# Bulk Electric Load Cost Calculation Methods: Iraqi Network Comparative Study

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## Abstract

It is vital in any industry to regain the spent capitals plus running costs and a margin of profits for the industry to flourish. The electricity industry is an everyday life touching industry which follows the same finance-economic strategy. Cost allocation is a major issue in all sectors of the electric industry, viz, generation, transmission and distribution. Generation and distribution service costing's well documented in the literature, while the transmission share is still of need for research. In this work, the cost of supplying a bulk electric load connected to the EHV system is calculated. A sample basic lump-average method is used to provide a rough costing guide. Also, two transmission pricing methods are employed, namely, the postage-stamp and the load-flow based MW-distance methods to calculate transmission share in the total cost of each individual bulk load. The three costing methods results are then analyzed and compared for the 400kV Iraqi power grid considered for a case study.

**Key word:** Power system economics; MW-mile method; Postage-stamp method; Transmission pricing; Power flow tracing.

## الخلاصة

من الضروري لأي قطاع صناعي ان يستعيد رأس المال والمصاريف التشغيلية مع هامش ربحي معين لكي يتقدم ويزدهر ذلك القطاع. قطاع صناعة الكهرباء لا يختلف في ذلك مع مساسه المباشر بالحياة اليومية بكافة مرافقها للمجتمع. تسعير انتاج وتوزيع الطاقة الكهربائية موثقة بشكل واسع في ادبيات اقتصاد منظومات القدرة بخلاف تسعير كلف نقل الطاقة، فهذا الجانب لازال بحاجة لدراسات شاملة وموسعة.

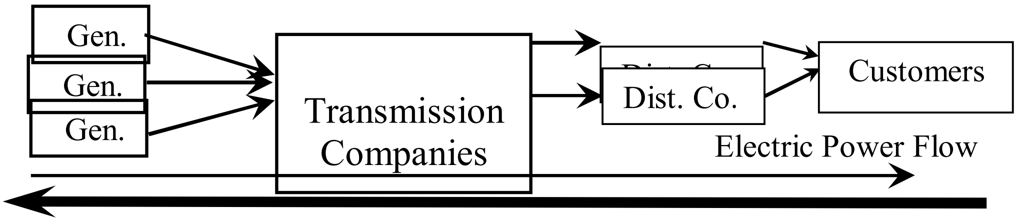
يعرض في هذا البحث حساب كلف تجهيز حمل رئيس مجهز من منظومة الضغط العالي. قُدمت حسابات الكلفة بطريقة "متوسط-جملة" البسيطة لإعطاء فكرة عن المبالغ المتعامل معها. اضافة لذلك استخدمت طريقة "رسم الطابع البريدي" وطريقة "القدرة-مسافة" لحساب كلفة جانب النقل لطاقة الاحمال الكهربائية كل على حدة. عُرضت وقورنت نتائج الطرق اعلاه للكلف الكلية لأحمال شبكة القدرة العراقية ذات جهد 400kV.

**الكلمات المفتاحية:** الاقتصاد نظام الطاقة . طريقة MW- ميل . طريقة الطوابع البريدية . التسعير انتقال . تتبع تدفق الطاقة

## 1. Introduction:

The traditional vertically integrated electric power industry in many countries is moving toward disintegration. The disintegration or unbundling to the different sectors of, generation, transmission, and distribution, along with financial processes imposes a huge burden on the overall power market. Samples of such burdens are the strategies and programs to follow and adopt in market operations and system operations. The market operations are associated with the energy scheduling and trading for the different line horizons, while the system operations are related to the system control, security, dispatch, reliability,…etc.[Warkad *et. al*., 2009; Loi 2001].

In unbundled electricity industry, where a single firm owns all the industry sectors and no competition, economic and pricing studies are of no prime concern in the energy unit price decision. For the unbundled or deregulated industry, there is a need for lots of economic and operation related economic studies. Moreover, importing and exporting energy considering time zones add complications in calculating energy unit cost and marketing. In the deregulated electricity sector market operations, the generation, the transmission and the distribution utilities are considered each separately for utmost beneficial economic operation. A distribution utility might have the freedom to buy power from various producing sites (generations) in a certain time period. That of course provided the transmission facilities are available. For the Iraqi power market, figure (1) shows a simple power and cash flow block diagram summarizing the electricity industry.




Money Cash Flow + Gov. Subsidies

Figure (1) Electricity market block representation

With modern life requirements and the excessive demand for the clean, easy to use electric power, deregulation and competition overtook the electric power industry. Therefore, clear boundaries are set for the main three sectors of generation, transmission and distribution. These boundaries regard the operation as well as the financial and economic aspects.

The cost of power generation depends largely on fuel type and its market price plus the system demand and the available generation mix. Moreover, the generation cost includes incremental charges of specific nature to the particular plant. These incremental include capital, interest, operation and maintenance, waste treatment, insurance etc. [Rothwell 2003]. Throughout this work, a normalized generation cost for the types of generating stations mostly used in Iraq is used. It is estimated that a kWh unit costs 41.0 I.D., 44.4 I.D., and 11.067 I.D. from a thermal, gas and hydro generators respectively.

The cost of transmitting energy from sources to loads; do not differ from that mentioned for generation except regarding fuels. Generally, costing transmission services consists of, (i) return on and depreciation of the capital, (ii) operation, connection and maintenance, and (iii) power losses and resolving transmission congestions. The very basic transmission costing strategy is based on simple averaging of the total funds spent (over a certain time period) over the total transmitted MWh's. This strategy is the base of the postage-stamp method [Murali *et. al.,*2013]. More elaborate transmission costing methods were proposed in the literature. These include, the MW-mile, the MVA-mile, the distribution factors, load-flow based, Bialek tracing based etc. [Murali *et. al*., 2013; Krause ,2003].

In this work, a bulk load demand cost is to be calculated. The calculations are to be done for a practical operative power system. The generation mix contains thermal units, gas units and hydro stations. In the transmission cost calculation, a fixed Lump-average, the postage-stamp, and load-flow based MW-distance methods are used. All calculations were performed using Matlab 2010a routines built for the above mentioned methods.

## 2. Generation Costing Methods

In most types of generating stations, there are three kinds of costs. These are fixed, semi-fixed, and proportional. A fixed cost is independent of the maximum output or the energy produced. A semi-fixed cost, which depends upon the maximum demand and is independent of the total energy output. The proportional one is output dependent and in proportion to it. The fixed cost is due to the capital cost of land, the official's salaries ….etc. The semi-fixed cost is due to salaries of engineers, technicians, maintenance staff, cost of buildings and equipment's including spares ….etc. The proportional cost is mainly due to fuel and related activities [Raja *et. al.*, 2006]. The overall annual cost of the power station ($AC_{annuual}$) is;

$$AC_{annual} = A + B \times Station(MW) + C \times Station(MWh) \quad (1)$$

Where;

A= constant in I.D. (station dependent)

B= constant in I.D./MW (station dependent)

C= constant in I.D./MWh (station and fuel dependent)

In this work, the Ministry of Electricity lump-average costing method for the generation is considered first. This method adopts $34.254*10^3$I.D./MWh for unit generated irrespective of the producing station type.A miscellaneous charge of $5.116*10^3$ I.D/MWh is added for a wide variety of activities in the electricity sector. Also in this work, the calculations of the stations capitals were performed using the mean values of these given in table (1).

Table (1) Station capital costs

| Station type | Cost ($/MW) |
|---|---|
| Thermal | $(1.0\text{-}1.2)*10^6$ |
| Gas | $(0.8\text{-}1.0)*10^6$ |
| Hydro | $(1.8\text{-}2.5)*10^6$ |

Table (2) presents the fixed and variable operation and maintenance (O&M) costs used here for the three types of generating stations [National Renewable Energy Lab. 2012].

Table (2) Operation and maintenance costs

| Station type | Variable O&M costs (I.D/MWh) | Fixed O&M costs (I.D/MW) |
|---|---|---|
| Thermal | 4587.5 | 7887.5 |
| Gas | 37375 | 6575 |
| Hydro | 7500 | 18750 |

Finally, the overall power production cost for the different types of generating stations is calculated. The calculations are based on 8% to 20% salvage on the capitals and an assumed 50 years life for the station. Table (3) summarizes the final results for the power production costs used in this work for the three station types.

Table (3) Production costs

| Station type | Production cost ($C_i$) I.D/MWh |
|---|---|
| Thermal | $41*10^3$ |
| Gas | $44.4*10^3$ |
| Hydro | $11.067*10^3$ |

## 3. Transmission Costing Methods

The main objective of any used transmission pricing method is to recover the system costs plus some profit. Transmission pricing method is the overall process of translating system costs into overall transmission charges. Again, like generation costing, the simplest is the lump-average to provide the transmission charge. Such a simple method is adopted by the Ministry of Electricity to produce a transmission charge of $6.63*10^3$ I.D./WMh and it is used throughout this work for the lump-average calculations.

Globally, there exist several transmission pricing methods. These methods may be categorized in, embedded methods, incremental methods, and composite embedded/incremental methods. The methods used in this work fall in the embedded transmission pricing category. The methods dealt with here are the postage-stamp and the load-flow based MW-distance methods.

### 3.1 Postage-stamp method

It is the most used method for the transmission service pricing. It provides a price which is independent of, the distance between load and supply station, the transmission losses, and the method totally ignores the actual system operation state [Krause,2003]. The transmission charge, called postage-stamp tariff (pst) is calculated at the system peak powers and given as:

$$ps_t = \frac{C_T}{\sum_i P_{Gi}} \tag{2}$$

Where;

pst= flat rate tariff in I.D./MW

$C_T$ = transmission system total expenses in I.D.

$P_{Gi}$ = generator (i) output in MW

The total cost for a bulk load-j demand is then given by:

$$C_{Dj} = pst \times P_{Dj} \tag{3}$$

Where;

$C_{Dj}$= I.D. total cost of the bulk load-j.

$P_{Dj}$= MW active power demand of load-j.

### 3.2 Load-flow based MW-distance method

The MW-distance basically known as the MW-mile method was among the first methods proposed for recovering the fixed transmission costs. It also reflects the actual usage of the transmission system [Krause 2003]. Many varieties of this method are spotted in the literature [Kharbas et al 2011, Anjaneyulu et al 2013] and most of them provide for minor difference in the final transmission cost results of a particular system. Equation (4) gives the mathematical interpretation of the MW-distance method and as:

$$C_{Dj} = \sum_{all\ k} C_k \frac{F_k(Dj)}{\sum_{all\ s} F_k(S)} \tag{4}$$

Where;

$C_{Dj}$= I.D. total cost of bulk load-j.

$C_k$ = I.D. cost of line-k.

$F_k(Dj)$ = line-k active power flow caused by load-j.

$F_k(s)$ = line-k total active power flow.

## 4. Power Tracking in Power Systems

A prerequisite of economical and beneficial operation of a multi owned power system are the shares participated by each party (i.e., generation sites and loads). Generation forward tracking and/or load back tracking are techniques based on load flow, proportionality and graph theory principles [Felix *et. al*.,2000].These techniques lead to generation contribution to each load and line power flow proportion from a particular generator. The load flow analysis is the corner stone of every power tracking study. Therefore, a robust, reliable, and convergent load flow method is required and can be any of the well-developed DC-load flow or Newton-Raphson based methods. Throughout this work, the conventional Newton-Raphson load flow is used [Saadat,1999]. In this work, the upstream tracking (load back tracking) technique presented in reference [Felix *et. al.*, 2000] is used to trace the load back to supply nodes. Moreover, extraction factors of the loads from line flows were also calculated. Quoted from reference [Felix *et. al.*, 2000], "two main matrices need to be built. One is the contribution matrix of lines and generators to bus total passing power. The other is extraction factor matrix of loads from bus total passing power. The product of these two matrices constitutes the extraction factors of loads from line flows and generators".Summarizing the algorithm buildup presented in reference [Felix *et. al.*,2000], equations (5) and (6) are the outcome of matrix manipulations and given as:

$$P_l = C_l \text{ x } P = C_l \text{ x } D \text{ x } P_L = K_{lL} \text{ x } P_L \quad (5)$$

And,

$$P_G = C_G \text{ x } P = C_G \text{ x } D \text{ x } P_L = K_{GL} \text{ x } P_L \quad (6)$$

Where;

$C_G$: a contribution factor matrix of generator to the bus total passing power.
$C_l$ : a contribution factor matrix of lines to the total passing power of their downstream terminal buses.
D : an extraction factor matrix of loads from bus total passing power.
P : the vector of bus total passing power in the bus sequence of upstream tracing and calculated from ac load flow solution.
$P_G$ : the vector of generator powers.
$P_l$ : the vector of line flow powers.
$P_L$ : the vector of load powers.

## 5. The Study Procedure

The comparative study in this work regards the costing of a bulk load connected to the EHV power system. The first costing method is that of a lump-average nature. That is, estimating the whole expenditure of the sectors concerned (in this case, the generation, and the EHV-transmission), then divide by the total MWh's traded during a certain time period. That produces the unit price, then, multiply by the units consumed by a bulk load to find its total cost.

The second and third methods require a load flow study to find generator participation to loads and flows. Once decided, the generation shares in the bulk load cost can be calculated. As for the transmission share in the bulk load cost, either the postage-stamp or the load flow based MW-distance method is used.

## 6. Cases Studied and Results

The Iraqi 400kV power grid is considered here for a case study. The single line diagram of the system is shown in figure (2). It contains 24 buses, 39 transmission lines, 12 of the buses are generation buses and 19 buses have load connected to. The generation and load profiles of 2008-2010 were considered in the study. The fuel prices used in this work were the average during the mentioned period. Samples of the system relevant bus and line data are given in tables (4) and (5).

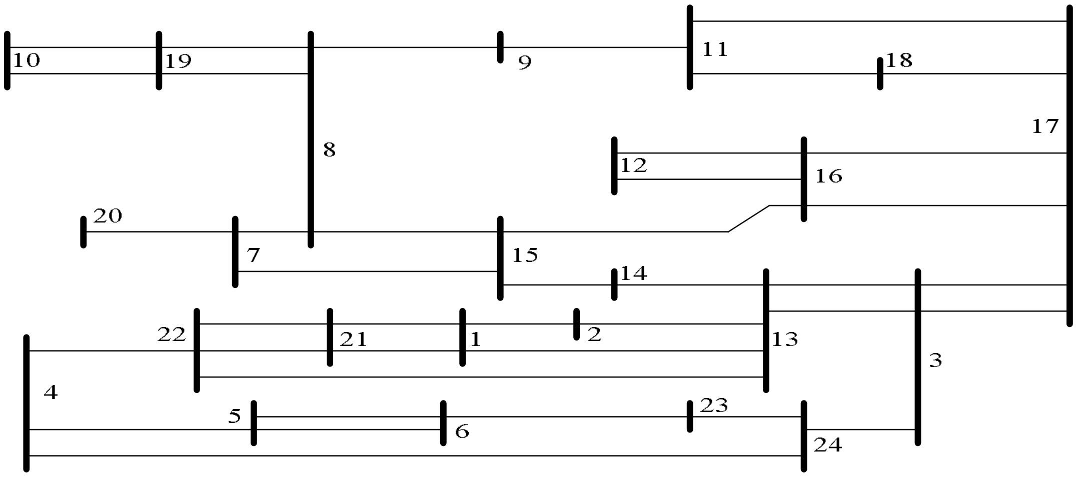



Figure (2) System single line diagram

Table (4) Sample system bus data

| Bus No. | Voltage Mag. (PU) | Voltage Angle (Degrees) | ------Load------ (MW) [Mvar] | ---Generation-- (MW) [Mvar] | Injected Mvar |
|---|---|---|---|---|---|
| 1 | 1.04 | 0 | (199.780) [116.633] | (1102.520) [241.326] | 0 |
| 2 | 1.04 | -0.045 | (0.000) [0.000] | (369.036) [176.010] | 0 |
| .<br>. | | | | | |
| 23 | 0.995 | -9.949 | (311.022) [160.371] | (0.000) [0.000] | 0 |
| 24 | 1.008 | -4.296 | (259.713) [108.176] | (0.000) [0.000] | 0 |

Table (5) Sample system line data (pu)

| From bus | To bus | R | X | ½ B | Line length (km) |
|---|---|---|---|---|---|
| 1 | 2 | 0.000125 | 0.001043 | 0.0163955 | 6 |
| 1 | 13 | 0.00122 | 0.01015 | 0.159485 | 56 |
| .<br>. | | | | | |
| 21 | 22 | 0.001165 | 0.009675 | 0.60812 | 102 |
| 24 | 23 | 0.00479 | 0.04354 | 0.64499 | 221 |

The costs calculated are for a full calendar year. The generation and load profiles were changed to consider a deviation of +25%, +60% and -10% from a base case values. The study procedure of section-5 is followed for all the above mentioned system states.

### 6.1 The lump-average method

The total cost of a unit MWh energy delivered to a bulk load is estimated to be 46.046*$10^3$ I.D/MWh. This is generalized for all the loads connected to the grid. Table (6) shows sample bulk loads costs for the different loading scenarios.

Table (6) Sample load costs, lump average method

| Load at bus | Cost (*$10^9$) I.D | | | |
|---|---|---|---|---|
| | base case | (10%) load decrease decrease decrease decrease | (25%) load increase increase | (60%) load increase increase |
| 1 | 80.584 | 72.526 | 100.73 | 128.934 |
| 3 | 51.055 | 45.949 | 63.819 | 81.68 |
| 4 | 170.573 | 153.516 | 213.2163 | 272.91 |
| 5 | 228.321 | 205.4889 | 285.4013 | 365.3113 |
| 6 | 62.454 | 56.209 | 78.0675 | 99.924 |
| 7 | 102.076 | 91.868 | 127.595 | 163.3162 |
| 8 | 50.37 | 45.333 | 62.9625 | 80.584 |
| 11 | 52.38 | 47.142 | 65.475 | 83.81 |
| 14 | 20.94 | 18.846 | 26.175 | 32.234 |
| 15 | 232.353 | 209.118 | 290.4413 | 371.76 |

### 6.2 Generation costs

Using the information presented in section-2, and performing the tracking procedure of section-4, the bulk loads powers are broken down to their constituents from the different power plants. The bulk load total generation cost ($C^{G}_{Load\text{-}j}$) can be calculated using equation (7), given by:

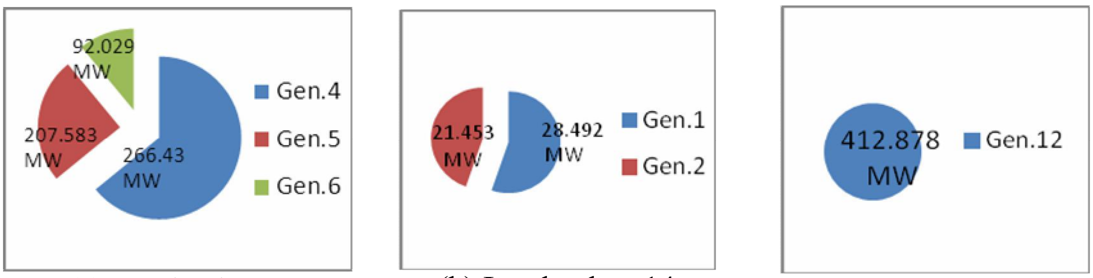
$$C^{G}_{Load\text{-}j} = L^{Thermal}_{Load\text{-}j} \times C^{Thermal}_{i} + L^{Gas}_{Load\text{-}j} \times C^{Gas}_{i} + L^{Hydro}_{Load\text{-}j} \times C^{Hydro}_{i} \qquad (7)$$

Where;

$L^{@}_{Load\text{-}j}$ Is the bulk load active power at bus-j from the superscripted generation type.

$C^{@}_{i}$ Cost already defined in table (3).

Figure (3) shows a sample generator participation in the bulk loads of buses 16, 14, and bus 5. Table (7) shows a sample of the generator participation picture for the base- case loading study.




(c) Load at bus-5 (b) Load at bus-14 (a) Load at bus-16

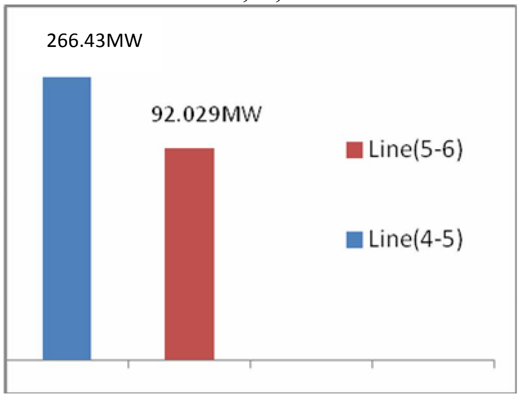
Figure (3) Base-case sample generator participation

Table (7) Sample load MW-extraction from generators/ base-case

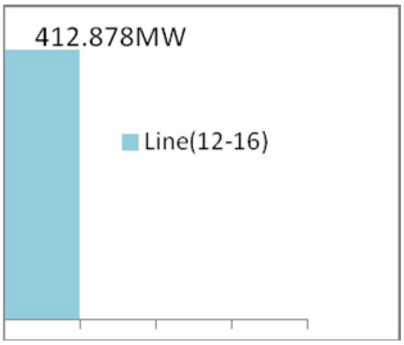
| **Load bus** / **Gen.** | 1 | 3 | 4 | 5 | 6 | 7 | 8 | 11 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 199.78 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28.49 | 67.2 |
| **2** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21.45 | 50.59 |
| **3** | 0 | 126.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **4** | 0 | 0 | 422.86 | 266.43 | 0 | 0 | 0 | 0 | 0 | 0 |
| **5** | 0 | 0 | 0 | 207.58 | 0 | 0 | 0 | 0 | 0 | 0 |
| **6** | 0 | 0 | 0 | 92.02 | 154.82 | 0 | 0 | 0 | 0 | 0 |

### 6.3 Transmission costs

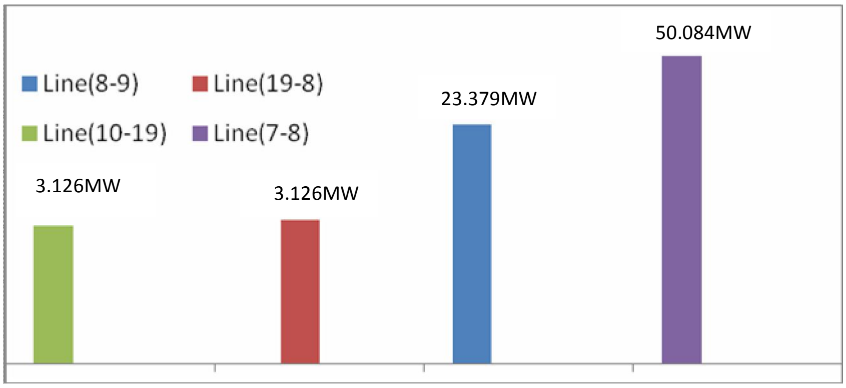
For both the postage-stamp and the load flow based MW-distance methods, an investment cost of $8.75*10^6$ I.D./km.year is considered for the 400kV transmission network [Malaki et al 2001]. Figure (4) shows a sample of line flow load shares for the load at buses 16, 5, and bus 7.




(b) Load at bus-5




(a) Load at bus-16




(c) Load at bus-7

Figure (4) Base-case sample line flow load shares

Table (8) shows the overall load MW-extraction from line flows for the base-case loading study.

Table (8) Sample load MW-extractions from line flows/ base-case

| 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 7 | 5 | Load / line |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 18.938 | 0 | 10.914 | 4.627 | 0 | 0 | 1-2 |
| 0 | 0 | 0 | 0 | 97.667 | 0 | 56.286 | 23.865 | 0 | 0 | 1-13 |
| 307.993 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1-21 |
| 0 | 0 | 0 | 0 | 106.735 | 0 | 61.512 | 26.08 | 0 | 0 | 2-13 |
| 0 | 0 | 0 | 0 | 204.402 | 0 | 0 | 0 | 0 | 0 | 3-13 |
| 0 | 0 | 0 | 0 | 224.262 | 0 | 0 | 0 | 0 | 0 | 3-17 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3-24 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 266.43 | 4-5 |

### 6.3 Total load cost

Finally summing up the generation and the transmission costs for each bulk load in the system, yielding the results, samples of which are presented in tables (9) and (10). In table (9) the results for the costs using the postage-stamp transmission method are presented. In table (10), the relevant results for load flow based MW-distance method are presented.

Table (9) Sample bus-load cost with postage-stamp transmission pricing

| **Load at bus** | **Cost (*$10^9$) I.D** | | | |
|---|---|---|---|---|
| | **base case** | **(10%) load decrease** | **(25%) load increase** | **(60%) load increase** |
| 1 | 72.66 | 65.48 | 90.59 | 115.71 |
| 3 | 49.80 | 44.87 | 62.10 | 79.33 |
| 4 | 153.79 | 138.60 | 191.76 | 244.91 |
| 5 | 212.04 | 191.09 | 265.07 | 339.53 |
| 6 | 56.31 | 50.75 | 70.21 | 89.67 |
| 7 | 38.68 | 34.93 | 63.36 | 96.74 |
| 8 | 45.41 | 40.92 | 56.62 | 72.32 |
| 11 | 51.09 | 46.04 | 63.72 | 81.40 |

Table (10) Sample bus-load cost with MW-distance transmission pricing method

| **Load at bus** | **Cost (*$10^9$) I.D** | | | |
|---|---|---|---|---|
| | **base case** | **(10%) load decrease** | **(25%) load increase** | **(60%) load increase** |
| 1 | 71.75 | 64.58 | 89.69 | 114.8 |
| 3 | 49.22 | 44.30 | 61.53 | 78.76 |
| 4 | 151.88 | 136.69 | 189.85 | 243.00 |
| 5 | 211.73 | 190.78 | 262.51 | 339.22 |
| 6 | 55.61 | 50.05 | 69.51 | 88.97 |
| 7 | 37.93 | 33.98 | 62.21 | 96.17 |
| 8 | 44.85 | 40.36 | 56.06 | 71.75 |
| 11 | 50.51 | 45.46 | 63.13 | 80.81 |

## 7. Conclusions

Costing strategies and or methods for charging bulk load distributers in power systems are major issue in the electricity sector economy. The cost of providing service to bulk loads is interpreted as the cost of generation, transmission, and connection with all include capitals and running costs.

The lump-average method provided a rough base as the geographical position of the load is of no importance. Also, ignored in this method is the generation mix which supplies a particular load.

The better treatment of the problem regarding known mix of generation and transmission path for a particular bulk load lowered down the electricity bill for that load. That was true for both results of postage-stamp and the MW-distance based transmission costing. Moreover, costs calculated using the MW-distance pricing method exhibit slight decrease compared to those obtained by the postage-stamp method. It need be realized that adoption of one method is very much dependent on socioeconomic and geopolitical factors.

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