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Research Article

Performance Analysis of Fuzzy Logic Controller-based dc-Link Shunt Compensator in Single-Phase Grid-Connected Mode

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ABSTRACT

In grid-connected motor drive system, the important problem is dc-link voltage regulation and it also creates the harmonics in input grid current. To avoid this problem, we need to use large capacitance per unit volume or grid filter inductor. We propose the solution to suppress the harmonics problem by implementing fuzzy logic controller-based dc-link shunt compensator (DSC) for small dc-link capacitor systems. Parallel located DSC is on dc-node and behaves like as voltage source which yields the system performance improvement. This circuit performs the grid current-shaping control during grid-connected mode, and during grid-disconnected mode, it diminishes the flux-weakening current by contributing the energy to the motor. The attainability of DSC is verified using MATLAB simulation tool.

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INTRODUCTION

In general, the single-phase grid-connected systems have been used in numerous applications, such as home utilizations, renewable energy structures, and electrical vehicle chargers. Fundamentally, the single-phase grid supplies the wrinkle power to the loads, and thus, the system needs adequate energy buffer to rivet this wrinkle power. Commonly, the electrolytic capacitor is cast off as the energy buffer, owing to its large capacitance per unit volume.

Even though large dc-link capacitor system demands the heavy inactive series filter and the cascaded boost converter shown in Figure 1a and 1b , they fulfill grid harmonic principles as grid harmonic reimbursement circuits.

Furthermore, the electrolytic capacitor has high catastrophe rate and lowers the dependability of the overall system.[1-3] Many researchers are demanding to intention the system which is cheaper, reduced, and more reliable. One of the substitutes is the system with the film or ceramic capacitors in the dc link, as shown in Figure 1c.[4-6] Film or ceramic capacitor has a much lower failure rate than the electrolytic one, so it can highly enhance the reliability of the system. Furthermore, the size and cost of the system can be abridged by changing the dc-link capacitor. Meanwhile, using the film or ceramic capacitor at the dc-link creates the capacitance of the system very lesser, the grid current is curtained by the output power of the load.

Consequently, this system can gratify the harmonics regulation without surplus filters by determining the output power. In the shaping methods of single-phase small dc-link capacitor system ,which does not need any additional circuit to satisfy the grid current harmonics regulation IEC 61000-3-2 but heavy grid filter inductors are introduced. Due to these qualities, the small dc-link capacitor systems have been inspected and have initiated to be applied in many areas recently.[1-9] However, since the grid ripple power is straightly distributed to the load, the output torque is certainly fluctuated and the topmost value of load current is extremely amplified in the small dc-link capacitor system. Moreover, due to its changeable dc-link voltage related to the absolute value of grid voltage $|v_g|$, load drive circuit always requires a certain amount of flux-axis load current to safe control margin. These supplementary currents bring out unwanted losses. In this paper, the fuzzy logic controller (FLC)-based dc-link shunt compensator (DSC), which is connected in dc-link in parallel, is proposed to increase the performances of the single-phase diode rectifier-fed system with small dc-link capacitor. DSC achieves the grid current shaping control throughout the grid connection time and increases the dc-link voltage throughout the grid disconnection time. The dc-link boosting control improves the efficiency of small dc-link capacitor system and overwhelms the disadvantage in the small capacitor system. In fact, topologies to decrease dc-link capacitance and to fascinate wrinkle power grid in the system are called as power disconnecting units or energy buffer and previously have been far and wide investigated. Proposed topologies are employed laterally with power factor correction (PFC) as the forms of gushed or combined structures, but then these topologies involve relatively many components which become more costly.

Even though they have some performance restrictions, such as the shortened grid current harmonics and minimized average dc-link voltage, topologies without PFC were assessed as one of the best solutions; meanwhile, they generally show good cost-effectiveness in assessment with the PFC-based topologies. Unlike the predictable topologies, DSC conjoins with load drive circuit and reimburses the power by the perception of current injection. Due to its equivalent connection and the inserted currents, dc-link shunt capacitor can be deliberated in the desired range; however, there are some trade-offs between the performance and the cost. In Shin *et al*. study,[10] dc-link shunt capacitor was proposed. This paper presents the design of DSC and its control method based on FLC. The design guideline for the proposed method is also included, and the design tradeoff is discussed in comparison with the unoriginal small dc-link capacitor system. The simulations results verify the strength of the proposed DSC system.

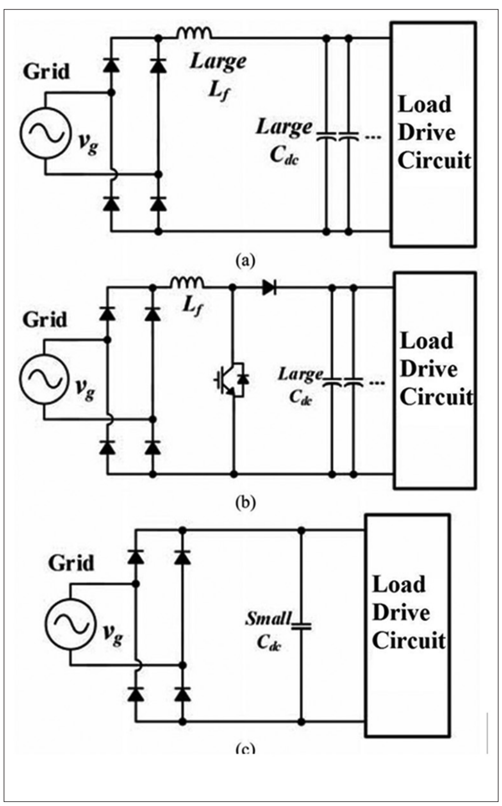

Figure 1: Single-phase grid-tied systems with (a) series compensation by filter inductor, (b) cascaded boost converter, and (c) only small dc-link capacitor

PROPOSED DSC

Proposed diagram

The total load drive system together with FLC-based DSC is shown in Figure 2. L_{in} is an inductor filter used to riddle the swapping ripple current. This can be changed as very small value in comparison with conventional heavyweight filter inductor for weakening low-order harmonics. DC-link shunt capacitor structure can be designed in such a way as transferring the power between floating capacitor C_{dc2} and dc-link capacitor C_{dc1}, such as buck, boost, and H-bridge converters. Of these, the boost converter-based DSC is implemented in this paper. Since the H-bridge type requires relatively more components, moreover H-bridge converter has lower efficiency than the boost or buck type.

As shown in Figure 2, with the inverter ground, the ground node of DSC is connected. Implementation of FLC-based DSC is easier if the system is designed as non-isolation circuit whose power grounds and digital signal are tied and also it is cheaper because the shunt current sensing resistor, bootstrap circuit for gate driver, and non-isolated voltage sensor can be used.[11] Due to this, our system is cost-effective circuit in comparison with the conventional inductor filter and capacitor filter reduction topologies.

Working principle

First of all, as shown in Figure 3, control method of PI control, an inverter in small dc-link capacitor system, is simply introduced. As above mentioned, vdc1 of small dc-link capacitor system is similar. Since the diode rectifier is conducted during most of the grid period, the shape of grid current gives the shape of inverter output power Pinv.

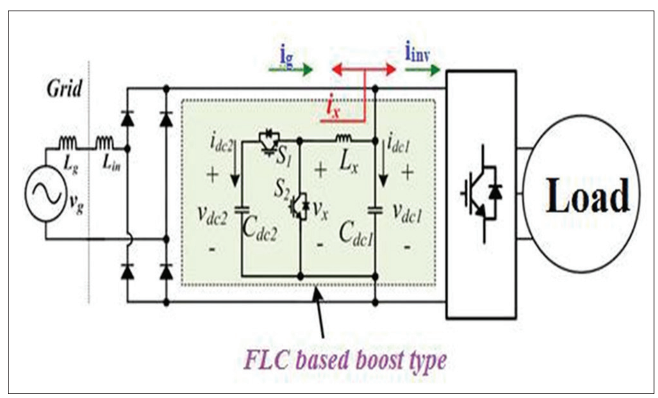

Figure 2: Configuration of fuzzy logic controller-based dc-link shunt compensator system.

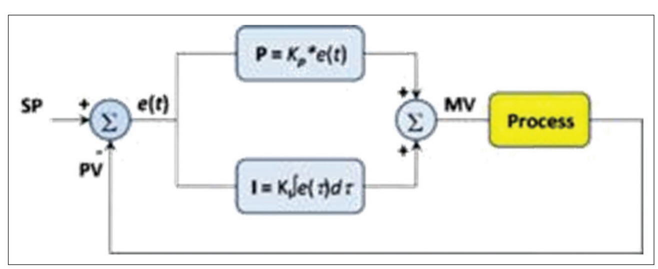

Figure 3: Basic diagram of PI controller

Assuming that the grid current is sinusoidal, the grid power is given by Pg = νg · ig = Vg · Ig · sin2θ g where Ig is a peak value of grid current. Next, the active power of the dc-link capacitor can be calculated as Pdc = Cdc · νdc dνdc dt. Using these equations, the required inverter power Pinv to make grid current sinusoidal can be obtained as Pinv = Pg − Pdc. Since Cdc is quite small value, Pinv equals to Pg and shows the square of sinusoidal waveform. In previous studies which are based on a small dc-link capacitor, many methods have been proposed for generating Pinv.[3,5,8] Among them, a method in Lee et al.[6] is chosen in the proposed system because the method can flexibly control an instantaneous output power by modifying power reference. Since a power controller in this method directly manipulates output voltage reference, bandwidth of the power controller does not limit by that of the current controller. The key point of the proposed operation method is that DSC performs the grid current shaping during T_{GC} as in Figure 4a and supports the load drive during T_{GD} as in Figure 4b.

Here, the energy in C_{dc2} is charged and discharged in T_{GC} and T_{GD}, respectively. In T_{GC}, ν_{dc1} is regulated to the voltage similar to the desired V_{dc} and shunt compensator injects the compensation current to control the grid current. On the other hand, T_{GD} starts when V_{dc} becomes lower than the minimum dc-link voltage V_{dc1min} and DSC begins to boost ν_{dc}. In this time, the grid current becomes zero and DSC supplies the required load power to the inverter. The dc-link voltage reference ν∗ dc1 in overall time can be described.

DSC controller

The control block diagram for the existing method is shown in Figure 5. It is divided into five parts: Phase-locked loop (PLL), ν_{dc2} voltage controller, νdc1 voltage controller, grid current shaping block, and current controller. No isolated voltage sensor is required for the grid angle detection method in PLL, since θg can be detected from νdc1 which is equal to νg during TGC. In small dc-link capacitor system, a single-phase PLL using dc-link voltage has been widely used and this block can be implemented with various methods.[3,6] With the angle information from the PLL block, other references related with the grid side can be established in the grid current-shaping block.

This i_{comp} adjusts the ripple power between the grid and the inverter to shape ig as i_g whatever the shape of i_{inv} is. In addition to this i_{comp}, there are extra two currents that need to be controlled; they are the outputs of two voltage controllers, i νc1 and i* νc2. The former is for controlling νdc1 to Vdc1. min, and the latter is for regulating the average level of ν_{dc2} to its reference voltage ν_{dc2}. However, these two currents work to control the input and output voltages of DSC, i.e. boost converter. It obviously causes a conflict since they try to move opposite direction to achieve their own goals. Therefore, to avoid this conflict, two voltage controllers require to be activated alternately. Since the νdc1 controller is activated during TGD, the ν_{dc2}

controller is working during the rest of the time, i.e. TGC. It means that the average value of ν_{dc2} is temporarily out of the control during TGD. This results to increase of ν_{dc2} ripple, but it does not matter because ν_{dc2} is originally supposed to be fluctuated by i_{comp}. Considering this fact, it is good to give margin when we design C_{dc2}. In the νdc1 control, on the other hand, since the grid is strongly tied to dc link during TGC, temporary inactivation of the νdc1 controller is not a problem. As a result, the control loops during 2 time durations, TGC and TGD, can be illustrated as in Figure 5.

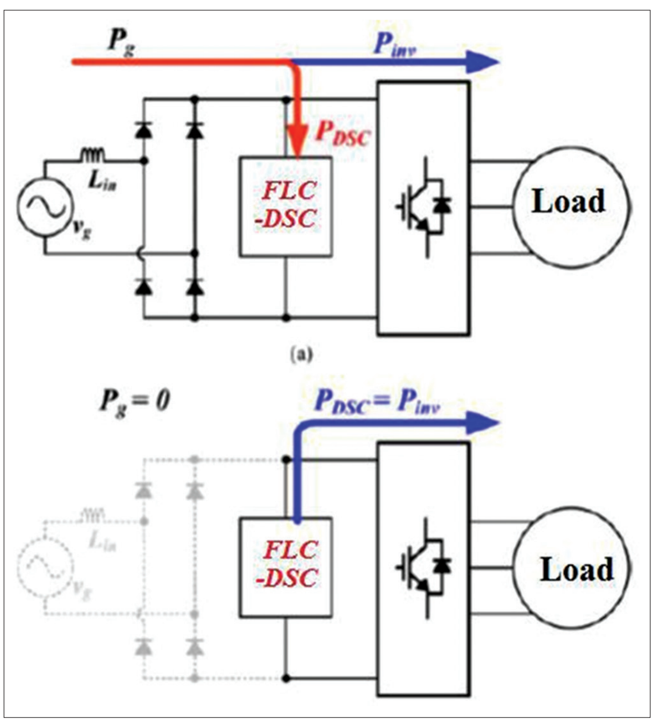

Figure 4: Power flow on the conditions of (a) T_{GC} (νg > Vdc1.min) and (b) T_{GD} (νg ≤ Vdc1.min)

Proposed control method for dSC

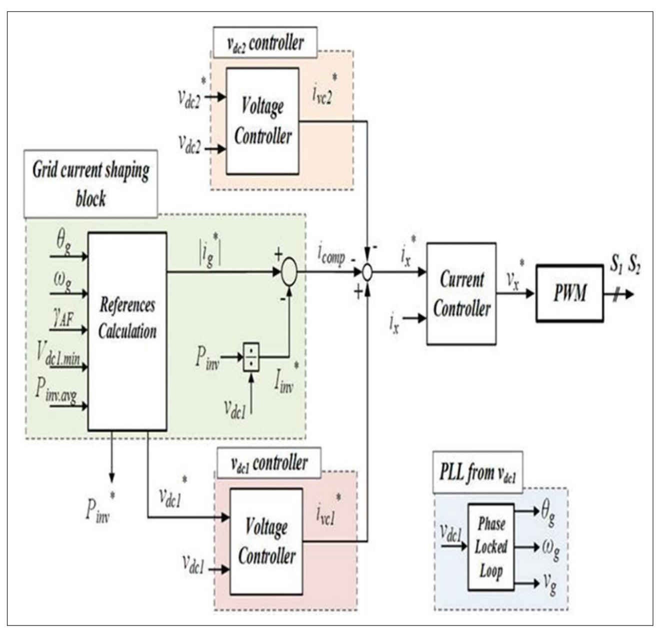

Figure 5: Block diagram of the control method for a single-phase dc-link shunt compensator system

In the proposed system, there are two capacitors: Cdc1 and C_{dc2}. The capacitance of C_{dc1} is involved in switching ripple current absorbing and instantaneous power control of DSC. It is seen that i*x is increased if i<c1 proportional to C_{dc1} is increased.

This means that DSC should supply more currents to the load drive system to control grid current.

Therefore, it is recommended that C_{dc1} is set to the value of several microfarads. This paper selects C_{dc1} as 6 μF, where the system is connected to 220-V_{rms} grid and the switching frequency is 15 kHz. C_{dc2}, which is main energy storage of DSC, is designed so that v_{dc2} is bounded between V_{dc2}.min and V_{dc2}.max. As described in Section II-A, V_{dc2}.min and V_{dc2}.max are 310 (peak of vdc1) and 400 V, respectively [Figures 6 and 7].

SIMULATION AND EXPERIMENTAL RESULTS

The simulations were conducted with the motor drive system, and the system conditions and parameters are shown in Figures 8-10.

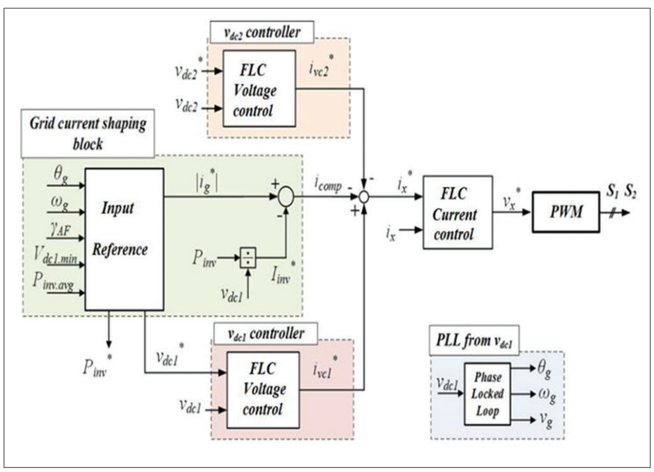

Figure 6: Block diagram of the control method for a single-phase dc-link shunt compensator system

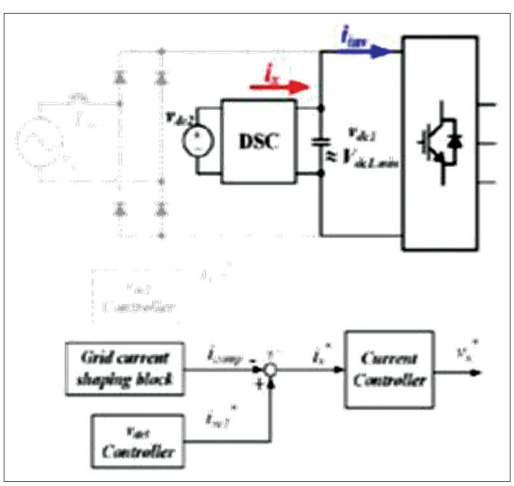

Figure 7: Circuit diagram and control-loop blocks during (a) *T*GC and (b) *T*GD

CONCLUSION

This paper proposes the design of FLC-DSC with small dc-link capacitor and the single-phase diode rectifier.

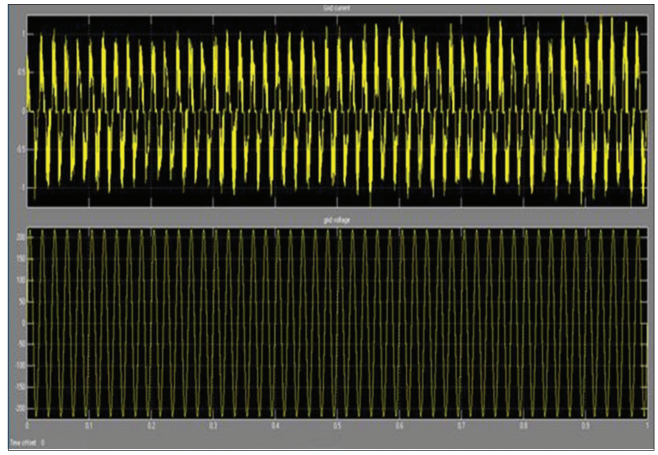

Figure 8: Grid current not in shape for the existing system

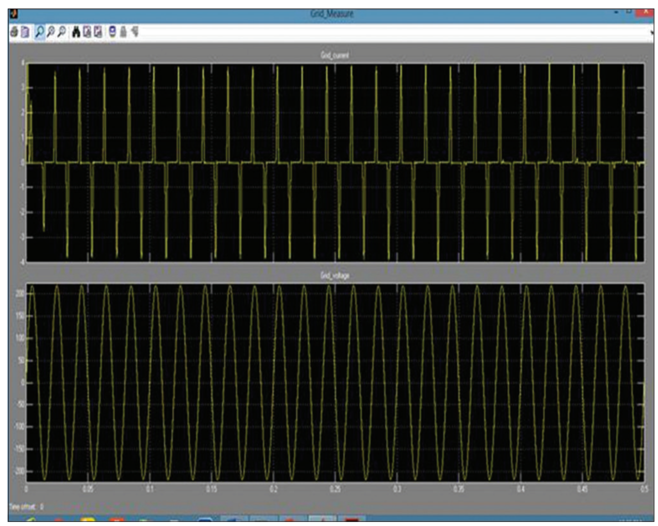

Figure 9: Grid current and grid voltage for interconnecting dc-link shunt compensator

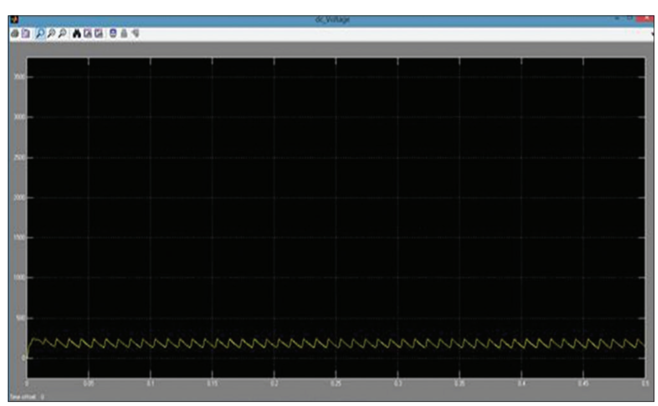

Figure 10: Dc-link voltage interconnection of dc-link shunt compensator

The proposed DSC compensates the power difference between the grid and the drive system, i.e., operates as the energy buffer. Average dc-link voltage is increased by applying DSC, and the efficiency of the system is improved.

The simulation results verified the merits of the proposed DSC system in comparison with the conventional small dc-link capacitor system. Design considerations based on the results are yet to be improved.

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