# Residential Tariff Modification to Cater Impacts of Poor Power Factor

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***Abstract:*** *Modern power electronic controlled consumer appliances and trend towards energy conservation have resulted in extremely low power factor for residential and commercial consumers being billed without considering their load power factor. Poor power factor of the consumer appliances increase load current and thus power losses are increased resulting in decreased overall system efficiency. Additionally high rating distribution transformers and conductors are required to supply such loads causing increased initial cost.*

*In this research work, residential consumer survey is conducted to observe their running power factor at different times. Survey reveals that consumer power factor is well below 0.8 lagging and confirms that such consumers are contributing in power losses. Apparent power tariff is proposed to incorporate impacts of power factor directly in bill. Base power factor is set at 0.866 where billed amount of consumer for existing and proposed tariff will be equal. With proposed tariff, consumers having power factor greater than base power factor will pay less whereas with lower power factors will pay more. Hence variation in billed amount is inversely proportional to power factor. Proposed tariff will benefit utility by either recovering amount for power losses or having reduced power losses.*

***Key Words:*** *Power factor, Tariff, Apparent power, kVA based tariff.*

## 1. INTRODUCTION:

Electrical energy is most widely used form of energy due to its cleanliness and ease of control [1]. A power system mainly consists of large generating stations, interconnected transmission network and distribution system, Modern power systems have incorporated a small portion of distributed generation (DG) directly connected to distribution network [2]. In Pakistan distribution system is radial in nature where secondary distribution starts from 132/11 kV substation. 11 kV feeders run around the area to supply loads. At different locations utilization transformer convert 11 kV into 400V three phase which is equivalent to 230V for single phase connection [2].

Electricity consumers are classified according to nature of use as residential, commercial, industrial, agriculture and bulk supply. Industrial consumers are required to maintain their power factor above 0.9 lagging. If consumer power factor falls below 0.9 lagging, they are bound to pay power factor penalty for reduced power factor [3]. For this purpose, both active and reactive energy meters are installed along with a maximum demand meter. If X and Y are respectively number of active and reactive energy units consumed in a month. Z is maximum demand recorded by meter. Recorded Power Factor (RPF) is calculated using relation given in Eq. (1)

$$RPF = \sqrt{\frac{X^2}{X^2+Y^2}} \qquad (1)$$

If value of RFF is less than 0.9, consumer is bound to pay power factor penalty for low power factor. If F is fixed charges in Rs. per kW, then amount for penalty is calculated as given in Eq. (2)

$$Penalty = (0.9 - RFF) * 2 * Z * F \qquad (2)$$

Residential and commercial consumers are billed for number of active energy units consumed during a month. Taxes are included in monthly bill, which are collected and handed over to Government. Consumers are unaware of the load power factor and thus using electricity just considering active power to have reduced bill. An example of consumer load is Compact Fluorescent Lamp (CFL), which is commonly referred as energy saver. Power factor of commercially available CFLs are found to be around 0.6 lagging and below [4]. Similarly power electronic controlled modern inverter Air conditioners, fans and other home appliances have poor power factor. Hence such energy conservation techniques have decreased consumer power factor resulting in additional power losses and thus reduced efficiency of the power system network [5].

In this research work, case for residential consumers of Hyderabad Electric Supply Company is taken in consideration. Different consumers are surveyed at different time intervals to record their power factor. Owing to poor power factor of consumers, tariff based on apparent energy consumption is proposed. Proposed tariff is used to analyze variation in billed amount of the surveyed consumers and results are concluded.

## 2. RESIDENTIAL CONSUMER SURVEY:

Residential consumers from Tando Muhammad Khan city area are selected for survey. Survey results for 22 consumers are presented in Table 1, which contains number of units billed for three consecutive months and average power factor found during survey.

**Table 1: Consumer billed units and power factor**

| Sr. # | Billed Units | | | Average Power Factor |
|---|---|---|---|---|
| | Month 1 | Month 2 | Month 3 | |
| 1 | 242 | 258 | 278 | 0.74 |
| 2 | 157 | 226 | 213 | 0.92 |
| 3 | 229 | 156 | 168 | 0.79 |
| 4 | 172 | 189 | 173 | 0.77 |
| 5 | 212 | 205 | 201 | 0.71 |
| 6 | 354 | 355 | 294 | 0.75 |
| 7 | 159 | 165 | 174 | 0.68 |
| 8 | 214 | 229 | 236 | 0.72 |
| 9 | 223 | 245 | 257 | 0.77 |
| 10 | 336 | 356 | 375 | 0.88 |
| 11 | 216 | 229 | 218 | 0.58 |
| 12 | 284 | 295 | 275 | 0.74 |
| 13 | 382 | 376 | 383 | 0.75 |
| 14 | 558 | 532 | 622 | 0.74 |
| 15 | 531 | 445 | 573 | 0.68 |
| 16 | 281 | 259 | 319 | 0.78 |
| 17 | 461 | 486 | 521 | 0.69 |
| 18 | 107 | 110 | 116 | 0.58 |
| 19 | 398 | 406 | 518 | 0.7 |
| 20 | 530 | 549 | 482 | 0.73 |
| 21 | 146 | 159 | 214 | 0.71 |
| 22 | 459 | 498 | 539 | 0.69 |

Survey results given in Table 1 clearly shows that majority of the consumers are having very poor power factor without being penalized. Electric utility is bearing the cost of energy losses and initial cost of equipment required to supply these consumers. Higher rating of transformers will also include higher no load losses or iron losses in the system [6]. Additionally it is observed that average monthly billed units are 311 units. Such billed units represent maximum of the residential consumers in rural and city areas in absence of the air conditioners. Consumers with air conditioners will have higher billed units [7].

## 3. PROPOSED TARIFF:

Apparent power includes active and reactive power components as indicated in Eq. (3)

$$Apparent\ Power^2 = Active\ Power^2 + Reactive\ Power^2 \quad (3)$$

If consumer is having low power means higher apparent power is required for the active power. Considering this fact, apparent energy requirement increases with decreasing power factor for same amount of active energy requirement. Hence a tariff based on apparent energy billing will be able to include effects of power factor just like a power factor penalty for industrial consumers discussed in section I. In case of consumer having high power factor, consumer will also get reduction in billed amount, which is an additional feature of this tariff. This feature

An apparent power tariff is proposed for residential and commercial consumers. Base power is selected as 0.866 lagging. A consumers having a monthly power factor equal to base power factor will have equal electricity charges on existing active power based and proposed apparent power based tariffs. Assuming a fixed energy charges of Rs. 15 per kWh of the existing tariff. Per unit charges for proposed kVAh based tariff will be Rs. 13 as calculated in Eq. (3)

$$\frac{15}{0.866} = 13 \quad (3)$$

If consumer power factor is below 0.866, billed amount will increase as compared to the billed amount for the existing kWh based tariff. On the other hand, consumers with power factor higher than 0.866 will have reduced billed amount with the proposed tariff. Hence variation in billed amount in proposed tariff is inversely proportional with power factor considering constant active energy consumption.

As an example considering a consumer with connected load of 1 kW. At a load factor of 0.4, monthly consumption of consumer will be 288 kWh. Considering an average unit price of Rs. 15, monthly electricity charges for consumer will be Rs. 4320. Now considering different monthly power factors and calculating apparent energy units. Table 2 shows apparent energy units with different power factors and electricity charges at Rs. 13 per unit. Increase or decrease as compared to existing electricity charges are also included in Table. 2. Fig. 1 graphically compares variation in electricity bill for energy charges between existing and proposed tariffs.

**Table. 2: Comparison of electricity charges between proposed and existing tariff for 1 kW load**

| Power Factor | kVAh Units | Electricity Charges | |
|---|---|---|---|
| | | Existing Tariff | Proposed Tariff |
| 0.95 | 303.16 | 3941 | -379 |
| 0.92 | 313.04 | 4070 | -250 |
| 0.9 | 320.00 | 4160 | -160 |
| 0.866 | 332.56 | 4323 | 3 |
| 0.83 | 346.99 | 4511 | 191 |
| 0.8 | 360.00 | 4680 | 360 |
| 0.77 | 374.03 | 4862 | 542 |
| 0.74 | 389.19 | 5059 | 739 |
| 0.7 | 411.43 | 5349 | 1029 |
| 0.67 | 429.85 | 5588 | 1268 |
| 0.64 | 450.00 | 5850 | 1530 |
| 0.6 | 480.00 | 6240 | 1920 |

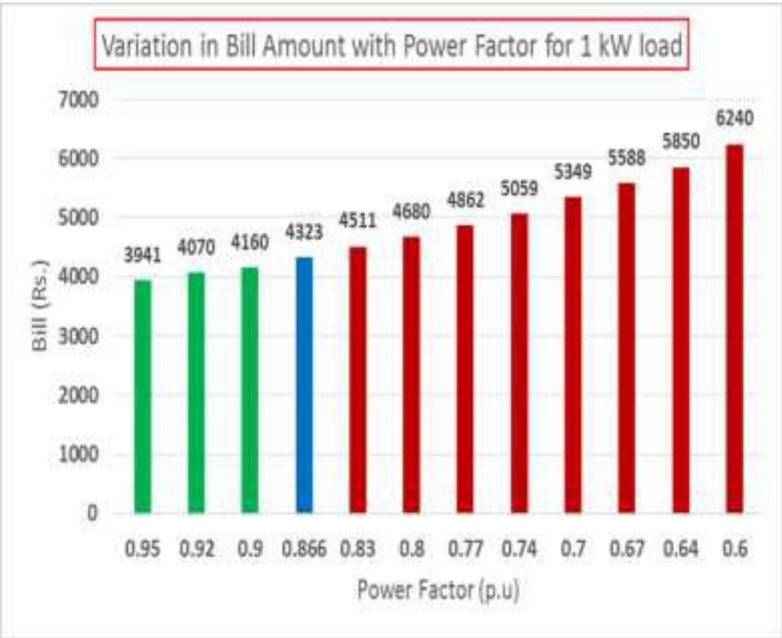


**Fig. 2: Comparison of electricity charges between proposed and existing tariff for 1 kW load**

## 4. CONSUMER BILL ANALYSIS :

Selected 22 consumers are analyzed for electricity bills of existing tariff and proposed tariff. Table 3 gives comparison of bill amount for each consumer for three months. Comparison shows that most of the consumers have increased. Two consumers having power factor better than 0.866 have reduction in bill. For the analyzed consumers bill amount has increased from Rs. 307920 to Rs. 367495. It means Rs. 59575 have been billed additionally for the contribution of poor power factor in losses.

**Table. 3: Comparison of billed amount for consumers between existing and proposed tariffs**

| Consumer # | Billed amount (Rs.) | | |
|---|---|---|---|
| | Existing Tariff | Proposed Tariff | Difference |
| 1 | 11670 | 13668 | 1998 |
| 2 | 8940 | 8422 | -518 |
| 3 | 8295 | 9100 | 805 |
| 4 | 8010 | 9016 | 1006 |
| 5 | 9270 | 11315 | 2045 |
| 6 | 15045 | 17385 | 2340 |
| 7 | 7470 | 9521 | 2051 |
| 8 | 10185 | 12260 | 2075 |
| 9 | 10875 | 12240 | 1365 |
| 10 | 16005 | 15763 | -243 |
| 11 | 9945 | 14860 | 4915 |
| 12 | 12810 | 15003 | 2193 |
| 13 | 17115 | 19777 | 2662 |
| 14 | 25680 | 30076 | 4396 |
| 15 | 23235 | 29613 | 6378 |
| 16 | 12885 | 14317 | 1432 |
| 17 | 22020 | 27658 | 5638 |
| 18 | 4995 | 7464 | 2469 |
| 19 | 19830 | 24551 | 4721 |
| 20 | 23415 | 27799 | 4384 |
| 21 | 7785 | 9503 | 1718 |
| 22 | 22440 | 28186 | 5746 |
| **Total** | **307920** | **367495** | **59575** |

## 5. CONCLUSION:

Residential and commercial consumers are billed on active energy consumed during a month. Poor power factor results in increased losses and require higher capacities of transformers and line conductors. In this research work, consumer power factor is analyzed through field survey and observed to be well below 0.8 causing increased power losses. Apparent energy based tariff structure is proposed to cater issues of increased losses. Case study for 1 kW consumer is presented and consumer bills are compared between proposed and existing tariffs. Results show that proposed tariff is suitable for residential and commercial consumers and billed amount is inversely proportional to power factor.

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