

## Harmonic Distortion Improving of Insulator String Model by Nonlinear Resistive under Polluted Condition

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**Abstract:** Designing of power distribution system must be simulated the flashover occurring in any case. To flashover prediction by leakage current observing, the harmonic distortion of current waveform is one factor that be considered. This study focused on insulator model improving to inclusive of harmonic distortion of leakage current in different pollution level by nonlinear resistive from arcing gap model as structure of insulator. So, the aimed to compare to the results of the primitive model and the nonlinear model that can be applied from arc characteristics divided in two parts. The part of measurement include resistance collecting and voltage current relating of insulators which were treated in different pollution levels as to very light, light, moderate and heavy pollution by different NaCl addition through soaking. The part of simulation of a string insulator with 6 series insulator by both of model. The model including nonlinear resistive can significantly generated more harmonic in order 3rd and 5th where higher pollution level different from primitive model. However, the model must be developed to generate more harmonic distortion.

**Key words:** Insulator model, harmonic order, nonlinear model, ESDD, high voltage, current

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### INTRODUCTION

The electrical energy of the electricity is considered as necessary resources in daily life. The system must reduce the flashover for the high efficiency and stability of transmission system. There are many factors why loss on high voltage system are occurring and also more and more researches have been conducted searching for the causes and ways to fix the problem. One of the factors that affect the flashover on high voltage system is the leakage current at insulators. In the transmission system there is insulator installation between conductor and tower to prevent the current flow from the conductor to ground. If there is a leakage current with the voltage across the insulator there has not only a deterioration on the insulator and the flashover across it but also power loss at the insulator. The flashover that could be affected by a power that has been insufficient to distribution may result into the state's black out. To predict flashover of insulator there are more researches about behaviour of leakage current before the flashover occurring. Some results found harmonic distortion of the leakage current increasing affect to flashover. Normally, the insulators have a very high resistance and a lower leakage of current. However, if the insulator is located outdoor, the insulator has been stained by various conductive pollution such as dust, soil or rain. The leakage current is higher with the more pollution stains the insulator (Mekhaldi *et al.*, 1999; Siderakis *et al.*, 2004). Noticeably

there have been more studies conducted Suwarno and (Pakpahan, 2006) to model the leakage current of insulator to further predict the waveform of leakage current in different pollution levels. Generally, the high voltage insulator can be replaced by circuit model including normal resistor and capacitor but the current waveform from this model does not include frequency distortion that is necessary to flashover prediction (Ramirez *et al.*, 2012; Venkataraman and Gorur, 2006). Some researchers noted that the pollution on the insulator has the characteristic as arc gap (Hampton, 1964; Obenaus, 1960). In arcing model, the gap would be replaced by nonlinear resistance (Pakpahan, 2006). With the aforesaid observations, the researchers are interested to focus on the application of the nonlinear arc model to high voltage insulator model to improve the harmonic distortion of leakage current waveform. Comparison the model of insulator between the normal model and nonlinear model through experiments and simulations.

**Flashover prediction:** There are more technique of predict the flashover. One of general technique is prediction by leakage current harmonic distortion. The frequency spectrum of the leakage current it can be noted that the fundamental components are the only significant portion of the frequency characteristics during early aging. As the resistive currents starts to develop, the 3rd harmonics will have the highest intensity among other harmonic components. When local arcs start to appear

other odd harmonics will grow rapidly and become more significant. The 3rd and 5th harmonics have a higher rate of increase compared to the fundamental component during dry band arcing. However with increased degradation due to nearly the flashover occurring. Harmonic contents will decrease, while the fundamental component increases. Therefore, the 3rd and 5th harmonic content can indicate the start of dry band arcing.

**MATERIALS AND METHODS**

**Insulator model**

**Primitive insulator model:** The circuit diagram for high voltage insulator is replaced by capacitance with a very high resistance parameter by structure of insulator consists of metal parts as cap and pin. The insulator resistance is normally high about 4-8 GΩ. So, the diagram can be only instead by capacitor (Fig. 1).

In distribution system with high voltage, the corona is inevitable cause of wet pollution on insulator’s surface. The pollution with moisture on insulator with high across voltage cause the corona. This phenomena will depend leakage current as resistance reducing. The circuit diagram of high voltage insulator with the pollution can be represented by a capacitor which is parallel with a resistor (Lloydand and Schneider, 1982; Looms, 1988; Mekhaldi *et al.*, 1999). Range of the resistance is about 40-80 MΩ.

**Nonlinear insulator model:** The space of metallic structure in high voltage are compared as arcing gap. Cap and pin of insulator structure that be metallic in the pollution condition can be represented as arcing gaps with nonlinear characteristic. By this characteristic, the resistance of insulator is represent by nonlinear resistor with voltage increasing that shown in Fig. 2. The relation of voltage and current are different in each of pollution level and pollution type.

**Pollution:** The pollution on a surface of insulators is generally non-conducting but the moisture intermittently renders conductive which produces much of the soluble contamination of the pollution on a surface. The conductivity of the resulting thin conductive layer depends on the amount of moisture as well as the chemical composition of the contaminant. The level of severity (degree) of the pollution is characterized by the Equivalent Salt Deposit Density (ESDD). The density of ESDD equals an amount of sodium chloride which solved in water, will change water’s conductivity to the level equal to that resulting from the solution of polluted deposits gathered from insulator surface divided by the

insulator’s surface area mg/cm<sup>2</sup>. Equivalent salt deposit density is measured by periodically washing down the pollution from selected insulators with distilled water. After carefully collecting the water, the conductivity of the collected water is measured and the equivalent amount of salt which produces the same conductivity is calculated. The obtained mg value of salt is divided by the cleaned area of the insulator to obtain the ESDD value. The pollution level can be described in Table 1 (Patel and Parekh, 2013; Kuffel and Kuffel, 2000; Lloydand and Schneider, 1982; Looms, 1988).

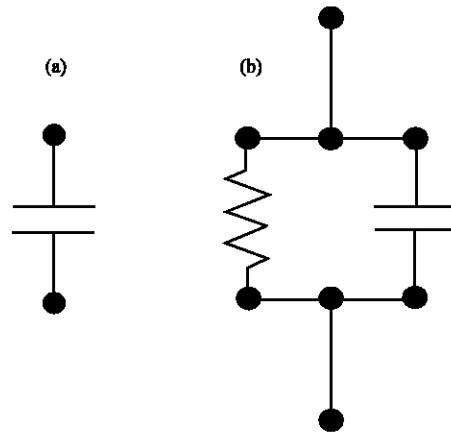


Fig. 1: Primitive diagram of insulator; a) Clean insulator and b) Polluted insulator

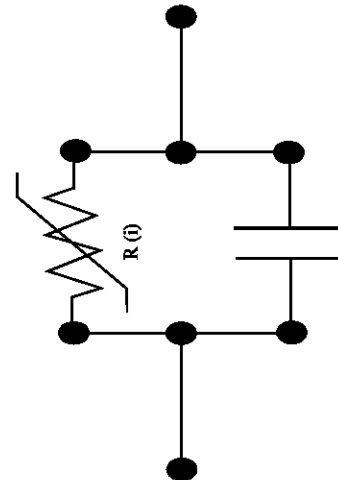


Fig. 2: Primitive diagram of clean insulator with pollution

Table 1: Ranges of salinity and ESDD for pollution level		
Pollution level	Salinity (kg/m <sup>3</sup> )	ESDD
Very light	0-10	0-0.03
Light	10-20	0.03-0.06
Moderate	20-40	0.06-0.1
Heavy	≥40	≥0.1

**Experiment:** This study experiment is a simulation for leakage current waveform by the 115 kV insulator model including primitive model and nonlinear model with different pollution levels. To pollute the insulator, the insulators were soaked in 0.1 m<sup>3</sup> water with different amounts of volume of NaCl as pollution levels shown in Table 2.

Measured for resistance of the insulators by a mega ohm meter and measured for relation of voltage and current by an amp meter and electrostatic voltmeter with the setting shown in Fig. 3. Each pollution level including 6 insulator measurements.

The measured resistance from a mega-ohm meter would be represented to resistive parameter of insulator for primitive insulator model. For nonlinear insulator model, the characteristics of resistor in the model would be defined by a relation of voltage and current from measurement. Leakage current simulation for the leakage current waveform and harmonic order would be simulated by ATP/EMTP program by insulator model in Fig. 4 included a series 30 pF capacitance of 6 insulators with stray capacitance 10% of insulator capacitance.

Table 2: Mass of sodium chloride in pollution level

Pollution levels	NaCl (kg)
Very light	0
Light	1.5
Moderate	3
Heavy	5

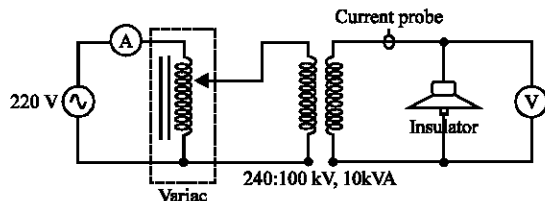


Fig. 3: Equipment setup for measurement

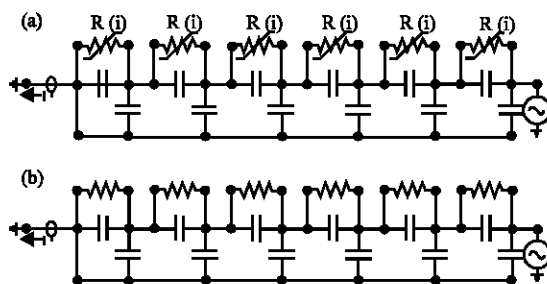


Fig. 4: a) Simulation diagram of primitive insulator model and b) nonlinear insulator model

## RESULTS AND DISCUSSION

The insulator was polluted by water with NaCl. The insulator resistance was measured. The results of insulator average resistance are shown in Table 3. The resistance of insulator is decreased in the condition of a higher pollution level. The relation of voltage from electrostatic voltmeter and current from amp meter is shown in Fig. 5.

Both of insulator model were simulated with 115 kV 50 Hz sinusoidal. For primitive model, the resistance parameter was represented by measured resistance in Table 3. For nonlinear model, the characteristic of resistance was instead by relation in Fig. 5.

The leakage current waveform of very light pollution insulator level (without NaCl) is shown in Fig. 6a. The FFT analysis of the leakage current in different harmonic order is also shown in Fig. 6b.

Figure 7-9 show the leakage current waveform in time domain and the harmonic order for higher pollution level, respectively. In time domain, it can be observed that the amplitude of leakage current is more increased in higher pollution level. The results of nonlinear model is higher than by primitive model. In harmonic order. The percent of total harmonic distortion of both model results are shown in Table 4. The results of primitive model are less of the harmonic distortion. The results of

Table 3: Mass of sodium chloride in pollution level

Pollution levels	Insulator resistance (MΩ)
Very light	62.8
Light	34.2
Moderate	12.8
Heavy	2.8

Table 4: Percent of total harmonic distortion

Pollution levels	%THD	
	Primitive	Nonlinear
Very light	0.079	2.35
Light	0.064	2.53
Moderate	0.044	11.86
Heavy	0.037	22.63

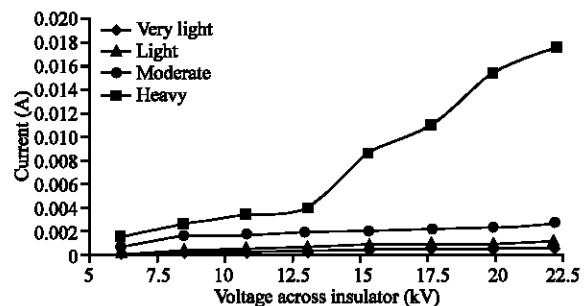


Fig. 5: Relation of voltage and current of insulator

the nonlinear model including more the 3rd harmonic distortion in moderate and heavy pollution levels as Fig. 8b and 9b. The magnitude of harmonic order 3rd and 5th of nonlinear model results are described in Table 5.

Table 5: Harmonic order of nonlinear model

Pollution levels	Harmonic order magnitude (mA)	
	3rd	5th
Very light	0.009	0.006
Light	0.009	0.008
Moderate	0.260	0.070
Heavy	2.500	0.080

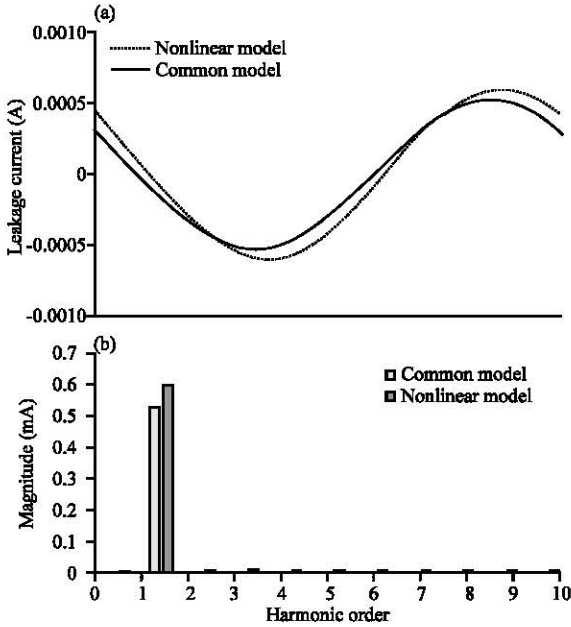


Fig. 6: a, b) Simulation results of insulator in very light pollution level

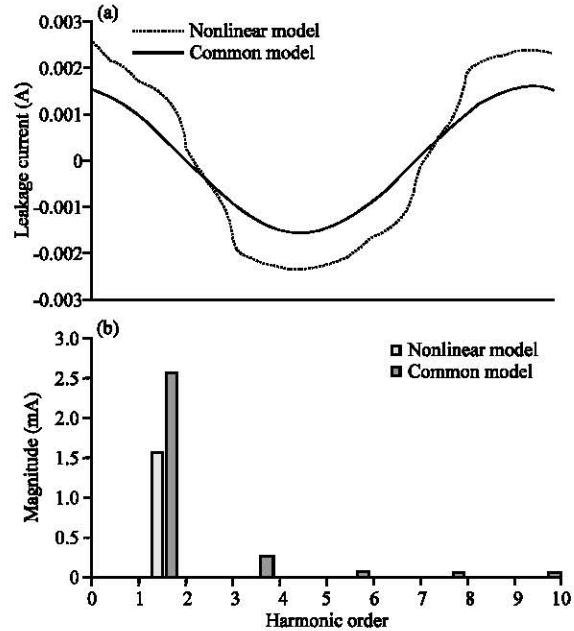


Fig. 8: a, b) Simulation results of insulator in moderate pollution level

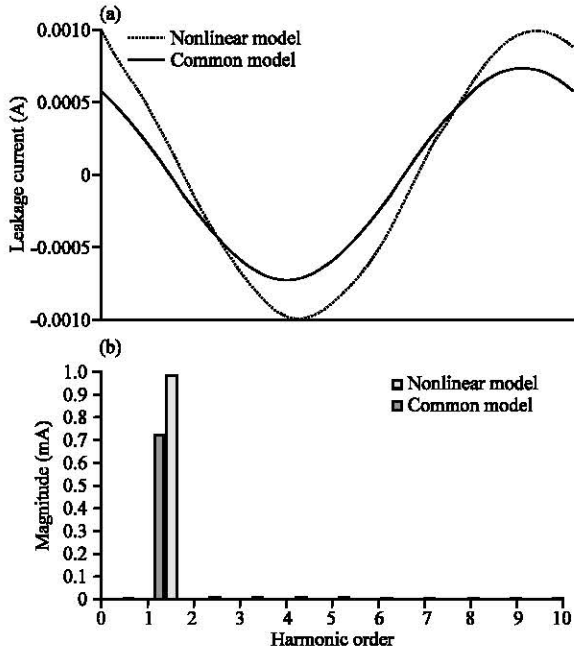


Fig. 7: a, b) Simulation results of insulator in light pollution level

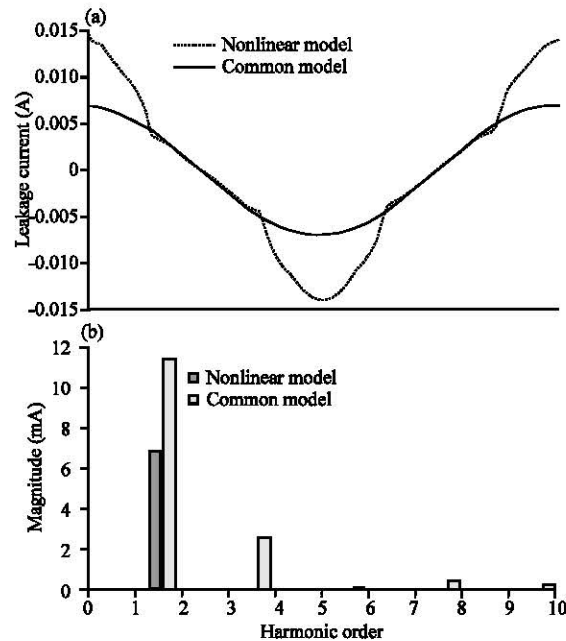


Fig. 9: a, b) Simulation results of insulator in heavy pollution level

From the results can observe that the harmonic component in 3rd and 5th of nonlinear model are significantly increase with higher pollution level.

### CONCLUSION

The study of high voltage string insulator model that be developed by arc gap characteristic to improve the harmonic distortion for flashover prediction by compare the result of the primitive model and the nonlinear model are divided in two parts including measurement part to get the resistance and voltage-current relation of insulators in different pollution levels as to very light, light, moderate and heavy pollution. Insulators were polluted by adding different amounts of volume of NaCl through soaking. NaCl was contaminated in water 0, 1.5, 3 and 5 kg pollution, respectively. The high pollution insulator has more conductive than low pollution insulator and current increasing rate of high pollution insulator tends to increase more than rate of low pollution insulator in same voltage. The model with be included nonlinear resistance gives significantly higher 3rd order harmonic distortion in higher pollution condition than the model that without the nonlinear parameter but the 5th order that slightly increase. The improvement of the high voltage insulator with harmonic distortion can be developed by the nonlinear resistive of the arcing model.

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