Study of Energy Utilization in a Metro Rail Limited Company

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***Abstract-* A metro rail company in India has recently completed first phase of its construction work and started operation of its services. Utilization of electrical energy contributes to major part of the operational cost and therefore must be carefully planned to provide economical service to customers. Considering the increase in electricity tariff each year, management and conserving of energy is very important. This paper gives a brief insight into energy utilization of above company during its service period. It is important to understand the composition of electricity bill for effective electricity cost reduction. From the analysis it is found that during the operational period of the metro rail the power factor has decreased significantly. The increase in reactive and apparent power during this period and its effect on power factor variation are discussed.**

***Index Terms*: Metro rail, Reactive power, Power factor, Energy utilization, Energy cost**

I INTRODUCTION

India occupies second rank as thickly populated country in the globe with a population of 1.27 billion definitely requires a transportation system that can accommodate more number of people. This compels the citizens to use private transport which results in traffic congestion, air pollution and traffic accidents. These problems are growing rapidly and thereby demands development of an effective public transportation means that are able to deliver favorable environmental conditions, speedy and fast travel, better mobility and effective growth of economy. The solution is Metro Rail transport system. It is a reliable means of public transport which has the capacity to carry equal amount of passengers as five lanes of bus traffic or twelve lanes of private two and four wheelers. Metro railways [1] can be defined as modern urban, automated, and electrical and environment friendly transportation means having high passenger carrying capacity and it runs at a very fast speed as it has separate track which is totally independent from other traffic roads or pedestrians However, due to the large-scale operations of metro systems and high-frequency services, a great amount of energy is consumed for the daily operation.

Advantages of Metro systems [2]

- Requires 1/5th energy per passenger km compared to road-based system.
- Causes no air pollution in the city.
- Causes lesser noise level
- Occupies no road space if underground and only about 2 meters width of the road if elevated.
- Carries same amount of traffic as 5 lanes of bus traffic or 12 lanes of private motor cars (either way), if it is a light capacity system.
- Is more reliable, comfortable and safer than road based system
- Reduces journey time by anything between 50% and 75% depending on road conditions.

However, Metro rail systems capital costs deter their further adoption in growing cities. Capital costs include, planning, initial construction, and technical equipment cost. For instance, the capital cost for Delhi Metro Rail Cooperation (DMRC) for Phase III expansion is estimated to be 552cr per kilometer. Japan International Cooperation Agency (JICA) is going to provide 48.57 percent of the total fund requirement while the Government of India and the government of Delhi will pay 10.04 percent. On the other hand, in Chennai metro rail, the capital cost is 150 cr per kilometer.

According to Rajabi and Beheiry [3],the initial capital costs of metro systems (stations, routes and carriages) depend mostly on the price of building materials and labor, planning institutions and permitting procedures, geological conditions, as well as the extent of grade separation needed and right-of-away arrangements. A Comparison of capital costs per route-kilometer in urban rail [4] attempts to find the average cost per kilometer of urban metro rail projects constructed in the recent past.

Cost of energy also play vital role in total operational cost .Some researchers have developed models to reduce the energy cost by maximizing the energy efficiencies which include the include the trip time, trip distance, maximum traction force, the maximum braking force and speed limit. Su [5] developed some energy-efficient strategies with the optimal train control model. Arturo [6] described a logical methodology to optimally define and implement energy saving schemes in urban rail systems.

A modeling approach to capture energy consumption differences associated with train, route and operational parameters is presented by Flyvbjerg[7]. Other than energy consumption, the metro rail operators must also pay for the demand charge. The impact of the demand charge on DC railway systems and a solution based on Energy Storage Systems (ESSs) to reduce the demand charge was proposed by David [8]. In this case the installations of other systems are not economically feasible as the project has started its operation recently only.

II ENERGY UTILISATION STUDY

Metro rails in India operate on 25kv ac power supply which may be transmitted as overhead or third rail. The components of ac power results in many energy losses in traction as well as auxiliary power systems. Other than iron loss and heat loss, the capacitive and inductive loads cause reactive component of ac power to increase. According to Gazafrudi [9] major power quality issues in railway electrification is the reactive power.

Traction load is varied dynamically once the metro rail is operated and this may lead to several power quality issues. Rolling stock relies on power electronic converters combined with transformers, which inject low amounts of current harmonics into the supply system. Harmonics, along with underground cable capacitance causes the reactive power of the system to increase. In this section, we details four components of energy consumption that is, active energy, reactive loss, power factor and penalty, and excess demand charges.

Active power [10] (also known as real or true power) is the 'useful' component of the AC power and is what contributes to the work done in a system (e.g. rotation of a motor shaft or the glowing of a light bulb). It is measured in Watt(W).The electricity is required for operation of Metro system for running of trains, station services (e.g. lighting, lifts, escalators, signaling & telecom, firefighting etc) and workshops, depots & other maintenance infrastructure within premises of metro system. The power requirements of a metro system are determined by peak-hour demands of power for traction and auxiliary applications. Reactive power [10] oscillates between the generation source and the load, and does no work in the system. Reactive power however is needed to maintain the voltage in the system, provide magnetizing power to motors and facilitate the transmission of the active power through the AC circuit. Unit of reactive power is VAr(Volt-Amps-Reactive).Apparent power is the vectors for active power (W) and reactive power (measures in Volt Amps reactive – (VAr) are added at right angles to give apparent power (measured in VA). Apparent power is what a generator must produce. Other than the components of ac power, the electricity bill also gives the measure of the phase difference between the voltage and current in an AC power system which is called power factor. In purely resistive loads (such as an incandescent light bulb or electric kettle) the current is in phase with the voltage and there is 'unity' power factor. Capacitive and inductive loads (such as a capacitor banks or inductive motor respectively) will cause the current to 'lead' or 'lag' the voltage, resulting in a 'non-unity' power factor. A non-unity power factor means a load is consuming both active and reactive power.

To study the utilization of electricity in metro rail, the electricity bill issued by the state electricity board is analyzed from the period January 2017 to September 2017. Basic graphic statistical tools are used to study the components of electricity bill and also the variation of active energy over time zone. Figure 1 shows the four major components of total electricity charges during the study period. Active energy comprises 60% of total electricity charge, penalty causes 19% apparent power leads to 12 % and surcharge causes 9% of electricity bill.

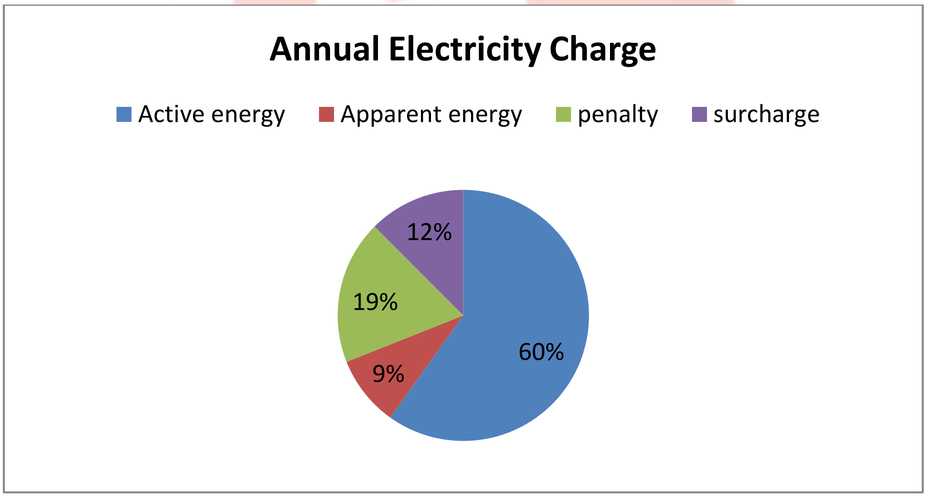

Figure 1

a) Active Power

Major component accounting to electricity charge is the active energy consumption which is nearly 60% of total electricity bill. The electricity pricing of active power is classified into three time zones. Zone 1 which is also called the Normal time zone is between 6.00 and 18.00 hrs. Zone 2 is called the Peak zone and is between 18.00 and 22.00 hrs, and Zone 3 called the Off Peak zone is from 22.00 to 6.00 hrs. The pricing is such that unit consumed during the normal time zone is charged the normal rate per unit whereas the energy consumption in peak time is 1.5 times the normal rate and that in Zone 3 is 0.75 times the normal rate. Figure 2 gives the box plot representation of energy consumption in three zones. A box plot is a graph for comparing the groups. It gives a five number summery of the data that consists of minimum value, the first quartile (Q1) or the 25th percentile, the median and the third quartile (Q3) or the 75th percentile and the minimum value. It is clear from the figure that median value of energy consumption in zone 1 is greater than zone 2 and zone 3 which gives us a conclusion that active energy utilization is maximum in normal time zone.

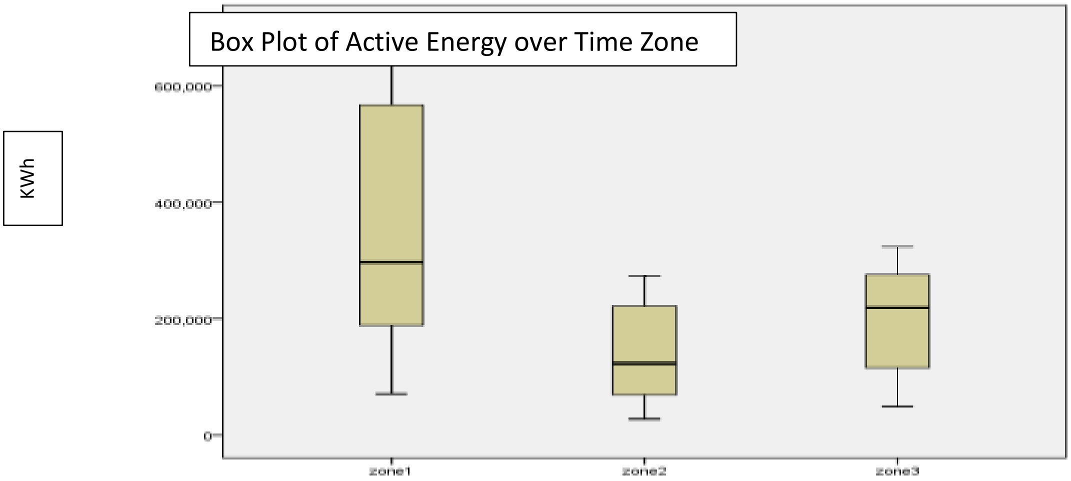

Figure 2

b) Reactive power consumption

Figure 3 shows the variation of apparent power over time. Reactive power increase has resulted in corresponding increase in apparent power and the state electricity board is forced to supply energy than required. As a result, the reliability of power systems gets affected and electricity board bills a penalty to compensate their losses.

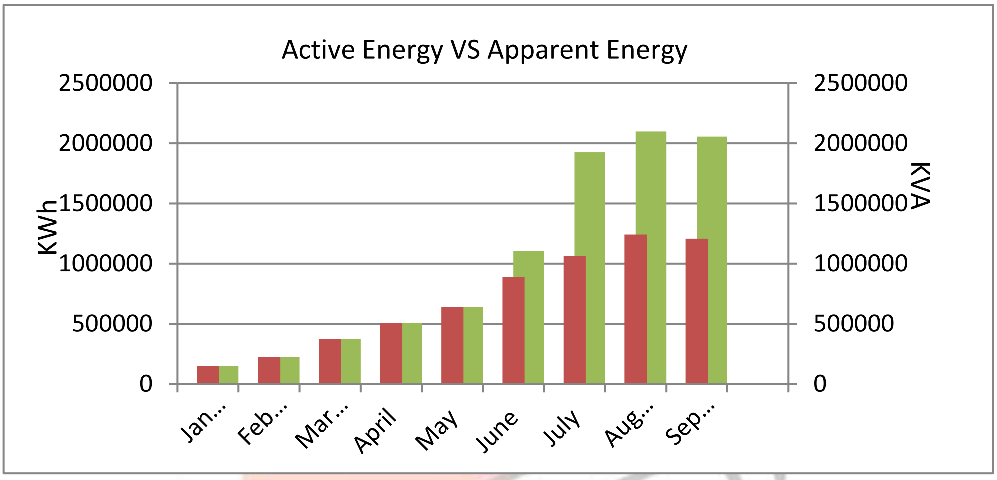

Figure 3

c) Power factor and penalty

Power factor which is measured as Active power/Apparent Power decreases with increase in apparent power. As per regulations of electricity board, for each .01 drop fall of power factor from 0.9, penalty at 1% of energy charge is induced. Similarly, an incentive of 0.50% of energy charge is applied for every .01 increase of power factor from 0.90. From figure 4 it is clear that the power factor is dropped to 50% from initial period and has resulted in penalty in the months of low power factor.

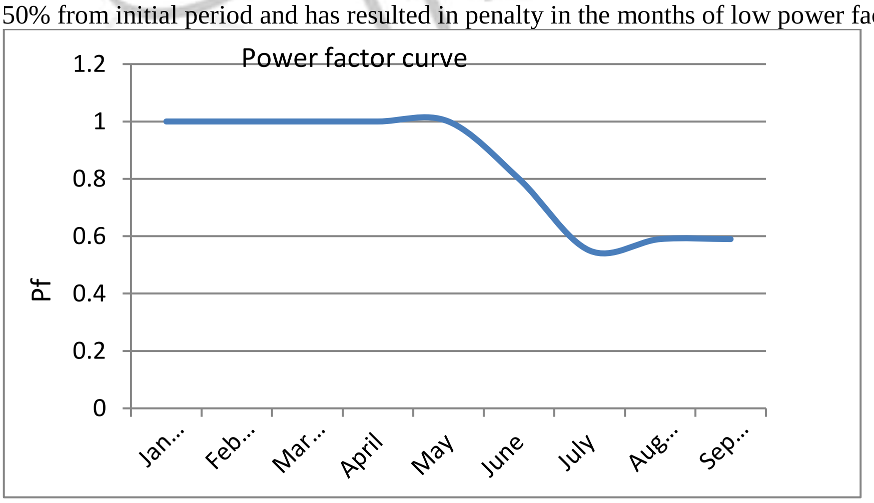

Figure 4

d) Excess Demand charge

Usually in electricity bills, the highest maximum demand value recorded by the meter is compared to the contracted power. Whenever this value is higher than the contracted power, there will be an economic penalty. Therefore, if during the billing month the power exceeds the one contracted, the customer will pay a penalty. Figure 5 shows that maximum demand of the metro rail was less than the contract demand in initial months and steady increase is seen till the month of June. The contract demand is revised in July but has resulted in excess demand charge and the new contract demand of 3500KVA is developed between metro rail and electricity board.

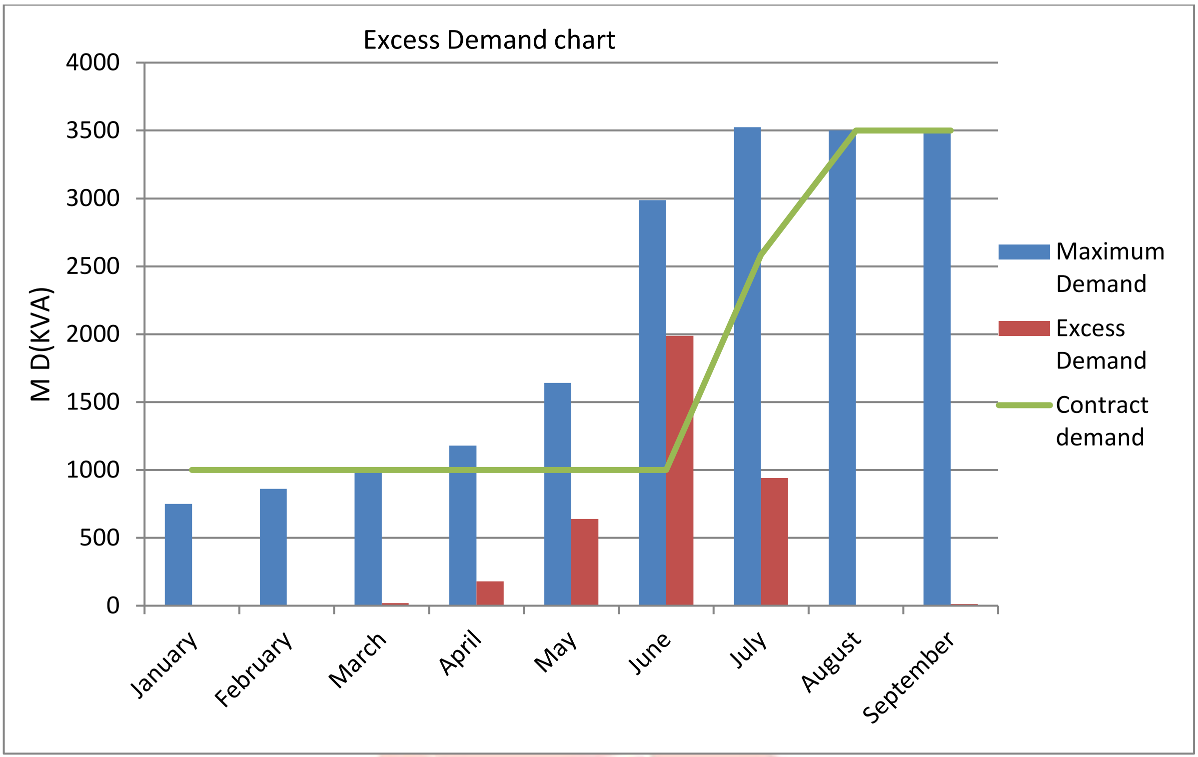

Figure 5

III CONCLUSION

Conservation and utilization of energy has become the central objective of metro rail systems for reducing the operational cost and provide economic service to the customers. Modern metro rails are technologically advanced and does implement all the available resources for the minimum consumption of energy. This paper has studied the energy utilization in a metro rail. Influences of energy under various time zones are analyzed and the entire penalty factors affecting the electricity cost are studied. For effective utilization of energy, it is important to maintain the power factor at unity. Devices like static compensators should be installed in power system to maintain the power factor. Even if energy consumption is higher during the normal time zone research must be done to study the impact of energy consumption in peak and off peak hours as energy cost in peak hour is higher than the normal rate. Study can also be extended to understand the variation of maximum demand which helps to renew the contract demand with electricity board to reduce the excess demand charge.

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