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

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30kW급 CVCF 인버터 기반의 Micro-grid의 구현 및 과도상태 운용특성

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Abstract

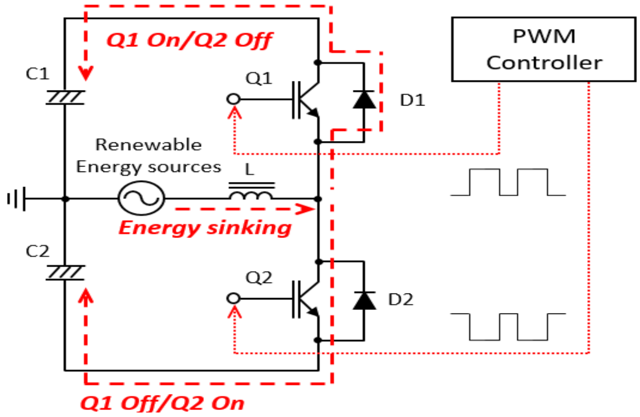
Recently, in order to reduce CO_2(carbon dioxide) emissions in the island area with the increase of RES(renewable energy sources), CVCF(constant voltage & constant frequency) inverter-based MG(micro-grid) system replacing diesel generators are being required and its stable operation methods are also being developed. CVCF inverter-based MG system may cause a phenomenon of energy sinking if the total output of RES is larger than total customer loads. In the case of energy sinking, the voltage of CVCF battery could be rapidly increased according to the condition of SOC(state of charge) of its battery, and blackout issues in MG system could be occurred by the operation of a protection device in CVCF inverter. Therefore, in order to overcome these problems, this paper analyzes the operation characteristics of CVCF inverter-based MG system when energy sinking is occurred and proposes transient operation strategy to prevent the shut-down of CVCF inverter in case of energy sinking in advance. And also, this paper implements a test device of 30kW CVCF inverter-based MG system and then presents transient operation characteristics for an energy sinking phenomenon. From the test results based on the proposed operation strategy and 30kW MG test device, it is confirmed that the blackout problems of CVCF inverter-based MG system can be properly prevented in advanced according to conditions of SOC and voltage in CVCF battery.

1. Introduction

These days, the interest of MG system has been increased as one of the alternatives to solve the problems of existing large scale power systems such as the location of large power plants and the public acceptance of power utilities. These MG systems are a small power source which is consisted of RES(renewable energy sources), ESS(energy storage system) and customer, it is categorized into a stand-alone and the grid-connected mode according to the introduction of grid-connected in a distribution system. In particular, the stand-alone MG system is an effective way to supply power to island areas that are not interconnected with the main distribution system where MG system is operated by the diesel generators as the main power sources. And also, in order to reduce CO_2 emission in the island areas with the increase of RES and ESS, CVCF inverter-based MG system replacing diesel generators are being required and its stable operation methods are being developed. However, in the operation of CVCF inverter-based MG system, energy sinking may occur if the output of RES is greater than customer loads. At this time, the phenomenon of energy sinking has occurred and the voltage of CVCF battery could be rapidly increased depending on the condition of SOC of its battery and blackout problems in MG system could be occurred by the operation of the protection device of CVCF inverter. Therefore, in order to overcome these problems, this paper performs an operation characteristic of CVCF inverter-based MG system, when the energy sinking has happened and the proposed for transient operation strategy to prevent the shut-down of CVCF inverter in advance if energy sinking is being occurred. Furthermore, this paper implements a test device of 30kW CVCF inverter-based MG system and then presents transient operation characteristics for the energy sinking phenomenon. From the test results based on the proposed operation strategy and 30kW MG test device, it is confirmed that the blackout problems of CVCF inverter-based MG system can be properly prevented in advanced according to conditions of SOC and voltage in CVCF battery.

2. Operation characteristics of transient state of CVCF inverter-based MG system

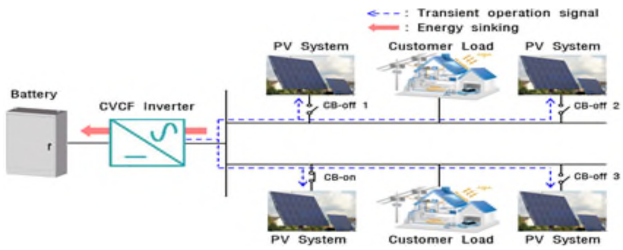
If the capacity of RES is greater than the total load consumption in the island areas, the phenomenon of energy sinking has occurred at the internal of CVCF inverter which is illustrated as shown in Fig. 1. Here, the inverter is operated in a constant voltage and constant frequency to control signal by PWM controller and the output of RES is supplied to customer load and the reminded energy is sending to a DC side through a semiconductor switch at the internal inverter and the reflux diode. In other words, in order to decrease an over-voltage and increases the surplus energy and voltage at the AC inverter side, the PWM controller increases a pulse width of Q1 switch to the pulse width of Q2 switch then accumulated energy and transferred into inductor(L). And also, when DC voltage of an inductor increases, Q2 switch may not be conducted the energy discharged through a reflux diode (D1) and passed to the capacitor. by this reason, the phenomenon of energy sinking may happen if the output of RES is larger than customer loads, while CVCF inverter battery could be rapidly increased according to the condition of SOC and the blackout issues are occurred due to over-voltage protection that causes the shut-down of CVCF inverter at carbon-free island MG system based on the CVCF inverter.



[Fig. 1] Concept of energy sinking in CVCF inverter

3. Operation strategy of transient state CVCF inverter-based MG system

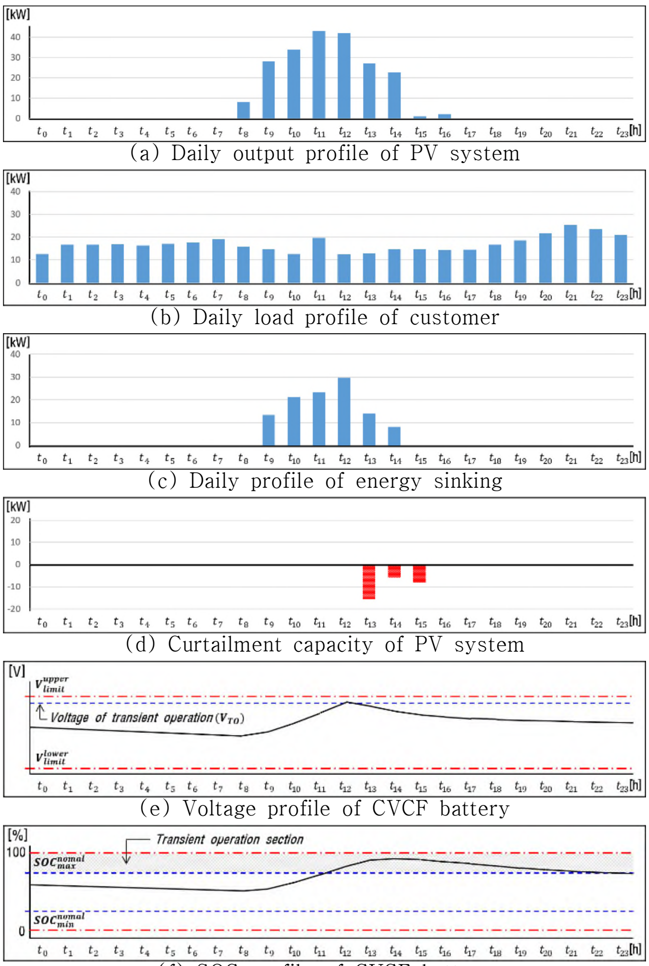
In order to possibly prevent the shut-down of CVCF inverter in advance in case of energy sinking, this paper presents a transient operation strategy of MG system to control a PV system and CVCF inverter. In order words, it is possible to operate MG system in a stable manner if CVCF inverter allows the amount of energy skinking, PV system can be gradually shut-down before a voltage of the battery side violating the allowable range, which is illustrated, as shown in Fig. 2.



[Fig. 2] Configuration of CVCF inverter-based MG system

Furthermore, the detailed proposes for a transient operation state of MG system for the island areas are demonstrated, as shown in Fig. 3. Here, each daily pattern of customer load and the variation of daily output pattern in PV system is illustrated, as shown in (a) and (b) of Fig. 3. And also, the amount of energy sinking is generated if the output of PV system is larger than the load pattern and then PV system may be shut-down due to the transient operation strategy as shown in (c) and (d) of Fig. 3. Furthermore, the operation pattern of CVCF with the characteristics of the time interval of SOC battery, as shown in (e) and (f) of Fig. 3. Where, the time interval at

t_8~t_{12} with high solar radiation, the battery voltage for a CVCF inverter and capacity of energy sinking is generated by the SOC can be rapidly increased. At this time, when the battery voltage violates the operating range (V_{LL}~V_{UL}) of CVCF inverter and the operation of MG system can be immediately stopped due to the over-voltage protection of CVCF inverter. Based on this prevention method, a transient operation state of MG system at t_{12}~t_{15} is indicated as shown in Fig. 3, and it is controlled to reduce an interconnection of PV system or increased the capacity of ESS. Therefore, a large amount of energy sinking that generated from CVCF inverter is being reduced, as shown in (e) and (f) of Fig. 3, while battery voltage and SOC are decreased during the period of time at t_{12}~t_{15} and return back to normal operation.



(a) Daily output profile of PV system

(b) Daily load profile of customer

(c) Daily profile of energy sinking

(d) Curtailment capacity of PV system

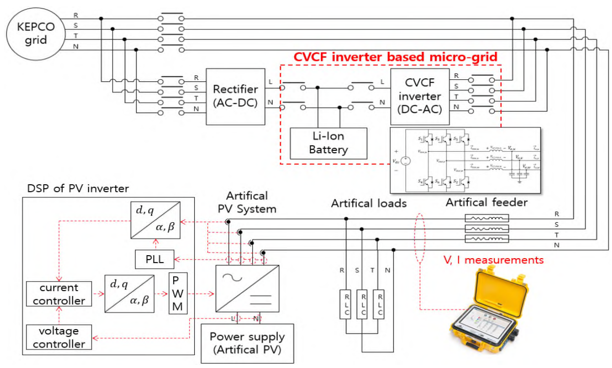
(e) Voltage profile of CVCF battery

(f) SOC profile of CVCF battery

[Fig. 3] Transient operation strategy of CVCF inverter-based MG system

4. Implementation of 30kW MG system based on test devices

In order to maintain a constant voltage and constant frequency of CVCF inverter-based MG system, this paper implements a 30kW scale CVCF inverter-based MG system which is illustrated, as shown in Fig. 4. Here, the entire system is composed of 20[kWh] Li-ion battery, CVCF inverter, 30[kW] artificial customer load, and 20[kW] artificial PV system.



[Fig. 4] Configuration of entire system

5. Case studies

5.1 Test conditions

In order to analyze the transient operation state of 30kW CVCF based MG system, this paper assumes the test conditions and setting point of test devices for each component which are demonstrated, as shown in Table 1. Here, the operating limit of SOC battery in CVCF inverter is 85%, and the operating voltage limit is 131.8[V] which can be calculated at a margin of about 95% at the maximum voltage of an inverter. And also, to generate energy sinking, the load capacity is assumed as 6[kW], the output of PV system is gradually increased from 0[kW] to 18[kW] in units of 3[kW].

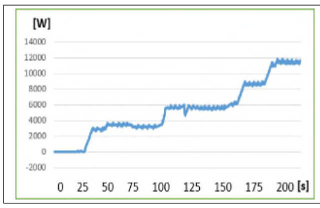
[Table 1] Test conditions of 30kW MG test devices

items		conditions
battery (rack)	cell type	ICR 18650-22F (32S84P)
	range of operation voltage (BMS)	89.6 ~ 134.4[V]
	setting of SOC_M	85[%]
CVCF inverter	range of operation voltage(DC input)	90 ~ 134[V]
	AC output voltage & frequency	$220 \pm 6\%$[V] & 60 ± 0.2[Hz]
	setting of V_M	131.8[V] (η=0.95)
customer load		6 [kW]
PV system		0 ~ 18[kW]

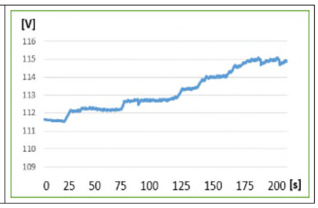
5.2 Characteristics of transient operation state of 30kW scale MG system using test devices

(1) Characteristics within normal operation ranges

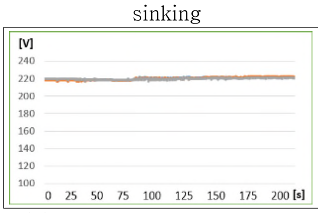
This paper implements a 30kW scale MG system as the test device to analyze the transient operation characteristics of battery CVCF inverter in case of the operating limit of SOC is 50%, which can be illustrated, as shown in Fig. 5. Here, (a) of Fig. 5 represents a magnitude of energy sinking at the specific time, (b) of Fig. 5 shows a voltage of battery CVCF inverter according to the magnitude of energy sinking, (c) and (d) of Fig. 5 are each voltage and frequency of MG system. And also, the magnitude of energy sinking is increased from 0[kW] to 12[kW] in units 3[kW] then the voltage of the battery rises from 111.5[V] to 115.1[V]. However, as the voltage of the battery cannot be violated from the allowable limit of the inverter, it is confirmed that voltage and frequency of MG system are being normally supplied.



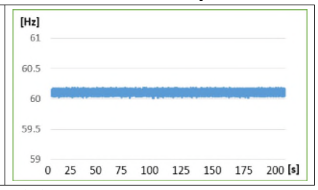
(a) Characteristics of energy sinking



(b) Voltage characteristics of battery



(c) Voltage characteristics of MG system

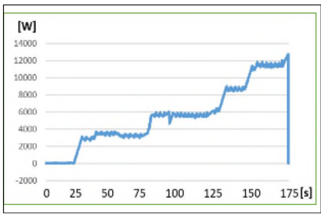


(d) Frequency characteristics of MG system

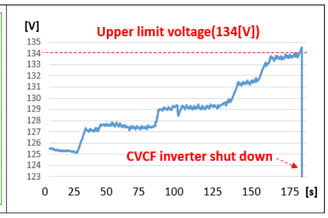
[Fig. 5] Characteristics of transient operation state

(2) Characteristics within transient operation ranges

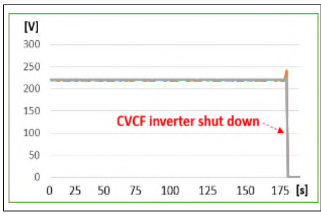
This paper implements a 30kW scale MG system as the test device to analyze transient operation characteristics of battery CVCF inverter in case of operating limit of SOC is 90%, which can be illustrated, as shown in Fig. 6. Here, (a) of Fig. 6 represents a magnitude of energy sinking at the specific time, (b) of Fig. 6 shows a voltage of battery CVCF inverter according to the magnitude of energy sinking, (c) and (d) of Fig. 6 are each voltage and frequency of MG system. And also, if the energy sinking occurs under the same conditions as, the voltage of battery CVCF inverter can be rapidly increased from 125.2[V] to 134.2[V], it is confirmed that the inverter may cause shut-down within the allowable voltage limit of 90 to 134[V].



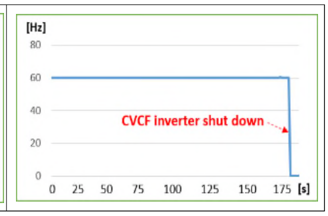
(a) Characteristics of energy sinking



(b) Voltage characteristics of battery



(c) Voltage characteristics of MG system



(d) Frequency characteristics of MG system

[Fig. 6] Characteristics of transient operation state

6. Conclusions

This paper has implemented the test device of 30kW CVCF inverter-based MG system in order to analyzes a transient operation characteristic for the energy sinking phenomenon. And also, this paper performs a transient operation strategy to prevent the shut-down of CVCF inverter in advance when energy sinking has occurred. Furthermore, from the test results based on the proposed operation strategy and 30kW MG test device, it is confirmed that the blackout problems of the CVCF inverter-based MG system can be properly prevented in advance according to conditions of SOC and voltage in CVCF battery.

감사의 글

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References

[1] IEC white paper, “Microgrids for disaster preparedness and recovery with electricity continuity plans systems”, originally published in March, 2014.