DC micro-grid with an AC grid. The voltage-source converter (VSC) is a converter topology that is commonly used to interface a DC micro-grid with a utility AC grid that has a bidirectional power flow capability. However, reliability of this converter is low due to the presence of a large electrolytic capacitor across the DC-link. In contrast, a conventional current-source inverter (CSI) does not require any electrolytic capacitor for energy storage, and an additional DC–DC converter for DC-side voltage boosting. Therefore, CSI exhibits higher reliability and power density than the VSC+DC–DC boost converter topology, with comparable efficiency. However, neither the DC-link inductor current of the CSI nor the DC micro-grid bus voltage can be reversed. Therefore, this inverter has a unidirectional power flow capability.

II. LITERATURE SURVEY

A Study of research papers available from various investigators shows a variety of good attempts & solutions given for the interfacing of AC & DC grid. As given in [1], a single-stage, bidirectional, CSC topology is used to interface a DC micro grid with an AC main grid under symmetrical grid voltage behavior condition. DC-link inductor current was controlled on a large range of zero to rated value while the AC-side current was maintained at low harmonic pollution. Due to asymmetrical grid voltages, second order harmonic was observed on the DC side of the converter. Also, AC-side currents was unbalanced it contained negative sequence components, which can result in tripping of the converter if any phase currents exceeded its nominal value. Control schemes for optimal operation of voltage-source converter (VSC) under distorted grid voltage conditions are available, but not possible using a CSC control, as stability is not achieved. As described in [2], use of small film capacitors replacing electrolytic capacitor for DC-link in 1-phase inverters applications is advantageous in many aspects. A low value of capacitance can be achieved at optimum cost. It is known that, high amount of low-frequency fluctuations at 100Hz/120Hz is found in DC-link, but the capacitor bank dilutes the ripples in current at the inverter. As basic control strategies for inverters operate at constant input voltage and are not suitable for low-frequency voltage fluctuations that are more than 10%. As described in [3], In case of any converter breakdown, the component seen responsible is Electrolytic filter capacitors. An increase in Equivalent Series Resistance (ESR) value is the best indicator for fault in these capacitors. The output-voltage ripple, V of the converter is proportional to ESR. To avoid problems caused by load variations, output voltage is filtered at switching frequency of converter. The filtered component is dependent on the aging of the capacitors, ambient temperature, output current, and input voltage of the converter, and to calculate the value, all these parameters needs to be considered. The method implemented for it is as below:

- A reference system containing every parameter of converter was designed at its proper working condition state using sound electrolytic filter capacitors
- Processing of actual real time input parameters is done for results
- Results are compared with the reference system and the lifetime of capacitors is estimated

As described in [4], most energy conversion systems based on renewable energy generates power in DC power form, which is boosted and converted to an AC voltage having fixed amplitude and frequency. A converter switching scheme developed on Space Vector Pulse Width-Modulated (SVPWM) method for single-stage, 3-phase boost inverters using the architecture of CSC inverters. The scheme consists of three-charging cycles and six discharging cycles with only two switches conducting for any given instant. The charging states needed to boost the DC input voltage. As described in [5] The Current source inverter

(CSI) technology is still an immature technology despite the knowledge of self-commutated inverter scheme. It is opposing the use of such inverters, in applications like grid integration of renewable sources. One promising scheme is the pulse width - modulated CSI with inbuilt capability to step up voltage along with the indirect CSI systems with only two switches having high frequency operation, as it provides low switching losses and high power density for the inductors. As described in [6], Voltage-source inverter (VSI) design of inverter is quite extensively used for grid interfacing of distributed generation systems. In some systems, it is used as power conditioning unit for DC systems. VSI schemes takes help of secondary power electronic converter stage to increase the voltage, thus increasing the gross cost and complexity of the system. The current-source inverter (CSI) scheme proves to be better than VSI because of its inbuilt boosting and short-circuit protection capacity, controllability of output current, and has a simpler AC-side filter structure. A good economical option, needs to maintain lower cost, better performance, and high life expectancy of the power electronic interface. Advanced power electronic converters are helping to enable efficient and flexible processing of power generated from renewable energy sources, usage of electricity in electric vehicles, and applications in adjustable-speed drives. Efforts are going on to improve reliability, ensure high availability, long operation lifetime, sufficient robustness, and low maintenance cost and low cost of energy [7]. A collection of methodologies based on Physics-of-Failure approach and mission profile analysis are performed. The analysis described here takes care of the following:

a) basic operation of the power electronic circuit and system;
b) electrical and thermal stress analysis based on the system specifications and mission profile for preliminary selection of components to meet the stress-strength requirement;
c) Failure Mode Effect and Analysis (FMEA) to identify the failure mechanisms

As described in [8] DC-link capacitors forms an interim part of all major power electronic converters which contribute to the cost, size and failure rate of the system at a considerably high rate. So, it is important to work towards improvement of reliability of DC link capacitor to improve working of converters. The Failure mechanisms, modes of failures and lifetime estimation models of capacitors that are suitable for the applications in AC-DC interface are done accordance to the physics-of-failure. The analysis of power electronic converters is done from two aspects:

− Reliability-oriented DC-link design solutions
− Conditioning monitoring of DC-link capacitors during operation.

As described in [9], Selection of a DC link capacitor for an inverter is a difficult process because of many mixed and conflicting ratings and merits considered. It also complicates this application by the temperature requirements of the application environment. Fluorenyl polyester (FPE) capacitor, of 10μF is tested up to 200◦C at 250 V. It has recorded satisfactory ESR and stability. FDAPE material, with the addition of hydrocarbon 4, 9-diamantyl to the polymer backbone gives less than 2% variation in capacitance between room temperature and 350◦C, and a DF of less than 0.3% across the same range. A fluorinated poly benzoxazole copolymer and a fluorinated polyimide (PI-ADE), have lower glass transition temperatures and so are only tested to 250◦C. Up to this temperature they both exhibit capacitance variations of less than 2.5%. The measured DFs are 1.4-1.7% and 0.5-0.8% respectively, making them competitive. Therefore, a control algorithm needs to be developed to implement current injection scheme at balanced 3-phase currents condition into the AC grid under unbalanced grid voltage situation. It is proposed in this paper. The stability of the The described control scheme is detailed using a small signal model of the converter. Performance of the implemented control algorithm is studied using MATLAB Simulink and is experimentally validated.

III. PROBLEM DEFINITION

The presence of single-phase loads and unsymmetrical faults cause unbalance in grid voltages at the distribution level. These unbalanced grid voltages result in a second-harmonic pulsation in the power, voltage, and current on the dc side of the converter. This pulsation in the current results in a fundamental frequency negative-sequence and third-harmonic positive-sequence currents on the ac side. The converter current will be unbalanced due to the presence of this negative-sequence component. Under such condition, the converter would trip if one of the phase currents exceeded the rated value. This may cause system instability and cascaded failure of the power system if the generation or load on the dc side is significantly high.

IV. METHODOLOGY

In this paper, a control strategy is proposed to inject balanced three-phase currents into the utility AC grid under unbalanced grid voltage conditions. However, injection of balanced AC currents into unbalanced grid voltages introduces a 100-Hz oscillation in an instantaneous active power. As a result, it is impossible to make the DC-link inductor current constant. Therefore, the DC-link inductor current is controlled around an average value. Further, it is proposed to eliminate the negative-sequence current component from the grid current by introducing a second-harmonic oscillation in the modulation index. The desired amplitude and phase of this oscillation are derived using PI regulators, such that the negative-sequence dq-axes current components observed in the negatively rotating synchronous reference frame are regulated to zero. Further, a small-signal model of the CSC is developed. The stability of the proposed control loop is studied using this Simulink model of the converter. Three-phase Bidirectional CSC: The topology for three-phase bidirectional CSC is as shown in Figure 1. The converter is a combination of a three-phase CSI and a three-phase three-switch Current-source rectifier (3SWCSR). It has two broad modes of operation, namely, inverter and rectifier.
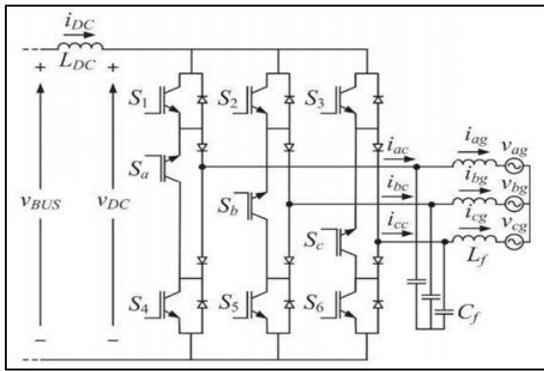
Fig. 1: Bidirectional Current Source Converter (CSC)

Figure 2 shows the block diagram of the control strategy to regulate the DC-link inductor current. The phase angle information of the AC grid voltage is obtained using a three-phase phase-locked loop. Depending on the direction and magnitude of the desired active power flow, the DC-link current reference i^*_{DC} is generated by an external controller (not shown in the block diagram).The error between i^*_{DC} and the sensed inductor current i^*_{DC} is processed by the PI regulator. The output of the PI regulator is the d-axis reference current i^*_d of the converter. The external controller also sets the q-axis reference current value i^*_q based on the desired reactive power flow. The current references i^*_d and i^*_q are then transformed from a synchronous to a stationary reference frame. Magnitude and angular position of the reference current space vector $| i^*_q |$ and γ, respectively, are calculated using the stationary frame reference currents i*α and i*β. Further, the modulation index m is calculated by dividing the reference current space vector magnitude $| i^*_q |$ by the actual dc-link current I_{DC}, as shown in Figure 2. The modulation index m and the angular position γ are fed to the converter SVM block. This block computes the active time periods of the switching states and generates the gate signals. The inverter section is activated if the reference dc-link current i^*_{DC} is positive, and gate pulses for switches S1–S6 are generated. In this case, the gate pulses of switches Sa –Sc are disabled. The rectifier section, which generates gate pulses Sa-Sc is activated if i^*_{DC} is negative. In this case, gate pulses of S1-S6 are disabled This eliminate the need for a multistep commutation process. Unlike that in VSC, in this converter, the maximum value of the reactive power that can be supplied depends on the amount of the active power exchanged with the grid. Further, the 3SW-CSR can have a maximum displacement angle of ±30◦ only.
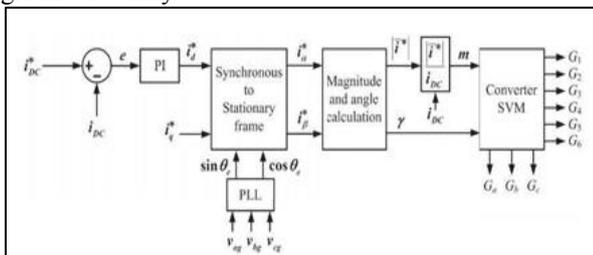

Fig. 2: Block diagram of the control scheme to regulate the dc-link inductor current

Evaluation of the stability of this closed-loop controller is important owing to the inherent lower phase margin of CSC compared to VSC and the delays introduced by the filters in the control loop. It is not possible to control the CSC using the similar control loop structures that of VSC. In the proposed control strategy, the negative-sequence current component is eliminated from the grid current. The effectiveness of the proposed control scheme is tested based on the percentage unbalance in the grid currents, grid current total harmonic distortion (THD), peak-to-peak ripple in the DC-link current, current stress, and voltage stress on the devices at various unbalance levels in the grid voltages. A small-signal model of the CSC is developed which is useful to evaluate the stability of the conventional and the proposed control loops.

V. CONCLUSION

A three-phase bidirectional converter based on a current source topology to interface a DC micro-grid with the main AC grid is Suggested Under unbalanced grid voltage condition the DC-link current has a second harmonic pulsation. In addition, the AC-side currents are unbalanced due to the presence of a negative-sequence component. This might result in undesired tripping of the converter. Balanced three-phase currents can be injected into the unbalanced grid voltages using a modified control scheme. However, it is found that the modified control scheme becomes unstable in the inverter mode of operation because of the notch filter and the (1/iDC) term is used to generate the modulation index. Therefore, a control scheme is proposed, where (1/i DC) term in the control loop is avoided. The DC stability of the proposed control scheme is analyzed using a small-signal model of the converter. The performance of the proposed control scheme is studied using MATLAB/Simulink.

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