Electrical Energy Consumption and Markets

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Electricity Market Structure

GENERATORS

Responsible for generating the electrical energy

NATIONAL GRID

Generated electricity flows into the National Transmission network and through to the regional Distribution networks.

DISTRIBUTORS

- **Owners and operators of the network of towers and cables that transport electricity from the National Transmission Network to homes and businesses.**
- **They are not the organisations that sell electricity to the end consumer.**

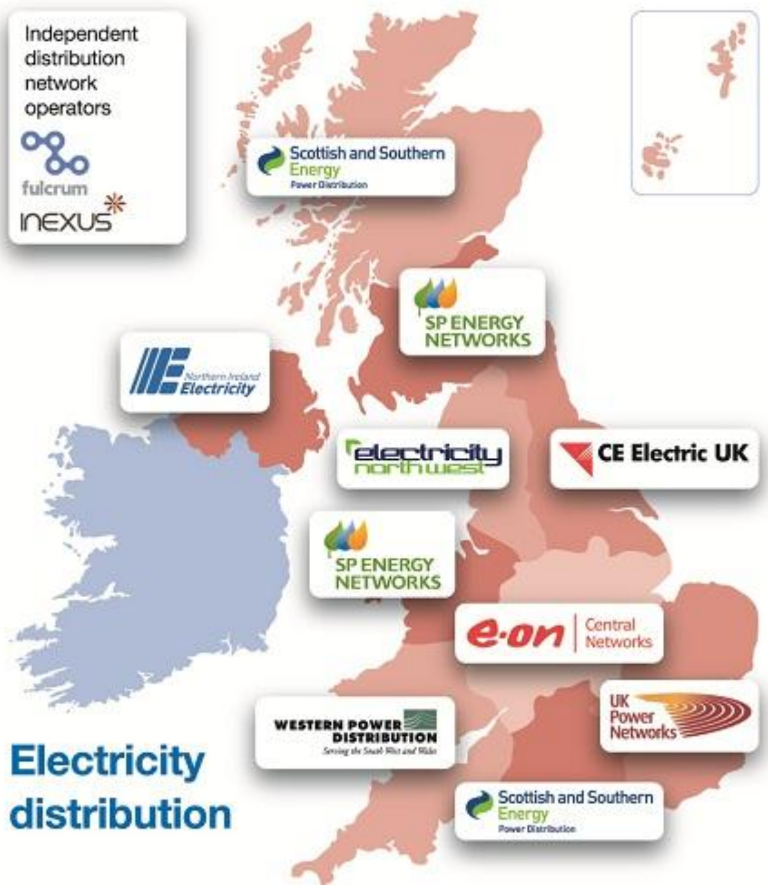
SUPPLIERS

- **Companies who supply and sell electricity to the consumer. The suppliers are the first point of contact when arranging an electricity supply to domestic, commercial and smaller industrial premises.**

Electricity Distribution

Distribution Network Operators (DNOs)

There are currently 14 Distribution Network Operators (DNOs) in the UK.



Electricity Regulator

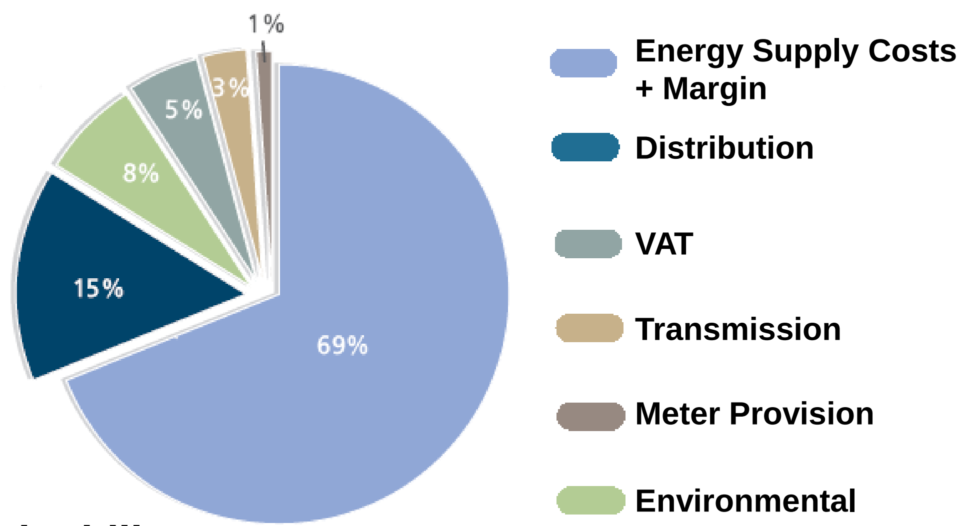
OFGEM - Office of the Gas and Electricity Markets

- Protecting consumers by promoting competition
- Regulating the monopoly companies which run the gas and electricity networks
- Helping to secure Britain's energy supplies by promoting competitive gas and electricity markets
- Ensuring there is adequate investment in the networks
- Contributing to the drive to curb climate change and other work aimed at sustainable development
- Funded by the licensed companies they regulate, but is independent of them

Electricity Tariffs

DOMESTIC TARIFFS

- Household loads are predominantly resistive – operate at unity power-factor
- Domestic customers only charged for the energy used - charges based on kiloWatt-hours (kWh)
- Customers can choose to use a two tier pricing system with standard and off-peak rates (Economy 7) - electricity prices are lower through the night when there is lower demand



Breakdown of typical domestic electricity bill June 2010 – Average household bill £500

Electricity Tariffs

E-Futures

DOMESTIC TARIFFS

- Wholesale energy costs account for around 60% of bill
- Retail energy bills not price regulated
  - monitored by Ofgem and no evidence that suppliers not passing on wholesale cost savings
- Other factors lead to increase in domestic energy bills:
  - Cost of Government's environmental programs increasing
  - Need to renew infrastructure and connect more renewable sources
- Suppliers buy a large proportion of there energy requirement in advance
  - Allows fluctuation in wholesale prices to be averaged over year
- Some energy suppliers have better forward buying strategies than others
- Global price of oil, coal and gas drives wholesale costs – very volatile. Gas price linked closely to oil.
  - Cost of oil per barrel: $145 in Jul 08; $35 in Jan 09; Nov 2011 ~$115
  - Cost of coal per tonne: $210 in July 08; currently ~$70
- Current energy policy aims to increase diversity to reduce dependency on international energy markets.

Electricity Tariffs

DOMESTIC TARIFFS

Element of bill	How have these costs shifted over time?
Wholesale energy costs (the costs of the gas, oil, coal)	Risen in recent years as international commodity price have increased and dependence on international gas markets increases
Supply costs (costs of metering, billing, and supplier margin)	No significant changes.
Network charges (costs of transporting and distributing energy to homes and businesses)	These were reduced significantly since privatisation as a result of the network companies becoming more efficient under Ofgem's regulation. But costs are now rising due to increases to renew ageing assets and help the drive to a low carbon economy
Environmental levies (costs of Government schemes to promote renewables, low carbon technologies and energy efficiency)	A decade ago these costs were not part of the bill but are now significant and are set to rise further as new Government schemes to support the move to a low carbon economy come on stream

Source: Ofgem, Household energy bills explained

Electricity Tariffs

COST OF COMBATING CLIMATE CHANGE

A number of Government environmental programs now effecting energy bills

- **EU Emissions Trading Scheme (EUETS)**

  - puts levy on pollution emitted by electrical generators.
  (For average domestic electricity customer ~£24/annum)

- **Carbon Emissions Reduction Target (CERT)**

  - Government's main method of delivering energy efficiency. Obliges suppliers to reduce CO_2 emissions and promotes household based electricity generation to domestic energy users

  (For average customer using gas and electricity ~£45/annum)

- **Community Energy Saving Program (CESP)**

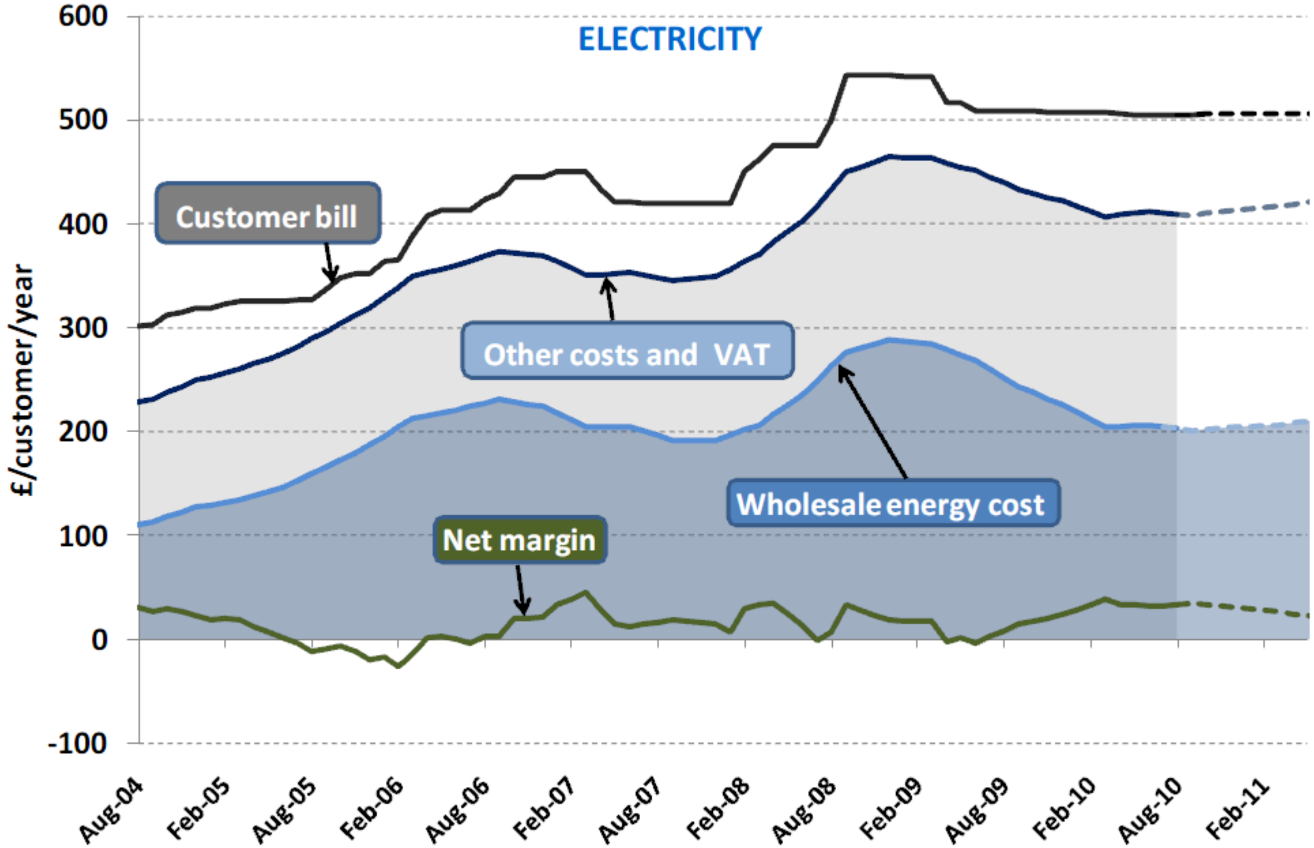
  - Obliges electricity suppliers and generators to promote energy efficiency in areas with high levels of low income households
  (For average gas and electricity customer ~£3/annum)

- **The Renewables Obligation (RO)**

  - Electricity suppliers obliged to source an annually increasing amount of electricity from renewable sources
  (For average domestic customer ~£12/annum)

Electricity Tariffs

Typical electricity customer bill, costs and net margin



Source: Ofgem, Electricity & Gas supply market report (Sept.2010)

Net margin = Customer bill – Wholesale costs – Other supply costs – Operating costs

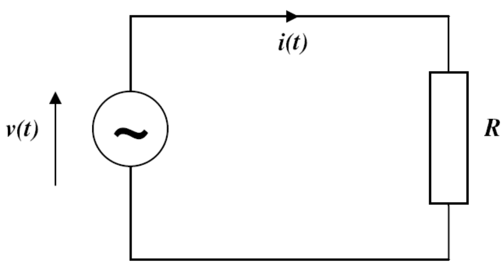
Other supply costs include transmission, metering, environmental;

Operating costs include staffing, billing, IT, marketing

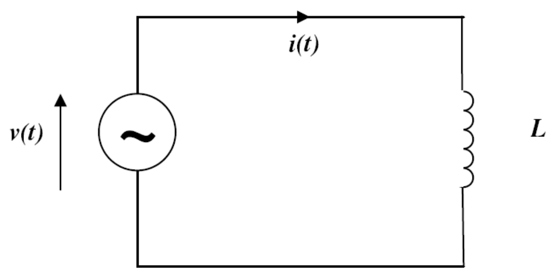
AC Circuits

Circuits supplied from a sinusoidal voltage source

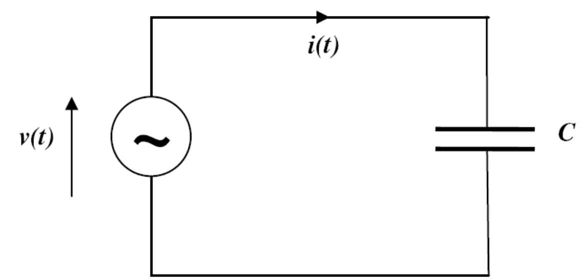
Resistance R

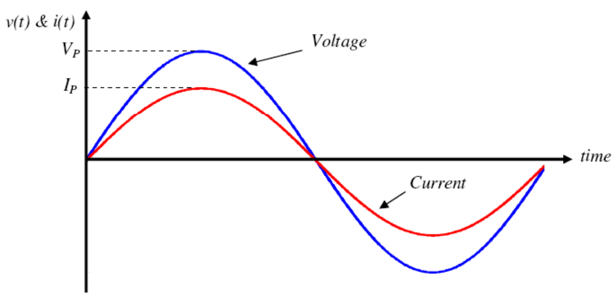


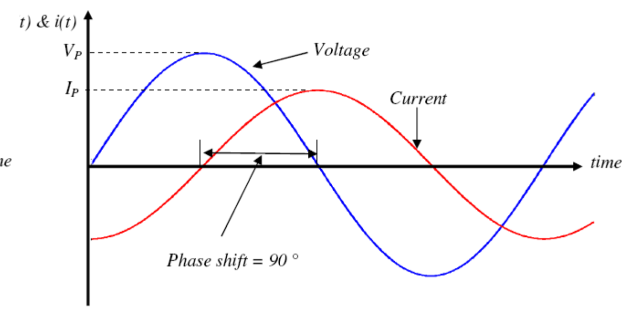
Inductance L

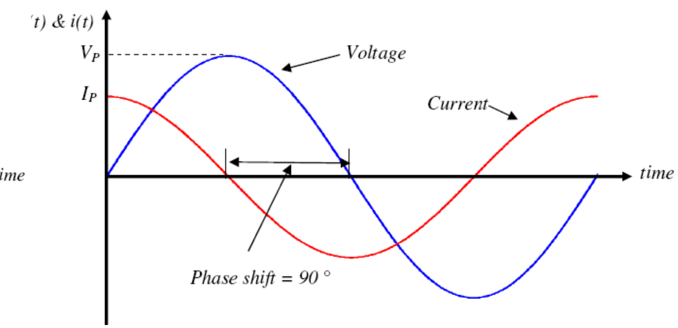


Capacitance C









Current is in-phase with voltage

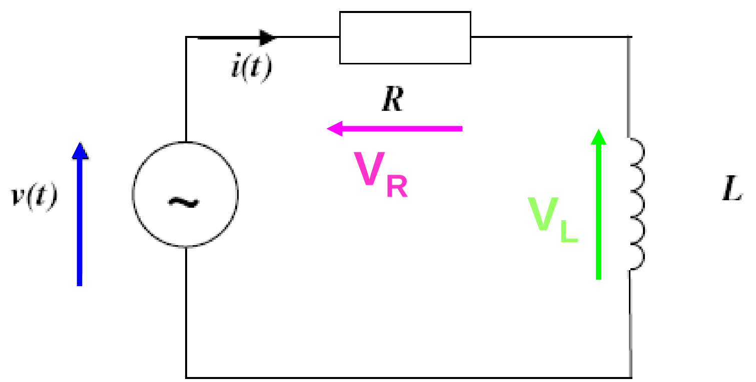
Current lags voltage by 90°

Current leads voltage by 90°

Power Calculation

E-Futures

Circuit containing R and L with sinusoidal voltage supply



$$v(t) = V_{PK}\sin(\omega t) \quad \textbf{and} \quad i(t) = I_{PK}\sin(\omega t - \varphi)$$

$$P = v(t)\times i(t) = V_{PK}\sin(\omega t)\times I_{PK}\sin(\omega t - \varphi)$$

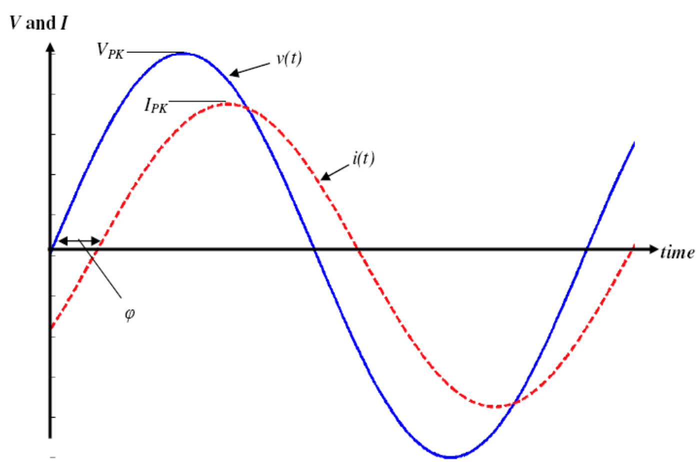
$$P = \frac{1}{2}V_{PK}I_{PK}\cos(\varphi) \quad + \quad \frac{1}{2}V_{PK}I_{PK}\cos(2\omega t - \varphi)$$

Second term has average of zero

$$P_{AVE} = \frac{1}{2}V_{pk}I_{PK}\cos(\varphi) = \frac{V_{pk}}{\sqrt{2}}\frac{I_{PK}}{\sqrt{2}}\cos(\varphi) = V_{rms}I_{rms}\cos(\varphi)$$

Real Power = Vrms Irms Cos φ

Cos φ = Power Factor (0 to 1.0)



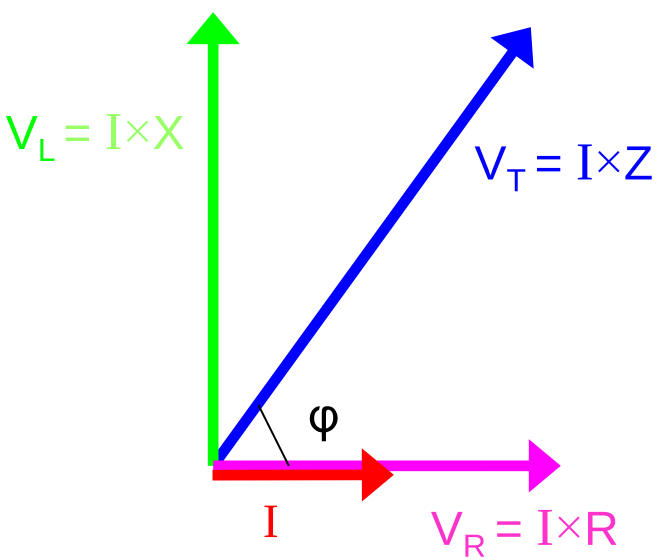
Current lags voltage by angle φ

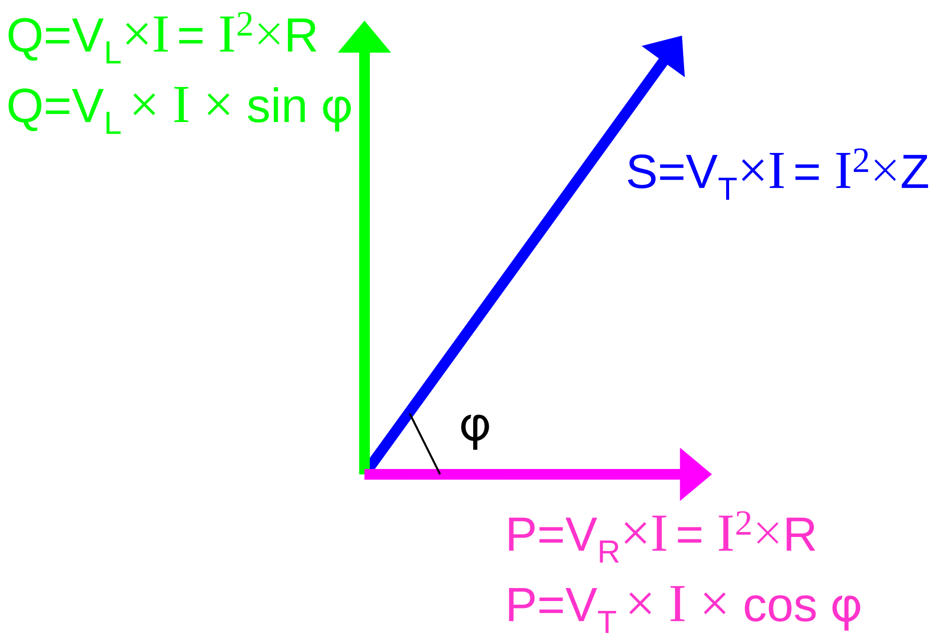
Circuit with only R	**φ = 0°**	**P.f. = 1**
Circuit with only L	**φ = −90°**	**P.f. = 0**
Circuit with only C	**φ = 0°**	**P.f. = 0**

Power only dissipated in R

L and C can store energy

Power Triangle





R = Resistance (Ω)

X = Reactance (Ω)

Z = Impedance (Ω)

$Z = R + j\,Z$

S = Apparent Power (VA)

P = Real Power (Watts)

Q = Reactive Power (VAR)

$S = P + j\,Q$

Electricity Tariffs

E-Futures

INDUSTRIAL TARIFFS

- **Many different forms of tariff in place in the private energy market**
- **Large customers will negotiate their own supply contracts, however Traditional Tariff Structures form the basis of most contracts**
- **Three main elements**

  - **Energy - Energy meters record the REAL power (kWh) consumed over a prescribed period (e.g. 1 month)**
  - **Maximum Demand – The measure of the highest average value of apparent power (VA) of any 30 minute period, taken over one month. Half-hourly meters mandatory for all sites over 100kVA**

    If a user takes a steady load of 10kVA for 23 ½ hours, but the load peaks at 25kVA for ½ hour, 25 kVA will be recorded and charged for, for the whole month.

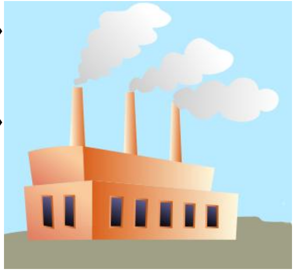
  - **Availability (Capacity) Charge - Based on the highest maximum demand recorded over a 12 month period. Essentially a charge by the supplier for being "available" and providing the infrastructure of appropriate rating**

Electricity Tariffs

EXAMPLE

A small factory has a demand of 150kVA at 0.8 p.f. lagging.
To supplement their energy requirements they install a wind turbine which provides 70kW of real power but draws 70kVAR of reactive power.

120kW →
90kVAR →
150kVA
0.8lag



+ 70kW ←
70kVAR →

= 50kW + 160kVAR
≡ 168kVA at 0.3lag

Real Power reduced from 120 to 50kW; Maximum Demand increases from 150 to 168kVA
This has financial consequences from Maximum Demand and Availability Charge

To correct overall p.f. to unity add a capacitor bank to compensate for the 160kVAR

Total load now ≡ 50kVA at unity p.f.

However, if no wind overall load would be 120kW −70kVAr ≡ 139kVA at 0.86 p.f. leading

Electricity Usage

E-Futures

DOMESTIC ENERGY CONSUMPTION

- Total annual domestic energy consumption is 115TWh
  - 36% of all end user electrical energy usage generates 47% of all electricity revenue
  - 58% of all domestic electricity is consumed by general domestic appliances, the remainder is used for space and water heating
- Domestic appliances represent ~20% of national electrical energy total and ~23% of the maximum power demand
- Breakdown of Domestic Energy Consumption

Refrigerator	18%
Cooker	25%
Lighting	11%
Washing	6%
Drying	8%
Dishwasher	13%
TV	7%
Other	11%

High motor consumption in laundry appliances (but still dominated by heating load) and refrigeration

Energy labelling legislation now in place - e.g. A-G bands 'high' efficiency banding still largely met without modifications to motor/drives

Electricity Usage

DOMESTIC ENERGY EFFICIENT APPLIANCES

- **Modern appliances are much more energy efficient than their counterparts from a decade ago.**
- **Effect of replacing an average appliance purchased new in 1998 with an Energy Saving Recommended model of similar size and an electricity cost of 13p/kWh.**

Appliance	EU Energy rating	Saving a year (max)	CO_2 saving a year (max)
Fridge freezer	A+ or A++	£36	140 kg
Upright/ Chest Freezer	A+ or A++	£22	80 kg
Refrigerator	A+ or A++	£12	45 kg
Dishwasher	A	£12	48 kg
Integrated digital televisions	(no EU label for TV's)	£7	24 kg

- Heat Replacement Effect
  - **Electrical appliances and lighting give out heat when they are switched on or are on standby. (e.g. incandescent light bulb 5% light, 95% heat)**
  - **Using appliances to heat home not recommended when gas heating is installed**
  - **Electricity is typically 3-4 times more expensive than natural gas and emits more than twice as much CO_2 for each unit of energy used (0.543kgCO2/kWh vs 0.204kgCO2/kWh).**

Case Study

Use of high efficiency permanent magnet (PM) motor in a washing machine

- Typical peak power of 600W, market currently dominated by universal (brushed) motors
- Findings from a design study undertaken at Sheffield (based on bonded NdFeB):

Motor Technology	Low speed operating point	High speed operating point
Existing universal motor	46%	31%
Replacement (PM)	66%	90%
Direct-drive – i.e. no belt (PM)	60%	86%

Energy consumed by the PM replacement motor during one standard cycle = 55 Wh (compared with 88 Wh for universal motor). Some further improvements (but marginal) may be obtainable with sintered NdFeB, albeit at potentially higher cost

Lifetime Analysis

- - Estimates based on 5 washing cycles/week with a machine lifetime of 8 years

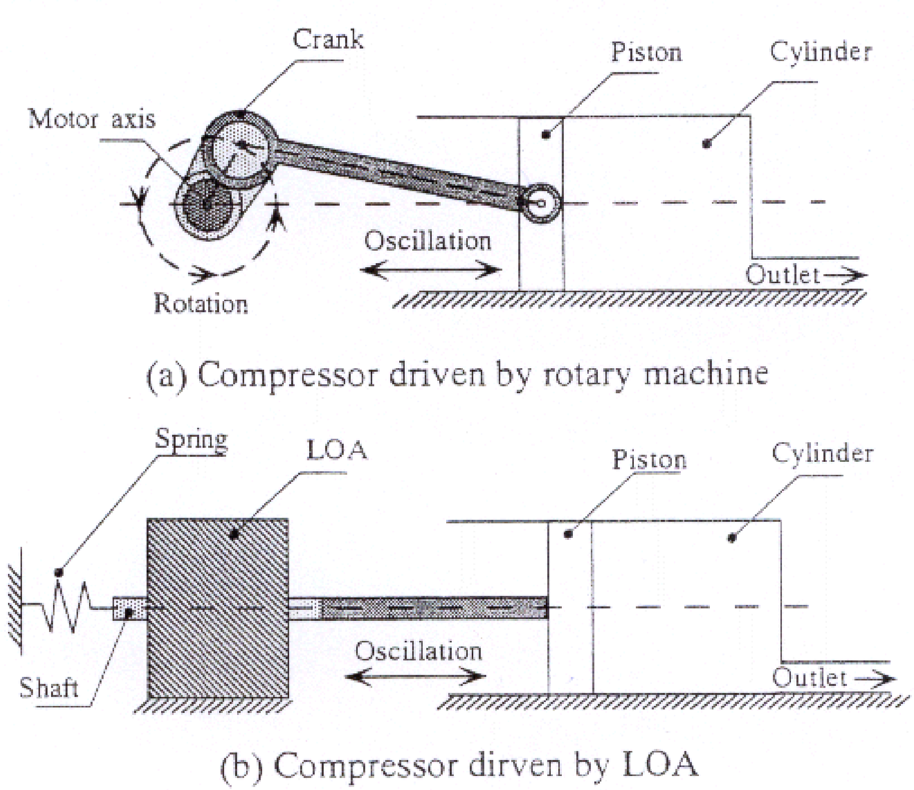
Lifetime energy saving in using a PM motor	48kWh (~£5 over lifetime)
Annual energy saving from PM motor	6kWh
Estimated total number of UK machines	10 million

Annual energy saving - full replacement of motors 60GWh

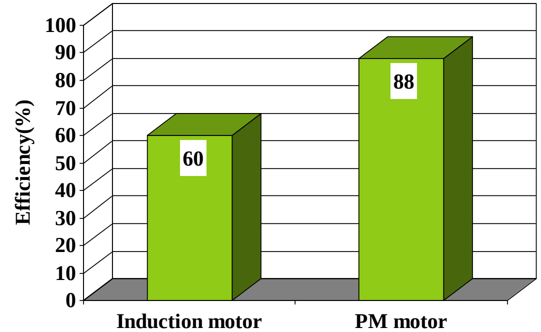
Case Study

Energy consumption of refrigerators

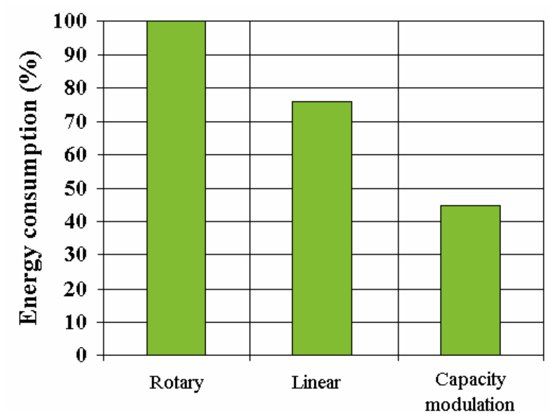
- **A significant and growing electrical load, currently accounting for ~18% of domestic electricity consumption in UK**



Conceptual diagrams of the compressor drive.



Source: Aalborg University/Danfoss A/S, Denmark



Source: LG Electronics Inc

E-Futures

Case Study

DOMESTIC LIGHTING

- **Switch to more energy efficient lighting LED CFL OLED**
- **Phasing out of traditional incandescent bulbs already started – completed 2011**
  - **Government, retailers and energy companies working to phase out inefficient bulbs.**
  - **Light bulb manufacturers are working to change their factories, to produce enough energy saving light bulbs to meet the growing global demand.**

	Incandescent	CFL	LED
Life Span (in hours)	1,500	10,000	60,000
Watts	60	14	6
KWh of electricity (60000 hours)	3,600	840	360
Electricity Cost (@ 13p/kWh	£468	£110	£47
Bulbs required (60000 hours)	40	6	1

E-Futures

Case Study

TECHNOLOGIES

- **Compact Fluorescent Lights (CFL)**

-Typically 4 times more efficient and last up to 10 times longer than the incandescent bulb

- Replacing a single incandescent bulb with a CFL will keep a half-ton of CO2 out of the atmosphere over the life of the bulb

- Early versions slow to warm up, harsh light, and much more expensive. Studies into the rapid flicker causing eyestrain headaches and migraines

-Contain small amounts of mercury

- **Light Emitting Diodes (LED)**

- Small extremely energy-efficient light bulbs

- Until recent times been limited to single-bulb use. Clusters now common

- LED bulbs can last up to 10 times longer than CFL's and 100 times longer than incandescent bulbs

- LED lights contain no mercury and therefore don’t fall under the WEEE directive for disposal.

- No flicker so avoids problems of headaches and migraines

- **Organic light emitting diode (OLED),**

- (LED) constructed from a film of organic compounds.

- Can be used for tv screens, computer monitors as well as general lighting