**Proceedings of the Institute of Acoustics**

# 400 kV OVERHEAD LINE CORONA NOISE ASSESSMENT: PROPOSED BLACK POINT CIRCUITS

Honry Cheng(1), Shaun Knight(1), Kelman Tang(1), Timothy Lam(1), Steven K.H. Chan(2)

(1) Scientific Services Department, China Light & Power Co. Ltd., Hong Kong
(2) Transmission Projects Department, China Light & Power Co. Ltd., Hong Kong

## 1. INTRODUCTION

Transmission of electrical energy from the currently being constructed 6000 MW Large Thermal Power Station at Black Point to load centres will be met by the use of extra-high-voltage overhead lines (OHL). Two main 400 kV lines had been proposed, namely (i) between the proposed Black Point Power Station and the existing Castle Peak Power Station and (ii) between the proposed Black Point Power Station and the existing Shatin 400 kV Substation(see Figure 4). Details of the proposed line routes are contained in the Executive Summary Report issued by UTML[1].

Following a series of public consultations and discussions with the relevant District Boards and Rural Committees in 1992, China Light & Power (CLP) agreed to voluntarily embark on its own internal studies to address one of the issues discussed: Noise from 400 kV OHL. The main noise problem of high voltage bundled lines is noise generated from the corona discharge phenomenon.

Corona is a temporary glow phenomenon that occurs when dielectric surrounding an energised conductor is stressed beyond the breakdown level, yet not sufficiently so to result in flashover. Depending upon the extent of the effect, audible hissing noise is sometimes generated. From past experiences corona noise[4], though not normally intrusive, could pose psychological difficulties to communities near the lines. Such phenomenon is particularly renowned in circumstances of unavoidable, uneven high field strength of a line conductor.

At the request of the Transmission Projects Department(TPD)[2], a study was undertaken by Scientific Services Department(SSD) with the following main objectives:-

- To present a description of the study method.
- To characterise and determine nature of corona noise from an existing 400 kV line.
- To generalise impact results obtained from a selected monitoring site to locations of interest along the proposed line routes.

The proposed transmission tower and line arrangement is basically identical to that of the existing Yuen Long - Lai Chi Kok 400 kV line but of higher electrical and power transfer capability. The line conductors will be arranged in two vertical rows of three quadruples. For the Black Point - Shatin Line, the thermal resistant aluminium alloy conductor steel reinforced (TACSR) type will be used, whilst the common aluminium conductor steel reinforced (ACSR) type will be used for the Black Point - Castle Peak Line. An advanced methodology of noise data gathering, aimed at minimising the manpower requirement, was adopted. Basically, an omni-directional microphone was used to capture data beneath a selected line-tower site. This was performed over a period of six months during many random individual visits. This paper addresses the above objectives and presents a description of the likely impact for the proposed transmission lines.

**400 kV OVERHEAD LINE CORONA NOISE ASSESSMENT: PROPOSED BLACK POINT CIRCUITS**

## 2. THEORY & METHOD

Acoustic noise generated from high voltage line conductors is largely dependent upon the electric field near the conductor surface and the surface quality and atmospheric conditions[6, 7 & 8]. Assuming a uniform distribution of point sources along a line conductor, a relation between the acoustic intensity I reaching a measurement point P and power W generated per unit area is given by:

$$I=\int f(x)dx+k\int f'(x)dx$$

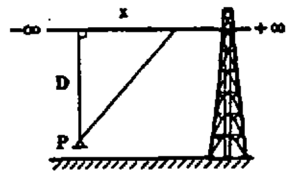



Figure 1a

where $f(x) = W/4\pi(D^2 + x^2)$ ; $f'(x) = W/4\pi(D'^2 + x^2)$

D = perpendicular slant distance from measurement point P to line.

D' = perpendicular slant distance from measurement point P to "image" of line

x = variable distance along conductor

k = reflection coefficient (between 0 and 1 according to local geography)

The 1st term of the equation represents the direct acoustic wave reaching point P and the 2nd term the reflected wave. By integrating RHS of the above equation from $+\infty$ to $-\infty$, the total acoustic intensity at point P for a single phase line is

$$I=\frac{W}{4D}+k*\frac{W}{4D'}$$

For measurement point near the ground $D \approx D'$, the above equation may be simplified as

$$I=\frac{W}{4D}*(1+k)$$

For a double circuit three-phase line arrangement, the total acoustic power would be the sum of contributions from each phase and circuit. Mathematically, it may be expressed in a general form as follows:-

$$I_T=\sum_{j=1}^{j=2}\sum_{i=1}^{i=3}(\frac{W}{4D_{ij}})*(1+k)$$

where i denotes phase lines and j the circuit numbers

In practice, the above model suffers some drawback. The reasons are twofold. Firstly, the line conductors are not arranged in a linear straight form but strung between steel lattice towers which are normally located at different levels. Indeed, they would assume the outline of a curve known as a catenary if strung between two supports. A close approximation to the catenary is the parabola. Thus, f(x) and f'(x) used in the above model would theoretically take a different form. Secondly, because of the presence of steel lattice towers, continuity of line conductors is achieved by the use of clamps and jumpers (see Figures 3b & 3c). The irregularity of these devices create non-uniform field gradient in the interfacing regions. As a result, local corona effect is prone to occur more easily and frequently around these regions rather than at the line conductors. In view of these, the analysis can be simplified by treating the sources as local point sources. The physical characteristics of the noise can thus be determined by locating an omni-directional microphone directly beneath a line at a known distance. Under free-field conditions, the acoustic intensity I approximates the acoustic pressure level. A quick desk-top evaluation of impact is thus possible having known the sound power of these sources.

In the study, a Brüel & Kjær (B&K) microphone Type 4165 coupled to a B&K Real-time Frequency Analyser Type 2144 was used at a sampling point P as shown in Figures 1a & 1b. Both third octave spectra and short-term $L_{eq}$ were obtained using multi-spectrum measurements. Data measurements and observations were carried out and recorded on each individual visit to the site over a period of six months whenever the climate allowed.

The assessment process was then based upon activities ranging from reviewing facts from literature, meteorological data and trends from the Hong Kong Royal Observatory, the proposed line design setting and the on-site data acquisition exercise of the corona effects.

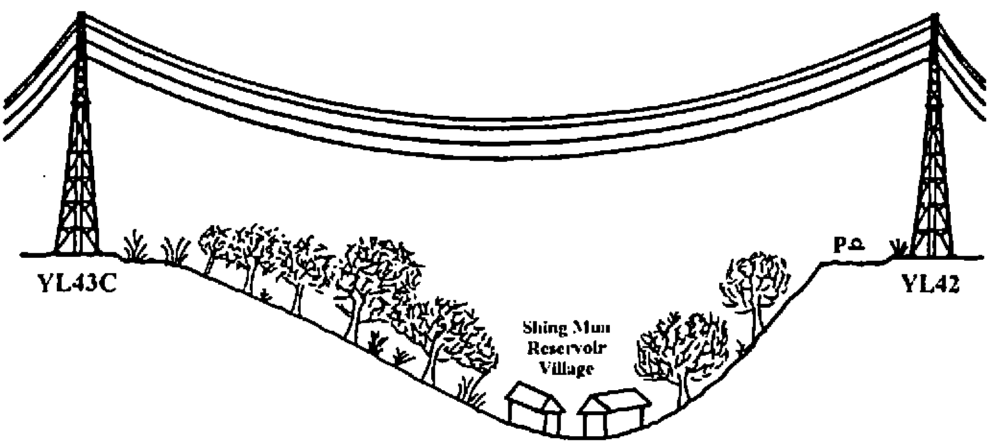


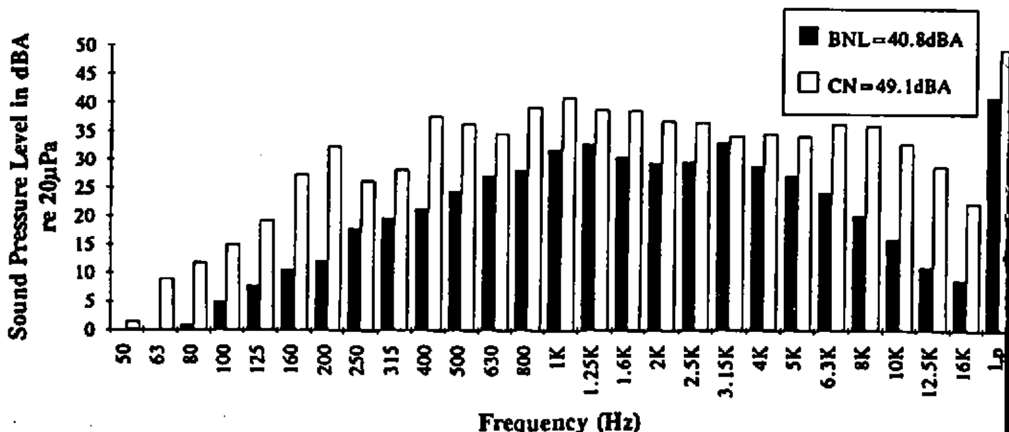

Figure 1b: Site Setting in the Vicinity of the Monitoring Point P

## 3. RESULTS & DISCUSSION

The background noise level (BNL) in this context refer to the total ambient noise level above which the corona noise was measured. Two clear scenarios were identified from the on-site surveys. At one extreme, the corona noise effect was non-existent or too small to constitute discernible noise discharge to the environment. Thus, it was not possible to subjectively differentiate at all, even by the most sensitive surveyor. This was the consequence of the background noise overwhelming the corona noise and making it indistinguishable to that of the background. At the other extreme, the corona noise was clearly perceptible even in the wider vicinity of the monitoring site. In this case, the corona noise level must be a few decibels above the baseline background noise level and/or of unique spectral characteristics. Indeed, there were many intermediate effects between the two extremes over the period of many visits made to the site. The following discusses results and observations recorded from the monitoring site and impact of the corona noise effect on the nearby community in relation to the noise climate change, the local rainfall climate and the proposed line design and configuration.

Steady state $L_{eq}$ recorded at site P ranged from around 40 to 45 dBA during day-time situation in the absence of the corona effect. This could be considered as the typical background noise climate in the locality of the line-tower arrangement. The background noise activities largely comprised of natural sources, such as sounds from sparrows, cicadas and passing vehicles in nearby roads. They were of random, intermittent, repetitive and incoherent in nature and of high variability in terms of noise spectral content and magnitude. Night-time ambient noise climate data had been excluded from the study due to the high level irrelevant contributions of insect noise from the woodland in this part of suburban zone, where $L_{eq}$ in excess of 50 dBA were frequently recorded.

Figure 2: Third Octave Noise Spectra Recorded at Point P




A graph illustrating the two extreme scenarios with spectra for background noise level (BNL) and corona noise (CN) from the line conductors is shown in Figure 2. Despite being influenced by background sources, the corona noise spectral characteristics can still be loosely defined and its shape is identified by comparing with the average baseline background level. Broadly speaking, noise generated by the corona process is of broadband character. It is noticed that its spectrum contains considerable amount of spectral energy in the vicinity of the 6.3 kHz band, i.e. in the range of third octave bands from 6.3 to 10 kHz. Such spectral content was found to be in good correlation with the on-site subjective perception. It was also interesting to note that such pattern was consistent with spectra obtained under many different meteorological occasions when the effect occurred. This was supported by the fact that these spectral components maintained their state of steadiness during the time of real-time sampling of the corona noise while it was slightly modulated by the temporal, random background natural causes.

**400 kV OVERHEAD LINE CORONA NOISE ASSESSMENT: PROPOSED BLACK POINT CIRCUITS**

Community response to noise disturbance is largely based on the relatively simple concept of noise change over the prevailing background levels. In general, the average inception level being around 3 dB above the prevailing background noise level. Complaints tend to be raised beyond such an increase. From the measured characteristics of the corona noise (i.e. its spectral content and loudness), it may be true to describe the phenomenon as a localised effect since spatial excess attenuation by the atmosphere tends to be more effective for high frequency components[5]. Thus, noise arising from the worst scenario of corona effect is unlikely to be of significant impact outside either side of the sterilisation zone of the power lines corridor. In CLP, the corridor is set to be in width of 50 metres. In fact, the physical and visual obstruction effect plays a part in reminding the existence of the line-tower structures as a noise source, despite their impacts not being significant. It is of such popular perception that a program of public education may be necessary to mitigate the psychological dimension of the general public and to provide corona noise information if necessary.

Extensive studies carried out by Taylor et al (1969) [6] to investigate corona effects under different conductor sizes, bundle arrangements and environments had demonstrated their subtle relationship with the corona phenomenon. In supporting the above impact argument, two major aspects have been considered and included here.

**Rain induced Corona Noise:**

During the 6-month period of many visits made to the monitoring site, there were occasions of having corona discharge occurring under wet or dry meteorological conditions. The former is often termed as wet corona and the latter as dry corona.

The results of the site-log, as shown in Appendix A, reveal that 20 out of the 45 visits to the monitoring site recorded the corona phenomenon. 8 out of the 20 corona events were recorded under wet days, i.e. either rain had just occurred or intermittent drizzle; whereas the remainder occurred under dry and calm meteorological conditions. For ease of interpretation, the on-site subjective audibility effects are summarised into 4 categories as shown in Table 1:

**Table 1: Subjective Audibility Effects**

| Level above the BNL (dB) | Subjective Effect |
|---|---|
| ≤ 0 | none |
| < 3 | barely audible |
| ≥ 3 | marginally audible |
| ≥ 5 | clearly audible |

Visits without the audible effect were largely at meteorological conditions similar to that of having dry corona. It should be borne in mind that visits made to the site were of random arrangement, i.e. whenever weather conditions permitted. The chance of having more corona events could have increased or decreased if more visits were made. As indicated in Appendix A and subjectively experienced at the site, those considered as dry corona were normally of lesser degree of audibility whilst those with rain induced association were much more audible. The dry corona noise was therefore not an easily quantifiable effect. It depends on factors such as cleanliness of line surfaces and associated parts for a well-designed line. Dirt or raindrops deposited on the line could enhance the field gradient around the line and induce the effect.

## 400 kV OVERHEAD LINE CORONA NOISE ASSESSMENT: PROPOSED BLACK POINT CIRCUITS

Since wet corona noise was found to be of more concern, the local rainfall rate is utilised to predict the likelihood for the effect to occur. For an average inception rate of 0.5 mm per hour which corresponds to daily rainfall rate of 12 mm, wet corona noise will be induced. From statistics of the Hong Kong Royal Observatory during the period from 1961 to 1990, there were on average 75 occasions annually having such an average daily rainfall rate. Thus, this suggests a probability of around 21% annually having rain induced corona noise clearly perceptible near to a line-tower setting.

**Line Design and Configuration:**

In the design of high voltage power lines, there are two major considerations that dictate the size and configuration of a line conductor, i.e. its ability to carry the required current and to do this at high voltage without permitting corona on the conductor. The field strength necessary to initiate a corona discharge at convenient locations depends upon the local field required to accelerate electrons sufficiently to produce ionising collisions in the atmosphere. Thus, the process is clearly limited by the dielectric breakdown of air. The average breakdown value for air is around 30 kV/cm. For convenience, a comparison of the existing and proposed line conductor details is summarised in Table 2.

Table 2: Comparison of Line Conductor Details

| Type of conductor: | ACSR | TACSR |
|---|---|---|
| Construction of conductor (Nos./mm)<br>Aluminium (ACSR); Aluminium alloy (TACSR)<br>Aluminium-steel (ACSR); Aluminium-clad steel (TACSR) | <br>54/2.92<br>7/2.92 | <br>30/3.27<br>7/3.27 |
| Approximate overall diameter of conductor (mm) | 26.28 | 22.90 |
| Calculated Cross-sectional area ($mm^2$)<br>Aluminium portion ($mm^2$)<br>Complete conductor ($mm^2$) | <br>361.6<br>408.5 | <br>251.9<br>310.7 |
| Phase; Bundle spacing (mm) | 3 ; 500 | 3 ; 500 |
| Approximate weight of conductor (kg/km) | 1,367 | 1,084 |
| Approximate grease weight of conductor (kg/km) | 1,401 | 1,117 |
| Double Tension Insulator String:<br>suitable conductor size of clamp<br>Compression Clamp main material - aluminium alloy | ✓ | ✓ |
| V Suspension Insulator Set<br>Suspension Clamp main material - aluminium alloy | ✓ | ✓ |
| Onset Corona field $E_c$ at 1 atm, 25°C, smooth conductor (kV/cm) | 30.69 | 32.58 |

Using Peek (1929) semi-empirical formula [7], it enables the onset corona field $E_c$ to be deduced. As shown in Table 2, a higher onset corona gradient for the TACSR line would result for adopting a smaller line conductor size. Although the improvement is not very significant, a benefit of having less probability for corona discharge formation is gained. Indeed, for a line roughness factor of 0.95 applied to the above results (considered a reasonably practical scenario), a slight line gradient reduction will result in an ignition gradient around the commonly considered breakdown value of 30 kV/cm. As discussed in [8], the breakdown process does not normally occur until electric field at the discharge point is at least two or three orders of magnitude greater than 30 kV/cm. Thus, the proposed TACSR line is considered to be well-designed from the point of corona consideration. Short-term and intermittent effects are more likely to prevail when they do occur because of the high field gradient required to initiate and sustain a persistent effect.

Since the above calculations are based on a single line arrangement, a quadruple geometry may not give the same $E_c$. In fact, the number of parameters associated with the corona phenomenon is so high that a systematic ordering and separation of effects are essential to fully understand the variation laws. Such efforts must be based on experimental research and the application of valid theories.

## 4. CONCLUDING REMARKS

Based on a review of available literature on the subject, observations and measurement results recorded from an existing 400 kV transmission line-tower site, rainfall data from the Hong Kong Royal Observatory and the proposed line design and configuration, the following points are concluded:

- Corona noise generated by the proposed high voltage lines is unlikely to produce significant impact on communities located outside the sterilisation zone of the proposed lines and the associated steel lattice towers because of the magnitude and nature of the noise.

- Individuals and communities responses to corona noise from OHL are largely of psychological nature. Proactive public education may provide good alleviation of the concern.

- Clearly perceptible corona noise is likely to be of short-term, intermittent nature and largely rain induced in Hong Kong. Dry corona noise is in general found to be subjectively weaker than the wet corona noise.

- Using Hong Kong Royal Observatory's past 30 years statistics on average rainfall rate and trend, it can be predicted that the probability of having rain induced corona noise is about 21% annually near a line-tower setting.

- The TACSR line is calculated to have a higher onset corona field than the ACSR line. Under normal circumstances, corona discharges would not easily occur for both types of line, however.

- A complete picture and understanding on corona noise phenomena for a particular line configuration, conductor size and surface conditions must be based on experimental research and the application of reliable theories.

## 5. REFERENCES

[1] 'Environmental Route Assessment Study for the Black Point 400 kV Power Transmission System: Executive Summary', Urbis Travers Morgan Limited (UTML), May 1992

[2] TPD Fax. Ref. 543-7/Fax.A125/93/WAA/JFB/SC
'400 kV Overhead Line Corona Noise Measurement' dated 15.1.93

[3] National Grid, UK, Technical Advice Note NG RDC/HVT/0102/TAN91
'A Method for Assessing the Community Response to Overhead Line Noise', 1991

[4] SSD Report SS/ES/R145-92
'An Investigation of an alleged Overhead Line Noise Problem in Peng Cheng, PRC', May 1992.

[5] Hassell, J.R. ; Zaveri, K., June 1988
'Acoustic Noise Measurements' P.21, Brüel & Kjær

[6] Taylor, E.R. ; Chartier, V.L. ; Rice, D.N.
'Audible Noise and Visual Corona from HV and EHV Transmission Lines and Substation Conductors - Laboratory Tests' IEEE EHV Transmission Conference, 1968

[7] Cross, J.A.
'Electrostatics: Principles, Problems and Applications' P.479, Adam Hilger

[8] Moore, A.D. ; Arbor, A.
'Electrostatics and its Applications' P.397, John Wiley & Sons

400 kV OVERHEAD LINE CORONA NOISE ASSESSMENT: PROPOSED BLACK POINT CIRCUITS

**Appendix A:** Site Observations Log Re Corona Noise Emission

| Date | Meteorological Conditions | Degree of Audibility |
|---|---|---|
| 24.3.93 | calm, rel. humidity:88%, temperature:23°C | barely audible |
| 25.3.93 | rel. humidity:85%, temperature:25°C | none |
| 29.3.93 | light drizzle, rel. humidity:90%, temperature:16°C | marginally audible |
| 30.3.93 | fine, rel. humidity:85%, temperature:17°C | clearly audible |
| 6.4.93 | light drizzle, rel. humidity:86%, temperature:18°C | clearly audible |
| 7.4.93 | light wind, dry, rel. humidity:80%, temperature:15.5°C | marginally audible |
| 8.4.93 | windy, rel. humidity:71%, temperature:17°C | barely audible |
| 13.4.93 | sunny, dry, calm, rel. humidity:65%, temperature:24.5°C | none |
| 14.4.93 | cloudy, calm, rel.humidity:76%, temperature:21.5°C | none |
| 15.4.93 | calm, rel. humidity:76%, temperature:22.5°C | marginally audible |
| 17.4.93 | wet, breeze, rel. humidity:93%, temperature:22°C | clearly audible |
| 19.4.93 | sunny, dry, rel. humidity:83%, temperature:26.5°C | none |
| 20.4.93 | cloudy, dry, rel. humidity:84%, temperature:24.5°C | barely audible |
| 21.4.93 | wet, foggy, rel. humidity:96%, temperature:21°C | barely audible |
| 22.4.93 | dry, calm, rel. humidity:76%, temperature:26°C | none |
| 27.4.93 | wet, rel. humidity:95%, temperature:22.5°C | clearly audible |
| 28.4.93 | sunny, dry, rel. humidity:78%, temperature:29.5°C | clearly audible |
| 29.4.93 | light drizzle, rel. humidity:96%, temperature:24.5°C | clearly audible |
| 30.4.93 | light wind, rel. humidity:86%, temperature:24°C | none |
| 3.5.93 | cloudy, dry, light wind, rel. humidity:84%, temperature:23.5°C | none |
| 4.5.93 | cloudy, moderate wind, rel. humidity:91%, temperature:21°C | none |
| 5.5.93 | cloudy, light wind, rel. humidity:84%, temperature:25.5°C | none |
| 7.5.93 | sunny, moderate wind, dry, rel. humidity:72%, temperature:31°C | none |
| 10.5.93 | cloudy, dry, calm, rel. humidity:81%, temperature:28°C | none |
| 11.5.93 | cloudy, light wind, rel. humidity:86%, temperature:25.5°C | none |
| 12.5.93 | sunny, calm, rel. humidity:80%, temperature:27.5°C | none |
| 17.5.93 | sunny, calm, rel. humidity:70%, temperature:27.5°C | none |
| 22.5.93 | wet, rel. humidity:92%, temperature:26°C | none |
| 24.5.93 | wet, rel. humidity:88%, temperature:26.5°C | none |
| 26.5.93 | wet, calm, rel. humidity:84%, temperature:27°C | none |
| 7.6.93 | calm, dry, rel. humidity:85%, temperature:28°C | none |
| 29.6.93 | cloudy, windy, rel. humidity:82%, temperature:29.2°C | marginally audible |
| 2.7.93 | sunny, light wind, rel. humidity:73%, temperature:29.5°C | marginally audible |
| 23.7.93 | sunny, dry, light wind, rel. humidity:79%, temperature:31°C | marginally audible |
| 26.7.93 | sunny, calm, rel. humidity:73%, temperature:31°C | barely audible |
| 28.7.93 | sunny, dry, calm, rel. humidity:71%, temperature:32.5°C | marginally audible |
| 30.7.93 | wet, cloudy, calm, rel. humidity:96%, temperature:28°C | barely audible |
| 4.8.93 | sunny, light wind, rel. humidity:70%, temperature:31°C | none |
| 5.8.93 | sunny, light wind, rel. humidity:76%, temperature:31°C | none |
| 7.8.93 | sunny, light wind, rel. humidity:86%, temperature:30°C | none |
| 9.8.93 | wet, cloudy, calm, rel. humidity:83%, temperature:30.5°C | none |
| 19.8.93 | sunny, wet, strong wind, rel.humidity:73%, temperature:30°C | none |
| 21.8.93 | cloudy, strong wind, rel. humidity:85%, temperature:27°C | clearly audible |
| 23.8.93 | sunny, calm, rel. humidity:68%, temperature:29°C | none |
| 7.9.93 | sunny, breeze, rel.humidity:49%, temperature:30.5°C | none |

400 kV OVERHEAD LINE CORONA NOISE ASSESSMENT: PROPOSED BLACK POINT CIRCUITS

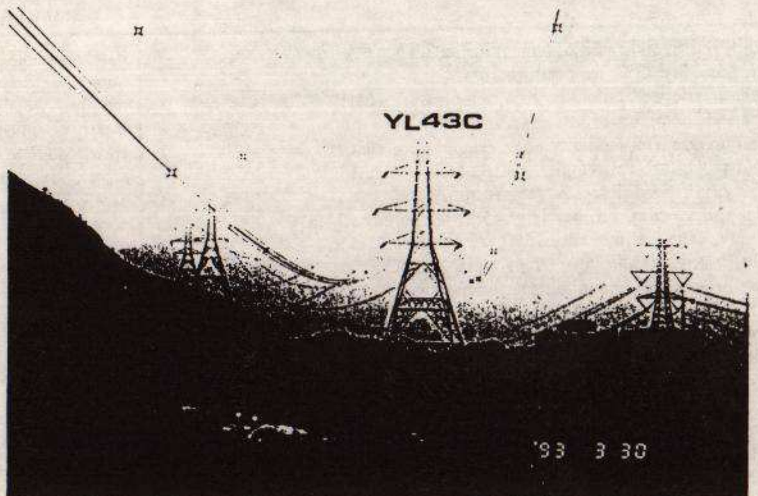



Figure 3a: Standing under Tower YL42 & Looking towards Tower YL43C

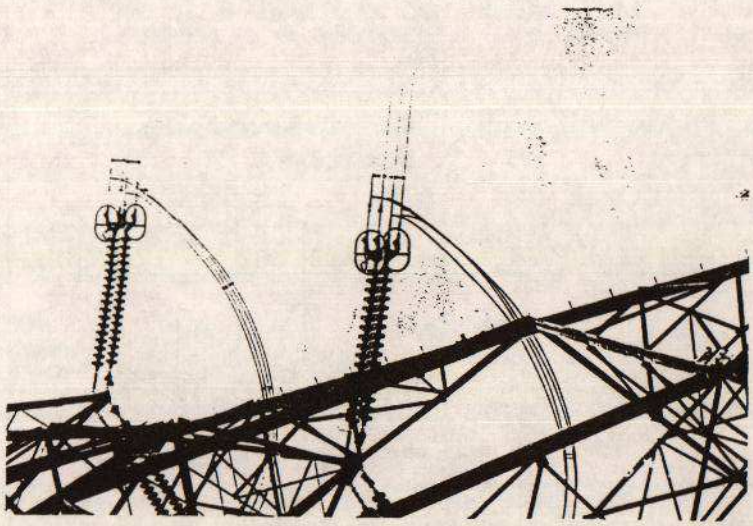


Figure 3c: View of Corona Ring, Suspension Clamp, Dead End Clamp, Jumpers & Spacers



Figure 3b: Close View of Tower YL42

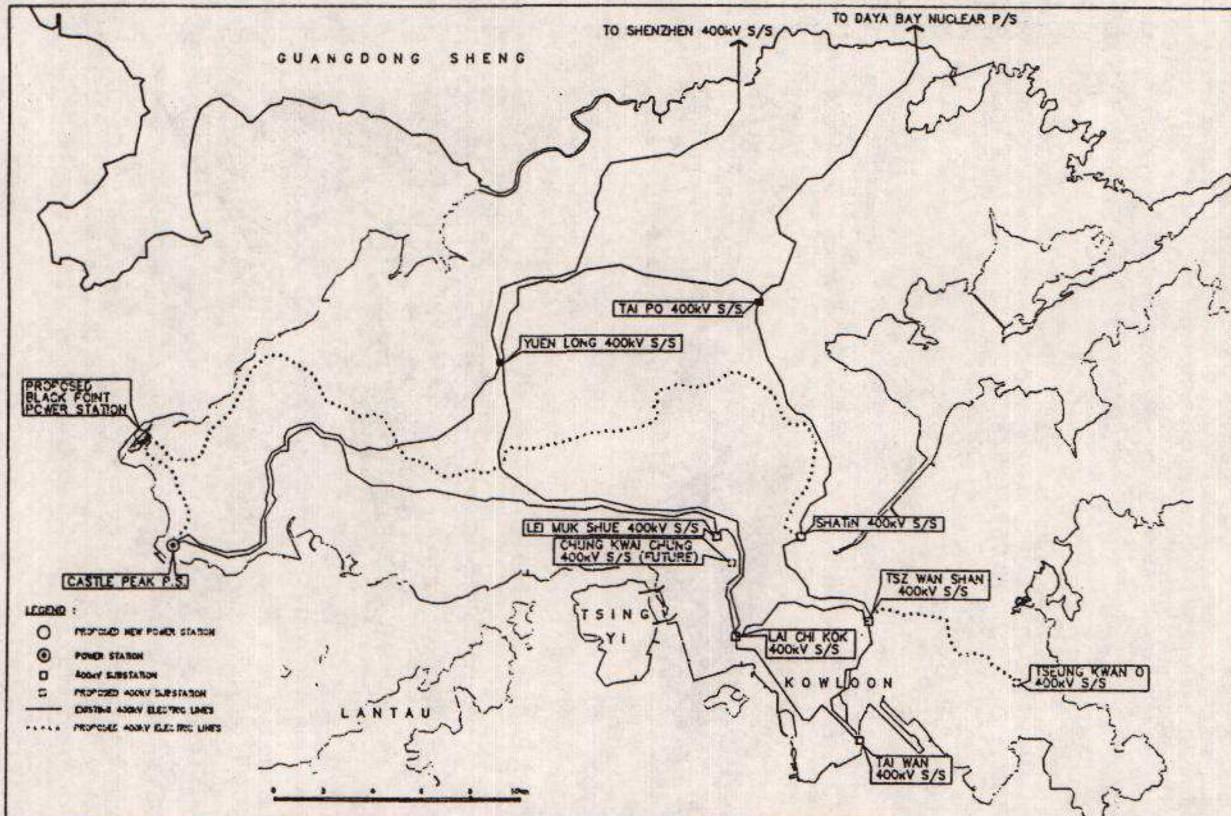



FIGURE 4: PROPOSED BLACK POINT 400 kV TRANSMISSION LINKS