KVAH BASED TARIFF

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ABSTRACT

In this article the disadvantages of kWh/kVARh based tariff and the benefits of kVAh metering &billing are studied from the viewpoint of suppliers. And new formulae for electricity billing calculation are innovated as new billing standards.

INTRODUCTION

Edison in 1892 starts up electricity metering by his first electric company for incandescent illumination. Initially he started out with a per-lamp rate. This was unsatisfactory so he developed a chemical ampere-hour meter that consisted of a jar holding two zinc plates connected across a shunt in the customer's circuit. Each month the electrodes were weighed and the customer's bill determined from the change in their weight. This meter was inefficient and error-prone. Thomson in 1989 by his Thomson-Houston Electric Company introduced his recording wattmeter. This was the first true watt-hours meter, and it was an immediate commercial success, many utilities adopting it as their "standard" model.

Since that time the kWh& kW has remained as fixed units for electricity energy&demand metering, although the pursuit of kVARh meters dates back to about 1915 and kVAh metering to about 1935. In spite of the fact that electricity metering technology has developed step by step, the kWh& kW remained as valid units for electricity energy &demand measuring through the century. By comparing the electricity billing and metering, it is noticed that the electricity tariffs and billing hasn't developed in proportion to metering devices technology. Hence it must be developed to agree with the new conditions such as: electricity marketing and networking, international electricity trade, power quality standards. The electricity charges must contain quantitative as well as qualitative components motivating the customers to improve their quality criterion. The electricity meters are manufactured according to international standards. But there aren't any identified standards for electricity billing .So it is necessary that the electricity based tariffs and metering units be redefined and reproduced.

The national electricity regulations for tariffs & billing must be substituted by international regulations for networking in an open electricity market, not restricted by national borders. It is not accepted that the electricity power that transfers by the speed of light, be confined within national limits.

ELECTRICITY BILL COMPONENTS

The electricity billing commonly is consisted of three variable components plus at least one constant charge.

The variable components are as follows:

1- Active energy charge that is metered per kWh unit.
2- Reactive energy charge (power factor penalty) that is metered per kVARh unit.
3- Demand charge that is metered per kW unit in consecutive periods of time.

The electricity charges are two kinds: tariffs & penalties

Tariffs are those charges that are applied to quantitative components and are levied in any condition and by any amount, like active energy and demand.

Penalties are those charges that are applied to quantitative components and are suspended to the amount of quality criterion limited by ideal amounts (threshold limits). If the amount consumption of a qualitative component cause the quality criterion exceeds the threshold limit, the penalty will be levied, like reactive penalty that is limited by an ideal power factor (threshold limit) between 0.8-0.95.

KWH/KVARH BASED TARIFF

The electricity power in normal condition (fundamental harmony) is consisted of two components; active and reactive.

The active or real power is actually consumed and converted into useful work for creating heat, light and motion and is measured in (kW) and is totalized by the electric meter in (kWh).

The reactive power that is measured by (kVAR) and is totalized by the meter in (kVARh) unit is the power used to provide the electromagnetic field in inductive and capacitive equipment. It isn't actually consumed but it is conserved as a potential energy in electromagnetic field and has a periodic movement (oscillation) between power supplier and power consumer. Therefore the reactive power can not be converted to work but its existence is necessary for converting the electric energy to work and vice versa. Hence the reactive power occupy the capacity of electricity network and reduce the useful capacity of system for generation and distribution of the active power& energy and so increase the power& energy losses in electricity network. In any case the customer compensates the losses either by power factor penalty or by locally individual capacitive compensator and in either case the customer is charged.

For reactive compensation the customer has two options: Either pays monthly low charges for penalty, or pay a high charge once for ever.

The story of separation

Why the electricity energy &demand are separated into two active & reactive components?

This story dates back to the records of metering technology development.

There were three sons in Bill family. At first the kW was born in 1889 and then the kVAR was born in 1915 and at last the kVA was born in 1935.

So the active and reactive meters were made separately as well as the active and reactive tariffs were appeared separately in electricity bill.
On the other side the conventional electromagnetic meters couldn't measure the apparent: energy & demand. A conventional electromagnetic meter can measure either active or reactive component. So there were two separated meters and two separated charges for active &reactive components.

The end of story

Since innovating the trivector electronic meters the time has ended for separated active and reactive electricity component metering and billing by development of electricity metering technology. But the effects of conventional meters are still remaining in electricity billing. The electricity billing hasn't developed as well as the electricity metering technology.
Whereas the trivector electronic meters can measure the apparent energy & demand, why must they be divided in two active and reactive components?
There is no satisfactory answer to this question, unless to say we respect the old traditions. If it be true it would be better returning back to Edison's chemical meter and weighing the zinc electrodes monthly.
But the time cannot return to the past. The time of application of kWh/kVARh meters and tariffs is ended and it must be put in the museum of electricity history, like Edison's meter as well as his per lamp and ampere-hour billing.

Struggle for existence

The conventional meters and their manufacturers still struggle for existence. But who can accept that the orange, peeled, be weighed and sold, or who can visualize that the orange's nucleus and its skins be bought, separately with different prices?
The apparent power & energy like orange have two components, the active power & energy like orange's nucleus is consumable and reactive power & energy like orange's skin isn't consumable and must be thrown away.
As the existence of orange skin is natural and necessary for its consumption, likewise the electricity reactive existence is necessary for its use. Therefore the separation of two power electric components is unnatural and unnecessary by the electricity supplier like peeling the orange by orange seller. The reactive energy isn't consumed but it is necessary for energy consumption by maintaining the magnetic field in the load .If the reactive is not available at the load end locally, the same is drawn from the Gird system leading to additional current flow in the transmission and distribution lines, cables, transformers and switchgears all leading to higher losses in the network leading to missing occasions for real consumption. Only the apparent energy must be metered and sold and billed by the supplier to the customer without its components. The separation of active and reactive components should be optional and must be left to the customers' choice.

KVA/KVAH METERING &BILLIN

kVA metering

There are 3definitions of kVA:
Phasor kVA(S):
The phasor power in a nonharmonic environment with liner loads and elements is consisted of two active and reactive components. According to CBIP88 standard it is defined as the vector sum of the active and reactive components and is measured per kVA. In such condition the phasor power is equal to apparent power:

$$\vec{S} = \vec{P} + \vec{Q} \Rightarrow S = \sqrt{P^2 + Q^2} \Rightarrow kVA = \sqrt{kW^2 + kVAR^2}$$

Computing of kVAh based on kWh and kVARh gives erroneous results under varying power factor condition and therefore, cannot be used. Hence the issue of kVA measurement for a consumer was limited to kVA maximum demand for a particular period, and too for large consumers.
Apparent kVA:
In a harmonic environment with nonlinear loads and elements the apparent power is consisted of three components, included distortion component (D), in this condition the apparent power is greater than phasor power. Present standards such as CBIP88 have not included D in the definition of kVA.The apparent kVA in 1phase systems is the vector sum of P, Q and D; it is also the simple product of Vrms and Arms.

$$\vec{U} = apparent\ kVA = \sqrt{P^2 + Q^2 + D^2} = V_{rms} A_{rms}$$

The 3ph apparent kVA is defined as the vector sum of the 3×1ph apparent kVA:

$$\vec{U}_{3ph} = 3\,ph\,apparent\ kVA = \vec{U}_1 + \vec{U}_2 + \vec{U}_3 = \vec{V}_1\vec{A}_1 + \vec{V}_2\vec{A}_2 + \vec{V}_3\vec{A}_3 = V_{rms} A_{rms}$$

$$\vec{U}_{3ph} = \sqrt{(P_1 + P_2 + P_3)^2 + (Q_1 + Q_2 + Q_3)^2 + (D_1 + D_2 + D_3)^2}$$

Arithmetic kVA:
The 3ph arithmetic kVA is defined as the scalar sum of the 3×1ph apparent kVA:

$$U_{3ph} = arithmetic\ kVA = U_1 + U_2 + U_3 = V_1 A_1 + V_2 A_2 + V_3 A_3$$

$$U_{3ph} = \sqrt{P_1^2 + Q_1^2 + D_1^2} + \sqrt{P_2^2 + Q_2^2 + D_2^2} + \sqrt{P_3^2 + Q_3^2 + D_3^2}$$

The 3 phase arithmetic kVA doesn't care about the angles of the phase-wise VA vectors and stacks them straight up, end to end. Whereas, the apparent power addition carries out vector addition in 3D.The difference between two recent kVA definitions appears only in 3 phase calculations.
The arithmetic kVA is normally not defined in terms of Spectrum, but can contain many more bands than apparent kVA .So the arithmetic kVA is the greatest kVA and therefore is suitable for unbalance power consumption penalization while the apparent kVA is greater than the phasor kVA: $S \le \vec{U}_{3ph} \le U_{3ph}$

The advantages of kVA/kVAh billing

1-calculation of distortion component:
In a nonharmonic environment (sinusoidal waveform of current &voltage) the apparent power (kVA) is the vector sum of the active and reactive power and represents the complete burden on the electrical system.
But in a harmonic condition that is produced by nonlinear elements and loads the kW/kVAR spectra do not contain many of the harmonics in current. So, true RMS, harmonic sensing meters still sense relatively few harmonics in W,

VAR, only those that are common to voltage and current. The difference is present in D. The apparent kVA includes the kW / kVAR as well as the Distortion component that is disregarded now in kWh/kVAh separated metering& billing, while it would be considered and calculated in kVAh based tariff.

2- The exemption of leading power factors is eliminated: There is no difference between leading and lagging power factor in reduction of network capacity and increasing the energy and power losses. But traditionally the power factor penalty is calculated only for lagging power factor because in conventional electromagnetic meters, the rotating disk in lagging or leading states rotates in two different direction and measure net reactive power. So it isn't permitted to rotate in leading state by a brake system.

While in apparent based tariff there is no difference between leading and lagging reactive power and there would be no exemption for leading power factor.

3-The exemption of p.f threshold limit is eliminated: An incentive threshold limit is defined for lagging power factor between 0.8- 0.95 varying in any utility according to regulation or contract. The power factors greater than the threshold limit are exempted from penalization. While the power factors less than the threshold limit are levied p.f penalty. For example by threshold limit of 90% the customer is permitted to reduce 10% of network capacity without levying penalty: kW ≥ 0.9kVA→p.f penalty = 0

The incentive power factor motivates the consumers to improve their power factors achieving higher power factors. According to kVAh based tariff, the accepted threshold limit of p.f is just 1, therefore wouldn't be any penalty exemption for power factor neither lagging nor leading.

4-The1phase customers will be levied p.f penalty: As a billing tradition the p.f penalty is defined only for 3ph customers, therefore 1ph customers pay no charges for their reactive consumption. The pursuit of this tradition dates back to capability of conventional electromagnetic meters that were unable to measure 1ph reactive power consumption because the angle between voltage and current vectors could not be measured by them directly, unless the voltage and current coils of 1ph meter be fed by two different phases. This exemption is incentive for 1ph customers that load the most reactive power to the network by usage of poor power factor equipments and don't care about their power factor improvement. This is the sever harm that is loaded by electricity customers to suppliers because of kWh/kVARh based tariff and will be eliminated by kVAh based tariff. If so, all customers will pay their apparent energy consumption charges including reactive component either 1ph or 3ph consumer.

POWER FACTOR MEASURMMENT

There are various methods for power factor calculation:

Average power factor

The average power factor is the average since the last demand reset. The power factor calculations are selectable, based on RMS or Time Delay (TD) method.

RMS method:

average p.f = kWh /kVAh (rms)

kVAh (rms) does not distinguish between lead and lag.

TD ignore lead method:

average p.f =kWh/kVAh where:

$$kVAh = \sqrt{kWh^2 + kVARh.lag^2}$$

TD add lead method:

average p.f = kWh/kVAh where:

$$kVAh = \sqrt{kWh^2 + (kVARh.lag + kVARh.lead)^2}$$

TD net method:

average p.f = kWh / kVAh where:

$$kVAh = \sqrt{kWh^2 + (kVARh.lag - kVARh.lead)^2}$$

The kVAh that is derived from kWh and kVARh by time TD method is much smaller than genuine kVAh (rms) integrated continuously by meter. Therefore the power factors calculated by TD method are not true. This error will be eliminated by kVAh based tariff.

POWER FACTOR PENALTY CALCULATIONS

There are various power factor penalty calculation methods for electricity billing as follows:

Power factor penalty rated by ¢ /kVAR fee

In this method the power factor penalty is applied to the reactive demand as an additional demand charge. While the active and reactive demands are measured simultaneously. If the reactive demand in(kVAR) is lagging and exceeds a definitive percentage of such metered active demand (power factor became lower than the threshold limit) , in the same period that the customer's highest active demand metered occurs ,therefore shall be added to the customer's bill a reactive charge rated by definitive ¢ /kVAR fee.

If the reactive demand (in kVAR)is leading in the same period that the customer's lowest metered demand occurs , there shall be added to the customer's bill a reactive demand charge rated by definitive ¢ /kVAR fee.

Power factor penalty rated by ¢/kW fee

In this method the power factor penalty is calculated as an additional demand charge. If the normal demand charge be $5per kW per month, the power factor penalty might add $2 additional per kW per month to the charge for total of $7 per kW per month. This extra amount would be the penalty paid because of the power factors lower than the threshold limit.

p.f penalty as a percentage of total charges

In this billing method, the power factor penalty is levied as an additional charge (surcharge) for both component (demand and energy) charges. It is calculated as a definitive percentage of total charges including: demand and energy. The percentage amount depends on the power factor amount. For example the penalty of 1%, 2%, and 3% of total charges may be levied for the power factors of 0.85, 0.8, and 0.75.

Formulation of power factor penalty

Based on the previous billing methods the power factor penalty is calculated either by rating the active& reactive demand by (¢ /kW&¢ /kVAR) fee or by stairal percentages of total billing charges. But there is not defined an equation relating power factor and penalty together. Two billing methods can be used for formulating the p.f penalty:

Difference of power factors method:

P.f penalty = (ideal p.f- real p.f) (Demand charge)

P.f penalty= (ideal p.f- real p.f) (demand+ energy) charges

Where the ideal p.f is the threshold limit of power factor and the real p.f is the measured power factor. According to above equations the p.f penalty is defined as a function of either demand charge or total charge.

Ratio of power factors method:

$$P.f\ penalty = \left(\frac{ideal\ p.f.}{real\ p.f.} - 1\right)\ (demand\ charge)$$

$$p.f\ penalty = \left(\frac{ideal\ p.f.}{real\ p.f.} - 1\right)\ (demand\ +active)\ charges$$

According to above formulae if the real p.f be equal to ideal p.f, then the power factor penalty is zero. By the power factors lower than the ideal amount the penalty is greater than zero. The penalty calculated by this method is greater than the previous method.

$$real\ p.f. \geq ideal\ p.f. \Rightarrow p.f.\ penalty = 0$$

$$real\ p.f. \leq ideal\ p.f. \Rightarrow p.f.\ penalty \geq 0$$

By substituting the units and rates in the above formulae:

$$P.f\ penalty = \left(\frac{ideal\ p.f.}{real\ p.f.} - 1\right)\ (kW \times ¢/kW) \qquad \underline{0}$$

$$P.f\ penalty = \left(\frac{ideal\ p.f.}{real\ p.f.} - 1\right)(kWh \times ¢/kWh + kW \times ¢/kW) \qquad \underline{1}$$

The equation ***1*** in compared with ***0*** attract more benefits for suppliers and has more match with the real, because the reactive power effects on both energy and demand consumption, so it is selected for billing.

Billing equation

The total electricity charge in abnormal condition (p.f lower than the ideal amount) is the sum of power factor penalty and the demand &energy charges in normal condition (p.f equal to or greater than the ideal amount):

Electricity bill =Total charge = normal charge + p.f penalty = (demand charge +energy charge) +p.f penalty

By substituting the equation***1***and electricity rates and units in above formula the electricity bill equation is derived as:

$$Electricity\ bill = \left(\frac{ideal\ p.f}{real\ p.f}\right)(kW \times ¢/kW + kWh \times ¢/kWh) \qquad \underline{2}$$

By the amount of 0.9 for ideal p.f, equation **2** is derived as:

$$Electricity\ bill = (0.9/p.f)\ (kW \times ¢/kW + kWh \times ¢/kWh) \qquad \underline{3}$$

This is the final billing equation for kWh/kVARh/kW based tariff that is suggested to be as the billing standard.

KVA/ KVAH BASED TARIFF

Equation ***3*** calculates the kVA/kVAh based tariff indeed:

$$Electricity\ bill = 0.9(\left(\frac{kW}{p.f}\right)¢/kW + \left(\frac{kWh}{p.f}\right)¢/kWh)$$

$$Electricity\ bill = kVA \times ¢/kVA + kVAh \times ¢/kVAh \qquad \underline{4}$$

When: ***1¢/kVA= 0.9¢/kW, 1¢/kVAh= 0.9¢/kWh***, there would be no changes in the amount of bill, in spite of changing the billing method.

When: ***1¢/kVA= 1¢/kW, 1¢/kVAh =1¢/kWh***, the ideal p.f is 1 instead of 0.9 and the incentive exemption is removed.

KVAH (DEMAND) BASED TARIFF

By kVA/kVAh based tariff, the effect of power factor in billing is eliminated and the billing components are reduced from 3 to 2 containing: apparent demand &energy tariffs.

By considering the time of use tariffs, each of those tariffs are separated at least to two components consisting of: peak &off peak loads. The time of use tariffs are defined for improving the customer's load factor. The load factor is the ratio of average power to maximum power (demand). BY load factor calculation, the load profile uniformity is measured. By the amount of 1 for load factor, the load profile will be a straight line parallel to the time axis.

Therefore the load factor can be substituted by time of use tariffs in the electricity billing calculation. On the other side the load factor has an inverse relation with demand.

By demand reduction the load factor is increased.

Then the load factor can be substituted by demand tariff. Therefore the load factor is playing two roles in billing calculation. Load factor improvement reduces both charges: demand tariff & peak load tariff. By substituting the load factor in equation ***4***, the all four tariff components consisting of; demand, energy, peak load, off peak load can be unified in one component as follows:

$$Electricity\ bill = (kVAh \times ¢/kVAh)\ /apparent\ load\ factor \qquad \underline{5}$$

$$apparent\ load\ factor = \frac{average\ apparent\ power}{apparent\ demand}$$

$$apparent\ load\ factor = \frac{apparent\ energy}{total\ time\ per\ hour \times apparent\ demand}$$

$$apparent\ load\ factor = \frac{kVAh / hours}{kVA(demand)} = \frac{kVAh}{hours \times kVA(demand)}$$

By substituting the amount of apparent load factor in equation**5**, the single component billing equation is derived:

$$Electricity\ bill = kVA\ (demand) \times hours \times ¢/kVAh$$

$$Electricity\ bill = kVAh\ (demand) \times ¢/kVAh \qquad \underline{6}$$

This tariff is suitable for suppliers and customers with approximately constant demands as nuclear plants and must be optional. An incentive ideal load factor (the threshold limit 0f 0.7, is suggested) must be applied in this tariff for motivating the customers to select this tariff and to improve their load factors. Then the final billing equation is derived:

$$Electricity\ bill = 0.7 \times kVAh\ (demand) \times ¢/kVAh \qquad \underline{7}$$

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