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Analysis of Lightning Strike in Offshore Wind Farm

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Abstract
In this paper, the effects of lightning strike based on the 2.5GW offshore wind farm data which planned in South Korea southwest seashore are analyzed by ATPdraw(Alternative Transient Program). The steady state characteristics of the offshore wind farm are presented and then the transient overvoltage from strike point which propagates to nearby turbine and transformer is recorded when the turbine is struck by 15kA lightning stroke. Based on the data of the currently used submarine cables, the lightning strike impact is analyzed in accordance with several values of grounding resistance of wind turbines and surge arresters modeled by MOV(Metal Oxide Varistor) the most efficient protection device.

Keywords
Offshore Wind Farm, Lighting Surge Impact, Transient Voltage, Grounding Resistance

1. INTRODUCTION

Recently, wind power generations become the fastest growing source in the electrical power industry. The latest wind turbines are being designed with longer blades and taller height to satisfy the growing capacity demands which, due to the geographically open space of the wind power generation facilities, are easily exposed to lightning strikes causing frequent overvoltage in wind power generation [1]. Many studies have conducted on the impact of lightning strike on wind farms and on the prevention of the loss of blades, generators, circuit and so on from the strike. On lightning caused turbine overvoltage, grounding methods were analyzed with constant and nonlinear resistance models based on soil ionization [2]. Using the models, lightning surge was analyzed by changing grounding resistance and lightning strike points on the model of wind turbines [3]. In another study, the back flow lightning surge in onshore wind farm was considered of whose wind turbines were connected to the grid in accordance with nonlinear grounding models [4]. As for surge propagation in wind farm, analyzes had been performed for its impact on earth inductivity and resistivity [5].
In case of the offshore wind farms, the generation facilities and elements are more vulnerable to lightning damage because of more severe, unpredictable weather conditions.
This paper reports the analysis of the lighting surge impacts on the 9 wind turbines, 2.5GW offshore wind farm planned in South Korea southwest seashore. The analysis focuses on the 15kA amplitude lightning surge on the fourth wind turbine and its effects on transmission lines and transformers in accordance with grounding resistance of the wind turbine and surge arrester. In addition, sensitivity analyses are performed in seeking minimization of the lightning impact on the offshore wind farm.

2. SYSTEM CONFIGURATION

2.1 Offshore Wind Farm

The configuration of the planned 2.5 GW offshore wind farm is shown in Fig. 1. The wind farm is composed of nine wind turbines placed in different distances as indicated in the figure, which are all electrically connected ("internal network") via submarine transmission cable to a step-up transformer. Also an offshore substation to be 154 kV HVAC connected to an onshore substation ("external network") via submarine cable is included in the system.

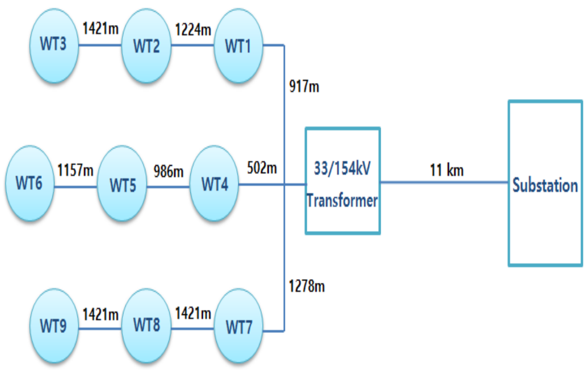

Fig. 1 Configuration of Offshore Wind Farm

2.2 Submarine Cable

According to the plan for the 2.5 GW wind farm, the submarine cables of transmission line are made up of 33kV internal network cables for connecting wind turbines to the offshore substation and 154kV external network cables for connecting the offshore substation to an onshore substation. Internal network cables consist of three 33kV nominal cross section areas of 70mm^2, 185mm^2 and 400mm^2 cables. On the other hand, the external network cables are of 154kV nominal cross section area 500mm^2. Fig. 2 represents one phase conductor of submarine cable, and the cable impedance and thickness data on the four different cross section areas for internal and external transmission lines are tabulated in Table 1. It is node that the 154kV HVAC submarine cable of external network includes one additional core in addition to the three cores for electric transmission. The submarine cables are planned to be grounded in seawater and the metal sheath be grounded in leading-in parts [6].

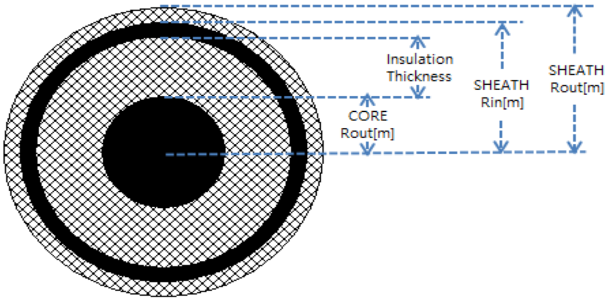

Fig. 2 One Phase Conductor of Submarine Cable

Table 1 Submarine Cable Data

	$70mm^2$	$185mm^2$	$400mm^2$	$500mm^2$
CORE Rout[m]	0.0047	0.00767	0.01128	0.01515
SHEATH Rin[m]	0.0159	0.01947	0.02318	0.03295
SHEATH Rout[m]	0.0181	0.02197	0.02588	0.03745
R[Ω/km]	0.344	0.13	0.064	0.056
X[Ω/km]	0.172	0.148	0.132	0.151
C[μF/km]	0.117	0.16	0.209	0.141

2.3 Surge Arrester

Surge arresters play an important role in lightning overvoltage relief in power generation and transmission system [7]. In this study, MOV(Metal Oxide Varistor)-type arrester is considered as protective devices against lightning overvoltage[8]. The MOV arresters made of zinc oxide blocks have long been used in overvoltage suppression circuits in various voltage and current ranges.

2.4 Lightning Stroke

Lightning stroke is constructed using Surge Type 15 Source element of ATP/EMTP. As an example, a lightning stroke with a magnitude of 15kA and duration of 0.5ms is formed and depicted in Fig. 3. The exponential surge function is given by equation (1). The constants for the strike for Fig. 3 are tabulated in Table 2.

$$\mathrm{f(t)} = \mathrm{Amplitude} \times (exp^{At} - exp^{Bt}) \qquad (1)$$

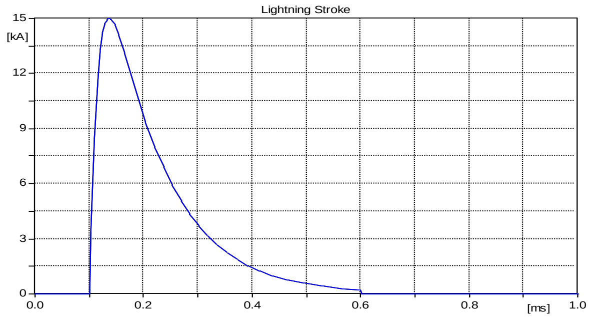

Fig. 3 Lightning Stroke – 15kA for 0.5ms

Table 2 Surge Type 15 Surge Function Values

Constant	Value
Amplitude	25200
A	-9500
B	-60000
T start	0.0001
T stop	0.0006

3. SIMULATION RESULT

The simulation results consist of the analysis of the steady state and transient state of the offshore wind farm when the WT4 is struck by 15kA magnitude lightning strike.

3.1 Steady State

Table 3 represents the steady state maximum voltage of internal and external network. About 5.64kV voltage flows in each wind turbine and primary circuit of offshore substation transformer and about 126.2kV voltage flows between onshore substation and secondary circuit of offshore substation. The current of internal network and MOV surge arrester are presented in Fig. 4 and Fig. 5. In the steady state, the current flowing through the MOV is 0.12mA and it is very small compared to 1A of the line current. Since the MOV surge arrester operates only when an overvoltage exceeds the limited voltage, no current flows at MOV in steady state.

Table 3 Steady State Voltage of Offshore Wind Farm

	Maximum voltage [kV]
Internal Network	26.95
External Network	125.8

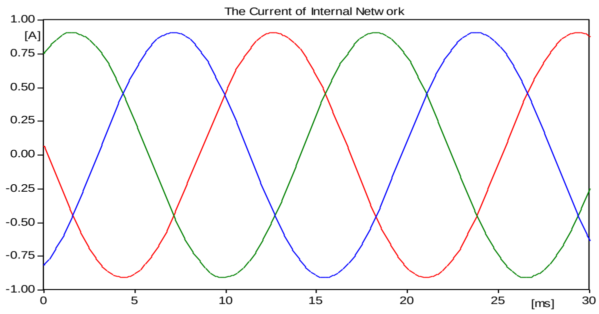

Fig. 4 Current of Internal Network – Steady State

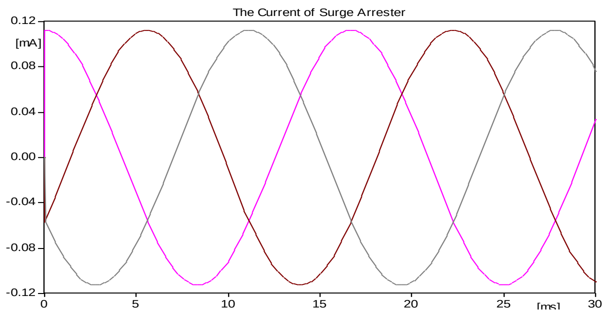

Fig. 5 Current of Surge Arrester – Steady State

3.2 Transient State under lightning strike

The transient overvoltage and current data of lightning strike point and nearby turbine are presented in Fig. 6, Fig. 7 and Fig. 8. Approximately 50% of lightning current flows through grounding system of the wind turbine and about 7kA of lightning current flows through the network circuit when the WT4 located in 502m away from the offshore substation is struck by lightning. If the surge arrester is not operating, about 7.2MV transient overvoltage is imposed to the strike point and about 5.4MV transient overvoltage in nearby turbine located in 986m away from the strike point.

In case of offshore substation transformer, about 43MV lightning overvoltage is registered in the secondary circuit. This means that it is possible to provide much larger impact on the network circuit when lightning impulse flows through the secondary circuit of the offshore transformer.

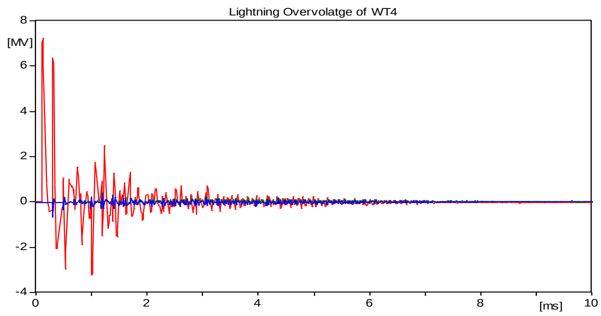

Fig. 6 Lightning Overvoltage of WT4

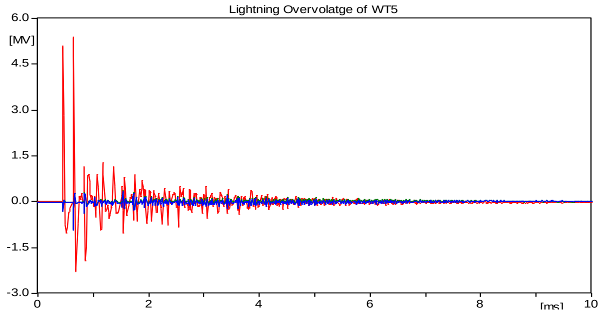

Fig. 7 Lightning Overvoltage of WT5

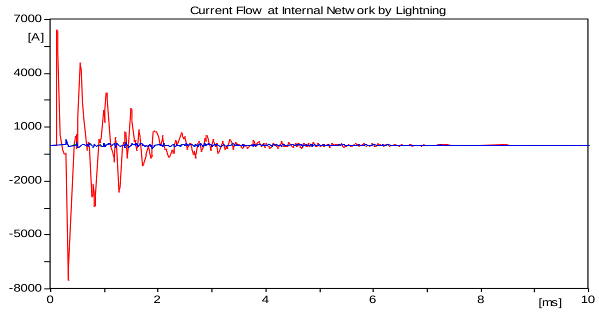

Fig. 8 Lightning Current at Internal Network

Table 4 presents the lightning overvoltage in accordance with various grounding resistance of the wind turbine. It shows that increased grounding resistance of wind turbines increases both internal and external network overvoltage, which advocates as low ground resistance as practically possible for the wind turbines.

Table 4 Transient Overvoltage of wind farm

	WT4 [MV]	WT5 [MV]	WT6 [MV]	External Network [MV]
1Ω	7.16	5.35	2.84	42.5
2Ω	7.18	5.38	2.87	42.6
5Ω	7.24	5.45	2.92	42.8
10Ω	7.3	5.5	2.98	43

The transient overvoltage data of lightning strike point and nearby turbine while MOV arresters are operating are presented in Fig. 9 and Fig. 10. It can be seen that, if ground resistance is same with normal conditions, the 7.24MV lightning overvoltage of the WT4 is now decreased to 124.42kV. Also, the 5.45MV lightning overvoltage of the WT5 is decreased to 81.2kV. Fig. 11 presents the current flow along MOV surge arrester when WT4 is struck by lightning. If the transient overvoltage exceeds the arrester rated voltage, the current flows through MOV surge arrester.

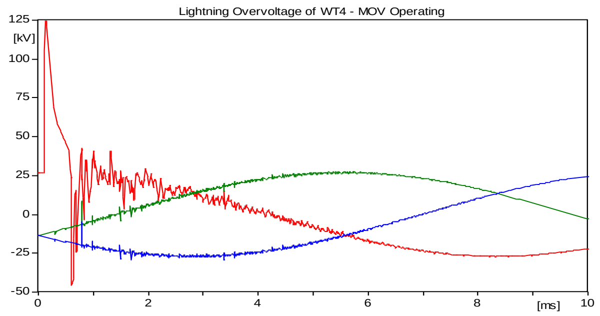

Fig. 9 Lightning Overvoltage of WT4

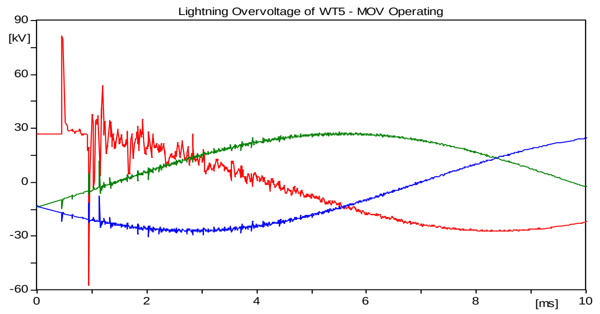

Fig. 10 Lightning Overvoltage of WT5

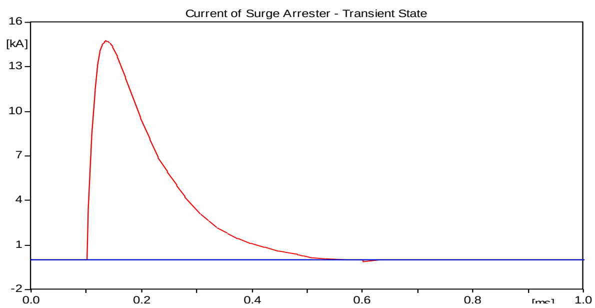

Fig. 11 Current of Surge Arrester – Transient State

Table 5 presents the lightning overvoltage of internal and external network in accordance with grounding resistance of the surge arrester. The protective effect of the surge arrester is decreased when arrester grounding resistance is increased.

Table 5 Transient Overvoltage of wind farm

	WT4 [kV]	WT5 [kV]	WT6 [kV]	External Network [kV]
5Ω	124.42	81.2	26.9	201.7
10Ω	196.6	119.8	27	215.7
15Ω	267.2	158.4	27.1	229.7

4. CONCLUSION

The effects of lightning strike based on the 2.5GW offshore wind farm data which planned in South Korea southwest seashore are analyzed in this study. When wind turbine is struck by lightning, the overvoltage of internal and external network are considerably higher than normal condition and it is significantly reduced when surge arrester is operating. However, depending on the magnitude of the grounding resistance of the wind turbine and surge arrester, the lightning overvoltage is greatly affected. Consequently, Ground resistance value of the wind turbine and surge arrester is required to be designed as low as possible. In case of surge arrester, even if the limited voltage is low, the protective effect is decreased due to higher grounding resistance.

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