PRELIMINARY SURVEY ON ELECTRIC ENERGY EFFICIENCY IN ETHIOPIA:- AREAS OF INTERVENTION

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ABSTRACT

In this paper the significance of electric energy efficiency improvement and major areas of loss in Ethiopia's electric power system are highlighted for further rigorous study. Major electric energy loss areas in the utility transmission and distribution systems and consumer premises are indicated. In the consumer area the loss associated with the energy conversion devices like lamps, electric motors, electric Mittad, and welding transformers are estimated. The investigation demonstrates that there is a possibility of electric energy saving which is at least equal to 10% of the present yearly generated electric energy.

Present trend in electrical engineering education; that is the inclination of students towards electronics and computer engineering areas abandoning power engineering area and the resulting danger of shortage of qualified pool of engineers for employment in the energy sector have been demonstrated.

Consorted efforts of Ethiopian universities and the sector players for sustainable, efficient, reliable, and high quality electric energy supply for Ethiopia and for sustainable qualified human power training for the sector have been recommended.

Keywords: *EEPCO, Efficiency, Electric mittad, Energy, Power factor, Technical loss.*

INTRODUCTION

Energy efficiency

In Engineering, efficiency is defined as the ratio of output power from a system or equipment to the input power to the system or equipment. However; efficiency applied to energy needs explanation. The total energy a country uses to produce a dollar of Gross Domestic Product (*GDP*) for example can be used as the energy efficiency of a country [1]. Energy in this definition is not limited to electric energy. It includes all forms of energy obtained from nuclear, fossil fuel, biomass, etc.

In this article electric energy efficiency is defined with respect to the electric utility operator and the consumer. With respect to the Utility operator, electric energy efficiency is the ratio of electric energy sold by the utility operator to electric energy generated as shown in Eq. 1.

$$\eta = \frac{Electric\ Energy\ Sold}{Electric\ Energy\ Generated} \qquad (1)$$

If a vertically integrated utility operator like Ethiopian Electric Power Corporation (EEPCo) is considered, the electric energy sold is total electric energy generated minus energy loss in the process of generation, transmission, distribution and sales. There are two components of loss; technical and non-technical losses [2]. *Technical loss* refers mainly to the electric energy lost on resistive effect of the electrical system (I^2R) throughout the system and core losses on machines and control systems. Non-technical loss on the other hand accounts for energy utilized but not paid for due to measuring errors, theft by some customers, etc.

Electric energy Efficiency with respect to the electric energy consumer can be defined as the ratio of the output of the consumer (in terms of product quantity or other form of energy) to the input electrical energy, Eq. 2.

$$\eta = \frac{Output\ (Product,\ Mechanical,\ Heat,\ \ldots,\ etc)}{Electric\ Energy\ Input\ in\ to\ the\ System} \qquad (2)$$

Why energy efficiency

Today, electric energy efficiency improvement and search for renewable energy sources are some of the top agenda of the world and research themes of scholars. This is because of the carbon-dioxide emission and the resulting environmental deterioration, limited fossil fuels as energy source, and the fast increase of energy demand in developing countries.

According to a study done in USA, energy saving by efficiency improvement is more attractive, because new conventional base–load production sources generate electricity at an estimated cost of *$0.073* to *$0.135* per kilowatt-hour while the saving cost through various improvements of efficiency is estimated to cost about *$0.03* per kilowatt-hour [4], which is two to four times.

Introducing Energy Efficiency Resource Standard (EERS) USA plans to reduce its electric energy consumption by 15% in 2020 [3] [4]. This standard includes efficient transmission and distribution plus efficient utilization of energy. This effort by the highly professional and developed country like USA, indicates that there is a lot to be done in our system both in respect of the utility operator, EEPCO system and its customers' systems to improve the electric energy efficiency.

EEPCo's and electric energy users' systems and components modeling and analysis, identification and quantification of sources of losses, and identification and recommendations on means of minimization of losses are what has to be done concertedly by stakeholders; the utility operator, the universities, the industries, and the public as a whole.

In the following sections EEPCo present estimated efficiency, sources of loss, potentials of loss reduction at consumer premises and some efforts of Electrical and Computer Engineering Department (ECED) in this respect are discussed.

EEPCO ELECTRICAL SYSTEM EFFICIENCY

Energy losses along the way from the generation point up to utilization point is the main reason for low efficiency in electrical system.

Technical loss in electric power system

There are two main components of technical loss in transmission and distribution systems. One is loss in the lines while the other is loss in transformers. Common reasons for high electric energy loss on the line are low voltage level compared to the size and length of the conductor, low power factor, load unbalance in the phases, harmonics in the current and voltage, improper design or installation using inappropriate materials and components, etc. There are at least three transformers in a power system transmission from generation point up to the consumer premises. These are step-up transformer at the generator switch yard, the step-down transformer at the distribution center, step-down to low voltage (400 V, 220 V) level. The transformer efficiency varies from 96 to 99.5 depending on the capacity, load, design, etc. Older transformers have high loss or lower efficiency. In our EEPCo system, if we assume two of the three transformers in the chain, what is generally the case, to have efficiency of 99% and the last transformer in the distribution to be 97% the overall efficiency of the transformers would be 95%. That is 5% energy loss on the three transformers overall.

Since 1980s, development of new transformer core materials has resulted in high efficiency transformers. A transmission and distribution loss, including the loss on transformers and the line I^2R loss, in Japan is 4%, USA about 6%, Europe average 6.5%, China 7%, UK 8% [5] [6]. There are also high loss systems like that of India 31%, Pakistan 26% and Tanzania 25% [6, 7].

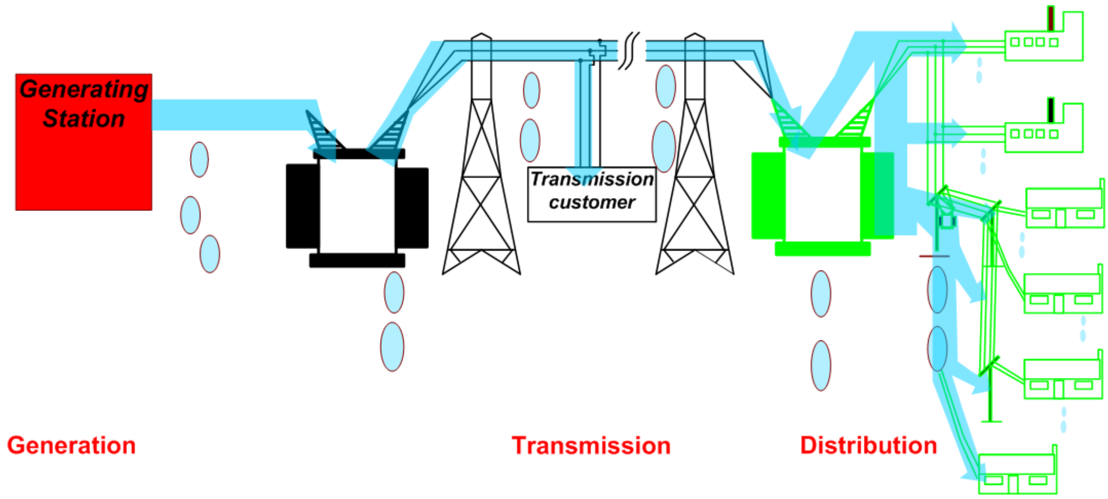

Figure 1 Electrical power system loss

EEPCO's Electrical System Loss

The current Electric Energy loss in EEPCo's system is about 18% of the electric energy generated [8]**.** In other words efficiency of the system is 82%.

The electric energy loss in transmission, distribution, and secondary circuits in EEPCo's system need modeling, analysis, and some measurements to quantify the level of each sources of loss (cable, and transformer, due to low power factor,…) and their contribution to the total electric energy loss. However, from the efficiency level of USA, Europe and Japan we can see that there is possibility of improvement in the efficiency of EEPCo's electrical energy system and save significant amount of energy.

For example; if we are able to reduce the system loss from 18% to 12% as a first stage, we would be able to have about 48 MW (~0.06x800MW) of electric power [9]. This saving which is equivalent to 6% of the yearly total energy generated, about 3,570 GWH, is equal to 214.2 GWH.

Efforts by Electrical and Computer Engineering Department towards Improvement of Energy Efficiency

There are some MSc students from EEPCo working on the modeling and analysis of major transmission lines like Koka to Diredawa and evaluation of main distribution system like Bahir-Dar distribution system. The intension is to make these as model and scale up for modeling and analysis of other similar transmission and distribution systems. The analysis is expected to result in quantified performance of the system based on which appropriate decisions can be made.

The ECED of Addis Ababa University is encouraging the electrical power MSc students to work on real problems in EEPCo so that they come up with feasible solutions for improving the electric energy efficiency.

ELECTRIC ENERGY EFFICIENCY AT CONSUMERS PREMISES

At the point of use electric energy is basically changed to other form of energy like light, kinetic, heat, and electronic outputs like audio, video, etc.

Lighting

The electrical energy efficiency with respect to the consumer can easily be demonstrated by considering the electric lighting. In Ethiopia almost in all domestic lightings, incandescent lamps are used. However, incandescent lamp is the most inefficient artificial light source as shown in Table 1. The efficacy of incandescent lamp at present varies from 10 to about 25 *Lumens/watt* while the Compact Florescent Lamp (CFL) efficacy reaches around *75 Lumens/watt*, three times that of incandescent lamp. That means a CFL gives light energy which is equal to three times that of incandescent lamp for the same electric energy consumed. We can save two-third of electric energy we are using for domestic lighting if we replace the incandescent lamps with CFLs.

At present, due to the relatively cheap initial cost and readily availability incandescent lamp is the first choice for domestic light source. This is true in European and American countries too. However, European Union and Australian government are considering a ban on the import and sale of incandescent lamps in favor of CFL and other more efficient light sources.

In CFLs the 50Hz, 220V power supply is processed to supply the florescent with high frequency. Due to the high frequency, the current limiting inductor, known as choke, becomes very small resulting in the compactness of the lamp.

EEPCO has about 1.3 million customers at the moment [6]. If one million of the customers are assumed to have two incandescent lamps of 40 Watts each replaced by two 11 Watts CFL, the power consumption reduces from 80 MW to 22 MW for the same light output if they are to operate at a time. If the lamps are to operate for fours hours per day, the total electric energy per year will be 83,510,000 kWH (3 *hours/day x 58,000 kW x 365days*).

Table 1: Efficacy of some electric lamps [10]

Lamp type	Efficacy, Lumens/Watt
Incandescent Lamp	10 to 25
Compact Fluorescent Lamp	20 to 75
Fluorescent full size and U-tube	70 to 100
Compact metal halide	45 to 80
High pressure sodium lamp	45 to 110
Low pressure sodium	110 to 155

In commercial buildings more than 25% electric energy is used for lighting. Exterior lightings, where the quality of light is not critical like street lightings need investigation to use the highest efficiency sodium lamps. Therefore; work on efficiency of lighting can save more energy than what is estimated above.

EEPCO has taken an initiative to distribute CFL free of charge to its customers recently to relieve the power shortage pressure on it. It has demonstrated the energy saving possible at the national level and energy cost reduction to its customers. This can be considered as significant awareness creation for energy efficiency issue. For the sustainability of energy saving through high efficiency light sources like CFL, the government may need to take appropriate majors to encourage the import or local manufacturing of these high efficiency lamps at an affordable price for the household while discouraging the import and manufactory of low efficiency lamps.

Electric machines

Electric machines are the main electric power loads in industry comprising up to 70% of electric energy in the processing and manufacturing industries. In US 64% of total generated electric energy is said to be consumed by electric motors. Electric machines do convert the electric energy into mechanical energy. The efficiency of induction machines, the most widely used in the industry range from 78% to 94% when they operate at the rated power. When they are partially loaded their efficiency drops much blow this range.

Traditional methods of speed adjustment like inserting resistors in the rotor circuit and mechanical braking have excessive loss. The conversion efficiency can be improved by using power processors, supplying the machine at a desired voltage level and frequency for best possible efficient conversion at a desired speed. Speed control of the electric machines and the driven units can be done by controlling the frequency and voltage of supply to the machine.

Over sizing electric machine is another important point to be considered. Electric machines operate at their best efficiency when they are operated at their rating. Over sizing electric motors result in less efficient operation. They also work at low power factor. The same holds for transformers.

Work must be done in industries to audit their energy utilization and determine the quantified energy saving possible.

Electric Mittad

Important electric energy load in domestic use in Ethiopia is the electric *Mittad*. On average it consumes about 3 kW. It uses resistor to convert electric energy to heat energy. The electric heat generated by the resistor is conducted to the plate made of clay. In the process, the heat transferred to the *injera* for baking is estimated to be very small while a huge amount of heat energy is lost to the environment [11]. Research should be done on this indigenous equipment to improve efficiency. Some preliminary investigations demonstrate that the efficiency of *injera* baking can be improved by more than double using induction heating rather than resistor heating. The department has filed a patent on induction *mittad* and is working on its further development.

If we estimate the number of electric *mittad* in the country to be 300,000 pcs, and each operate for two hours every week, the total electric energy consumption in a year can be calculated to be (3 kW x 52 weeks x 2 hours/week x 300,000 *mittads*) 93.60 *GWH*. If the electric energy consumption is halved, the saving can be 46.80 *GWH* per year.

Welding transformers

Recently metal workshops using locally made welding transformers have increased all over the country. Survey done by an MSc student in Electrical and Computer Engineering Department of Addis Ababa University has estimated the total number of locally produced welding generators in use to be about *60,000 to 80,000* [9]. The authors have measured the loss of samples of the locally manufactured transformers to be on average 1 kW compared to 0.23 kW of equivalent imported transformers.

It is possible to reduce the loss at least by half by proper design and material selection. If 170 working days and about 2 hrs effective working hours are assumed per day, the electric energy saving per year will be 10.2 GWH. These transformers are not well designed and core material used is not the proper material for the required efficiency [12]. Electrical and computer engineering department is working on proper design and material selection to help the local manufacturers to improve the efficiency of the transformers.

Sub-Standard electric components

In addition to the other disadvantages of substandard materials, electric loss associated is critical. Substandard materials, the appliances and equipments are expected to increase the energy loss where ever they are used.

Recently electrical and computer engineering has made survey on electrical cables, socket outlets and dividers with the finding that there is a significant and alarming amount of these materials in Ethiopian market and in use [13]. Similar survey has to be done on electric appliances, equipments and electronic devices.

The issue of substandard electrical materials and appliances require consorted effort of policy makers, the government bodies concerned with standards, professional societies, the business community, and the society as a whole.

Power factor

Alternating current system has two types of power flow in electrical cables; namely active power and reactive power. Active power is the power which is converted to the useful power at the point of use while the reactive power is power in the energy storage elements like inductors and capacitors. The reactive power is required for proper functioning of the electrical equipments. Fig. 3 demonstrates the problem of reactive power. In Fig. 3(a), the electric motor draws 80 Amps for active power and 60 Amps for reactive power. The electric generator should supply the vector sum of the two that is 100 Amps. The electric motor is said to operate at 0.8 or 80% power factor (*pf*); where pf is the ratio of active power component current to the vector sum of the two. The line from generator to the motor carries 100 Amps.

In Fig. 3(b), the reactive component current is supplied from capacitor bank, known as power factor compensator. In this case the electric generator is required to generate load current of only 80 Amps, the active power component. The cable from generator to the motor also carries the 80 Amps.

The power factor corrector solves four problems; congestion of the transmission and distribution system line by the reactive component current, relieving the generator from generating reactive power component current (instead it can generate additional 20 Amps active power current), reducing power loss in the transmission and distribution system due to the reactive power component current, reduction of voltage drop along the cable. Table 2 shows some electrical appliances and equipments requiring reactive power for proper operation with their approximate power factor.

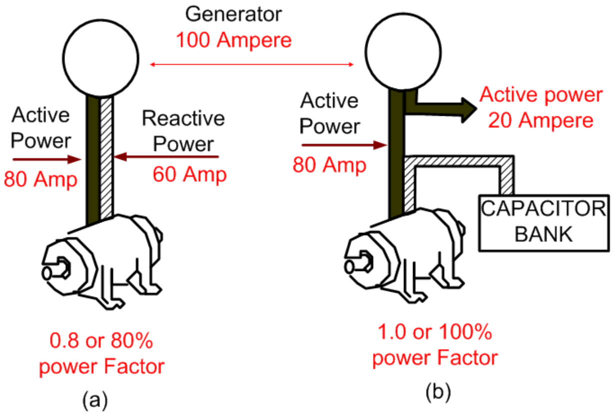

Figure 3 Electric motor power factor

Power factor correction becomes more important in rural electrification where the distribution lines are relatively long. Some details of capacitor bank selections for power factor correction are given in reference [14].

The electronic devices like computer and TV are also contributing to power factor reduction by introducing harmonics. Harmonic distortion results in power factor reduction.

Table 2: Power-factor of some electric equipment

Appliance	Power Factor
Induction motors	55%-90%
Arc welders	50%-70%
Solenoids	20%-50%
Induction heating equipment	60%-90%
Small “dry-pack” transformers	30%-95%
Fluorescent & HID lighting fixture ballasts	40%-80%

Economics of Electric Energy efficiency

The approximate energy saving possible from the above exercises has been summarized in Table 3. Total of about 334.71 *GWH* energy saving is possible per year. EEPCOs yearly energy production in 2001 EC is about 3570 GWH. Therefore; the electric energy saving is about 10% of the yearly production. If the electric energy is taken to be 0.45 Birr/kWH (the average domestic charge rate), the yearly saving in Birr is more than 150, 000,000.

The cost to be paid for such saving requires rigorous evaluations and may include the electric power down-time cost at the country level during the critical power shortage like in year 2001 EC in our country, Ethiopia. A study done in Nigeria on down-time cost has shown that the electric energy outage cost in that country varies between $0.94 and $3.12 per kWH. This is a potential research topic to be done in our country.

If efficiency improvement of electric motors in industry and conservation of energy by using electric energy only when and where required are considered the energy saving can be multiple of the above exercise result.

Table 3: Estimated possible energy saving

No.	Intervention point	GWH
1	Efficiency improvement from 18% to 12%	214.20
2	Lighting (CFL)	63.51
3	Electric Mittad	46.80
4	Welding Transformer design improvement	10.20
Sum		334.71

ELECTRICAL POWER ENGINEERING EDUCATION

Electrical power engineering in AAU

With the advent of microelectronics and computer technologies, the trend in electrical engineering education is towards the electronics, computer engineering and communication engineering. There were no applicants for Electrical Power Engineering MSc program in AAU until some two years. There are only two graduates from the program until now.

The largest admission to the electrical power engineering program was in 2000 EC, which were 25 students from EEPCo based on the postgraduate study and research agreement between AAU and EEPCo. About 20 of these are expected to graduate in year 2002 EC. The curriculum for Electrical Power Engineering masters program is a standard MSc program covering high-voltage engineering, transmission and distribution systems, renewable energy technologies and power electronics and derives.

The first batches of electrical power engineering masters students, from EEPCo are working on their MSc thesis proposal at present.

The followings are the main areas the students have worked on in their independent project and thesis.

- Transmission (including high voltage DC) and distribution system modeling and analysis for increasing capacity and loss reduction.
- Survey on welding transformer efficiency and ways of improving efficiency
- Electric power quality, power factor and efficiency at the consumers premises
- Renewable energy technologies as an alternative electric energy source
- Inverter technologies for integrating power from renewable energy source with the grid system.
- Generation system control and automation, etc.

EEPCo has been supporting the Faculty by finance so that its students get diversified knowledge and skills at a required level. Expatriate academic staffs, par-timers, and guest lecturers have been involved in the teaching EEPCo students.

Electrical power engineering in USA and South-Africa

The trend of electrical engineering education and the inclination of most students away from electrical power engineering have worried different electric utility operators and policy makers. South-Africa's ESKOM has introduced the so called Tertiary Education Support Program (TESP) in which it finances universities and research centers since 1980s to overcome the declining trend with the following specific benefits [15].

- Retention of academic staff in Electrical power area.
- Development of knowledge base of academic staff in the area.
- Development of capacity to do contract research with ESKOM.
- Development of students and potential pool of employees with an increased level of knowledge and skills.

ESKOM is south-Africa's utility company generating 35 GW, which is about 60% of the power generation of the whole sub-Saharan countries and about 80% of the southern African countries [16].

In response to critical concerns about the power and energy engineering workforce and the education system that supports it, the U.S. Power and Energy Engineering Workforce Collaborative, led by the IEEE Power & Energy Society, has developed a sweeping and detailed action plan. The plan envisages to double the number of graduate and undergraduate electrical engineering students in USA calling upon industry, government and educational institutions to take specific, reasonable and immediate actions to attract more young people to electric power engineering and to support the education system that will make them highly-qualified engineers [17]. Millions of dollars has been allocated for the implementation of the plan.

Consorted Effort Requirement for Today's Competitive World Challenges

In USA, companies on average allocate 3.5% of their revenue for research and development. Research and development (R and D) is investment by companies to continuously increase their competitiveness. The competition is in efficiency, quality of product or service, cost, etc.

Had it been operating in USA, EEPCo should have expended more than 35 million Birr each year for research and development.

It is generally expensive for industries to install and administer laboratories and employ highly qualified professionals to do research in-house for industries. The chipset way of doing R&D for industries is to work with universities. University postgraduate students guided by their professors can solve most problems. Universities also have basic research facilities as part of laboratories of education. The industries are required to cooperate with universities and come up with their problems and some finance. Students who have worked on problems of a particular industry can also be employed by the industry and continue on working on the solution of the problem.

AAU and EEPCo's agreement is a positive sign in this direction. It should be strengthened.

CONCLUSION & RECOMMENDATION

CONCLUSION

This paper has demonstrated that there is a lot to be done to improve the electrical energy efficiency of our utility and industry.

Improving energy efficiency can reduce new power plant generation requirements and can contribute to the effort being exerted to curb the energy shortage we are facing.

Energy efficiency in the utilization process can also reduce the industries' energy cost and improve their cost competitiveness in the global market.

Recently, the number of students in electrical power engineering area has been declining globally, as compared to the computer and communication engineering students. We need to take appropriate action to secure pool of employees and researchers in electrical power engineering.

RECOMMENDATION

The government, the energy sector players like EEPCO and higher education institutions have to work on policy framework to support the education, research and development in the energy sector for efficient, reliable, and quality energy supply which is essential for sustainable economic and technological development of Ethiopia.

Government should allocate a certain percentage of gross domestic product (GDP), and encourage industries to allocate a certain percent of their revenue for research and development for sustainability of development and competitiveness of the products and services.

EEPCo and AAU have to strengthen their existing cooperation to produce solutions for local problems and become a successful/ideal model for university-industry linkage.

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