DYNAMIC MODELLING OF POLLUTION FLASHOVER ON HIGH VOLTAGE OUTDOOR INSULATORS

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To my beloved parents, thank you

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ABSTRACT

The high voltage outdoor insulators are one of the most important components in the electrical power transmission system. During its lifetime, insulators are exposed to several failures. For this reason, it is crucial to continuously monitor its condition and investigate insulator performance under varying degrees of contamination. In this work, new techniques have been used to diagnose insulators' conditions based on Fast Fourier Transformer (FFT) Analysis of the leakage current. FFT analysis is commonly employed to investigate insulator statements under varying degrees of contamination and wetting rate using harmonic components and phase-shift angle of leakage current. It can be noted that proposed techniques have shown high efficiency in evaluating insulator status. The increase in pollution levels on insulators surfaces has affected the performance of insulators which leads to the occurrence of flashover on the insulator surface. The investigations carried out to understand the performance of polluted insulators may be grouped into three categories: natural testing, artificial testing or laboratory testing, and mathematical models. However, the method of actual testing of insulators suffers from limitations, for example, it is uneconomical, highly time-consuming, and gives non-reproducible results. So, artificial testing (experiments) and mathematical models have been used to understand and predict pollution flashover voltages of polluted insulators. In this study, a new mathematical model, based on the dimensional analysis method (DAM), is proposed. This model is used to forecast the contamination flashover voltage gradient of insulators under varying contamination and wetting conditions when subjected to AC voltages. The arc constants have been extracted from the V-I characteristics curve to estimate the dimensional constant. The Artificial Neural Network (ANN) and Adaptive Network-Based Fuzzy Inference System (ANFIS) were utilised also for the prediction of the mathematical model. Also, in this study, an improved static and dynamic mathematical model of critical parameters of polluted insulators is proposed based on an extended equivalent electric-circuit model of a polluted insulator. The effect of arc length and resistance of the pollution layer on critical flashover voltage investigated using the (RLC)

circuit model. Finally, the experimental test results validate the competency of the proposed dynamic model via accurate performance prediction of polluted insulators. There is a good agreement between the results of the experiments of polluted insulators obtained in the laboratory and values calculated from the developed models.

ABSTRAK

Penebat luaran voltan tinggi adalah salah satu komponen terpenting dalam sistem penghantaran kuasa elektrik. Sepanjang hayatnya, penebat terdedah kepada beberapa kerosakan. Atas sebab ini, sangat penting untuk terus memantau keadaannya dan menyiasat prestasi penebat di bawah pencemaran. Dalam karya ini, teknik baru telah digunakan untuk mendiagnosis keadaan penebat berdasarkan Analisis Fast Fourier Transformer (FFT) terhadap arus kebocoran. Yang biasa digunakan untuk menyiasat pernyataan penebat di bawah pelbagai tahap pencemaran dan pembasahan menggunakan komponen harmonik dan sudut peralihan fasa arus kebocoran. Ini dapat didapati bahawa teknik yang dicadangkan telah menunjukkan kecekapan tinggi untuk menilai status penebat. Peningkatan tahap pencemaran pada permukaan penebat telah mempengaruhi prestasi penebat, yang boleh menyebabkan terjadinya kilas pada permukaan penebat. Penyelidikan yang dilakukan untuk memahami prestasi pencemaran penebat dapat dikelompokkan menjadi tiga kategori seperti, ujian semula jadi, ujian buatan atau ujian makmal dan model matematik. Walau bagaimanapun, kaedah pengujian semula jadi penebat mengalami batasan seperti hasil yang tidak ekonomik, sangat memakan masa dan hasil yang tidak dapat dihasilkan semula. Oleh itu, ujian buatan (eksperimen) dan model matematik telah digunakan untuk memahami dan meramalkan voltan kilas pencemaran dari penebat yang tercemar. Dalam kajian ini, model matematik baru berdasarkan kaedah analisis dimensi (DAM) dicadangkan. Model ini digunakan untuk meramalkan kecerunan voltan kilas pencemaran dari penebat dalam keadaan pencemaran dan pembasahan yang berbeza-beza ketika dikenakan voltan AC. Pemalar arka telah diekstrak dari keluk ciri V-I untuk menganggar pemalar dimensi. Rangkaian neural buatan ANN dan Adaptive Network-based Fuzzy Inference System (ANFIS) digunakan juga untuk meramal model matematik ramalan. Juga, dalam kajian ini, model matematik statik dan dinamik parameter kritikal untuk penebat tercemar berdasarkan model litar elektrik setara

lanjutan dari penebat tercemar. Kesan panjang arka dan rintangan lapisan pencemaran pada voltan kilas kritikal disiasat menggunakan model litar (RLC). Akhirnya, keputusan ujian eksperimen mengesahkan kecekapan model dinamik yang dicadangkan dalam ramalan prestasi yang tepat dari penebat yang tercemar. Terdapat persetujuan yang baik antara ujian eksperimen penebat pencemaran yang diperoleh di makmal dan nilai yang dikira dari model yang dikembangkan.

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	Alternating current
ANN	Artificial neural network
ANFIS	Adaptive neuro-fuzzy inference system
BEM	Boundary element method
DC	Direct current
DSO	Digital storage oscilloscope
DAM	Dimensional Analysis method
ESDD	Equivalent salt deposit density
FEM	Finite element method
HV	High voltage
LC	Leakage current
MSE	Mean Squared Errors
NSDD	Non-Soluble Deposit Density
SiR	Silicone rubber
UHV	Ultra-high voltage
2D/3D	Two/three dimensional
THD	Total harmonic distortion
FFT	Fast Fourier Transformer
A	Static arc constant
A_i	Coefficient gas of kinetic
b	Factor depend to temperature
C_{arc}	Arc capacitor
C_p	Pollution layer capacitor
c_{arc}	Arc capacitor per unit length
c_p	Pollution layer capacitor per unit length
D	Insulator diameter

$D(l)$	Diameter of insulator at length l
dt	Change time
E	Nash coefficient
E_{arc}	Arc voltage gradient
FF	Form Factor
I_{arc}	Arc current
I_{cri}	Critical current
L	Insulator leakage distance
LC	Leakage Current
$L\text{-}x$	Pollution layer length
N	Number of experiment data
n	Dynamic arc constant
P_s	Population chromosomes
P_c	Probability of mutation
R_{arc}	Arc resistance
R_p	Pollution layer resistance
r_a	Arc radius
r_{arc}	Arc resistance per unit length
r_p	Pollution layer resistance per length
S	Cross section
S_a	Salinity
T	Surface temperature
U_{cri}	Critical voltage
U_{exp}	Critical voltage from Experiment
U_S	Supplied voltage
V	Volume of solution
V_{arc}	Arc voltage
V_p	Pollution layer voltage
v	Arc velocity
v_i	Volume fraction of part
x	Arc length
x_{cri}	Critical length of arc

Z_{arc}	Arc impedance
Z_p	Pollution layer impedance
Z_{eq}	Equivalent impedance
ρ_{arc}	Arc capacitor resistivity
ρ_p	Pollution layer resistivity
σ	Electrical conductivity
σ_{20}	Conductivity at 20 ˚C
σ_θ	Conductivity at θ ˚C
θ	Room temperature
ε_P	Permittivity
λ	Thermal conductivity
λ_i	Thermal conduction coefficient
λ_{av}	Average of
τ	Arc time constant
μ	Arc mobility
ω	Angular frequency which is equal to 2πf ($rad.s^{-1}$)

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CHAPTER 1

INTRODUCTION

1.1 Background

High-voltage insulating equipment, such as insulators in overhead electrical power transmission networks, are expected to operate reliably regardless of environmental conditions. A significant number of insulators are used in energy transmission networks in practice. Among the weather conditions, which an insulator subjected to, is the accumulation of pollutants, rain, and humidity. In some industrial and coastal areas, contaminant accumulation not only leads to mechanical damage to pylons and conductors but also affects the dielectric performance of insulation equipment [1]. Once their dielectric strength is weakened due to these accumulations, the insulation equipment undergoes electrical flashover which may lead to a partial or total interruption in the electrical distribution. Among the problems caused by heavy contamination accumulations, there are some flashovers which lead to out-stage of service on main networks. Around the world, several researchers have reported incidents caused by pollutant accumulation on insulators in several countries [2].

Electrical flashover results in a short circuit between the poles of high voltage and ground insulators created by an electric arc usually establishing itself at the surface of the pollutant layer covering the insulation equipment. The laboratory tests have shown that the appearance of partial arcs along with air gaps, i.e. areas not covered by contamination, may become initiators of electrical flashover of polluted insulators[3]. These arcs are mainly caused by changing the distribution of the electric field along

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