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Lightning Strike Impacts on Hybrid Photovoltaic-Wind System

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Abstract

Study the impacts of lightning-induced transient overvoltage on a hybrid PV-Wind system has been addressed in this work. Overvoltage that is generated due to lightning stroke travels along the system where it can be very harmful to the expensive equipment of the system such as PV models, inverters, charge controllers, batteries, transformers, and generator etc. The simulation model of a system has been completed by using PSCAD/EMTDC software. The system comprises of 2 MW PV farm, battery system, 2.1 MW wind farm and loads which are all connected to the common AC bus and then to the utility grid through an interfacing transformer. Lightning current is generated by using the double exponential function, from the simulation results, when the lightning current is injected to the AC and DC sides of PV system, the transient current and voltage have appeared at different points of the hybrid system. The results were obtained for 8/20 μs and 10/350 μs standards lightning waveforms with current magnitude of 100 kA.

Keywords: *Hybrid PV-Wind system modeling, Lightning, Transient impact, Overvoltage, Overcurrent*

1. Introduction

Renewable energy based on hybrid systems such as a combined generation of wind turbine and PV power has become more popular due to some significant factors like clean and pollution free, absence of fuel costs, security supply of electricity to clienteles, increased power reliability and availability, liberalization of the electricity market and grid support [1]. The hybrid system can also provide constant power supply and overcome the discontinuous issue in output power in standalone renewable energy source caused by natural factors. The hybrid PV-Wind system, however, has some issues, particularly those associated to transient overvoltage and current caused by direct or indirect lightning stroke, this is due to their expanded surface in wide-open areas and installation position. Lightning is a high impulsive electrostatic discharge generated during a thunderstorm that considers very complex physics which is not fully understood [2].

The transient current and voltage resulted from lightning stroke travel across the system, which can damage equipment and component specs such as (insulators, inverters, energy storage system, transformers, generator, etc.) [3]. In the previews works, several studies have been done on the effects of lightning strokes on the PV and wind turbine systems either experimentally by performing (laboratory or field measurement) [4-6] or theoretically by using appropriate (simulation tools) [7-10]. In this work, lightning effects on the grid-connected hybrid PV-Wind system will be investigated to find the transient overvoltage and current peak values, energy dissipation. These obtained parameters from the simulation can be used to design the lightning protection measure that is suitable to protect the hybrid system.

2. Modelling of the System in PSCAD

The 4.1 MW hybrid PV-Wind system design is completed by using PSCAD/EMTDC software. It consists of 2 MW PV farm, battery system, 2.1 MW wind farm and RLC load, the whole system connected to the grid through interfacing transformer. The transformer provides electrical isolation between the grid and hybrid system and raises the voltage from 0.480 kV to 33 kV; the system is operated at a frequency of 60 Hz.

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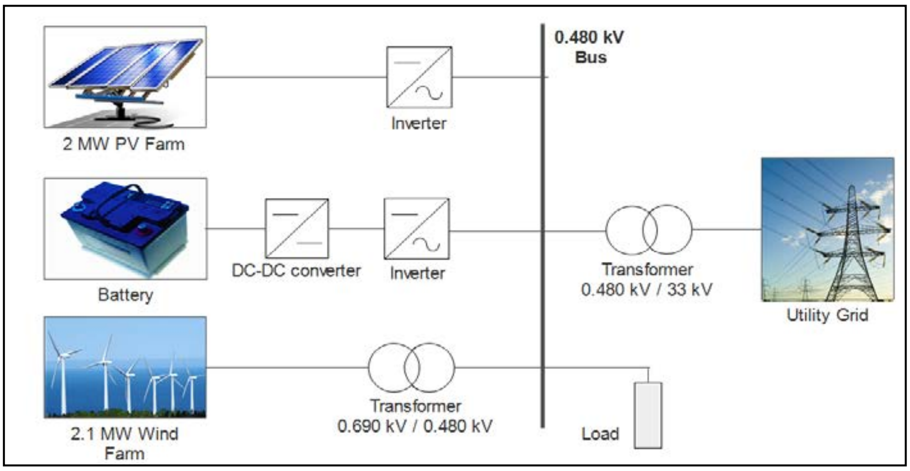

Figure 1. Hybrid PV-Wind system

2.1 PV Farm Model

PV is a type of renewable energy which is a term that converts the sunlight to electrical power by the solar cell; it's made up of boron-doped (P-type) silicon and phosphorus-doped (N-type) silicon called the P-N junction. Solar cells can produce electrical energy as long as there is sunlight [11-12]. In this work five units of PV system were modeled to produce of 2MW output power, each unit contains 4730 modules. The produced DC power of each unit is converted to AC power by using a voltage source inverter (VSI). The inverter is a three-phase configuration which comprises of six IGBT switches, 7800 μF dc-link capacitor, LCL filter, and control system to generate firing pulses for the switches.

The inverter control system was implemented by using current control technique, it depends on the Clarke and Park transformations, the grid voltage and currents are transformed from stationary reference (ABC) coordinates into a synchronous reference frame (DQ) coordinate, to obtain the required phase angle for ABC-DQ transformation a phase-locked loop (PLL) algorithm was used. After that the output of inverter regulated by using a proportional-integral (PI) controller. The coordinate DQ axis of the reference voltage is converted back to the voltage reference in the ABC axis using the Inverse Park Transformation. These produced voltage references are used to generate the gate pulses for the switching device (IGBTs) with the help of pulse width modulation (PWM) technique [13-15].

2.2 Wind Farm Model

The wind farm is modelled with rated capacity 2.1 MW using fixed-speed wind turbine connected to induction generator [16-17], the generator works to convert the mechanical power of the rotor into electrical power. Models related to wind energy, including a wind source model, wind turbine, generator, and governors are provided by PSCAD library. The rated voltage of the wind farm is set at 690 V. The output of a wind farm was connected to a step-down transformer rated at 0.690 kV/0.480 kV and then to a common bus.

Table 1. The parameters of wind farm

Wind Turbine and Induction Generator	Specifications
Turbine & generator rated power	2.1 [MVA]
Rotor blade radius (r)	40 m
Rotor area	5026 m2
Air density (ρ)	1.23 kg/m3
Wind speed (υ)	12 m/s
Mechanical speed of wind turbine [rad/s]	314
Power coefficient (Cp)	0.4 m
Operating frequency of the system (F)	60 Hz

The following Equations describe the output power of wind turbine [18]:

$$A = \pi r^2 \tag{1}$$

$$A = \pi \times 40^2$$
$$= 5026 m^2$$

$$P = \frac{1}{2}\rho A v^3 C_p \tag{2}$$

$$P = \frac{1}{2} \times 1.23 \times 5026 \times 12^3 \times 0.4$$

$$P = 2.13\ MW$$

2.3 Lightning Stroke Module

Two lightning currents have been modeled by using double exponential function in this work as it is given in formula;

$$I(t) = kI_0\,(e^{-\alpha t} - e^{-\beta t}) \tag{3}$$

Where I_0 is surge current magnitude, k is correction factor, α and β are exponential constants that need to be found to derive decay time and rise time of the lightning current impulse waveform [19-20]. The design of the lightning model is shown in Figure 2.

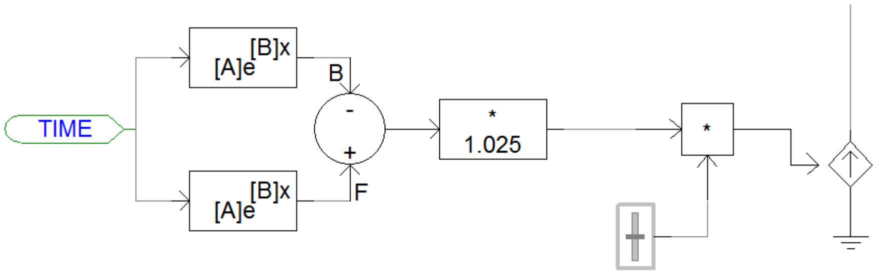

Figure 2. Lightning current model in PSCAD

Two different lightning impulse waveforms 8/20 μs and 10/350 μs with peak current 100 kA have been injected into the system in two different simulation cases.

3. Results and Discussions

To study the effect of transient overvoltage caused by direct lightning stroke the PSCAD/EMTDC simulation design of the 4.1 MW hybrid systems is done and the results were obtained under normal operation without injection of lightning current as shown in Figures 3-5. Then, different lightning strokes were injected to different points of the system (AC and DC) sides of the PV farm to establish the overvoltage (see Figure 6).

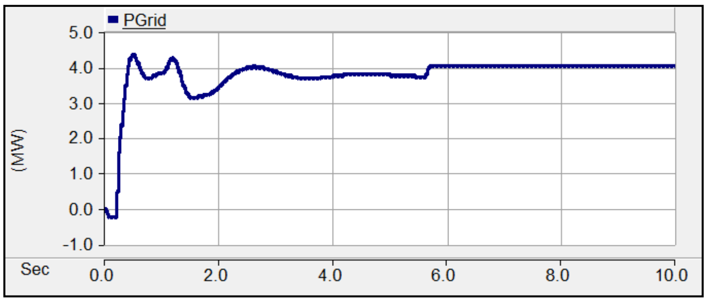

Figure 3. Output power of the hybrid system

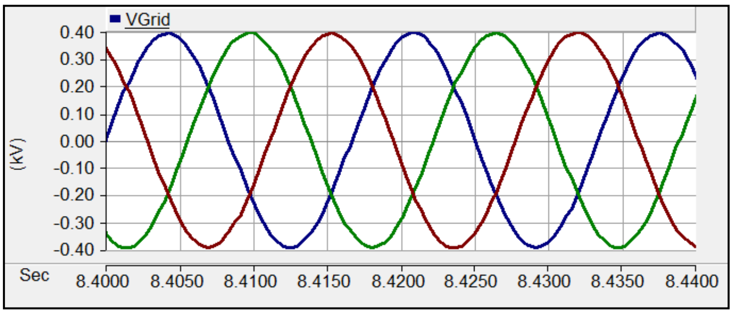

Figure 4. Output voltage of the hybrid system

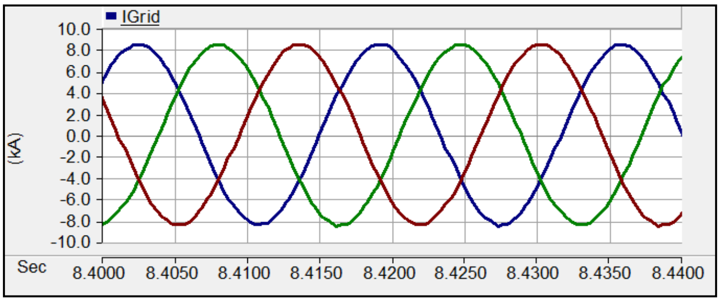

Figure 5. Output current of the hybrid system

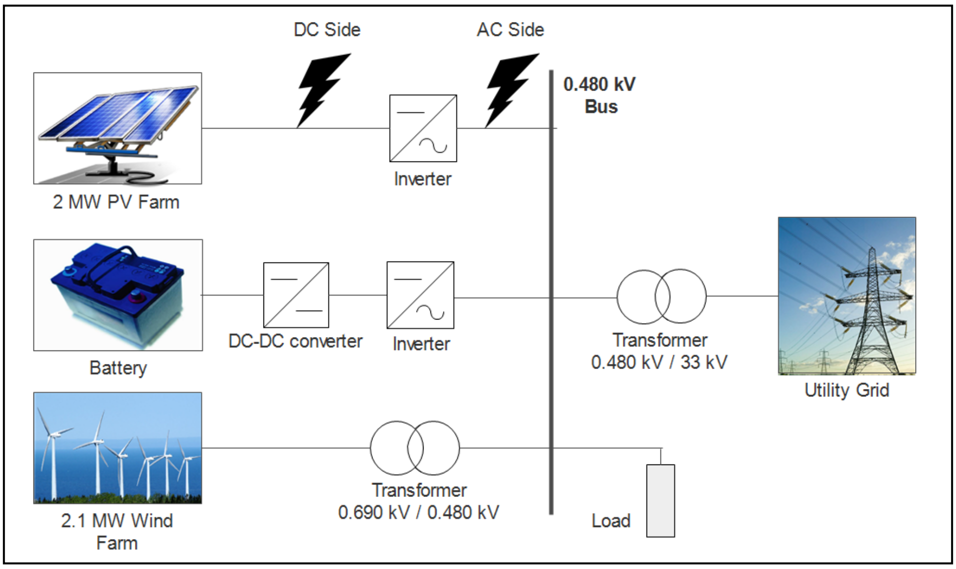

Figure 6. Lightning striking points at the system

Case 1: 8/20 μs, 100 kA lightning current waveform [21] with a single initial peak (see Figure 7) was injected into PV system at the both sides of the inverter (DC and AC) separately. Firstly, the lightning surge current was injected at the DC side which is between DC link capacitor and PV array. Secondly, the lightning surge was injected to the AC side of PV inverter, the results of the transient current and voltage due to 100 kA lightning current is shown in Tables 2 when no surge arresters are used for protection.

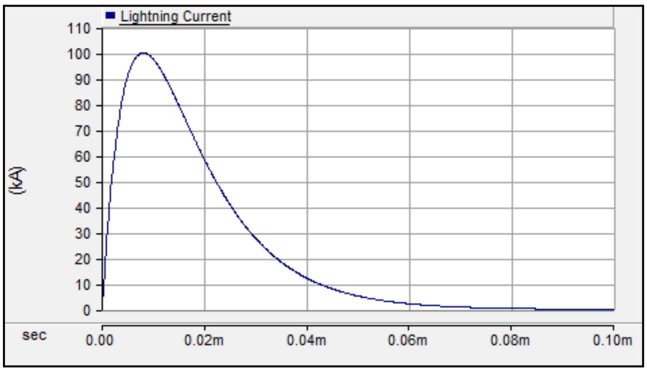

Figure 7. The 8/20 μs, 100 kA lightning impulse waveform

Table 2. transient current and voltage due to $8/20\ \mu s, 100\ kA$ lightning surge

Lightning at DC side of the PV inverter											
I & V at PV System				I & V at Wind System		I & V at Battery		I & V at Load		I & V at Grid Side	
DC		AC		AC		AC	AC	AC		AC	
I (kA)	V (kV)	I (kA)	V (kV)	I (kA)	V (kV)	I (kA)	V (kV)	I (kA)	V (kV)	I (kA)	V (kV)
100.5	0.231	33.33	5.63	-1.21	8.85	0	5.63	0.0013	5.63	33.60	5.63
Lightning at AC side of the PV inverter											
66.65	0.244	33.33	5.63	-1.21	8.85	0	5.63	0.0013	5.63	33.60	5.63

Case 2: the same simulations of the first case ware repeated but with 10/350 μs, 100 kA lightning current, Table 3 shows transient current and voltage for this case.

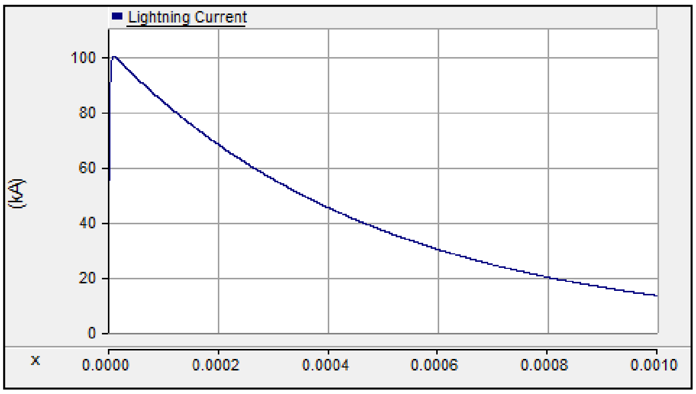

Figure 8. The 10/350 μs, 100 kA lightning impulse waveform

Table 3. transient current and voltage due to $10/350\ \mu s, 100\ kA$ lightning surge

Lightning at DC side of the PV inverter											
I & V at PV System				I & V at Wind System		I & V at Battery		I & V at Load		I & V at Grid Side	
DC		AC		AC		AC	AC	AC		AC	
I (kA)	V (kV)	I (kA)	V (kV)	I (kA)	V (kV)	I (kA)	V (kV)	I (kA)	V (kV)	I (kA)	V (kV)
100.54	3.4	33.35	7.65	0.61	11.96	0	7.65	0.016	7.65	33.45	7.65
Lightning at AC side of the PV inverter											
66.69	2.4	33.35	7.65	0.62	11.96	0	7.65	0.016	7.65	33.45	7.65

From the results which are shown in the Tables 1 and 2, an extremely high transient current and voltage were observed for both simulation cases when the lightning current was injected to DC and AC sides of PV inverter. The maximum overvoltage's value (Vmax) that is appeared on the system is 11.96 kV for the second simulation case while the value of Vmax is 8.85 kV for the first case. The maximum value of transient current is 100.54 kA for DC side and 33.35 kA for AC side which is the nearest point to the lightning strike. These transient current travel to the grid side through an inverter and propagates overvoltage in the hybrid system; serious damage might be caused to the equipment such (inverters, converters, transformers, insulators and connected loads in the hybrid system due to this large overvoltage, this depends on impulse withstand voltage of each equipment. These vital results are required to select SPDs with a most suitable rating for lightning protection of hybrid system equipment as the selection of SPDs to depend on threat level (Vmax), waveform rise time, maximum energy and impulse withstand voltage.

4. Conclusion

The effect of lightning was investigated on the 4.1 MW hybrid PV-Wind system by using PSCAD/EMTDC software. The results were obtained for two different waveforms of lightning surge currents that were injected to various points of the hybrid system in separate simulation cases. The investigation of lightning impact has been performed for the 8/20 µs and 10/350 µs lightning impulses. The system becomes unhealthy due to a transient overvoltage and current that appears when a high impulse lightning struck the system. According to the simulation results, the peak value of transient current observed at the nearest point to the stroke. This information is important to select a suitable lightning protective device with the most appropriate ratings for the hybrid system's equipment/ component specs.

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