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# 3상 시스템의 무효전력, 불평형 전류 보상 기능을 갖는 태양광 전력변환장치 설계

# (Design of a Photovoltaic PCS with Compensation Control of Reactive Power and Unbalance Current in Three-phase systems)

박상민[1)], 김창순[2)], 레딘브엉[3)], 박민원[4)], 유인근[5)*]
(Sang-Min Park, Chang-Soon Kim, Le Dinh Vuong, Minwon Park, and In-Keun Yu)

**요 약** 청정에너지 발전설비의 요구가 늘면서 태양광, 풍력, 연료 전지 등의 분산전원 개발이 급속도로 증가하고 있다. 반면에 이러한 증가로 인하여 배전시스템은 복잡해지고 있으며 무효전력으로 인한 역률 저감, 불평형 부하에 의한 불평형 전류 등의 문제점을 가지고 있다. 이러한 문제점들을 해결하기 위하여 본 논문에서는 태양광용 3상 4선 타입의 전력변환장치에 무효전력, 불평형 전류를 보상하는 알고리즘을 적용하였다. 제안한 태양광 전력변환장치는 기본 출력동작 뿐만 아니라 계통 전력 품질의 저해요소들에 대해서 보상이 가능하며 PSCAD/EMTDC를 이용한 시뮬레이션을 통하여 그 성능을 검증하였다.

**핵심주제어** : 보상기법, 전력변환장치, 태양광, 무효전력, 불평형 부하, 전압형 인버터

**Abstract** Development of the distributed energy resources such as photovoltaic, wind, and fuel cell has increased rapidly due to the rising demand for clean energy utilization. On the other hand, the distribution system became complex and has problems such as degradation of power factor and current unbalance caused by power converters, reactive power and unbalanced loads. To solve these problems, this paper proposes a 3-phase 4-leg type power conditioning system with compensation control algorithm for the reactive power and unbalance current in distribution system using photovoltaic resource. It is simulated in PSCAD/EMTDC and the effectiveness is confirmed.

**Key Words** : Compensation, PCS, PV, Reactive power, Unbalance load, VSI

## 1. Introduction

The development of the distributed energy resources (DERs) such as photovoltaic (PV), wind power generation system (WPGS), energy storage system (ESS) and fuel cell has increased rapidly due to the rising demand for clean energy utilization [1]. However, the power quality is a major concern for modern distribution system which faces with manifold

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problems such as degradation of power factor and unbalance current caused by reactive power and unbalanced loads [2-3].

This paper proposes a PV power conditioning system (PCS) with an individual phase control scheme for compensating the reactive power and unbalance load without additional compensators in the distribution system. The proposed PCS has not only normal operation functions but also compensation functions of the reactive power and unbalance current in the grid. The configuration of the PCS is composed of a three-phase four-leg type voltage source inverter (VSI) which uses a control scheme based on DQ transformation. Therefore, the proposed PCS can compensate the reactive power and unbalance current of the grid without PV output using N-phase loop of the inverter side [4]. The control algorithm contains MPPT control, DC voltage control, P-Q control, PLL control and individual phase control.

The proposed PV PCS is modeled and simulated using PSCAD/EMTDC. The simulation results show that the proposed PCS is able to compensate the reactive power and unbalance current caused by power converters and unbalanced loads in the distribution system simultaneously. The proposed PCS can apply to other DER required the power converter for connecting to the grid such as WPGS, ESS, etc. Therefore, the PCS is useful to increase the power quality of the distribution system.

## 2. Configuration of a PV PCS

Conventional three-phase PCS is composed of three-leg full-bridge VSI. In the case of the three-phase three-leg type VSI based on DQ transformation, the output is symmetric. In order to compensate the unbalance load, the VSI requires one more leg for compensating the unbalance current.

The structure of a three-phase four-leg type PV PCS based on individual phase control scheme is shown in Fig. 1, that integrates the DC link capacitors, a four-leg full-bridge type inverter, AC filters, and the grid to which the output is connected. The operation scheme for an individual phase control consists of three main blocks, namely control algorithm for the determining current reference, the current controller for output power, and the control strategy for generating pulse width modulation (PWM).

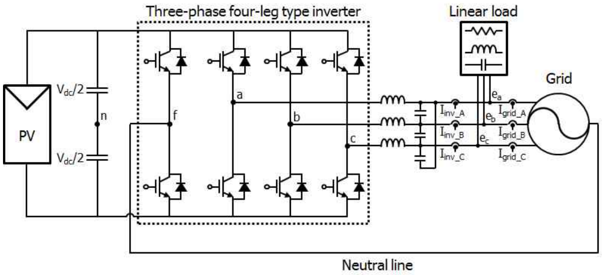

Fig. 1 The configuration of the PV PCS based on the three-phase four-leg type VSI

## 3. Control algorithm of the PV PCS

### 3.1 Determining of current reference

The purposes of this algorithm are to determine the reference current vectors for compensating the reactive power and unbalance current. The individual phase control scheme is the outer control loop employed to generate the reference current vectors $i_{d\_ref}$, $i_{q\_ref}$ and $i_{0\_ref}$ as shown in Fig. 2.

Each phase current of load $i_{a\_load}$, $i_{b\_load}$ and $i_{c\_load}$ can be transformed into rotating d-q-0 coordinate $i_{d\_ref}$, $i_{q\_ref}$ and $i_{0\_ref}$. The cut-off frequency of the low pass filter is 10 Hz. The $i_{a\_load}$, $i_{b\_load}$ and $i_{c\_load}$ consist of the harmonic components of the loads.

$$i_{d\_ref} = i_{d\_load} - i_{d\_lpf} \quad (1)$$
$$i_{q\_ref} = i_{q\_load} - i_{q\_lpf} \quad (2)$$
$$i_{0\_ref} = i_{0\_load} \quad (3)$$

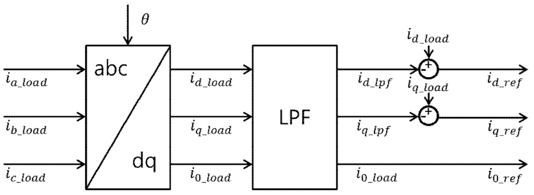

Fig. 2 The compensation algorithm for the reactive power

### 3.2 Output power control

The purpose of current controller is to ensure accurate tracking and short transients of the inverter output current. Fig. 3 shows the control block diagram of the current control algorithm based on a synchronous reference frame. The voltage phase angle Θ is estimated by the phase locked loop based Park's vector in the control block diagram. Three PI controllers are used to eliminate d-q-0 current components, and feed-forward loop considering grid voltage and inductance voltage is employed to improve the steady state and dynamic performances. As a result, the outputs of the controller represent the reference voltage signals (Vd_ref, Vq_ref, and V0_ref) in the d-q-0 reference frame, which are transformed into a-b-c reference frame using inverse DQ transformation.

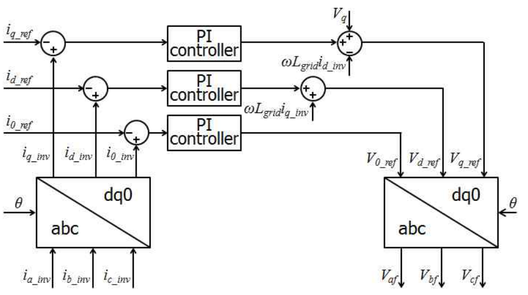

Fig. 3 The output power control algorithm of the PV PCS

### 3.3 Control strategy

To compensate the unbalance current of the grid, the controller is needed to calculate the magnitude of unbalance current of the loads. The final output of the controller is output voltage of the inverter. And the output voltage is able to separated to reference voltages and offset voltages. The resistive pole voltages for the four-leg IGBT valves can be calculated as given in:

$$V_{an} = V_{af} + V_{fn} \quad (4)$$
$$V_{bn} = V_{bf} + V_{fn} \quad (5)$$
$$V_{cn} = V_{cf} + V_{fn} \quad (6)$$

where $V_{an}$, $V_{bn}$ and $V_{cn}$ are the each phase reference voltage, and $V_{fn}$ is offset voltage which can be also determined as:

$$V_{fn} = \begin{cases} -\frac{V_{\max}}{2}, & V_{\min} > 0 \\ -\frac{V_{\min}}{2}, & V_{\max} < 0 \\ -\frac{V_{\max} + V_{\min}}{2}, & Otherwise \end{cases} \quad (7)$$

## 4. Simulation and the results

The proposed PV PCS is simulated using PSCAD/EMTDC. The simulation model is composed of the PV PCS, grid, unbalanced resistive loads and inductive loads. The PV PCS operates normally in steady states. The loads are made up of 10 kW, 20 kW and 30 kW of phase A, phase B and phase C, respectively. The compensation functions of the PV PCS starts at 1 second. At that time the current references are changed from inverter currents to load currents. The PCS operates to compensate the unbalance load and reactive power. The simulation results show that the PV PCS can compensate the unbalance condition and power factor as shown in Fig. 4 and Fig. 5. According to Eq. (8), the unbalance load in three-phase system can be defined as unbalance degree. The unbalance currents in load are 64.75 A of phase A, 127.16 A of phase B and 188.92 A of phase C which causes 48.83% unbalance degree. After compensating, the grid currents are 128.03 A, 126.38 A, and 125.96 A of phase A, B, and C, respectively. The unbalance degree was reduced from 48.83% to 0.98%. The power factor of load condition is 0.86. By using the PCS for compensating reactive power, the power factor of the grid was increased up to 0.98 compare to the 0.86 of the load.

$$Unbl\% = \frac{\max(P_{A/B/C} - P_{avr})}{P_{avr}} \times 100\% \qquad (8)$$

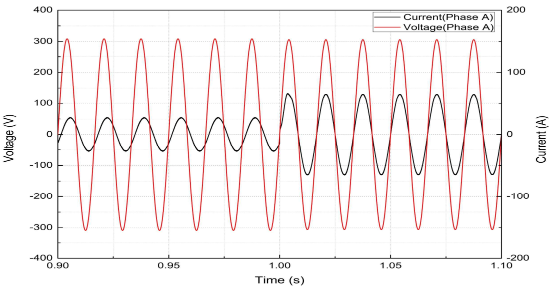

Fig. 4 The simulation result of reactive power compensation

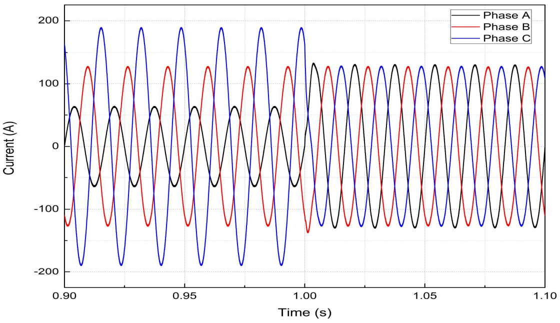

Fig. 5 The simulation result of unbalance load compensation

## 5. Conclusions

This paper proposed a PV PCS with compensation control scheme of the reactive power and unbalance load in the grid, and investigated the performances using PSCAD/EMTDC simulation. The simulation results demonstrate that the reactive power and unbalanced current in the grid are compensated by the PCS without additional compensators. The PV PCS can be utilized effectively for improving the power quality in the distribution system with PV system.

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