Implementation and Transient Operation Characteristics of 30kW CVCF Inverter-based Micro-grid System

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30kW급 CVCF 인버터 기반 마이크로그리드 시스템의 구현 및 과도상태 운용특성에 관한 연구

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Abstract

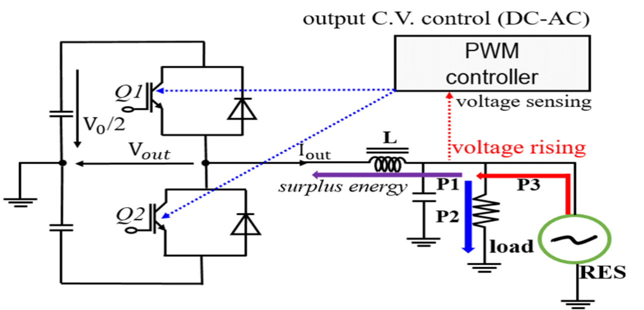
For the purpose of reducing carbon dioxide(CO_2) emissions in the island areas, the countermeasures to operate an off-grid micro-grid(MG) systems in a stable manner are being studied by increasing the proportion of renewable energy sources (RES) instead of diesel generators(DG). However, the phenomenon of energy sinking can be occurred when the output of RES(renewable energy sources) is greater than customer loads in the off-grid MG system. Where, the voltage of the battery system in CVCF inverter to form MG system can rapidly increase depending on the SOC(state of charge) condition, and then blackout in the entire MG system might be occurred due to the shut-down of CVCF inverter. Therefore, this paper implements a test device for 30kW CVCF inverter-based MG system in order to find out transient operation characteristics related to energy sinking in CVCF inverter. From the test results based on the transient operation characteristics, it is confirmed that the proposed methods are useful and effective to maintain the shut-down of CVCF inverter due to over voltage protection.

1. Introduction

These days, the installation and operation of an off-grid MG system have been significantly increasing in many countries as one of the alternatives to overcome environmental problems such as global warming, air pollution, fine dust, and so on. [1-2]. And also, the operation methods of the off-grid MG system using RES and diesel generators have been paid more and more attention. In order words, the countermeasures to increase the proportion of RES operation instead of diesel generator are being energetically studied. Particularly, in the carbon-free off-grid MG system, CVCF inverter is introduced to replace diesel generators for controlling the system voltage and frequency in MG system. However, CVCF inverter-based MG system has a possibility of an energy sinking phenomenon when the output of RES is greater than customer loads in MG system. During the phenomenon, voltage of the battery system in CVCF inverter can rapidly increase depending on the SOC condition of battery system, and then blackout in MG system might be occurred due to shut-down of CVCF inverter. Therefore, this paper implements a test device for 30kW CVCF inverter-based MG system, which is composed of CVCF inverter, artificial PV system, and artificial customer load to find out transient operation characteristics related energy sinking phenomenon in CVCF inverter. And then present operation characteristics of CVCF inverter-based MG system in 2 cases of operation modes including non-critical transient operation and critical transient operation. From test results based on transient operation characteristics, it is confirmed that the proposed methods are useful and effective to maintain the shut-down of CVCF inverter due to over voltage protection.

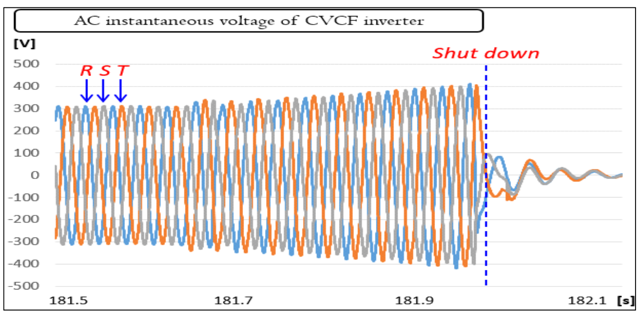
2. Transient operation characteristics of CVCF inverter-based MG system

The phenomenon of energy sinking can be occurred unintentionally in a CVCF inverter when the total output of RES is greater than the total customer load in the CVCF inverter-based MG system. Fig. 1 shows a detailed mechanism of energy sinking in a single-phase half-bridge inverter. As shown in Fig. 1, while the inverter is being operated with the constant voltage and constant frequency by the control signal from a PWM controller, the surplus energy of RES may flow into a DC side of the inverter through a semi-conductor switch and the freewheeling diode. However, the rectified voltage through a Q1 diode in Fig. 2 is not generally higher than voltage of DC side, the surplus energy cannot flow into a DC side. When a Q2 is switch-on, the surplus energy flows from the AC to DC side of an inverter due to the voltage boosting at an inductor(L) of the AC side. Furthermore, during the process of the surplus energy flow, voltage rising of RES in AC side may be accelerated to supply power to MG system depending on SOC condition of battery system in CVCF inverter and then PWM controller in CVCF is performed in order to reduce a pulse width [3].



[Fig. 1] Concept of energy sinking mechanism in half-bridge single phase inverter

Therefore, during the phenomenon of energy sinking, the battery system in CVCF inverter can be charged in an unintentional manner, and the voltage of the battery system can rapidly increase depending on the SOC condition, and then blackout in a MG system might be occurred due to over voltage protection operation of the CVCF inverter, as shown in Fig. 2.

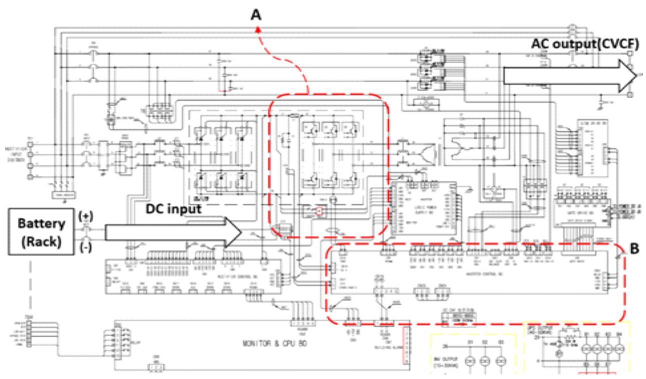


[Fig. 2] Shut-down of CVCF inverter in case of energy sinking

3. Implementation of test device for 30kW CVCF inverter-based MG system

3.1 CVCF inverter

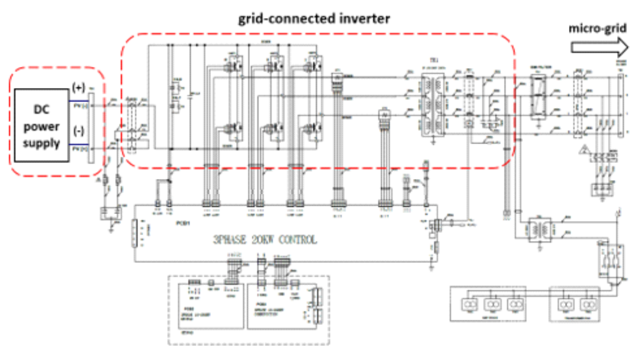
The hardware system of CVCF inverter is designed and implemented to receive power from a DC battery system and converted it into AC power through an insulated gate bipolar transistor(IGBT) component, as shown in Fig. 3. And also, it adapts a pulse width modulation(PWM) control method with the capacity of 30kW, and the efficiency is more than 90%. Furthermore, it plays an important role to maintain a constant voltage and constant frequency in the MG system.



[Fig. 3] Configuration of CVCF inverter

3.2 Artificial PV system

In order to design the output of an artificial PV system same as a real distribution system, this paper implements the artificial PV system, which is composed of 20[kVA] 3-phase inverter and 20[kW] DC power supply is illustrated in Fig. 4. And also, the output voltage of the artificial PV system can be adjusted by varying the DC currents.

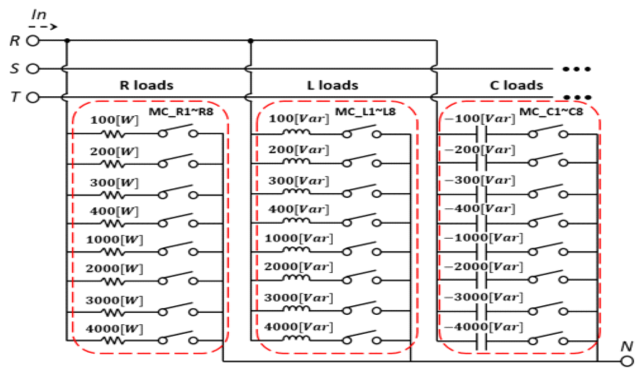


[Fig. 4] Configuration of CVCF inverter

3.3 Artificial customer load

The artificial customer load, which is composed of resistance(R), inductance(L), and capacitance(C) with the characteristics of constant impedance(Z) is implemented as shown in Fig. 5. Where, the resistance(R) component in Fig.

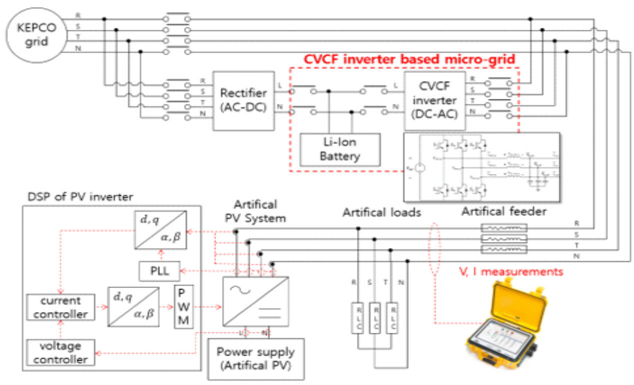
5 is controlled and adjusted using MC(magnetic contactor) from 100[W] to 10[kW]. And also, the capacitance(C) and inductance(L) components are designed from 100[Var] to 10[kVar] to consider the power factor.



[Fig. 5] Configuration of artificial customer load

3.4 Entire system

Based on the test devices as mentioned earlier, the entire configuration system of 30kW CVCF inverter-based MG system, which is composed of 30[kW] CVCF inverter, 20[kWh] Li-ion battery, 20[kW] artificial PV system and 30[kW] artificial customer, in order to maintain a constant voltage and constant frequency in the MG system is illustrated in Fig. 6.



[Fig. 6] Configuration of entire system

4. Case studies

4.1 Test conditions

In order to evaluate transient operation characteristics of 30kW CVCF inverter related to energy sinking phenomenon in CVCF inverter. this paper assumes the test conditions of setting values for each component, which are demonstrated in Table 1. Where, the condition of energy sinking is to increase the output of PV system from 0[kW] to 18[kW] by 3[kW] units when the capacity of customer load is fixed as 6[kW]. Furthermore, the operation limit of SOC setting value of the battery system in the CVCF inverter in Table 1 is assumed as 85% and the operation limit voltage is determined as 131.8[V] by considering an operation margin of 95% of the maximum voltage of the CVCF inverter. On the other hand, the scenarios of transient operation in the CVCF inverter-based MG system are classified into 2 cases. Here, Case I is a non-critical transient operation mode where the SOC of battery system in CVCF inverter is maintained as less than 85%, Case II is a critical transient operation mode where the SOC is more than 85%.

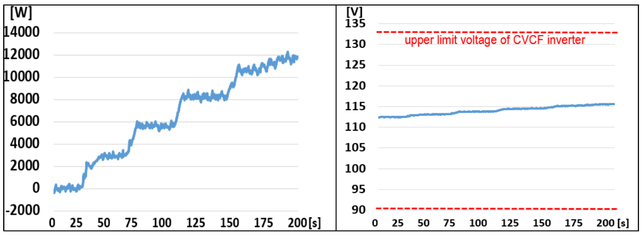
[Table 1] Test conditions

items	conditions	
battery (rack)	configuration of cell	32S84P (Lithium-ion cell, 3.7V)
	voltage operation range of (BMS)	89.6 ~ 134.4[V]
CVCF inverter	setting of SOC(SOC_M)	85[%]
	range of operation voltage(DC input)	90 ~ 134[V]
	AC output voltage & frequency	220±6%[V] & 60±0.2[Hz]
	setting of voltage(V_M)	131.8[V] (η=0.95)
	customer load	6[kW]
	PV system	0 ~ 18[kW]

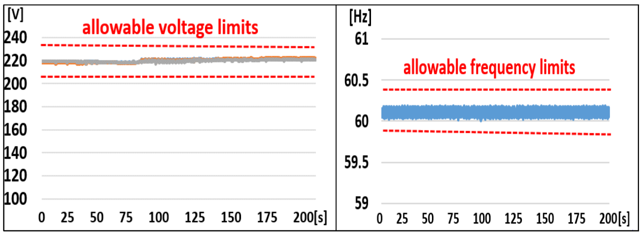
4.2 Transient operation characteristics of CVCF inverter-based MG system based on test device

(1) Characteristics of non-critical transient operation mode (Case I)

This paper implements a test device for 30kW CVCF inverter to evaluate operation characteristics of CVCF inverter-based MG system when the SOC of battery system is 50%, as shown in Fig. 7. Where, Fig. 7 (a) show magnitudes of energy sinking at time interval and Fig. 7 (b) is the voltage of the battery system in CVCF inverter along with the magnitude of energy sinking. And also, Fig. 7 (c) and (d) are the operation voltage and frequency of MG system. As shown in Fig. 7, when the magnitude of energy sinking increases from 0[kW] to 12[kW] by 3[kW] unit at each time interval, it is found that voltage of the battery system can significantly increase from 112.5[V] to 115.7[V]. However, since the voltage of battery system does not violate the operating voltage range of an inverter, it is confirmed that the operation voltage and frequency of MG system can be maintained in a stable manner.



(a) Magnitude of energy sinking (b) Voltage of battery system

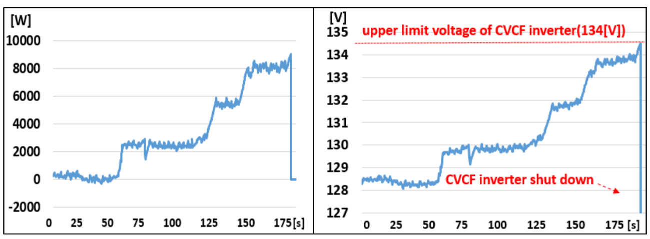


(c) Voltage of MG system (d) Frequency of MG system

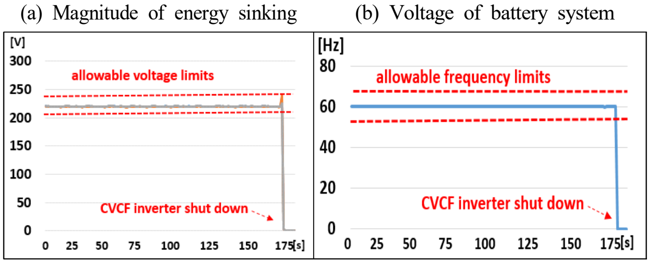
[Fig. 7] Characteristics of non-critical transient operation mode(Case I)

(2) Characteristics of critical transient operation mode(Case II)

When SOC of the battery system in CVCF inverter is 90%, which includes critical transient operation range, the characteristics of CVCF inverter-based MG system is illustrated in Fig. 8. Here, when the energy sinking occurs at 90% SOC of battery system with the lack of operation margin, it is confirmed that voltage of CVCF inverter can rapidly increase from 128.2[V] to 134.3[V], and then the inverter may result in shutting down due to the violation of the allowable voltage limit of 90~134[V].



(a) Magnitude of energy sinking (b) Voltage of battery system



(c) Voltage of MG system (d) Frequency MG system

[Fig. 8] Characteristics of critical transient operation mode(Case II)

5. Conclusions

This paper has implemented a test device for 30kW CVCF inverter-based MG system in order to evaluate transient operation characteristics related to the energy sinking phenomenon in CVCF inverter. The results are summarized as follows, First, in case of non-critical transient operation mode when SOC is assumed as 50%, it is confirmed that voltage of battery system are significantly increased from 112.5[V] to 115.7[V], frequency and voltage of MG system are operated in a stable manner due to plenty of margin in SOC of battery system. Second, in case of critical transient operation mode when SOC is assumed as 90% with the lack operation marge, it is validated that voltage of CVCF inverter can rapidly increase from 128.2[V] to 134.3[V], and then the inverter may result in shutting down due to the violation of the allowable voltage limit of 90~134[V]. From the test results based on the transient operation characteristics, it is confirmed that the proposed methods are useful and effective to maintain the shut-down of CVCF inverter due to over voltage protection.

감사의 글
본 연구는 산업통상자원부의 재원으로 한국에너지기술평가원(KETEP)의 지원을 받아 수행한 연구(No.20191210301940)로서, 관계부처에 감사드립니다.

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