# Elevgraphy for Lift Energy Code in Hong Kong

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## ABSTRACT

The Code of Practice for Energy Efficiency of Lift and Escalator Installations (Lift Energy Code) was drafted in 1998 in Hong Kong. Quite different from the conventional statutory regulations on lifts and escalators in Hong Kong, the Lift Energy Code places the emphasis on the performance of the installations in terms of motor drives, traffic analysis and electric power quality etc. In this paper, I shall introduce the various items inside the code. Furthermore, in order to check whether an installation complies with the electrical requirements inside the Lift Energy Code, a new system, Elevgraphy, was developed. Elevgraphy is a system consisting of a synchronised high-speed oscillogram and a synchronised comfort recorder. A software package, ElevWare, is used to analyse the raw data to produce 12 Elevgrams for each lift for either a full-load up or full-load down journey. Besides an assessment for the compliance of the Lift Energy Code, Elevgraphy is a useful system for condition based maintenance of elevator systems.

## 1. INTRODUCTION

Energy has been one of the key elements that ensure a continual economic growth of Hong Kong over the past decades (Lam 1999). Over the period from 1987 to 1997, the total primary energy consumption in Hong Kong has increased from around 333,000 TJ to about 472,000 TJ, with an average annual growth rate of about 4% which was 2.4 times the world's average over the same period. During the same period, the final energy consumption (Census 1996) for 1987 was around 187,000 TJ and about 294,000 TJ in 1997 with an average annual growth rate of about 5%. The concern about energy conservation reached its summit in 1973 due to the global impact from the oil crisis. Thereafter, technologies and policies related to energy saving have become very popular everywhere around the world. In 1996, the Energy Advisory Committee (EnAC) was established in Hong Kong to look into a wide scope of energy issues under which an Energy Efficiency and Conservation Sub-Committee (EE&C SC) was formed. Based on the recommendation by EE&C SC, a series of building energy codes has been prepared. The Code on Overall Thermal Transfer Value was completed by the Buildings Department in 1995. The Codes on Lighting, Air-conditioning and Electrical Energy were published by the Energy Efficiency Office of Electrical & Mechanical Services Department in 1998.

The last code, Code of Practice for Energy Efficiency of Lift and Escalator Installations (Lift Code) was drafted in late 1998 and it is now under public trial. The Lift Code has been quite different from all existing statutory regulations for lifts and escalators in Hong Kong in that its emphasis is placed upon the performance of the installation instead of the safety aspects. The performance is evaluated in three aspects, namely motor drives, traffic analysis and electric power quality. This paper will introduce various requirements inside the Lift Code and clarify the definition of some technical terms. In order to assess whether an installation complies with the electrical requirements of the Lift Code, a new system entitled Elevgraphy was developed, which gives a clear picture about the power consumption, total power factor and total harmonics distortion of a drive under a full trip.

## 2. THE LIFT CODE (Yip 1997, EEAC 1998)

The Lift Code sets out the minimum requirements for achieving energy efficient design of lift, escalator and passenger conveyor installations in buildings. The requirements can be categorised into five major areas:

(i) maximum allowable electrical power
(ii) zoning
(iii) lift system control
(iv) energy management
(v) electric power quality

### 2.1 Scope of Application

The Lift Code applies to passenger lifts (both traction type and hydraulic type), freight lifts, escalators and passenger conveyors in all buildings with some exemptions such as builders' lifts and service lifts etc. It applies to new installations and alterations of motor drive and controller only.

### 2.2 Maximum Allowable Electrical Power

The running electrical power of any traction lift system carrying a rated load at its rated speed in an upward direction is limited based on the rated speed and the rated load. An example is shown below in Table 1 where the rated load is between 1,350 kg and 1,600 kg.

*Table 1.*

| Rated Load L(kg) | Maximum Allowable Electrical Power (kW), P, of Traction Lift Systems for various Ranges of Rated Speed, $V_c$ (m/s) | | | | |
|---|---|---|---|---|---|
| P (kW) | | | | | |
| $1350 < L \le 1600$ | $V_c \le 1$ | $1 < V_c \le 1.5$ | $1.5 < V_c \le 2$ | $2 < V_c \le 2.5$ | $2.5 < V_c \le 3$ |
| P | 15 | 20 | 27 | 32 | 38 |

For hydraulic lifts, the maximum allowable electrical power under no-load condition depends on the rated load only. For example, P for a rated load between 2000 kg and 3000 kg is 75 kW, independent of rated speed. For escalators and passenger conveyors, P is dependant of the step width, the rise in metres in case of escalator and the rated speed in m/s.

## 2.3 Handling Capacity

A lift bank serving a sky lobby must have a passenger handling capacity not less than 20% while a lift bank serving zones shall have a passenger handling capacity not less than 10%.

## 2.4 Lift Traffic Design

For any passenger lift system which forms the main mode of vertical transportation and fulfilling all the conditions, i.e. rated speed of any car exceeds 1.5 m/s; building has at least 10 stories; building usage is of zone type, a lift traffic analysis has to be carried out to optimise lift traffic flow. The maximum interval of a lift bank is stipulated in Table 2.

*Table 2.*

| Zone Type | Office | Hotels | Institutional | Commercial | Industrial |
|---|---|---|---|---|---|
| Maximum Interval (s) | 30 | 40 | 45 | 30 | 55 |

## 2.5 Energy Management

Metering devices or provisions for connection with such devices for monitoring the electrical parameters of lift or escalator drives must be available. Suitable accessibility and sufficient space must be ensured during the design stage. In particular, for DC M-G approach of lift drives, a standby mode during off-peak period must be provided so that the lift car will not respond to passenger calls until it returns to the normal operational mode again.

## 2.6 Electric Power Quality

The total power factor of a lift drive or an escalator/conveyor drive must not be less than 0.85 when the lift car is carrying a rated load at its rated speed in an upward direction or when an escalator/conveyor is operating with no load at its rated speed. At the same conditions, the total harmonic distortion (THD) of both types of drives is under control according to the following Table 3.

*Table 3.*

| Circuit Fundamental Current of Drive | $I < 80$ A | $80\text{ A} \le I < 400$ A | $400\text{ A} \le I < 800$ A |
|---|---|---|---|
| Maximum THD (%) | 35.0 | 22.5 | 15.0 |

## 2.7 Definitions of Parameters (So 1997)

There are several definitions in the Lift Code, which are related to traffic analysis. "Interval" of a lift bank is equal to the up-peak Round Trip Time (s) divided by the quantity of lifts in the lift bank. "Passenger Handling Capacity" for a lift bank is defined as a ratio of 240 times the lift car contract capacity in terms of number of passengers to the a product of the interval (s) by the population above the terminal floor of the zone. "Round Trip Time" of a lift car refers to a value calculated by conventional method (CIBSE 1993).

There are also three important electrical parameters mentioned inside the Lift Code. The "Total Power Factor (TPF)" of a lift drive or an escalator drive is defined as:

$$\text{Total Power Factor (TPF)} = \frac{P}{\sqrt{P^2 + Q^2 + D^2}} \qquad (1)$$

where $P$ = active power (fundamental)
$Q$ = reactive power (fundamental)
$D$ = distortion power

Here, P is measured in kW; Q is measured in kVAr; D is measured in kVAd. All harmonic components contribute to the value of D. Another parameter is "Total Harmonic Distortion (THD)" which is defined as:

$$\text{Total Harmonic Distortion (THD)} = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \qquad (2)$$

where $I_1$ = r.m.s. value of fundamental current
$I_h$ = r.m.s. value of the $h^{th}$ harmonics

With the pollution of harmonics and the unavoidable imbalancing situation of the three-phase system, it is not so straight forward to measure the active power, in kW, of a lift drive or an escalator drive. Furthermore, it is extremely difficult, almost impossible, to determine the distortion power, D, directly. It is therefore difficult to determine the TPF.

We have been so familiar with definitions of electric power and power factor for fundamental frequency only, i.e. 50 Hz in our case or 60 Hz in USA. With the existence of harmonics, both voltage source and current source, it will not be so straight forward to define them. TPF is different from the classical power factor in that it includes the consideration of harmonics. Furthermore, it is easy to define power factor under single phase or balanced three phase conditions. Our experience has revealed that the electric power supplies of almost all lift and escalator motor drives are not equipped with a neutral cable and measurements, so far, have revealed that they are never totally balanced, normally a slightly heavier current loading with the red phase in Hong Kong. If the neutral wire is available, we can obtain the TPF of each phase, thus arriving at three different values. The Lift Code asks for one figure of power factor to represent the whole supply. What could we do?

Harmonic distortion complicates the computation of power and power factor because the conventional simplifications that power engineers have used for centuries on power analysis do not apply. There are three standard quantities associated with power. The apparent power (S) is proportional to the product of the r.m.s. values of voltage and current. The active power (P) is the average rate of delivery of energy, which can be defined in two ways as shown in equation (3).

$$P = V_1 I_1 \cos\theta_1 \quad (E.M.S.D.) \quad ; \quad P = \sum_{k=1}^{\infty} V_k I_k \cos\theta_k \qquad (3)$$

The first definition has been adopted by E.M.S.D. in the Electrical Code (EEAC 1998) while the second definition is used in most textbooks. The digital wattmeter available in the market usually gives us active power based on the second definition. Here, $V_1$ refers to the r.m.s. value of fundamental of the voltage waveform and $I_1$ refers to the r.m.s. value of fundamental of the current waveform. If a harmonics analyser is available, one can get $V_1$, $I_1$ and $\cos\theta_1$ easily and get P by manual calculation. Fortunately, when there is no distortion with the voltage waveform, both definitions will give identical results. The reactive power (Q) is the portion of the apparent power that is out of phase with the active power, at the fundamental frequency. Similarly, Q has two definitions, as shown below:

$$Q = V_1 I_1 \sin\theta_1 \; (E.M.S.D.) \quad ; \quad Q = \sum_{k=1}^{\infty} V_k I_k \sin\theta_k \tag{4}$$

The first one has been adopted by E.M.S.D. in the Electrical Code and the second one is used in most textbooks.

S, under a 3-phase balanced condition or a three phase supply with the neutral cable, and P are unambiguously defined with distorted voltage and current. P is usually measured by the famous two-wattmeter method. S is given by:

$$\begin{aligned} S &= \sqrt{3}\, V_{R\text{-}Y} I_R \quad \textit{for balanced 3-phase} \\ &= V_{R\text{-}N} I_R + V_{Y\text{-}N} I_Y + V_{B\text{-}N} I_B \quad \textit{for 3-phase with neutral} \end{aligned} \tag{5}$$

Here, $V_{R\text{-}Y}$ is the r.m.s. value of line voltage between red and yellow phases and $I_R$ is the r.m.s. value of line current of the red phase. $V_{R\text{-}N}$ refers to the r.m.s. value of phase voltage of red phase and so on.

It is almost impossible to define or measure S when the three phase supply is not under a balanced condition and at the same time, without a neutral cable. However, it is normal that the electric power supplies to lift and escalator drives are 3-phase 3-wire only. But, if S is unknown, TPF cannot be estimated. Hence, S can be measured by using equation (5) and replacing $V_{R\text{-}N}$ by $V_{R\text{-}E}$, so on and so forth. $V_{R\text{-}E}$ is the r.m.s. value of voltage across the red phase and the earth. Finally, the distortion power, D, is calculated by the following equation:

$$D = \sqrt{S^2 - P^2 - Q^2} \tag{6}$$

The fundamental frequency component of the reactive power, $Q_1$, is useful for helping electrical engineers size capacitors for power factor correction. The term, displacement power factor, i.e. $\cos\theta_1$, is used to describe the power factor using the fundamental frequency components only. Power quality monitoring instruments now commonly report the displacement power factor as well as the true power factor, or total power factor (TPF), which is defined by the following equation:

$$TPF = \frac{P}{S} \tag{7}$$

Nowadays, we have different grades of instruments for measuring the power quality of the supply to a lift or escalator drive or other power points. For comprehensive measurement, a typical example is the Power Platform of Dranetz which can monitor a 3-phase system. For single phase application, Fluke 49 and 41B devices are economical solutions. Recently, a very useful piece of equipment was developed by Johnson Controls Intelligent Building Research Centre of City University of Hong Kong, entitled BEPSA. BEPSA stands for Building Electric Power System Analyzer. It can be permanently installed to monitor any power point from 200 A to 2500 A, producing all useful real-time parameters of the power point and data can be freely transmitted to any Building Automation Systems via the standard RS 485 network. For measuring the electric power quality and other useful parameters to reveal the performance of a lift or an escalator, we have developed "Elevgraphy" which is described in the following section.

## 3. ELEVGRAPHY

### 3.1 The Hardware and Operation of Elevgraphy

There are mainly two sub-systems with respect to the hardware of Elevgraphy. One sub-system is placed inside the lift machine room or next to the machine compartment of an escalator drive. Three current transformers are used to record the 3-phase current of the controller. Three voltage probes are used to record the 3-phase supply voltage to the controller. The earth terminal of the controller is used as the reference point of voltage measurement. This is very important as almost all lift and escalator drive controllers are not supplied with the neutral cable. These seven leads are connected to a high speed 8-channel digital recorder. The digital recorder is controlled using a standard Pentium notebook computer. Besides the essential electrical parameters, an optical tachometer is used to record the real-time speed of the lift car. The tachometer continues to monitor the rotation of the driving sheave where some reflective tapes are stuck on. The real time vibrational level of the motor is monitored by a vibration sensor. The vibration sensor is supported by a magnetic holder so that it can be fixed on the external casing of the motor. The signal of the sensor is amplified by a coupler and then transferred to the digital recorder. The signal from the tachometer is directly fed to the digital recorder.

Another sub-system is placed inside the lift car. It is a PMT EVA-625 recorder. The recorder is controlled by another notebook computer. Synchronization between the two notebook computers is necessary in order to ensure the real-time recording commences at exactly the same time. The synchronization must be wireless because of the physical locations of the two sub-systems.

In the case of an escalator, the digital recorder is again interfaced to the notebook computer. The placement of the current transformers and the voltage probes is similar to that for the lift. The tachometer is supported on a tripod and used to measure the rotating speed of a turning wheel of the escalator. Again, the vibration sensor is attached to the motor casing of the drive magnetically. The PMT EVA-625 is put on one step and it is used to record the vibration and noise level when the escalator is travelling downwards and upwards.

It takes about forty minutes to set up the two sub-systems in the machine room and in the lift car. These forty minutes are for the preparation work. Ten minutes can be saved for an escalator or conveyor because the two sub-systems are quite close to one another physically. For a lift, a "no-load up" and a "no-load down" operations are performed for cost justification although the Lift Code asks for full-load operation. As the lift car is generally equipped with a counterweight, a "no-load down" journey is more or less equivalent to a "full-load up" journey while a "no-load up" journey is more or less equivalent to a "full-load down" journey. Each operation has a duration of about forty seconds. It normally takes twenty more minutes to pack up all devices. Hence, the whole exercise takes about one hour and ten minutes for a lift. For an escalator, the two operations are performed similarly, taking about one hour for the whole exercise.

### 3.2 The Elevgrams

The concept of Elevgrams is to display the profile of variation of all relevant parameters associated with a lift or an escalator for the compliance with the Lift Code. One complete journey consisting of acceleration, rated speed operation and deceleration is considered. A "no-load down" journey is first recorded, followed by a "no-load up" journey, which has been explained in the previous section. However, according to the statutory regulations for safe operation of escalators in Hong Kong, only "no-load" journey is considered for escalators.

There are 12 Elevgrams for each journey, displaying the three phase voltage in r.m.s. values, the three phase current in r.m.s. values, P, accumulated energy, TPF, THD of the three phase voltage, THD of the three phase current, displacement, speed, vertical and horizontal vibrations of the lift car or the step, sound level inside lift car or on the step and finally the motor vibration. With these 12 Elevgrams, both the electrical and mechanical parameters can be revealed along one full journey of either the lift or the escalator. The information is not just useful to check the installation against compliance with the Lift Code but is also providing an important clue for condition based maintenance of the installation.

## 4. CONCLUSION

The basic requirements of the Code of Practice for Energy Efficiency of Lift and Escalator Installations recently published have been discussed in reasonable details. It can be seen that the Lift Code concentrates on the performance of the installation instead of safety aspects. Five major items are included, namely maximum allowable electrical power, zoning, lift system control, energy management and electric power quality. Several technical parameters mentioned in the Lift Code have been explained and clarified in this paper, namely interval, passenger handling capacity, total harmonics distortion and total power factor etc. Finally, in order to check whether an installation complies with relevant clauses inside the Lift Code, a new system, Elevgraphy, has been developed. The hardware configuration and operational procedures have been discussed briefly. The contents of the 12 Elevgrams have also been hightlighted. It is hoped that readers can gain an in-depth understanding on the new Lift Code and the developed technologies associated with it.

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## 7. BIOGRAPHY

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