Transient Operation Algorithm of CVCF Inverter-based Micro-gird System

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CVCF 인버터기반 마이크로그리드의 과도상태 운용알고리즘

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Abstract

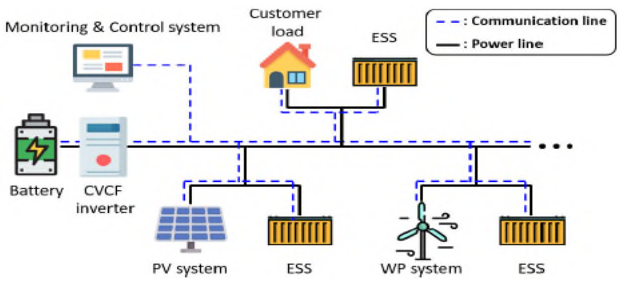
Recently, for the purposes of reducing CO_2(carbon dioxide) emission in the island areas, the countermeasures to operate the power system in a stable manner are being developed due decrease of the operation rate in DG(diesel generators) and the increase of RES(renewable energy sources). However, in the operation of CVCF-inverter based MG system the phenomenon of energy sinking can be observed if the output of RES(renewable energy sources) is greater than customer loads. In this case, the voltage of the battery for CVCF(constant voltage & constant frequency) inverter rapidly increases depending on the SOC(state of charge), and blackout can be occurred due to the shut-down of CVCF inverter. Therefore, in order to overcome these problems, this paper deals with the transient operation algorithm for CVCF inverter-based MG system to prevent the shut-down of inverter during the energy sinking in advance. Based on the proposed algorithm, this paper further performs the modeling of 30kW MG system using PSCAD/EMTDC software. From the simulation results of the proposed modeling and algorithm, it is confirmed that the shut-down of CVCF inverter can be accurately prevented despite the phenomenon of energy sinking.

1. Introduction

These days, the interest of MG system has been taken into account as one of the alternatives to overcome the problems of existing large-scale power systems including hosting capacity of power facilities and locations of large-scale power plants. Such MG system has a small-scale power source such as RES and ESS which can be classified into a stand-alone and grid-connected mode. In particular, an independent MG system that uses diesel generators as the main power source is considered as an effective way to supply power to island areas. Furthermore, for the purpose of reducing CO_2(carbon dioxide) emission in the island areas with an increase of RES, the CVCF inverter-based MG system replacing diesel generator is required and its stable operation methods are also being developed. However, in the operation of CVCF inverter-based MG system, the energy sinking occurs if the output of RES is greater than customer loads. Consequently, the voltage of battery for CVCF inverter rapidly increases depending on the SOC condition, and blackout can be occurred due to the shut-down of CVCF inverter. Therefore, in order to overcome these problems, this paper proposes a transient operation algorithm of CVCF inverter-based MG system in advance of preventing the shut-down of CVCF inverter during the energy sinking. Based on the proposed algorithm, this paper further performs the modeling of 30kW MG system using PSCAD/EMTDC. From the simulation results of the proposed modeling and algorithm, it is confirmed that the shut-down of CVCF inverter can be accurately prevented despite the phenomenon of energy sinking.

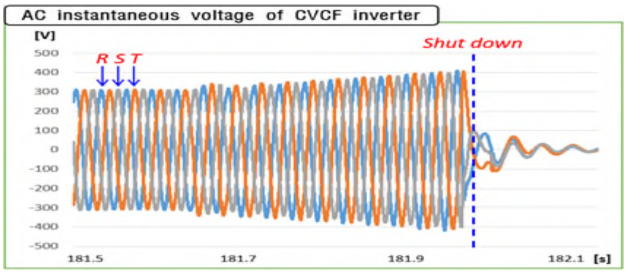
2. Operation characteristics of 30kW CVCF inverter-based MG system

Generally, a CVCF inverter-based MG system is composed of CVCF inverter with battery, RES, ESS, and customer loads which are illustrated in Fig. 1. Here, battery for CVCF inverter, ESS, and RES supply power to customer load, while CVCF inverter contributes to maintaining constant voltage and frequency in independent MG system if the output of customer load is greater than RES.



[Fig. 1] Configuration of CVCF inverter-based MG system

In contrast, the energy sinking that supplies power to the battery for a CVCF inverter might occur if the output of RES is greater than customer loads, and then the voltage of the battery may increase significantly depending on the SOC condition of the battery. As a result, the CVCF inverter might shut down due to the over-voltage protection which may cause a blackout in MG system, as shown in Fig. 2.



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

3. Transient operation algorithm of CVCF inverter-based MG system

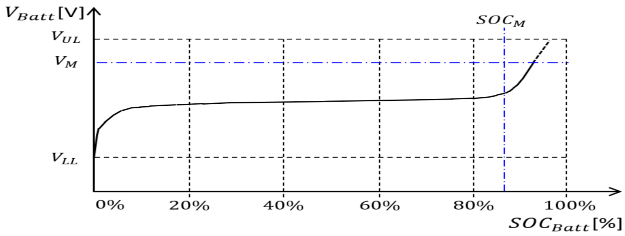
3.1 Operation modeling of transient state

In an independent MG system without any diesel generators, operating conditions of the CVCF inverter for maintaining constant voltage and frequency are expressed in Eqs. (1) and (2).

$$V_{inv}(t) = constant\ V \tag{1}$$

$$f_{inv}(t) = constant\ f \tag{2}$$

where $V_{inv}(t)$: output voltage of inverter: $Constant\ V$: constant voltage, $f_{inv}(t)$: output frequency of inverter: $Constant\ f$: constant frequency. On the other hand, the terminal voltage of the battery increases dramatically when the battery is charged with a constant voltage of approximately 85% of SOC, and the correlation between SOC and voltage of a lithium-ion battery is expressed as shown in Fig. 3.



[Fig. 3] Transient operation strategy of CVCF inverter

Namely, if the SOC is lower than 85% and the energy sinking happens in MG system, voltage at the DC side of CVCF inverter does not change significantly because of CC(charging characteristic), while it might rapidly increase in the case that SOC is higher than 85%. To prevent such problems, the operation limit SOC(SOC_M) is assumed to be 85%, while the operation limit voltage(V_M) of the battery can be calculated by multiplying the maximum voltage of the inverter by the margin factor(η). Therefore, a certain capacity of PV system can be cut-off from MG system when the SOC reaches its operation limit as well as the battery voltage, which caused by energy sinking. The operation limit voltage of the CVCF inverter battery is illustrated, in Eq. (3).

$$V_M = V_{LL} + (V_{UL} - V_{LL}) \times \eta \tag{3}$$

where V_M: operating limit voltage, V_{UL}: (DC) upper limit voltage of CVCF inverter, V_{LL} (DC) lower limit voltage of CVCF inverter and η: margin ratio.

Such cut-off of the PV system should be performed sequentially and the equation for energy sinking $E_S(t)$ appears during the transient state is shown in Eq. 4.

$$E_S(t) = (P_{PV}(t) - P_{PV-cut}(t)) - P_L(t) \tag{4}$$

where $E_S(t)$: the magnitude of energy sinking, $P_{PV}(t)$: total output power of PV system in MG system $P_L(t)$: total customer loads in MG system, $P_{PV-cut}(t)$: cut-off magnitude of PV system.

3.2 Operation algorithm of transient state

Based on the transient operation strategy and proposed operation modeling, the transient operation algorithm of a CVCF inverter-based MG system is demonstrated as follows.

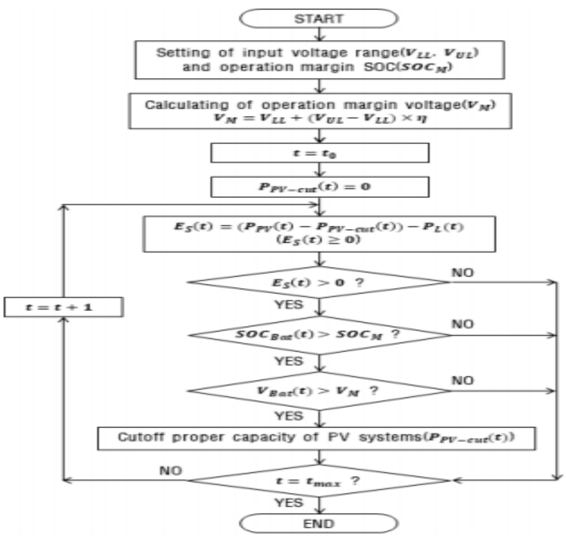
[Step 1] Estimating the operation limit voltage and SOC by taking into account the appropriate margin ratio from the upper limit voltage(V_{UL}) and lower limit voltage(V_{LL}) of the CVCF inverter, as well as the operation time interval of MG system(t) and cut-off magnitude of PV system($P_{PV-cut}(t)$).

[Step 2] Calculating the magnitude of energy sinking($E_S(t)$) by takin into account the time-specific output of PV system($P_{PV}(t)$) and capacity of customer load($P_L(t)$). And then, comparing the operation limit SOC(SOC_M) with the real-time SOC of battery ($SOC_{Bat}(t)$) if the CVCF inverter is confirmed to be in a transient state.

[Step 3] Comparing the operation limit voltage(V_M) with the time-specific voltage of the battery($V_{bat}(t)$) if the real-time SOC of battery($SOC_{Bat}(t)$) is greater than the operation limit SOC (SOC_M) from [Step 2].

[Step 4] Cut-off PV system sequentially as much as the magnitude of energy sinking if the time-specific voltage of the battery($V_{bat}(t)$) is greater than the operation limit voltage(V_M) from [Step 3].

[Step 5] Returning to [Step 2] if none energy sinking nor the violation of operation limit SOC(SOC_M) or voltage(V_M) are observed, and ending the repetition of the process once the time parameter(t) is reached to the maximum time($t_{\max}$). The detailed flow-chart is illustrated as shown in Fig. 4.



[Fig. 4] Transient operation algorithm of CVCF inverter-based MG system

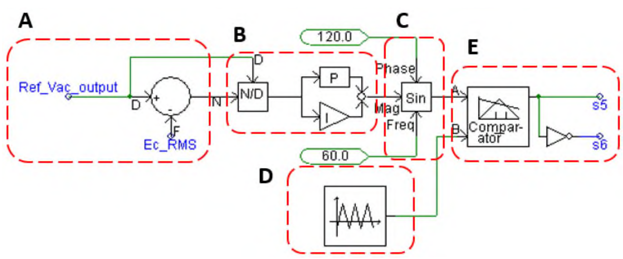
4. Modeling of 30kW MG system using PSCAD/EMTDC

The CVCF inverter is specifically designed to reduce errors of target voltage and accelerate the response characteristics using a PI(proportional-integral) control algorithm, which can be expressed in Eq. (5). Here, the first term of Eq. (5) generates a proportional control signal with the difference between target voltage(V_{ac-ref}) and output voltage ($V(t)$), the second term accumulates errors to obtain an integral control signal to determine waveform, frequency, and phase of target voltage.

$$Wave_{ref} = \left[K_p\left(1 - \frac{V(t)}{V_{ac-ref}}\right) + K_i \int_0^t \left(1 - \frac{V(\tau)}{V_{ac-ref}}\right) d\tau\right] \cdot \sin(2\pi f t + \phi) \tag{5}$$

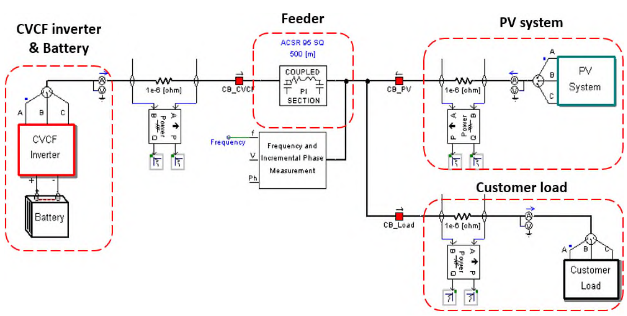
where, $Wave_{ref}(t)$: reference waveform, K_p : proportional factor, K_i: integral coefficient, $V(t)$: output voltage, V_{ref} : target voltage.

Based on the above Eq. (5) to obtain a reference waveform, the modeling of CVCF inverter is performed by using PSCAD/EMTDC, as shown in Fig. 4. Here, section A calculates an error value by comparing target voltage with output voltage, section B is a PI control for each error value, section C determines the waveform, frequency, and phase of target voltage. And also, section D shows an output of carrier to triangular wave, section E indicates a signal of comparator between a reference wave and carrier wave, which is converted into a PWM signal.



[Fig. 4] Modeling of voltage & frequency control in CVCF inverter

Furthermore, this paper performs the modeling of 30kW CVCF inverter-based MG system, which is composed of 30kW CVCF inverter, 20[kWh] Li-ion battery, 20[kW] PV system, 30[kW] customer loads and feeder as illustrated in Fig. 5, in order to maintain a constant voltage and constant frequency.



[Fig. 5] Entire system modeling of 30kW MG system

5. Case studies

5.1 Simulation conditions

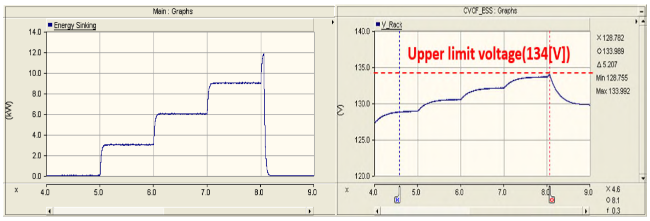
To analyze the transient operation state, this paper assumes a simulation condition as shown in Table 1. Here, the operation limit SOC of battery for CVCF inverter is 85%, and the operation limit voltage is 131.8[V] which is calculated on the margin of approximately 95% of the maximum voltage of CVCF inverter. Also, customer load is assumed as 6[kW] and the output of a PV system is increased from 0[kW] to 18[kW] in steps of 3[kW].

[Table 1] Simulation conditions

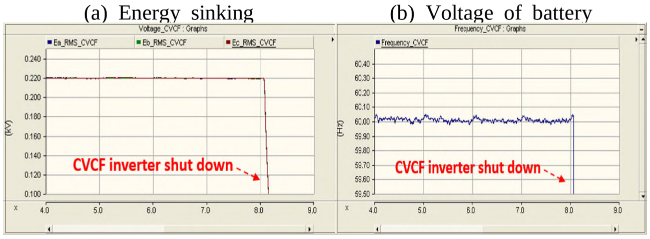
items		conditions
battery (rack)	cell type	ICR 18650-22F (32S84P)
	range of operation voltage (BMS)	89.6 ~ 134.4[V]
	setting of SOC_M	85[%]
CVCF inverter	range of operation voltage(DC input)	90 ~ 134[V]
	rated capacity	30[kW]
	AC output voltage & frequency	$220 \pm 6\%$[V] & 60 ± 0.2[Hz]
	setting of V_M	131.8[V] (η=0.95)
customer load		6 [kW]
PV system		0 ~ 18[kW]

5.2 Characteristics of transient operation state

The operation characteristics of the CVCF inverter when SOC is 90% is shown in Fig. 6, where (a) of Fig. 6 represents a magnitude of time-specific energy sinking, (b) is the voltage of the battery for CVCF inverter depending on the magnitude of energy sinking, (c) and (d) each indicates voltage and frequency of MG system, respectively. when the energy sinking occurs, the voltage of the CVCF inverter is significantly increased from 125.2[V] to 134.2[V]. Consequently, the inverter is shut down because of violating the allowable voltage limit of 134[V].



(a) Energy sinking (b) Voltage of battery

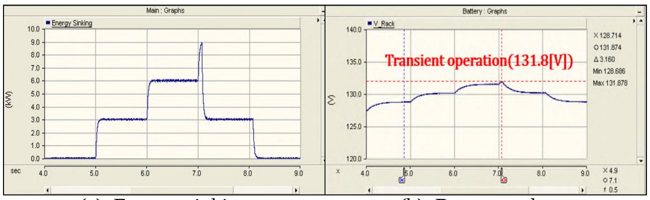


(c) Voltage of MG system (d) Frequency of MG system

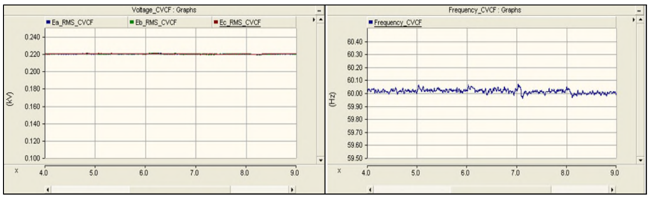
[Fig. 6] Characteristics of transient operation state (Case I)

5.3 Characteristics of transient operation with the proposed algorithm

To overcome the problems of shut-down in CVCF inverter, the operation characteristics of MG system by applying the proposed algorithm are shown in Fig. 7. In case the magnitude of energy sinking is 9[kW], the battery voltage increases from 125.3[V] to 131.8[V]($\eta = 95\%$), when PV system is increased by 3[kW], it is found that the magnitude of energy sinking and voltage of the battery is simultaneously decreased. Therefore, the battery voltage of the inverter does not violate the allowable voltage range(90~134[V]), and then, voltage and frequency of MG system are stably maintained which is confirmed that the proposed algorithm is useful.



(a) Energy sinking (b) Battery voltage



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

[Fig. 7] Transient operation characteristics(Case II)

6. Conclusions

This paper has performed modeling of a 30kW MG system using PSCAD/EMTDC in order to analyze the transient operation state in CVCF inverter-based MG system in advance for preventing the shut-down of CVCF inverter during the energy sinking. From the simulation results of performed modeling of 30kW MG system, it was confirmed that CVCF inverter can be accurately prevented from the shut-down based on the proposed transient operation algorithm in spite of energy sinking.

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References

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