Energy Efficiency

Dr. Mo. Helal

The Energy Supply Chain

Much of the energy content of the available energy sources is wasted by inefficiencies the energy conversion and distribution processes. Considering domestic electric lighting as a typical example, less than 1% of the energy consumed to provide the electricity is ultimately converted into light energy. The other 99% is wasted in the supply chain. Using conventional fossil fuelled generating plant, losses accumulate as follows:

- 10% of the energy content of the fuel is lost in combustion and only 90% of the calorific content is transferred to the steam.
- The steam turbine efficiency in converting the energy content of the steam into mechanical energy is limited to about 40%. (Carnot's Efficiency Law)
- The rotary electrical generator is very efficient by comparison. The conversion efficiency of a large machine can be as high as 98% or 99%.
- Transmission of the electrical energy over the distribution grid between the power station and the consumer results in a distribution loss of 10% mainly due to the resistance of the electrical cables.
- Further energy is lost due to the energy conversion efficiency of the end user's appliance. Incandescent lighting is particularly inefficient converting only 2% of the electrical energy into light.

The losses are considered in more detail below.

Generating Efficiency

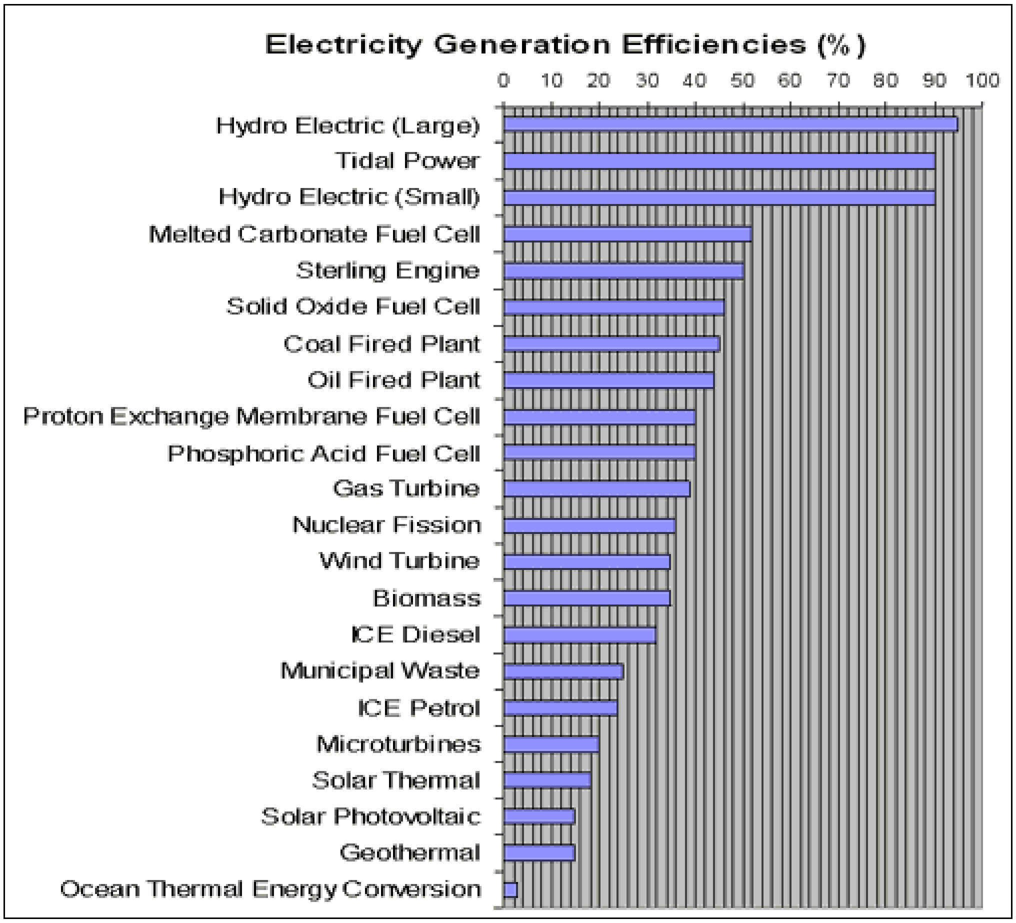
Electric power plant efficiency **η** is defined as the ratio between the useful electricity output from the generating unit, in a specific time, and the energy value of the energy source supplied to the unit in the same time period.

For electricity generation based on steam turbines 65% of all prime energy is wasted as heat.
The maximum theoretical energy efficiency is defined in more detail by the Rankine cycle. For modern practical systems this is about 40% but less for older generating plant.

The efficiency falls still further if fuels with lower energy content such as biomass are used to supply the plant.

Efficiency Comparisons

The table below shows the theoretical efficiency of converting various energy sources by a variety of methods into useful electrical energy.



Source - Eurelectric

Plant Utilisation Efficiency

In practice electricity generation installations rarely deliver their theoretical capacity on a full time basis due to variations in the demand and the need to shut down the equipment from time to time to carry out planned maintenance or emergency repairs. The following factors are used to indicate the effectiveness of the generating utility in managing its generating capacity.

Capacity Factor:

The capacity factor is a measure of operating efficiency which indicates the ability of a generating plant to deliver its full capacity. It is simply the generator's actual energy output for a given period divided by the theoretical energy output if the machine had operated at its full rated power output for the same period. It is indirectly an indicator of the reliability of supply.

The capacity factor of a conventional nuclear or coal fired power plant is under management control and may be over 80%, whereas the capacity factor of wind generators or solar power plants depends on the elements and is typically less than 40% with 25% not being unusual. This means that a 1000 kW wind-turbine would, at best, be expected to produce only as much energy in a year as a 500 kW of coal-fired power plant and probably much less.

Load Factor

The load factor is a measure of plant utilisation which indicates how effectively the plant capacity is matched to consumer peak demand. It is the ratio of the average load to peak load during a specified time interval. Poor load factor means inefficient use of plant and capital.

Base Load

Different types of generators operate with a range of planned load factors determined by the policies of the generating utility companies. High efficiency plants are normally scheduled to deliver the base load of the grid and consequently they are operated at a very high load factor.

In the UK during 2004, coal fired power stations had a load factor of around 62 per cent, gas fired power stations 60 per cent, nuclear power plants 71 per cent, hydroelectric plants 37 per cent and pumped storage hydro plants 10 per cent. During the same period the overall average load factor for the total UK electricity network was around 55 per cent.

Source: Digest of UK Energy Statistics (DUKES) 2005

Peak Loads

Load Patterns are considered in more detail on the Electricity Demand page and the section on Load Matching gives options for supplying peak loads. Generating plants supplying peak loads will normally have a very poor load factor and so older, less efficient plants are often designated for this purpose.

Plant Margin:

The utilisation of the electricity grid and the generating plants within it will be intentionally less than full capacity to ensure security of supply even when some generating plant is out of service or in case of unexpected peaks in customer demand.

The planned excess capacity is known as the plant margin.

The plant margin is an indicator of the security of supply. It is the amount by which the installed generation capacity exceeds the forecast peak demand and is expressed as a percentage. A plant margin of at least 20% is considered to be necessary to avoid blackouts and potential overloading of the electricity grid. A high plant margin thus results in a low load factor.

Electricity Distribution Efficiency

Distribution Loss Factors (DLF)

The resistance of the cables conducting the current flow between the generating plant and the end user's premises cause further efficiency losses due to the Joule heating (I^2R Losses) of the interconnecting power cables. There are two major influencing factors.

- **Location**

  The resistance of the cables increases with distance so that losses are typically 5% for supplies to urban locations close to the power source but as high as 10% to 20% for remote rural locations. The overall average for the USA is 7% to 8% , while for Egypt is estimated to be 15 to 20%
- **Voltage**

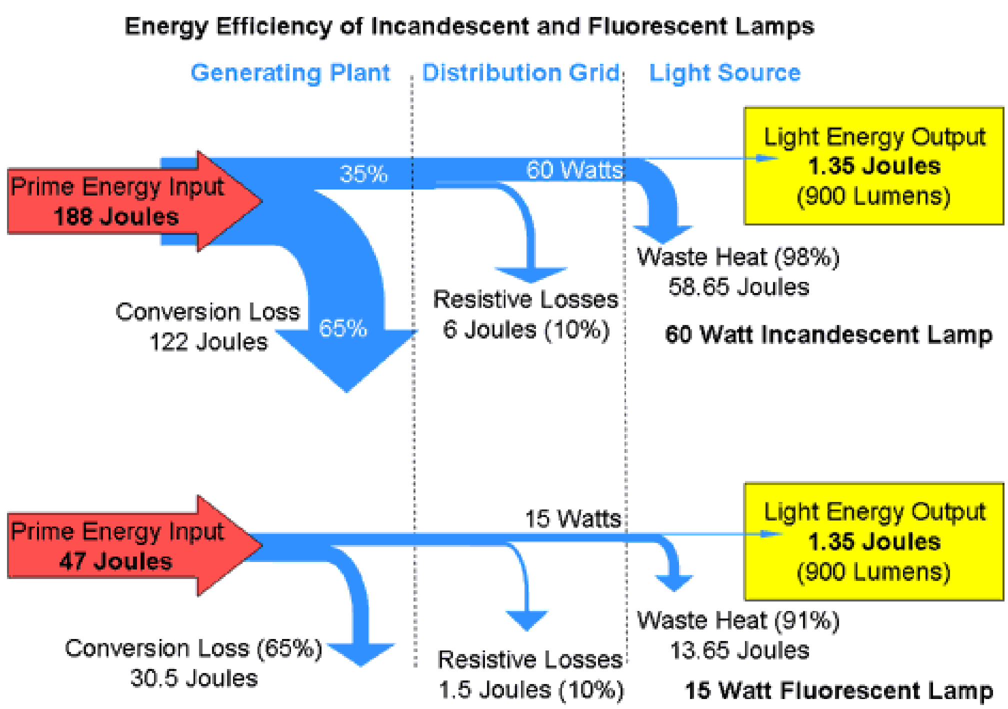
  Since Joule heating losses are proportional to the square of the current, distribution losses can be reduced by transmitting the power with as low current as possible by using higher transmission voltages. The upper voltage limit is set by the breakdown of the air insulation between the power cables and the earth, or more likely across the insulators suspending the cables from the transmission pylons (towers).

With high voltage transmission systems there are also additional, though minor, copper and iron losses in the transformers, stepping up the voltage at the generating station and stepping it down again at the point of consumption, due to the resistance of the windings and the hysteresis and eddy current losses in the transformer cores.

Note: Other factors may be valid nowadays because of the non linear loads wieldy used (see effect of harmonics on power factor)

Energy Usage Efficiency

The following example shows the inefficiencies involved in converting a primary energy supply into useful light output. A typical 60 Watt incandescent lamp produces illumination of about 15 lumens per Watt of applied power. The total light output from the bulb is therefore 900 lumens, which is equivalent to about 1.35 Watts or 1.35 Joules per second of radiated light power, and the conversion efficiency is 2.25%. The rest of the applied electrical energy is lost as heat. Taking into account the typical efficiency of electricity generating plant of 35% and 10% Joule heating losses in the distribution grid, the efficiency of converting primary energy into light energy is only 0.7%



For comparison, a compact fluorescent lamp (CFL) produces between 50 and 60 lumens per Watt. By using fluorescent rather than incandescent lamps, the power consumption of the lamps can be reduced from 60 Watts to 15 Watts for the same light output. The consumer saves a modest 45 Joules per second but the corresponding prime energy consumption is reduced by a massive 141 Joules per second.

Six points are worth making here:

1)Using incandescent lamps is a very inefficient way of providing illumination.

2)To power a 60 Watt incandescent light bulb for one year requires 200 to 300 Kg of good quality coal.

3)Considering the billions of incandescent lamps in use around the world today, an inordinate amount of energy is being wasted for lighting purposes.

4)Energy saving alternatives is available.

5)Energy saving appliances doesn’t just save the consumer money, the energy savings are amplified as you pass back down the supply chain. In this typical case, a saving of 1 Joule by the end user results in a reduction of over 3 Joules in the total energy consumed.

6)The savings amplification factor also applies to any energy savings made by the end user such as turning down the temperature on thermostats or switching off appliance that uses remote control and standby functions (TV , Satellite receivers , cell phone chargers , Computers ,)

A newer study about effect of high frequency harmonics and the effect on increasing the losses factor will demonstrates the urgent needs of strict energy efficiency rules within the energy usage sector to maximize efficiency.