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대용량 연료전지시스템의 계통외란 방지알고리즘에 관한 연구

A Study on the Countermeasure Algorithm for Power System Disturbances in Large Scale Fuel Cell Generation System

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Abstract - Recently, fuel cell generation system with high energy efficiency and low CO2 emission is energetically interconnected with distribution power system. Especially, MCFC(molten carbonate fuel cell) operating at high temperature conditions is commercialized and installed as a form of large scale power generation system. However, it is reported that power system disturbances such as harmonic distortion, surge phenomenon, unbalance current, EMI(Electromagnetic Interference), EMC (Electromagnetic Compatibility) and so on, have caused several problems including malfunction of protection device and damage of control devices in the large scale FCGS(Fuel Cell Generation System). Under these circumstances, this paper proposes countermeasure algorithms to prevent power system disturbances based on the modelling of PSCAD/EMTDC and P-SIM software. From the simulation results, it is confirmed that proposed algorithms are useful method for the stable operation of a large scale FCGS.

Key Words : Fuel cell generation system, Power system disturbances, Unbalance current, Surge, Harmonic, PSCAD/EMTDC, Protection device, Malfunction

1. Introduction

Recently, a large number of renewable power sources have been integrated with power distribution system due to environmental issues related with fossil fuel exhaustion and government incentive policy[1]. Especially, a large-scale fuel cell generation system (FCGS) is energetically interconnected with power system because of high energy efficiency and low CO2 emission. However, during the operation of the large scale FCGS, it is reported that power system disturbances such as harmonic distortion, surge phenomenon, unbalance current and so on, have caused several problems including malfunction of protection device, damage of control device and hunting of control signal [2-4]. Therefore, this paper proposes the countermeasure algorithm to solve the power system disturbances in the operation of FCGS. And also, this paper presents the modeling of large scale FCGS and power system disturbances based on the PSCAD/EMTDC and P-SIM software. From the simulation results, it is confirmed that the proposed algorithm is useful method for the stable operation in large scale FCGS.

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2. General Structure of Large Scale FCGS

Generally, a large scale FCGS consists of dozens of units which is connected to one bus in distribution system as shown in Fig. 1, and then various power system disturbances occurred in a unit may have impacts on neighboring units[5]. During the operation of large scale FCGS, it is reported that several power disturbances such as unbalance current, harmonic, surge, EMI and so on, which are known for severe power quality problems in distribution systems[6].

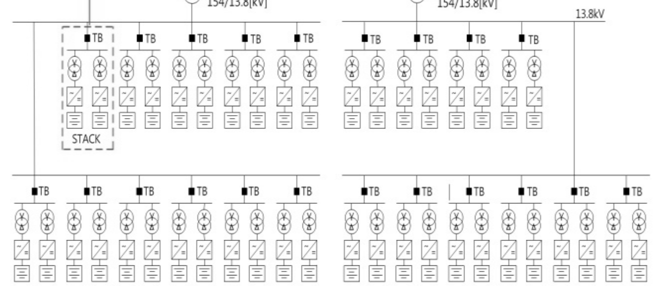

Fig. 1. Basic structure of large scale FCGS

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For example, if one unit of FCGS which is connected to same bus through a tie breaker(TB) as shown in Fig. 1, is tripped due to various types of faults and maintenance works, a TB of neighboring unit may be malfunctioned because the unbalance current resulting from TB operation can violate the setting value of over current ground relay(OCGR) in neighboring TB. Moreover, it is reported that many control devices of units were damaged and malfunctioned by power quality problems such as harmonic, surge, EMI, EMC and so on.

3. Modeling of FCGS and Power System Disturbances

In order to analyze the impacts from power system disturbances to FCGS, this paper proposes modeling of power system disturbances and FCGS based on PSCAD/EMTDC and P-SIM software.

3.1 Modeling of large scale FCGS

This paper presents a modeling of power distribution system and large scale FCGS in abnormal operation of tie breaker(TB) trip condition based on the PSCAD/EMTDC. Fig. 2 shows that FCGS with rated capacity of 2.8[MW] is composed of 2 fuel cells, 2 step up transformers and 2 power conditioning systems. Where, the transformer has a Y-△ winding connection type for 13.8/0.48[kV]. And also, the FCGS is interconnected with power distribution system through a main transformer of Y-Y winding connection type for 154/13.8[kV].

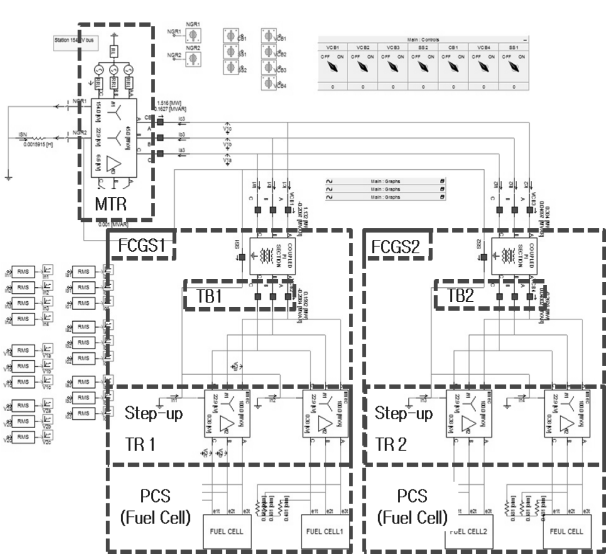


Fig. 2. Modeling of large scale FCGS in distribution system

3.2 Modeling of power system disturbances

This paper performs modeling of power system disturbances such as load unbalance, harmonic and surge in FCGS. In order to decrease unbalance current which could be occurred during the operation of TB trip, the modeling of neutral ground register(NGR) installed at neutral line of step up transformer is expressed as shown in Fig. 3. And also, the modeling of harmonic filter for power supply device(15kW) to reduce the 3th, 5th and 7th harmonic distortions is presented in Fig. 4.

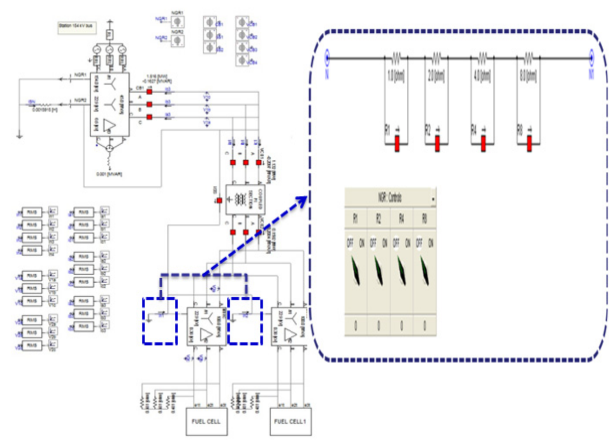


Fig. 3. Modeling of NGR

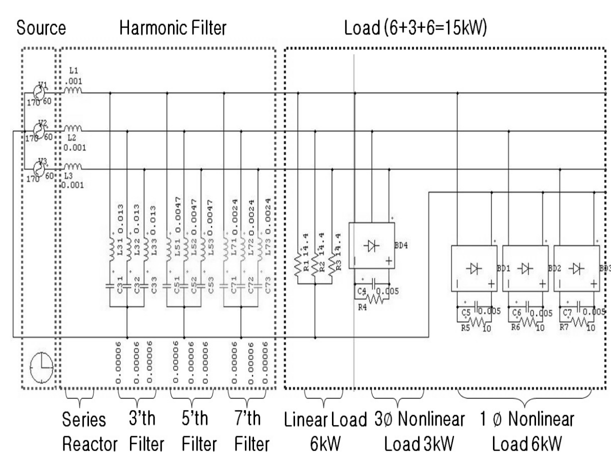


Fig. 4. Modeling of harmonic distortion

In addition, in order to protect control devices of FCGS from surge phenomenon, the modeling of surge protective device(SPD) is presented in Fig. 5. It is composed of surge arrester and R-L-C filters and is characterized by high impedance under a normal condition and low impedance under a surge condition[7].

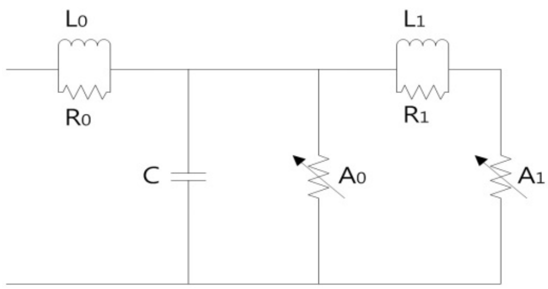


Fig. 5. Modeling of SPD

4. Countermeasure Algorithms for Power System Disturbances

In order to solve power disturbance problems such as protection device malfunction and control device damage, this paper presents several countermeasure algorithms for power system disturbances based on national electric technical guidelines and grid codes[6].

4.1 Operation algorithm of protection device

Main goal of operation algorithm in protection device is to estimate proper NGR capacity to reduce unbalance current. Generally, the ground fault current(I_{1f}) in distribution system interconnected with FCGS can be obtained by symmetrical component method using % impedance map. And also, proper capacity of NGR should be estimated under the conditions of both less than 30% of rated current which is a setting value of protection relay(OCGR) and the effective grounding range[8]. Therefore, NGR operation algorithm can be illustrated as;

[Step 1] Draw a schematic diagram and % impedance map of positive and zero phase for power distribution system interconnected with large scale FCGS.

[Step 2] Calculate a proper capacity of NGR to prevent malfunction of protection device based on the symmetrical component method using % impedance map. Where, the proper NGR capacity to reduce the unbalance current can be obtained by Eq. (1).

$$\frac{3\times 100}{3(Z_0+Z_f)}\times\frac{100[MVA]}{\sqrt{3}\times V[kV]}\le kI_{set} \tag{1}$$

where, Z_0 is zero sequence impedance, Z_f is a NGR capacity, I_{set} is setting value of OCGR, k is weighting factor and V is nominal voltage.

[Step 3] Calculate unbalance current(I_{unb}) under the normal condition.

[Step 4] Compare unbalance current(I_{unb}) with setting value of OCGR, if unbalance current is upper than the setting value, go back to [Step 2] and recalculate proper NGR capacity.

[Step 5] Finally, check if the condition of the effective grounding range and protection coordination with other protection devices are satisfied .

Based on the above algorithm, NGR operation can be illustrated as shown in Fig. 6.

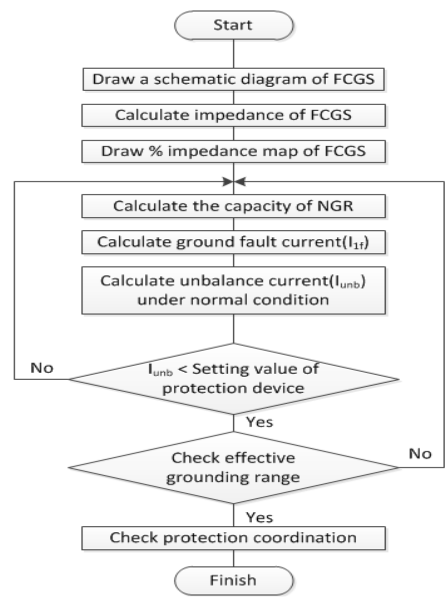


Fig. 6. NGR Operation Algorithm

4.2 Operation algorithm of harmonic filter

In order to keep harmonic distortion within the allowable limit which is less than 3% of fundamental current at each harmonic distortion value, L-C filter should be installed as following procedure[6].

[Step 1] Analyze the harmonic current and harmonic distortion rate.

[Step 2] By comparing each harmonic distortion rate with the allowable limit, if it violates the limit, calculate the proper capacity of harmonic filter to reduce harmonic current. Generally, configuration of harmonic filter is as shown in Fig. 7, and also, L and C components of harmonic filter can be obtained by Eq. (2) and Eq. (3).

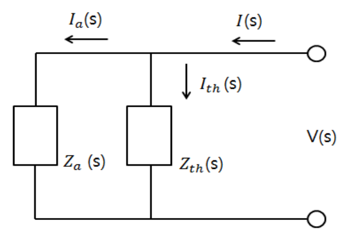


Fig. 7. Equivalent circuit of harmonic filter

$$Z_{th} = R + j(\omega L - \frac{1}{\omega C})[\Omega] \quad (2)$$

$$L = \frac{1}{4\pi^2 f^2 C}[H] \quad (3)$$

where, Z_{th} is impedance of harmonic filter.

[Step 3] Go back to [Step 1] for repeating each distortion rate from I_3 to I_{49}.

Based on the above algorithm, design procedure of harmonic filter can be illustrated as shown in Fig. 8.

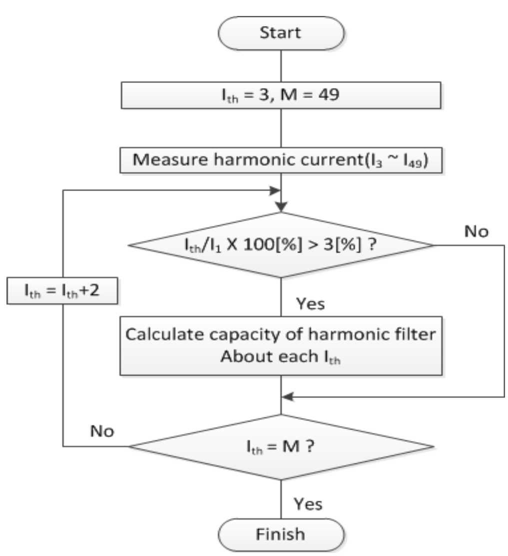


Fig. 8. Design algorithm of harmonic filter

4.3 Operation algorithm of surge protection

SPD of surge protection devices are classified according to energy level depending on the national and international electric technical guidelines. Usually, class I and class III SPDs are to protect high level and low level surge energies, respectively. The optimal level and location of SPD can be selected under conditions of protection and insulation coordination between SPD and other devices. Therefore, SPD operation algorithm can be expressed as following steps.

[Step 1] Select an appropriate SPD type including impulse current(I_{imp}) and nominal discharging current(I_n) depending on the installation place.

[Step 2] Considering the voltage class of installation place and the grounding condition, select the maximum continuous voltage(U_C) which is smaller than the transient over voltage(U_{TOV}) of SPD.

[Step 3] Determine the maximum discharging current($I_{\max}$) which is larger than the nominal discharging current(I_n) of SPD.

[Step 4] Select the voltage protection level(U_P) and the maximum continuous current(I_C), based on the installation environment of SPD as shown in Table 1 [9].

Table 1. Specific parameters of each SPD class

SPD Class	Iimp [kA]	In[kA] (8/20 [us])	Uoc [kV]	Uc[V]	Up[kV] (1.2/50 [us])
Class Ⅰ	5, 10, 20	5, 10, 20	-	110, 130, 230, 240, 420, 440	4, 2.5
Class Ⅱ	-	1, 2, 5, 10, 20	-		2.5, 1.5
Class Ⅲ	-	-	2, 4, 10, 20		1.5

[Step 5] Finally, check the protection and insulation coordination with other protection devices.

Based on the above algorithm, operation strategy of SPD can be illustrated as shown in Fig. 9.

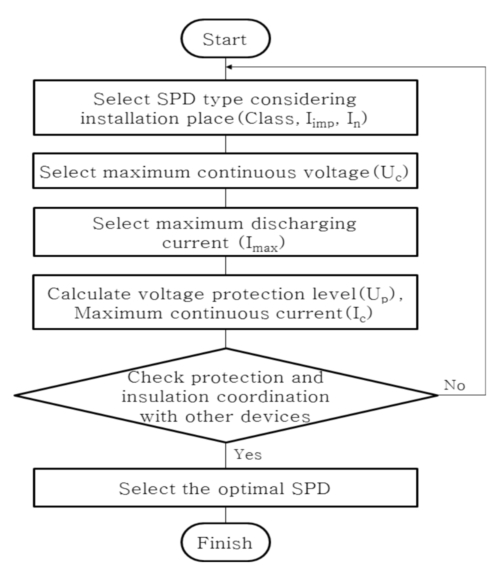
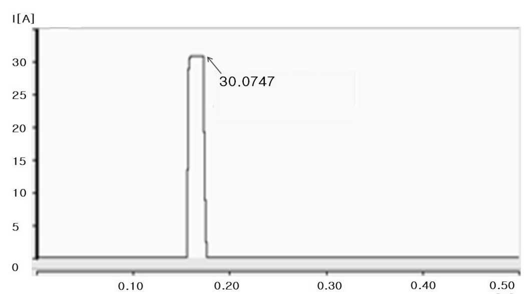


Fig. 9. SPD operation algorithm

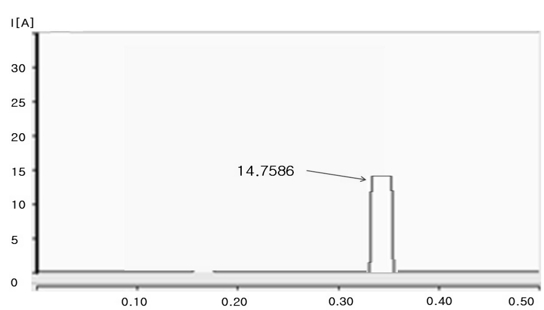
5. Case Studies

5.1 Characteristics of unbalance current

If a TB among units in large scale FCGS is tripped due to various types of faults and maintenance works, the unbalance current resulting from adjacent TB operation may occur as more than 30A as shown in Fig. 10 (a). This value has a possibility to violate the setting value of over current ground relay(OCGR), which can lead to malfunction of OCGR relay. However, if the proper NGR capacity of 0.53[H] obtained by presented NGR operation algorithm is introduced to FCGS, the unbalance current can be reduced to around 15[A] as shown in Fig. 10 (b), which is lower than the OCGR setting value of 30[A]. Therefore, it is confirmed that the presented NGR operation algorithm is useful one for preventing malfunction of protection device in FCGS.



(a) Without NGR

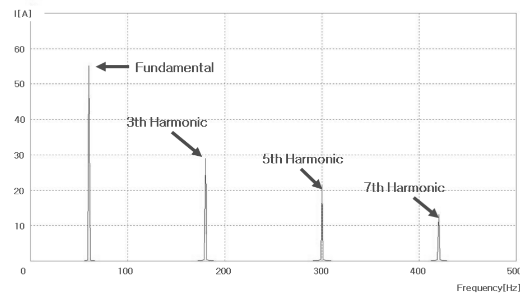


(b) With NGR

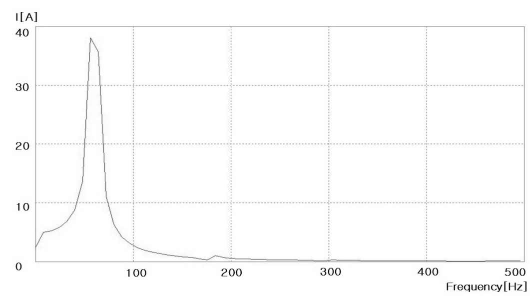
Fig. 10. Unbalance currents using PSCAD/EMTDC software

5.2 Characteristics of harmonic distortion

From the simulation based on the P-SIM software, harmonic distortion rates without L-C harmonic filter violate the allowable limit as shown in Fig. 11 (a). However, after installing L-C harmonic filter designed by the presented algorithm, harmonic distortion rate will be kept within the allowable limit which is normally 3% of fundamental current as shown in Fig. 11 (b). It is confirmed that the presented harmonic filter operation algorithm is practical method to reduce harmonic distortion in FCGS.



(a) Without harmonic filter



(b) With harmonic filter

Fig. 11. Harmonic currents

5.3 Characteristics of surge phenomenon

Based on the above the modeling of surge protective device(SPD) to protect control devices of FCGS from surge phenomenon, this paper performs simulations of surge characteristics by using PSCAD/EMTDC software. If a 2/1 [kA] surge waveform is assumed as power system disturbance, the residual voltages of class I SPD as shown in Fig. 12 are maintained as less than 1,200(V) which is

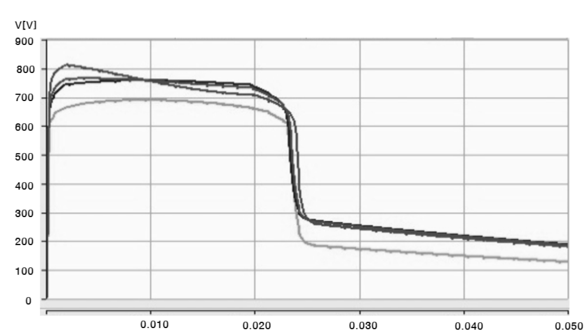


Fig. 12. Residual Voltage with SPD

specified in IEC 61643-1[10]. Therefore, it is confirmed that the presented SPD operation algorithm is valid solution for surge protection in large scale FCGS.

6. Conclusion

This paper proposes the countermeasure algorithm to overcome the power system disturbances such as harmonic distortion, surge phenomenon and unbalance current in FCGS. And also, this paper presents the modeling of large scale FCGS and power system disturbances based on the PSCAD/EMTDC and P-SIM software. Major study results are summarized as follows.

(1) If the proper capacity of NGR obtained by presented NGR operation algorithm is installed at large scale FCGS, the unbalance current can be reduced to reasonable level and malfunction of the OCGR relay can be prevented.
(2) After installing L-C harmonic filter designed by the presented algorithm, harmonic distortion rate can be kept within the allowable limit which is normally 3% of fundamental current.
(3) With the installation of SPD as a surge protection device based on the presented SPD operation algorithm, the residual voltages of SPD can be reduced to international standard(IEC 61643-1) and also surge problems in large scale FCGS can be prevented.

From the simulation results, it is clear that the proposed algorithms are useful tools for the proper operation in large scale FCGS.

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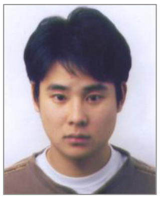

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