The Effect of the Over Voltage on the Stress Distribution at the Terminals of H.V. XLPE Cables

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Abstract

The power cables are usually subjected to over voltages from lightning impulses and switching surges, such over- voltages effects are concentrated at terminals of the high voltage cables .

The longitudinal and radial stresses through cable terminals are computed by using Schwarz christoffel transformation used for sketching the electrical fields.

The investigated cables are of rated voltage 33Kv and 132Kv insulated by cross-linked polyethylene (XLPE).

Electrical field sketching at the cable terminals is carried out theoretically by the aids of computer programs. The results give an indication of the maximum stresses occurs in the cables insulation at the terminals and the maximum longitudinal stresses along the cables screen at outer surface of the XLPE insulation. The results show that maximum stress occurred by lightning impulse is found much higher than that of switching operation but the later has longer period. And both are found depends on the polarity of the over voltages and the polarity of the (power/frequency) voltages.

Keywords: stress distribution ofover voltage XLPE cables, termination of XLPE cables

تأثير الفولتيات العالية على توزيع الاجهادات عند منطقة الأطراف لقابلوات الفولتية العالية ذوات عوازل البولي اثيلين متقاطع الأواصر

أ. فاروق خليل عموري سعد صاموئيل شيت

الهندسة الكهربائية الكلية التقنية

/الموصل

الخلاصة

قابلوات القدرة تتعرض عادة لفولتيات عالية ناتجة من نبضات الاندفاعة ونبضات الفتح والغلق. مثل هذه الفولتيات العالية تتركز بمقادير عالية في منطقة الأطراف لقابوات الفولتية العالية.

تم حساب ورسم المجال الكهربائي الطولي والقطري عند منطقة الأطراف بتطبيق نظرية تحويلة التوافق (تحويلة شوارتز كرستوفل).

اختير القابلو المستخدم والذي تم تطويره بتقنين الأول 33 كيلو فولت أما الثاني فهو 132 كيلو فولت وذو عازل صلب من نوع البولي اثيلين متقاطع الأواصر.

حسابات مخططات المجال الكهربائي عند منطقة الأطراف تمت وتنفيذها بصورة نظرية باستخدام الحاسبة الالكترونية. والنتائج أعطت مؤشر لحالة أعظم إجهاد كهربائي يحدث في عازل القابلو عند منطقة الأطراف وقيمة أعظم إجهاد كهربائي طولي يحدث عند الطبقة العليا لعازل البولي اثيلين متقاطع الأواصر. بينت النتائج التي تم الحصول عليها بان أعظم إجهاد يتم عند تعرض القابلو لنبضة الاندفاعة وتكون قيمة الاجهادات الكهربائية عالية جدا وبصورة غير قابلة للمقارنة عند حالة نبضات الفتح والغلق. بينما نبضات الفتح والغلق تكون ذات فترة أطول من نبضات الاندفاعة. كلا الفولتيتين العاليتين تم استخدامهم حسب القطبية للفولتية العالية وكذلك حسب القطبية للفولتية الاعتيادية التي يعمل عندها القابلو قبل تعرضه إلى الفولتيات العالية.

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Introduction

The cross-linked high density polyethylene is used as the insulating material in medium voltage cables (3.3Kv, 6.6Kv, 11Kv, 33Kv, 66Kv), high voltage cables (110Kv, 132Kv, 220Kv, 400Kv), and at present time used for more than 400Kv. Joints and termination in such cables are the most risky parts in the cables system. This is because it is not easy to get a purely uniform electric field in such positions even at power frequency voltages. High voltage cables are often connected with over head transmission lines, and so such cables are subjected to over voltages from lightning impulse as well as the over voltages from switching operation of the power transmission system. High voltage cables in underground power systems usually tested with lightning impulses according to the applicable (IEC) standard to proof it's capability against lightning over voltage [1].

High voltage switching operation and discharge phenomena in the gas gap circuit breakers electrodes cause, electromagnetic transients and such transients produced high electromagnetic fields and cause an over lap and concentration of electric fields specially at cable terminations [2,3].

Contribution deals with maximum stresses and field concentration at cable termination and at over voltages are produced in this paper. The contribution involves a field sketching at cable termination using Schwarz Christoffel transformation.

Theoretical Approach:

At rated working A.C. voltages on a cable and at over voltages the stress can be given by the following equations [4].

The stress near conductor E_r is:

…………(1)

$$E_r = (V + V_{o.v}) / (r \ln (R/r))$$

The stress near sheath E_R is:

…………(2)

$E_R = (V + V_{o.v}) / (R \ln (R/r))$

Where V: Working voltage in Kv at real value.

$V_{o.v}$: Over voltages at real value.

r: Radius of conductor in meter.

R: Radius of sheath in meter

The above two equations at the peak value of the electrical stresses can be defined at the conductor and at the sheath in case of no-load and at full load. The peak value of the stress near the sheath is higher than that near the conductor.

At the cable terminals the electric field or stress seems to be non-uniform and this is due to the presence of the longitudinal fields in addition to the radial fields.

In order to declare the effect of the two electrical fields at cable terminal, the field sketching at cable terminal is carried out theoretically at over voltage imposed on the working power/frequency voltages.

Sketching of the electric field at cable terminals is carried out by using Schwarz Christoffel transformation, such method was used in reference [3] and verified by experiments at (power/frequency) voltages [3]. The general form of this transformation is:

…………(3)

$$\frac{dZ}{dW} = S(W-a)^{\frac{\alpha}{\pi}-1}(W-b)^{\frac{\beta}{\pi}-1}(W-c)^{\frac{\gamma}{\pi}-1}(W-d)^{\frac{\delta}{\pi}-1}$$

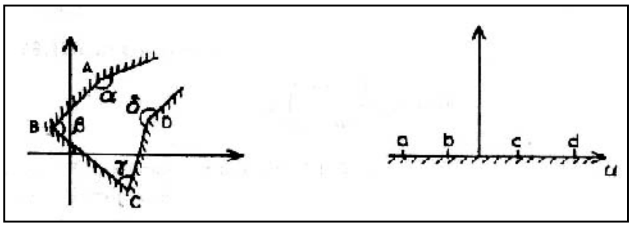
where:

S: rotation constant.

a, b, c, d: values on the real axis used to ensure transformation conditions.

α, β, γ, δ: right or zero angle of the polygon.

By using this method any polygon in Z-plane can be transformed to the upper half of W-plane. The polygon sides of Z-plane became the real axis of the W-plane as shown in figure(1).

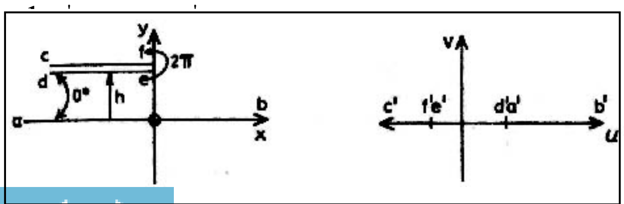


figure(1)

Representation of Schwarz Christoffel transformation

The values A, B, C, D shown in figure(1) are representing the vertices of the polygon.

For a certain cable two angle are used, the first $\alpha = 2\pi$, and the second $\beta = 0$, as shown in figure(2) and the representation of Z-plane and W-plane both



figure(2)

Representation of Schwarz Christoffel transformation for cable termination

The above equation will be:

$$\frac{dZ}{dW} = S(W-a)^{\frac{\alpha}{\pi}-1}(W-b)^{\frac{\beta}{\pi}-1} \qquad \text{............(4)}$$

a, b represents the value of located to assure the transformation condition of (a = -1), and(b = 0), and the equation will be:

$$Z = S(W + InW) + K \qquad \text{............(5)}$$

the two unknown values $S \& K$, can be used as:

$$S = K = \frac{h}{\pi}$$

where h: conductor radius

so that the equation will be:

............(6)

$$Z = \frac{h}{\pi}(W + InW + 1)$$

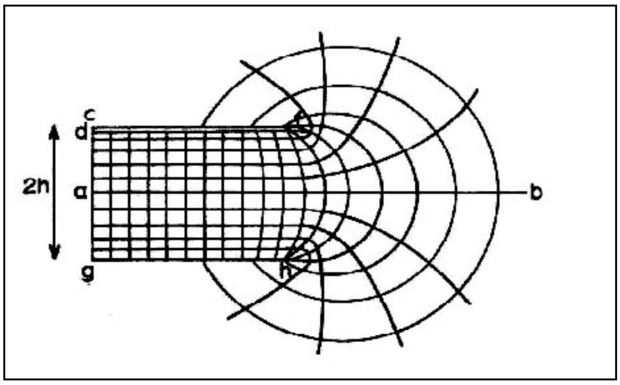
This equation represents the form of the equipotential lines. under transformation condition and the arrangement in the above form is a new form of equation wich can be developed as:

$$Z = \frac{h}{\pi}(e^{\omega} - \omega + jh) \qquad \text{............(7)}$$

This equation represents the form of the flux lines.

By representing the real and imaginary parts from the above equation and plotting, then the field distribution around the cable conductors can be defined.

The field map representation for cable termination by using method of Schwartz Christoffel transformation given in figure (3).



figure(3)

field map representation for cable termination

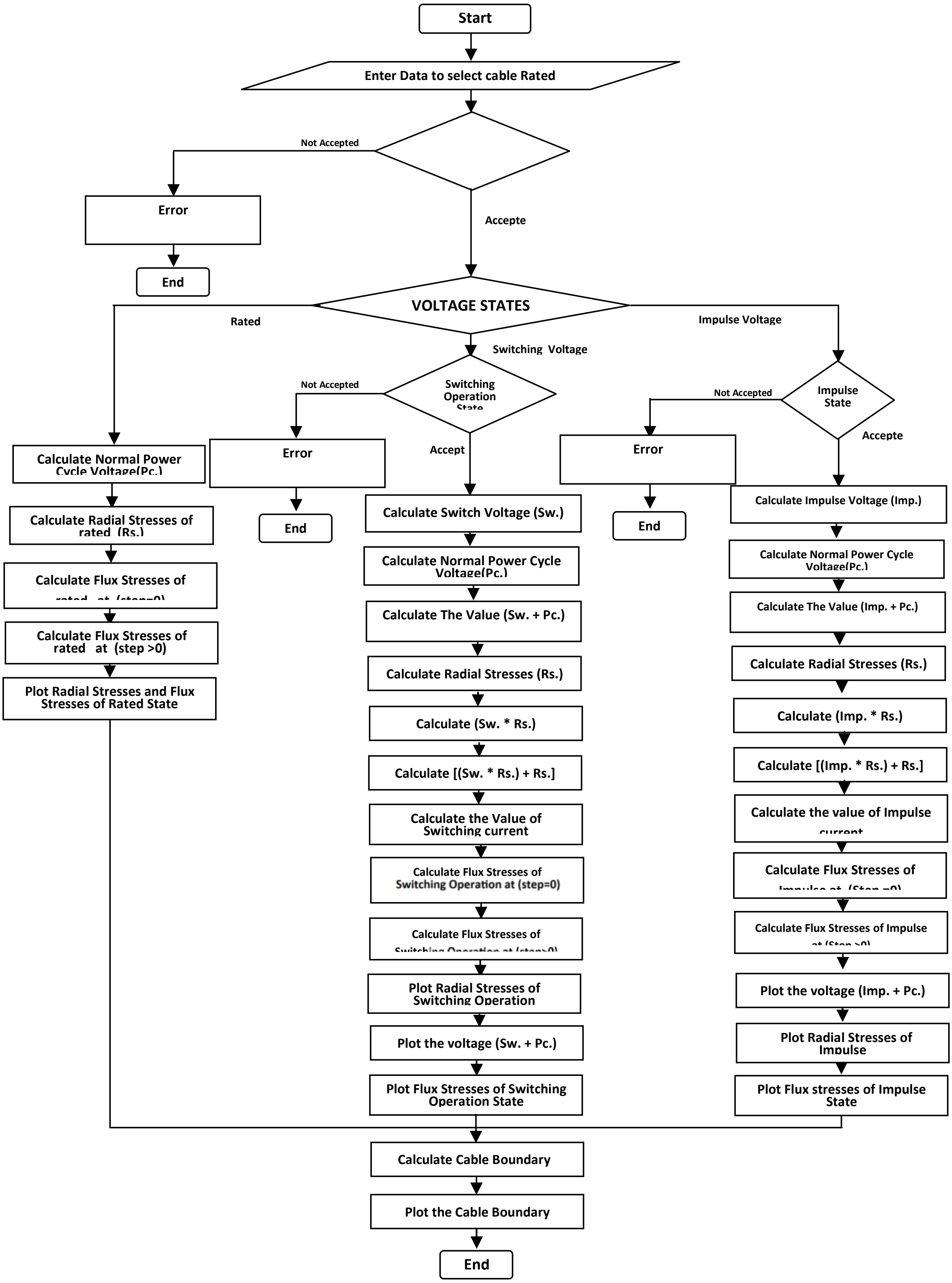
Designed Program:

The theoretical analysis is simulated by designing a computer program. The program used data of high voltage power cables rated at voltages of 33Kv, 132Kv. The simulation involve the use of lightning impulses of 1.2/50 µs and at peak values of 20 times that of working voltages and at both positive and negative impulses. For switching operation, the waveforms of the surges is at peak value of 4 times that of working voltage and at longer front and tail voltage 20/30 µs, this value is computed by varying the values of the impulse generator parameter (R_1,R_2,C_1,C_2). The designed computer programs is given by its flow chart is shown in figure (4).

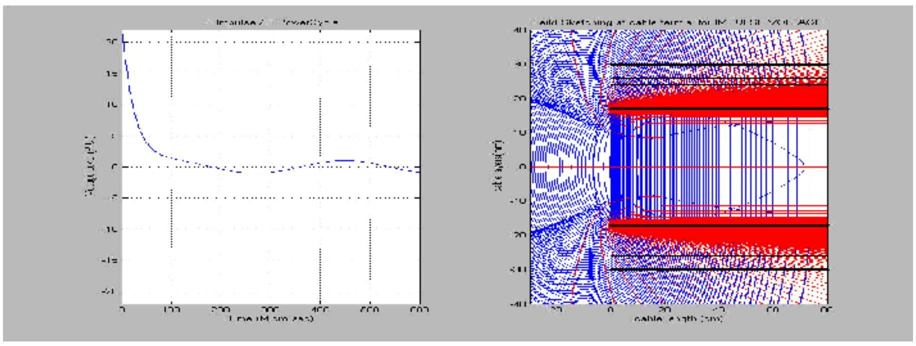
Results and Discussion:

Over voltages subjected on high voltage power cables are usually of two main forms,

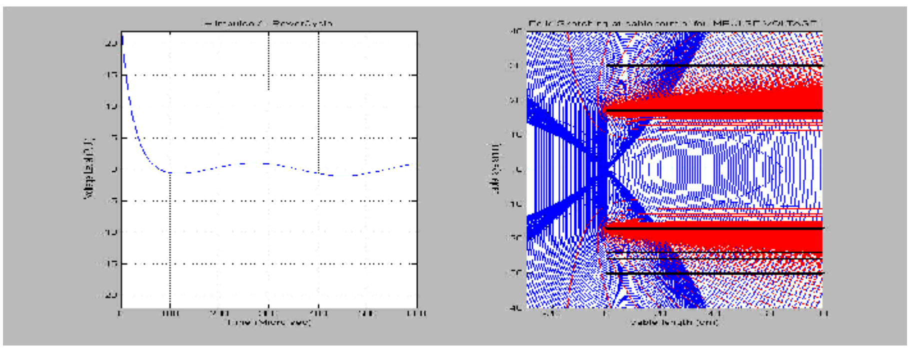
the first one is the impulse produced form lightning strokes and these are either positive or negative. Simulation of the positive and negative impulse waveform which are chosen and applied in the present study are given in figure(5) for 33Kv. The positive impulse voltages imposed on the positive (power/frequency) cycle is given in figure(5) – (case a) and the corresponding fields at cable terminal is given figure(5) – (case e). similar simulation for positive impulse voltages imposed on negative (power/frequency) cycle is given in figure(5) – (case b), and the corresponding field sketching at cable terminal is shown in figure(5) – (case f). The negative impulse imposed on positive power cycle as given in figure(5) – (case c) and it's corresponding field sketching at cable terminal is shown in figure(5) – (case g). The negative impulse imposed on negative (power/frequency) cycle with it's field sketching are given in (case d) and (case h). The calculated results from the field sketching in figure(5) indicate that maximum field concentration occurred at positive impulse imposed on negative (power/frequency) cycle, (case b) followed by the case negative impulse imposed on positive cycles, (case c), negative impulse imposed on negative (power/frequency) cycle, (case d) and positive impulse imposed on positive (power/frequency) cycle, figure (case a). Similar results are obtained in figure(6) were for 132Kv cable terminal and also at positive and negative imposed impulses on (power/frequency) voltages. As compared with 33Kv cable the only difference in found in the amplitude of the (power/frequency) voltages since it is higher in 132Kv cables, but for 33Kv the field concentration due impulse is more risky because the insulation thickness is less. As a result of this study the termination in 33Kv must be designed depending on the impulse withstand level. The design of lower level terminals in 33Kv is the main cause of the 33Kv termination failure. With switching operation at 33Kv cable termination, the surge voltage imposed on negative (power/frequency) voltage cycle (case b) results the most field concentration followed by (case d) of negative surge imposed on negative power cycle followed by (case c) of negative surge imposed on positive (power/frequency) and finally (case a) of positive surge imposed on positive power cycle. For 132Kv terminal at switching operation the results given in figure(7) and for the above four different cases are similar in form to that at 33Kv cable terminals.


Start
Enter Data to select cable Rated
Not Accepted
Error
End
Accepte
VOLTAGE STATES
Rated
Impulse Voltage
Switching Voltage
Not Accepted
Switching Operation State
Not Accepted
Impulse State
Accepte
Error
Accept
Error
Calculate Normal Power Cycle Voltage(Pc.)
Calculate Radial Stresses of rated (Rs.)
Calculate Flux Stresses of rated at (step=0)
Calculate Flux Stresses of rated at (step >0)
Plot Radial Stresses and Flux Stresses of Rated State
End
Calculate Switch Voltage (Sw.)
Calculate Normal Power Cycle Voltage(Pc.)
Calculate The Value (Sw. + Pc.)
Calculate Radial Stresses (Rs.)
Calculate (Sw. * Rs.)
Calculate [(Sw. * Rs.) + Rs.]
Calculate the Value of Switching current
Calculate Flux Stresses of Switching Operation at (step=0)
Calculate Flux Stresses of Switching Operation at (step>0)
Plot Radial Stresses of Switching Operation
Plot the voltage (Sw. + Pc.)
Plot Flux Stresses of Switching Operation State
End
Calculate Impulse Voltage (Imp.)
Calculate Normal Power Cycle Voltage(Pc.)
Calculate The Value (Imp. + Pc.)
Calculate Radial Stresses (Rs.)
Calculate (Imp. * Rs.)
Calculate [(Imp. * Rs.) + Rs.]
Calculate the value of Impulse current
Calculate Flux Stresses of Impulse at (Step =0)
Calculate Flux Stresses of Impulse at (Step >0)
Plot the voltage (Imp. + Pc.)
Plot Radial Stresses of Impulse
Plot Flux stresses of Impulse State
Calculate Cable Boundary
Plot the Cable Boundary
End

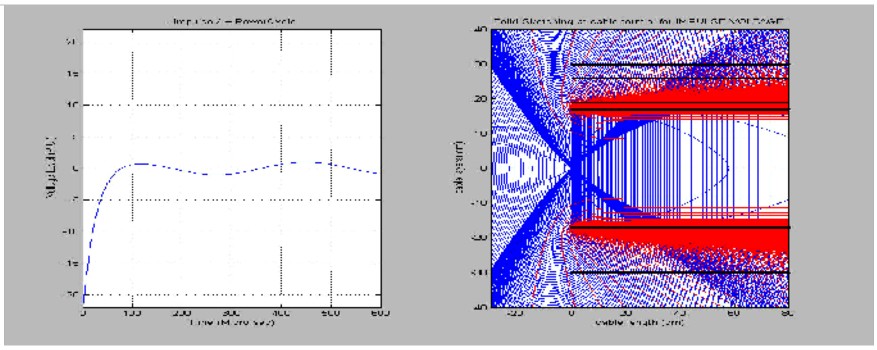
figure(4) flowchart of the designed program



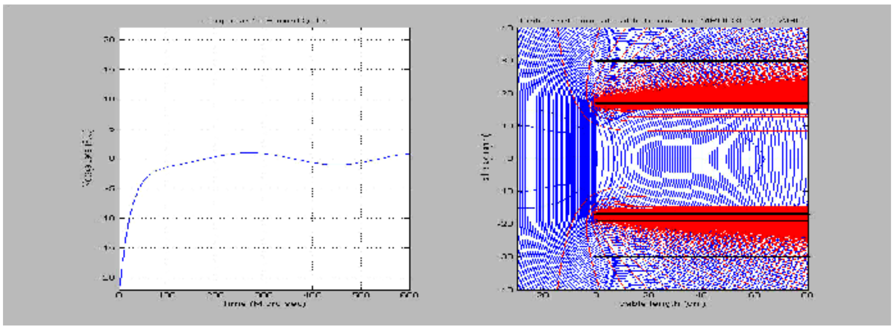
(a)
(e)



(b) (f)



(c) (g)

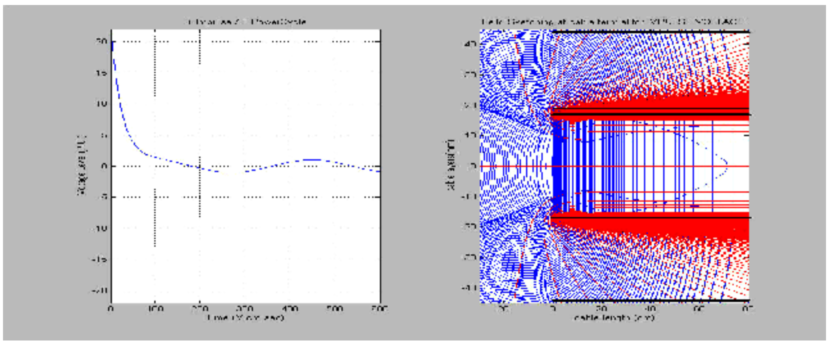


(d) (h)

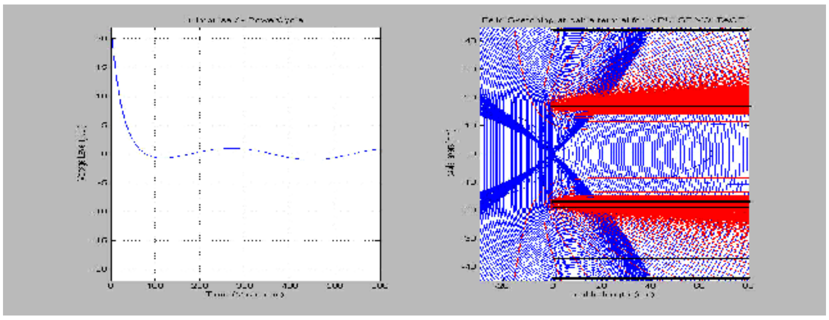
figure(5)

a, b, c, d, are wave forms of the imposed impulse waveforms on power/frequency voltage

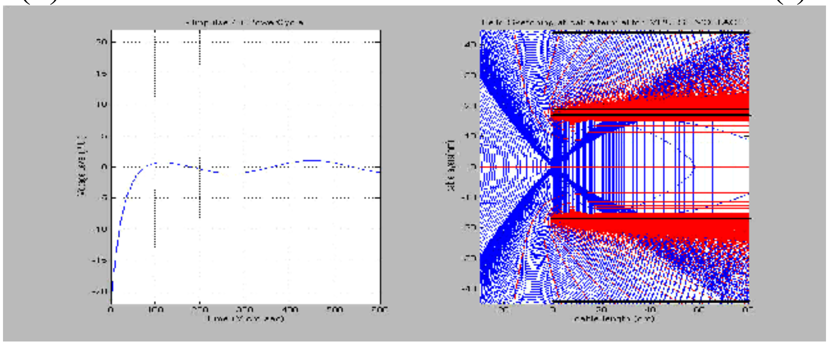
e, f, g, h are the field sketching for a, b, c, d cases in 33Kv power cable terminal



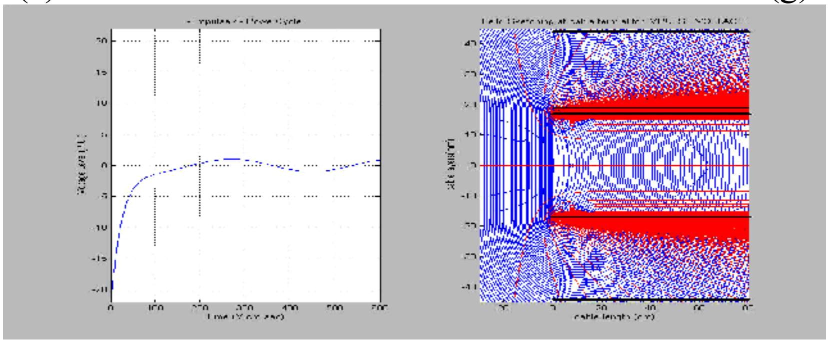
(a) (e)



(b) (f)



(c) (g)

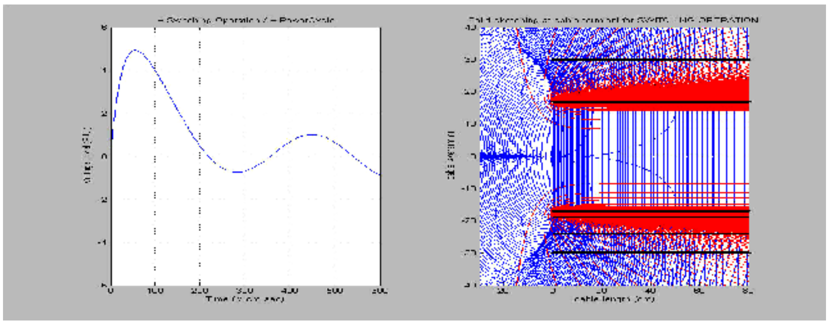


(d) (h)

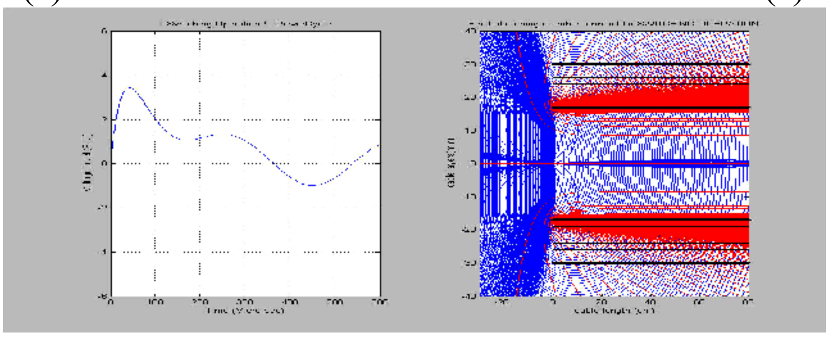
figure(6)

a, b, c, d, are wave forms of the imposed impulse waveforms on power/frequency voltage

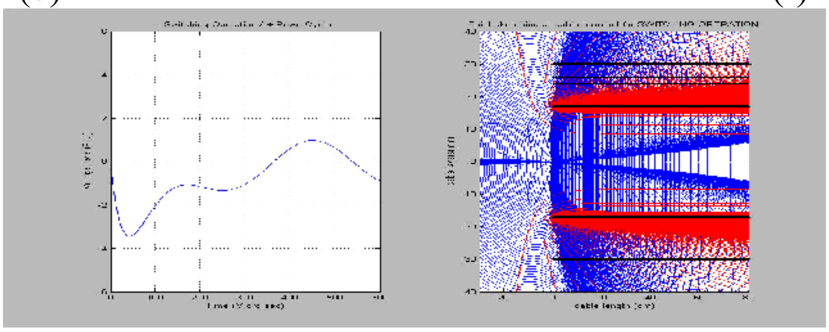
e, f, g, h are the field sketching for a, b, c, d cases in 132Kv power cable terminal



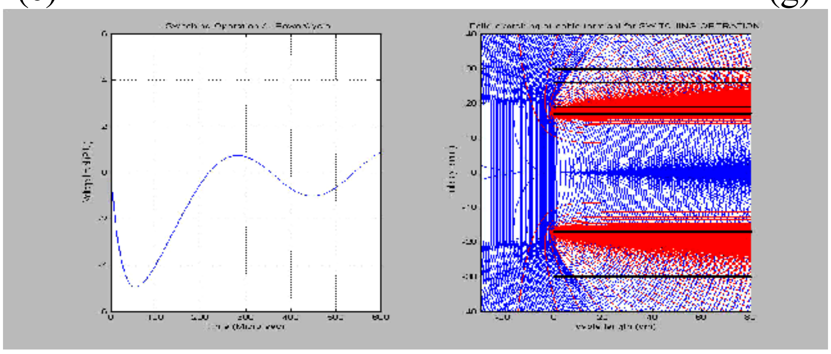
(a) (e)



(b) (f)



(c) (g)

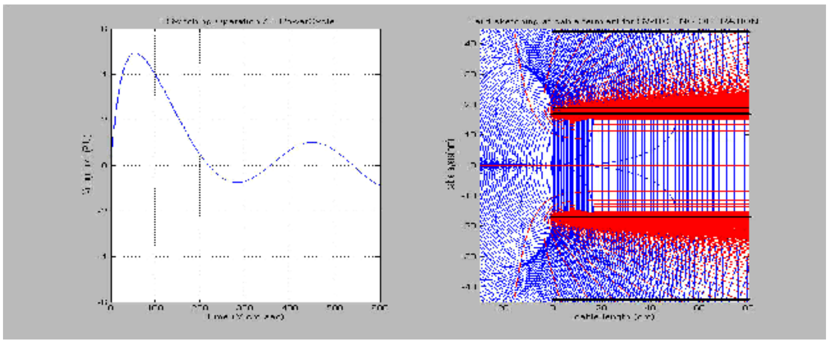


(d) (h)

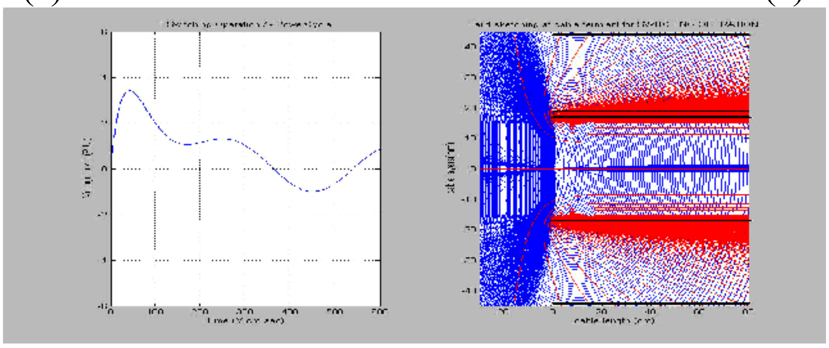
figure(7)

a, b, c, d, are wave forms of the imposed switching operation surges on power/frequency voltage

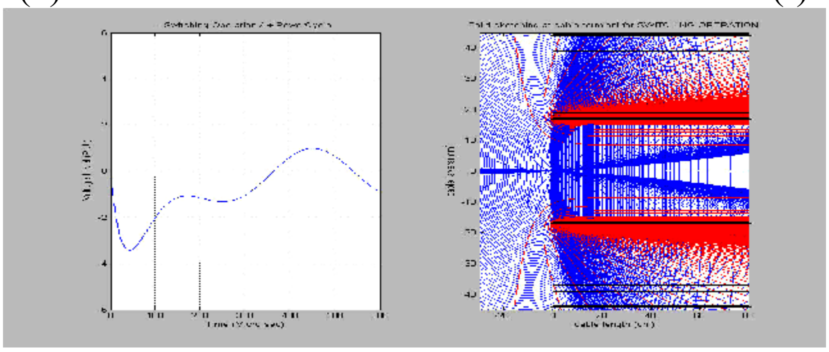
e, f, g, h are the field sketching for a, b, c, d cases in 33Kv power cable terminal



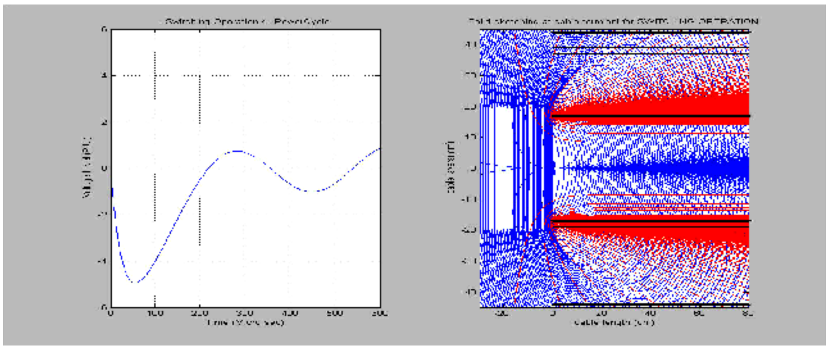
(a) (e)



(b) (f)



(c) (g)



(d) (h)

figure(8)

a, b, c, d, are wave forms of the imposed switching operation surges on power/frequency voltage

e, f, g, h are the field sketching for a, b, c, d cases in 132Kv power cable terminal

Conclusion:

Field concentration in high voltage cables subjected to over voltage imposed on power/frequency voltage indicates a very concentrated electrical field at cable terminals and this is found depends on the polarity of the (power/frequency) voltages. Such difference becomes very serious due to the variation in polarity of the (power/frequency) voltages specially in the cable insulators. In XLPE cable insulators the change in the space charge accumulation followed concentrated electrical field usually lag the variation in polarity and cause more space charge accumulation and more field concentration. Over voltage effect on 132Kv cable terminals is found to be nearly in the same manner as that for 33Kv cable.

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