Impact Assessment Study

Migration from kWh to kVAh based Tariff

Jharkhand Bijli Vitran Nigam Ltd. (JBVNL)

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Preface

The report on Impact Assessment Study of migration from kWh to kVAh based Tariff has been prepared in line with the directions of Hon'ble JSERC, with an objective to substantiate the proposal of migration from kVAh based billing from existing kWh based billing. The impact assessment study has been carried out by JBVNL along with the team of consultants from Deloitte.

This reports details the commercial impact of switching from kWh billing to kVAh billing on consumer majorly on account of incentives/ penalties in-built in the kVAh regime. This has been done by taking sample set of more than 50 HT consumers' electricity bill for a period of 3 months. The report also covers the benchmarking with other states along with challenges and merit involved in shifting.

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1. Background and Introduction

This chapter details out the background of the study and provides the details of the coverage of this report.

1.1 Background

1.1.1 Jharkhand Bijli Vitran Nigam Ltd. (herein after to be referred to as "JBVNL" or "erstwhile JSEB-Distribution function) is in the business of distribution and retail supply of electricity in the state of Jharkhand. JBVNL has been incorporated under Indian Companies Act, 1956 pursuant to decision of Government of Jharkhand to reorganize erstwhile Jharkhand State Electricity Board (herein after referred to as "JSEB").

1.1.2 The above reorganization of the JSEB has been done by Government of Jharkhand pursuant to "Part XIII – Reorganization of Board" read with section 131 of the Electricity Act 2003. JBVNL is a Company constituted under the provisions of Government of Jharkhand, General Resolution as notified by transfer scheme vide notification no. 8, dated 6th January 2014. JBVNL has been incorporated on 23rd October 2013 with the Registrar of Companies, Jharkhand, Ranchi and has obtained Certificate of Commencement of Business on 28th November 2013.

1.1.3 JBVNL is a Distribution Licensee under the provisions of the Electricity Act, 2003 (EA, 2003) having license to supply electricity in the State of Jharkhand. The Petitioner is functioning in accordance with the provisions envisaged in the Electricity Act, 2003 and is engaged, within the framework of the Electricity Act, 2003, in the business of Distribution of Electricity to its consumers situated over the entire State of Jharkhand.

1.1.4 JBVNL is the largest power distribution company in the state and holds the high consumer base of around 31 Lac consumers. JBVNL's systems comprise of 33 KV sub-transmission systems which forms the distribution backbone at the district level and 11 KV and LT distribution systems which delivers electricity to the majority of the end consumers.

1.1.5 Since inception, JBVNL is committed to transform itself into a vibrant, financially independent and consumer oriented utility. Numerous initiatives have been taken towards attainment of the transformational goals in past few years. The areas ranging from improving distribution infrastructure, rapid energization of rural premises, reducing AT&C losses, improving quality & duration of supply, streamlining the regulatory filing process, cost optimization and enhancing reach to consumers have been amongst the key focus areas. These are being targeted simultaneously for a sustainable solution to legacy problems in the distribution sector.

1.1.6 Considering the significance of enhancing regulatory effectiveness, JBVNL has filed the Business plan and Tariff Petition for MYT control Period FY 2016-17 to FY 2020-21 in July 2016. Hon'ble JSERC has issued the Tariff order against the aforementioned Petition 21st June 2017, where JBVNL has been directed to carry out an impact assessment study for switching from kWh billing to kVAh billing. The direction issued by Hon'ble JSERC is pronounced below-

> "*13.42 The Commission directs the Petitioners to carry out impact assessment study on transition from kWh billing to kVAh billing, for a sample set of consumers in the HTS and HTSS categories, and submit a report within six months of issuance of this Order*."

1.1.7 Thus, in order to comply with the directions of Hon'ble JSERC and also to substantiate the proposal for migration from kVAh based billing from existing kWh based billing, JBVNL has carried out the impact assessment study.

1.2 Introduction

1.2.1 Presently, JBVNL levies the electricity charges in two forms namely fixed charge and energy charge from consumers against power consumption. The fixed charges varies on consumer category/ sub-category and are being charged based on per connection, load and demand basis. However, energy charges are being imposed only in per unit (kWh) basis across consumer categories. Hence, it is evident that only active is being charged from consumers.

1.2.2 However, it is a well-known fact that the industrial load consist majorly of inductive load which generates some amount of reactive power for them to function. This reactive power is compensated by the capacitor bank installed in parallel to the load. Else, these equipment tend to draw the reactive power from the grid which JBVNL has to draw from the grid. These industrial units are required to maintain their equipment well and install the capacitors to maintain the power factor, however, not all industrial units do so. This leads to reduction in power factor and system inefficiency.

1.2.3 If the tariff is only fixed for active energy measured (kWh basis), the supplier has to meet the loss in the supply system due to this additional current drawn due to the poor power factor of the load maintained by the consumers. Else to eliminate the losses, regulatory measures have to be initiated upon the consumers who do not maintain the power factor of the load at unity or a specified value. Imposing penalty to consumers who create this burden, by identifying them through special tasks, are not practical and feasible for the utility, which further leads to billing disputes. Therefore, consideration of apparent power (active as well as reactive) or also known as KVAh while billing the consumers is inevitable as reactive power being the integral part of the power supplied to consumers.

1.2.4 With such impending issues on power factor, this report delve deep to unearth the entire impact on shifting consumer billing from kWh billing to kVAh billing. The subsequent sections contains the detailed explanation on technical aspects of kWh and kVAh, commercial impact of switching from kWh billing to kVAh billing on consumer as well as utility along with challenges and merit involved in shifting.

1.2.5 It is pertinent to mention that KVAh billing shall enable the responsibility of the consumer to maintain the quality of the load by improving its power factor or the consumers automatically pay themselves for the additional burden due to poor power factor of the load maintained by them. In kVAh billing system as the electricity bills conceive this additional burden for consumers who create it, no separate penalty need to be imposed.

2 Technical Evaluation – Understanding kWh Vs kVAh

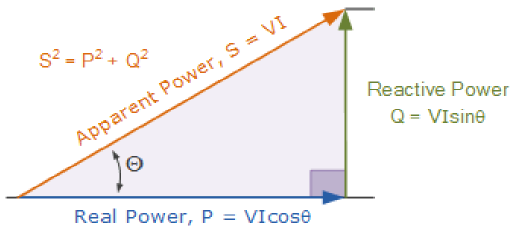
This chapter provides a detailed technical understanding of the kWh vs kVAh regime and charts out the need for reactive power in the electricity distribution system and importance of reduction of reactive power. The chapter tries to establish the rationale for lower

2.1 Understanding kVAh

2.1.1 Electric power has two components – active power (kWh) and reactive power (kVArh). The active and reactive power components combine to form the apparent power (kVAh). The apparent power can be calculated as a Pythagoras sum of active power (kWh) and reactive power (kVArh).

2.1.2 **Power Factor:** Power factor (pf) is defined as the ratio of active power to the apparent power of the system i.e. pf = kWh/kVAh

As shown in the figure, true power and apparent power form the adjacent and hypotenuse sides of a right triangle respectively.



2.1.3 Power factor ratio is also equal to the cosine of the phase angle between true power and apparent power. It should be noted that power factor, like all ratio measurements, is a unitless quantity.

2.1.4 As can be seen from the figure above, "power factor" can also be defined as the cosine of the electrical angle between the voltage and current vectors in an AC electrical circuit. However, power factor is not dependent upon the magnitude of the voltage and current but the phase angle between the voltage and current vectors.

The active power (kWh) is actually consumed by the electrical equipment and converted into work for creating heat, light, motion etc. However the reactive power (kVArh) is just used to provide the electromagnetic field in the inductive equipment, stored up in the windings of the equipment. Therefore while the kWh power is actually put to work, the kVArh power is just required to convert the electrical power into work.

Active power is the energy supplied to run a motor, heat a home, or illuminate an electric light bulb. Reactive power provides the important function of regulating voltage. If voltage on the system is not high enough, active power cannot be supplied. Reactive power is used to provide the voltage levels necessary for active power to do useful work and is essential to move active power through the transmission and distribution system to the customer. Reactive power is required to maintain the voltage to deliver active power (watts) through transmission lines. If there is not enough reactive power, the voltage sags down and it is not possible to push the power demanded by loads through the lines."

2.2 Need of Reactive Power in Power System

2.2.1 In case of purely resistive load like incandescent lamp, electrical energy is directly converted into useful work (light and heat energy in this particular case), no intermediate electric or magnetic field is required in between. Hence no power is wasted in creating electrical or magnetic field. Therefore the total Power is entirely Active Power that does useful work and there's no any requirement of Reactive Power.

2.2.2 However in case of inductive loads like motors, electrical energy can't directly be converted into useful work. This is because, to convert electrical energy into rotational energy, magnetic field has to be created in between the gaps of stator and rotor of the Motor. Hence, some amount of energy has to be used in creating magnetic field. The portion of power that contributes in creating magnetic field is known as Reactive Power.

2.2.3 From the efficiency point of view, reactive power may be seen as power loss because it's role is limited to creating magnetic field and does not contribute in driving load. Nevertheless, reactive power isn't actually a loss because it creates magnetic field without which electrical energy in stator could not have been converted to rotational energy in rotor.

2.3 Role of Reactive Power in Voltage Regulation

2.3.1 Decreasing reactive power causes voltage to fall while increasing reactive power causes voltage to rise. A voltage collapse may be occurs when the system try to serve much more load than the voltage can support.

2.3.2 When reactive power is lower in the system, supply voltage is reduced and as the voltage drops current increases to maintain the power supply, causing system to consume more reactive power and further drop in the voltage. If the current increase too much, transmission lines go off line, overloading other lines and potentially causing cascading failures. If the voltage drops too low, some generators will disconnect automatically to protect themselves. The result in these entire progressive and uncontrollable declines in voltage is that the system is unable to provide the reactive power required to meet the power demand.

2.4 Importance of Reactive Power

1. **Voltage Control:** First, both customer and power system equipment are designed to operate within a range of voltages, usually within±5% of the nominal voltage. At low voltages, many types of equipment perform poorly, light bulbs provide less illumination, induction motors can overheat and be damaged, and some electronic equipment will not operate at. High voltages can damage equipment and shorten their lifetimes.
2. **To Satisfy Reactive Power Demand:** Some loads such as transformers and HVDC converters need reactive power for their proper functioning. When the loads have large reactive power demand, the voltage drop will take place. As the voltage drops, more current will be drawn from the supply to maintain the power, causing the lines to consume more reactive power and hence voltage drop further. This will lead to voltage collapse if voltage drops too low. This voltage collapse causes to tripping of generators, instability of the system and tripping of other equipment connected to the power system. This voltage collapse is due to the fact that the power system unable to supply reactive power demand of load which is not being met due to shortage of reactive power generation and transmission. In order to overcome this, reactive power sources like series capacitors are connected to the loads locally where reactive power is required by the loads.

3. **To Reduce Electrical Blackouts:** Inadequate reactive power in electrical power system network has been a major reason in power outages in worldwide. As discussed, insufficient quantity of reactive power causes voltage collapse that ultimately leads to the shutdown of generating stations and various equipment.

Some of these blackouts include, at Tokyo in July 23, 1987; at London in Aug 28, 2003; at Sweden and Denmark in Sep 23, 2003.

4. **To Produce Magnetic Flux:** Most inductive loads such as motors, transformers, ballasts and induction heating equipment requires reactive power in order to produce a magnetic field. In every electrical machine, a part of input energy, i.e., reactive power is consumed for creating and maintaining magnetic flux to do so. However, it leads to lower the power factor. Thus, in order to achieve the high power factor, capacitors are generally connected across these devices to supply the reactive power.

2.5 Need for reducing reactive power in the system

2.5.1 The kVArh power occupies the capacity of electricity network and reduce the useful capacity of system for generation and distribution of the active power. If only active power kWh is measured, the kVArh power would constitute a part of the technical losses in the system.

2.5.2 The reactive kVAr becomes nil when power factor of the system is unity (1). As the power factor of the system (or any particular consumer/consumer category) falls below 1, the reactive power component increases and contributes to the increasing technical losses (copper losses) in the system. Working with poor power factor of the load leads to higher current drawn through the supply system than the current drawn with unity power factor for same kWh delivered. Since copper losses are proportional to square of current flowing (P = I x I x R), the technical losses would increase with falling pf in the ratio of 1/(pf^2). The table below depicts indicative calculations for increase in power purchase cost due to falling pf.

3 Review and Benchmarking with Other States

As detailed in the previous chapters, reactive power is an integral part of the power supplied by the distribution licensee. However, under the present kWh based billing, reactive power compensation is not considered while billing the consumers. Many other States like Maharashtra, Bihar, Chhattisgarh, Delhi, Uttar Pradesh etc. have already implemented the kVAh based billing for several consumer categories. Chhattisgarh started the kVAh based billing for HT and EHT consumers in FY 2005-06 itself.

3.1 kVAh based billing in Chhattisgarh

3.1.1 The Hon'ble CSERC in its tariff order for FY 15-16 quoted *"In continuation of the Commission's philosophy of moving from kWh based tariff to kVAh based tariff in order to improve the power factor and hence, voltage profile of the system, the Commission has introduced kVAh based energy charges for the remaining HT categories including the newly created categories, i.e., HV-1 (Steel Industry), HV-2 (Mines, Cement, Other Industries and General Purpose Non-Industries), HV-3 (Low Load Factor Industries), HV-4 (Residential, Irrigation & Agriculture Allied Activities) and HV-5 (Public Water Works). The Commission has appropriately determined kVAh tariff with respect to kWh tariffs, keeping in mind the average power factor of the consumer".*

"The Commission had introduced kVAh tariffs for all HV categories, in addition to the existing HV-5 and HV-6 categories, in continuation of the Commission's philosophy of moving from kWh based tariff to kVAh based tariff in order to improve the power factor and hence, voltage profile of the system and reduce the Copper loss (I2R)".

3.2 kVAh based billing in Bihar

3.2.1 The neighbouring State of Bihar has already implemented the kVAh based billing in FY 16-17. The Hon'ble BERC in its Tariff Order for FY 16-17 quoted that *"billing the energy charges on KVAh basis will motivate the HT consumers to maintain power factor nearer to unity which will not only benefit the consumer but also improves the system utilization and stability".*

3.3 kVAh based billing in Uttar Pradesh

3.3.1 Uttar Pradesh has implemented the kVAh based billing in FY 16-17 wherein the Hon'ble UPSERC in its Tariff Order for FY 16-17 quoted that *"Implementation of kVAh metering and kVAh tariff is seen as a commercial inducement on consumers to pay lesser electricity bill by ensuring that they do not draw reactive power It suggests that consumers must be billed as per the kVAh (apparent energy) drawl, and not as per the kWh (active energy). A change to a kVAh tariff is beneficial to non-defaulting consumer as the kVAh tariff is cheaper than the kWh tariff. The Distribution Licensee can benefit through the collection of more revenue from consumers having low power factor loads. Most importantly, the tariff is environmentally friendly due to improved efficiency. This will also prompt the consumers to take the initiative in correcting the power factor, using compensating capacitors at their end".*

4 Commercial Impact Assessment

This chapter details out the commercial impact of migration from kWh to kVAh regime on the consumer majorly on account of incentives/ penalties in-built in the kVAh regime.

4.1 Overall Approach & Key Assumptions

4.1.1 Based on the existing kWh based tariff structure and the applicable penalties and incentives for maintaining optimum power factor, the electricity bill of a typical HT consumer, with certain connected load and load factor has been estimated. The estimated electricity bill has been simulated to be under the kVAh regime, considering the power factor of 0.90.

4.1.2 The power factor of 0.90 for HT consumer has been arrived based on sample set of more than 50 HT consumers' electricity bill for a period of 3 months. Based on the power factor of 0.90, the existing kWh based tariff has been converted to kVAh based tariff for a consumer.

4.1.3 Based on the kVAh vis-à-vis kWh based tariff, the consumer's electricity bill has been estimated for different Power Factor (pf) levels, from as high as 0.95 to as low as 0.25. The difference in the estimated electricity bill can said to be the impact of migration from kWh to kVAh or the incentive/ penalty for kVArh consumption.

4.1.4 The impact assessment has been done to showcase the impact of change in power factor on the consumer's electricity bill and how the lower power factor leads to higher kVArh compensation, as the utility has to purchase more electricity.

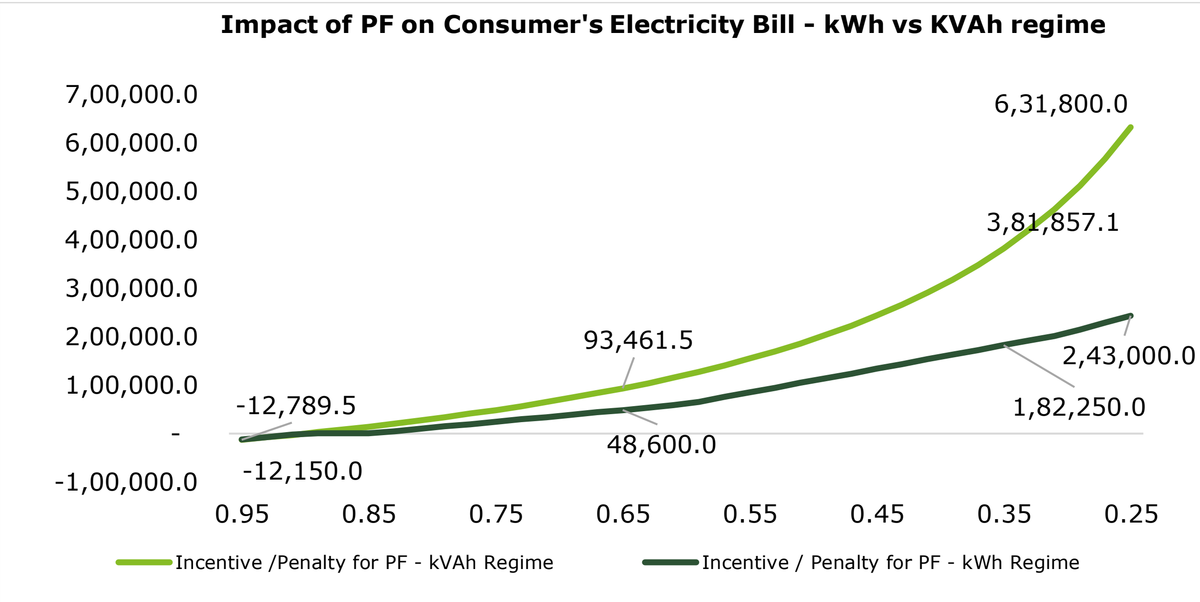
4.1.5 The key assumptions underlying the analysis are tabulated, as below:

Particulars	Units	Details
Connected load	kVA	100
Load Factor	%age	60%
Demand Charges	Rs./kVA	300
Energy Charges	Rs./kWh	6.25
Power Factor for conversion from kWh to kVAh	Unit	0.90
Incentive/ Penalties under kWh Regime	-	As per Tariff Order dated 21st June 2017

4.1.6 Based on the above underlying assumptions, an impact assessment from the perspective of consumer and the utility has been done, as detailed in the following sub-section.

4.2 Commercial Impact of migration from kWh to kVAh on Electricity Bill of Consumer

4.2.1 Based on the estimated electricity bill, the impact (increase/ decrease) of reactive power compensation has been depicted in the chart below, under the kWh based billing vs kVAh based billing regime.

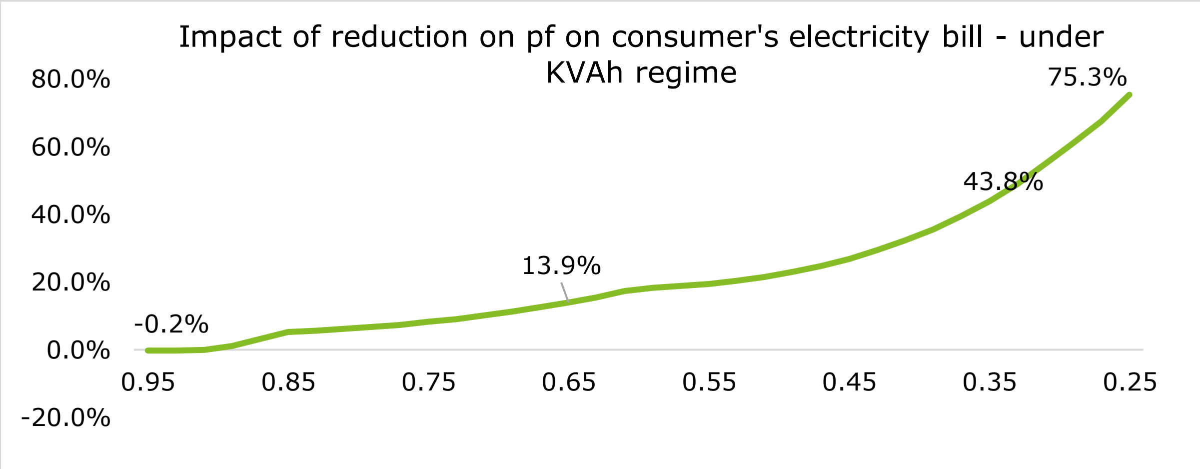


4.2.2 As the consumer’s pf goes down the reactive energy consumption increases, which should be suitably compensated. The kVAh based tariff regime ensures that the reactive power is also charged, whereas the power factor penalty being levied doesn’t adequately compensate the utility.

4.2.3 Further it can be seen from the chart above, the consumer pays proportionately higher penalties for lower power factor, thus encouraging the electricity consumers to improve their power factor and enabling adequate compensation for utility for reactive power consumption.

4.2.4 The impact of such increase in the penalties for lower pf is very limited to the extent consumer is able to maintain a pf up to 0.70, while it increases significantly as the pf goes lower than 0.55 and increases at a further higher rate if the pf goes below 0.40, which clearly reflects the existing regime of increasing pf penalties, however, with adequate compensation for reactive power consumption.

4.2.5 The chart below summarizes the impact of pf reduction on the electricity bill of a consumer under the kVAh regime.



4.3 Commercial Impact of Reactive Power on Utility (under kWh regime)

4.3.1 As the consumers' power factor falls, the utility has to buy additional power which goes unaccounted and the utility is not reimbursed the cost of such reactive power. The table below depicts indicative calculations for increase in power purchase cost due to falling pf.

PF	Technical Loss[1]	Energy input required for sales (MUs)	Power purchase cost (Rs. Crore)[2]	Increase in power purchase cost
1.00	5.0%	12,447.6	5,277.8	-
0.95	5.5%	12,511.7	5,305.0	0.51%
0.93	5.8%	12,540.2	5,317.1	0.74%
0.91	6.0%	12,570.7	5,330.0	0.99%
0.89	6.3%	12,603.2	5,343.8	1.25%
0.87	6.6%	12,638.0	5,358.5	1.53%

[1] Assuming 5% technical loss at unity power factor, the losses are increased with falling power factor by multiplying initial 5% loss level with 1/(pf^2)

[2] The overall average power purchase cost in FY16-17 of Rs. 4.24/kWh is multiplied with energy input required

PF	Technical Loss[1]	Energy input required for sales (MUs)	Power purchase cost (Rs. Crore)[2]	Increase in power purchase cost
0.85	6.9%	12,675.3	5,374.3	1.83%
0.83	7.3%	12,715.3	5,391.3	2.15%
0.81	7.6%	12,758.3	5,409.5	2.50%
0.79	8.0%	12,804.7	5,429.2	2.87%
0.77	8.4%	12,854.6	5,450.4	3.27%
0.75	8.9%	12,908.7	5,473.3	3.70%
0.73	9.4%	12,967.2	5,498.1	4.17%
0.71	9.9%	13,030.7	5,525.0	4.68%

4.3.2 As can be seen above, a 15 basis points reduction in pf, from the base pf of 0.85, increases the power purchase cost of a utility by up to 5%, thus resulting into losses. Moreover, from the section 4.2 above, it can be seen that the reactive power gets adequately compensated under the kVAh regime, which are not completely covered under the existing kWh based tariff and pf penalty regime.

5 kWh to kVAh – Challenges and Advantages

This chapter details out the key challenges and benefits of kVAh based billing vis-à-vis the major drawbacks of present kWh based regime.

5.1 Challenges in proposed (kVAh) based billing

5.1.1 Most of the LTIS consumers are not having MDI meters which is required to capture the Maximum Demand. However the Petitioner is committed towards the replacement of these non-MDI meters and has planned to replace all such meters in phased manner. However, till the time JBVNL process the shifting of consumers having Non-MDI meters to MDI meters, the Petitioner shall provide an option for consumers having installation based tariff to come forward and declare their own load (in KVA)

5.2 Benefits of proposed (kVAh) based billing

- **Complete recovery of costs of utility for active and reactive power:** Since reactive power is also a useful and integral part of the power supplied by the distribution licensee, charges for supplying the same are also recovered from the kVAh tariff.
- **Zero/ Minimal drawl of reactive power from consumers by use of Capacitor Banks**: Under kVAh billing, it would automatically become the responsibility of the consumer to generate reactive power locally through installation of capacitors banks.
- **Reduction in power purchase cost:** Under kVAh billing, the distribution licensee does not have to buy the additional power in order to compensate for the reactive power which goes unaccounted at present.
- **Reduction in (I^2)*R loss:** Lower reactive power in the system results into lowering of supply voltage, which in turn increases the current. Due to this increase in current, the I^2*R (heat loss) is increased resulting into higher technical losses.
- **Improvement in system voltage:** As explained in previous sections, decrease in reactive power causes voltage to fall while increasing reactive power causes

voltage to rise. Thus, generation of reactive power using capacitor banks by the consumers would help in the improvisation of supply voltage also.

5.3 Drawbacks of present (kWh) based billing

1. Consumers drawing more reactive power causes more loss and inconvenience to the system.
2. Lower PF penalty as compared to loss and inconvenience occurred due to reactive power drawl particularly in LTIS categories
3. The power drawn by the consumer is Apparent Power comprising of both Active and Reactive Power. However the present billing is done only for Active Power
4. Need to revise the penalty % from time to time depending upon the average pf of consumers
5. In case of low PF, the harmonics that gets generated disturbs the overall health of power system
6. In order to overcome the drawbacks, billing needs to be done for both Active and Reactive Power. This can be achieved by Reactive Power pricing using kVAh based tariff which includes both Active and Reactive Power.

6 Conclusion

6.1.1 As discussed in the chapters above, it is imperative to have reactive power in the electricity distribution system but must be reduced to maintain the efficiency of electricity distribution infrastructure. The reactive power consumed remains unaccounted in the existing kWh based tariff regime as the pf penalties do not adequately compensate the utility for unaccounted reactive energy.

6.1.2 Whereas, under the kVAh based tariff regime the reactive power is compensated and consumers are encouraged to maintain their pf, as the large reduction in pf of a consumer suitable penalizes the consumer.

6.1.3 Considering the above, many of the State in India have already migrated to the kVAh based tariff with certain States adopting the kVAh based tariff even for consumer categories other than HT as well. Such migration has resulted in the benefit to the consumers as well as utility as the billing disputes or anomalies due to pf and penalties/ incentives thereof are eliminated.

6.1.4 Thus, considering the larger benefit of consumers as well as the utility, it is important that the existing billing regime can be migrated to kVAh based billing.