Network effects of line start permanent magnet synchronous motors as replacements for induction motors

MSc thesis work of:

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Overview

- Why may another motor type be wanted?
- Why is this important? (P, Q, transients etc)
- What IS the LS-PMSM?
- Description of the models used
- Important simulation results
- Conclusions

The use of drive systems

- About half of worldwide electricity consumption is by motors…
- …as is more than half of industrial consumption.

this means that a widespread change in the characteristics of the type of motor used will have a strong effect on the power system and on bus-characteristics in industrial areas

- A lot of the motors are in pump and fan applications, e.g:-

32% pumps, 23% fans (from a recent U.K. source).

- Environmental concerns raise the need for more efficient motors

U.S. legislation on efficiencies, E.U. classifications EFF1 etc

this means that the LS-PMSM has a reasonable chance of gaining popularity, since it offers good efficiency, and suitability for pump and fan applications

Common motor types

- Induction Machine

simple and robust but not very good efficiency

- Synchronous Machine

can be more efficient, but mechanically more complex and will not start from the line in the same easy way as an IM

- Permanent Magnet Synchronous Machine

still the problem of starting, if not equipped with inverter control, but quite robust and has good efficiency

- Line-Start PMSM

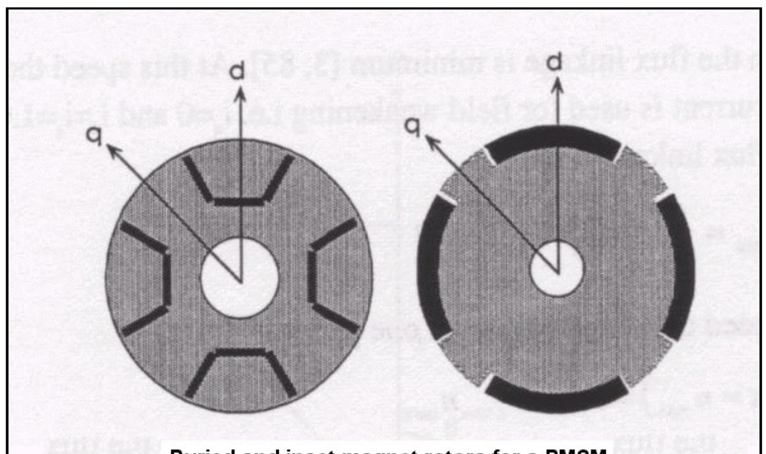
a hybrid, with good efficiency and (almost) the ease of starting and running as with an IM: no inverter needed

A typical LS-PMSM

- Many variants are possible:

  buried/surface/inset magnets, cage/wound/sheet rotor circuit, different magnet types (esp. Nd-Fe-B or Sm-Co)

- Here, 7.5kW motors have been considered, with buried magnets and cage-type rotor windings. These are a good design to provide a rugged machine to replace IMs in typical applications, e.g. pumps.



Buried and inset magnet rotors for a PMSM

Differences from the original IM

- Internal induced voltage
- No control over induced voltage (as opposed to a SM)
- Saliency
- Synchronous operation
- Different rotor electrical construction to reflect the different function (just as a damper when the motor is synchronised)

What may be expected?

- Different P response to voltage changes (speed is fixed)
- Different Q response to voltage changes (internal voltage)
- Worse starting (magnet braking torque, saliency effects)

Modelling for the simulations

- as the rotor moves, the simulation needs to allow for saliency altering stator inductances and for changes in inductance between stator and rotor windings
- Park's transform, with the rotor (d-axis) as the reference, provides a neat way to allow for these effects while keeping constant inductances in the transformed model
- the PM field was modelled as a further, constant flux in the d-axis
- models of an IM and PMSM were made in Simulink, and tested in comparison to Power System Blockset models. The 'hybrid' model was then formed. The blockset was not used because of its trouble with simulating an inductive supply
- magnetic saturation, iron losses and skin effect are not modelled: this has important implications in some simulations

The choice of motors

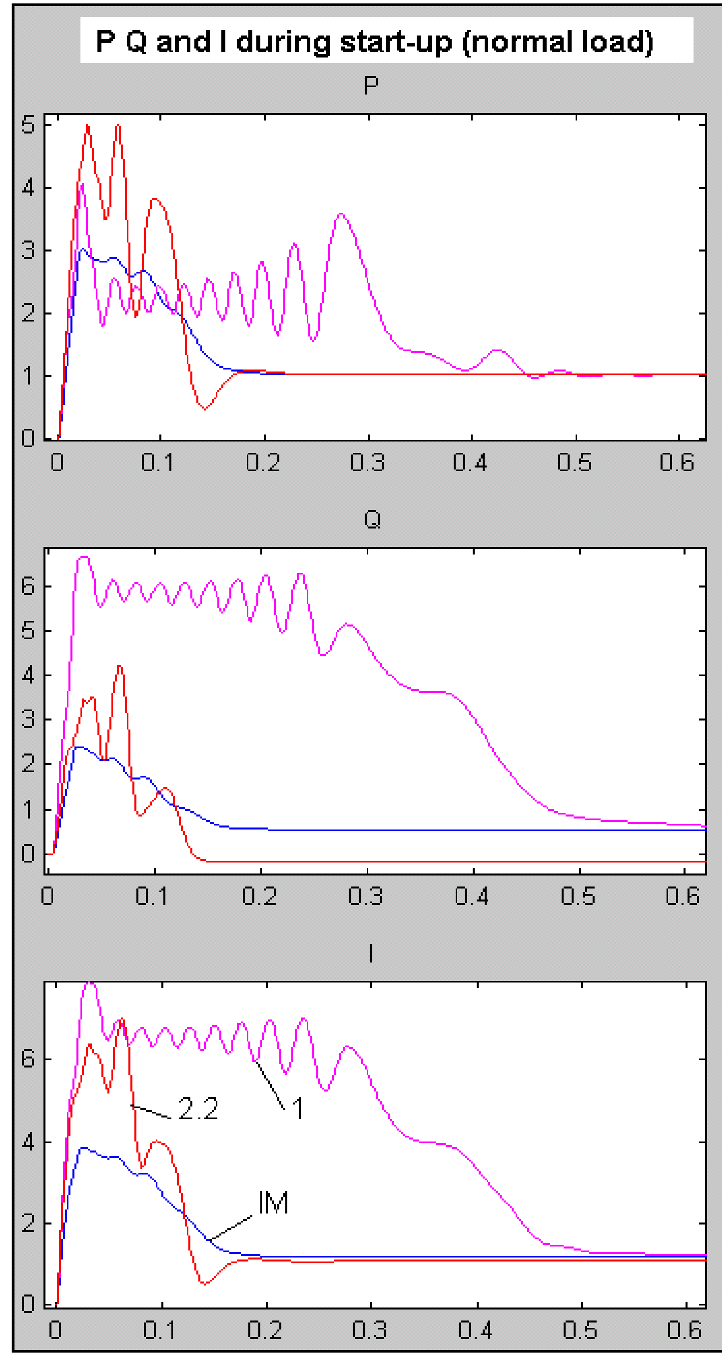
- Two LS-PMSMs were taken from specifications of motors being researched in the machines department of ETS, KTH.
- The first of these was not very good: it had some design flaws. It was included in simulations to show a different type of LS-PMSM behaviour.
- The second was a much better design, with an induced voltage (Eo) equal to the nominal supply voltage (400V line).
- An IM was chosen, of the same power and frame size, and from the same family as that from which the LS-PMSMs had been developed.
- In simulations, either all three were used, or else the worse LS-PMSM was omitted. Values were altered to note the effect.

Starting

LS-PMSM 2 takes rather more current, and more active power than the IM. This could be changed to an extent by changing electrical parameters.

LS-PMSM 1 has such poor starting torque that it takes a lot longer to start, and has high reactive power consumption.

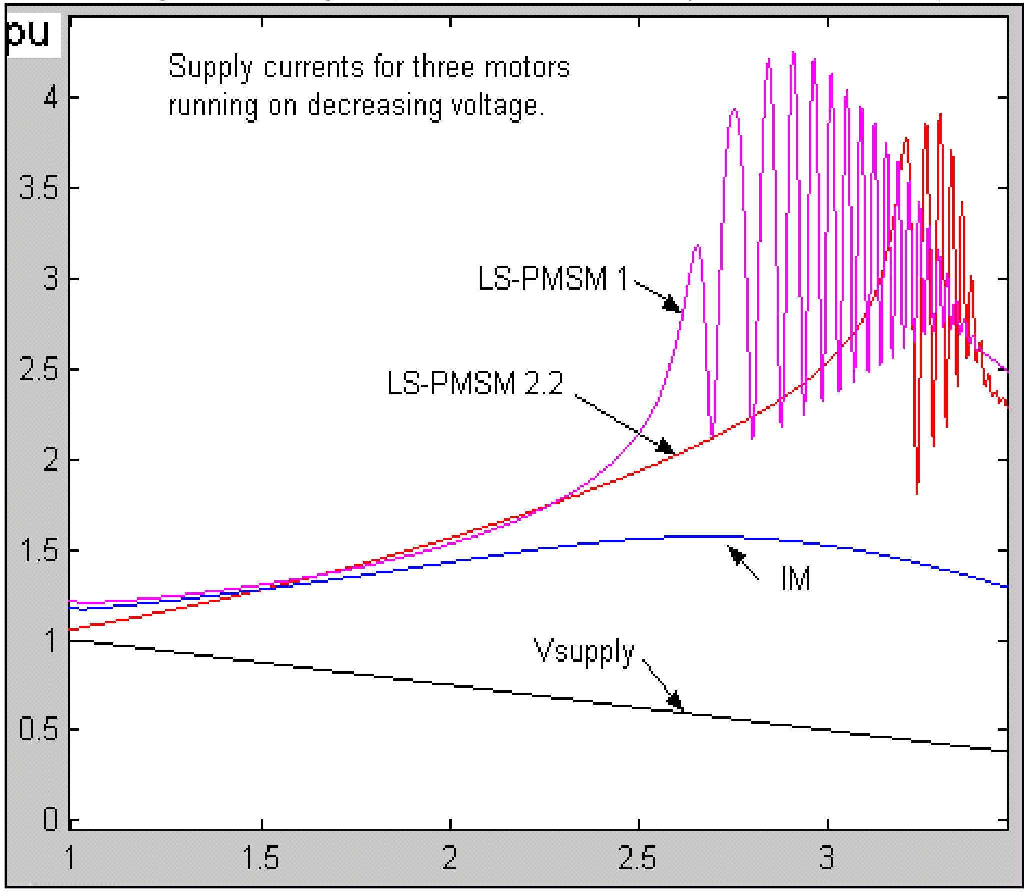
The main point is that the IM has a far smoother behaviour, as it has not the permanent field. A LS-PMSM can be reasonably expected to have a higher integral of power.



Response to voltage changes

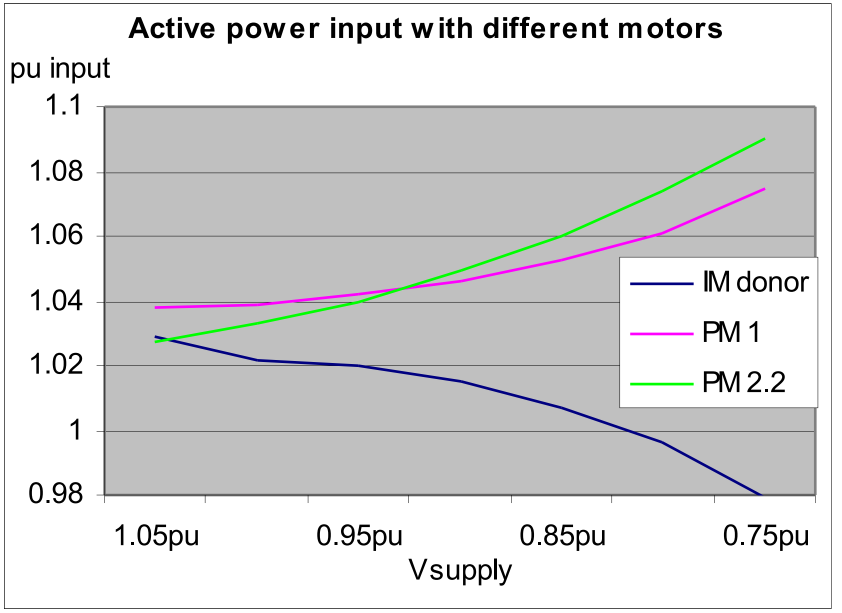
- The large rise in LS-PMSM currents as the voltage decreases is due to the synchronous operation.
- For less extreme cases, it is necessary to study the smaller range of voltage changes, where this plot does not show a great difference in behaviours.
- P and Q are of interest too.

A large change (until loss of synchronism)

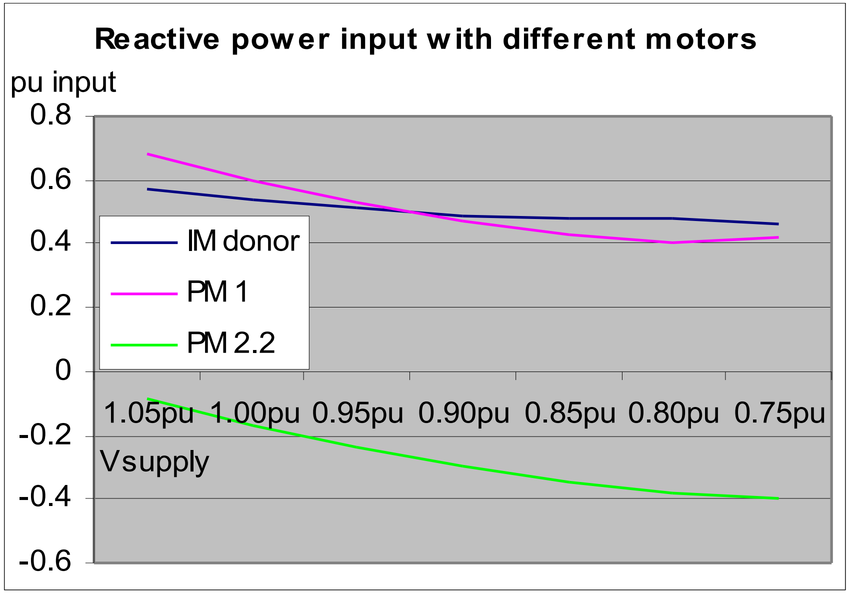


Moderate voltage changes

- The LS-PMSMs are very similar in the way that active power varies with voltage: synchronous versus asynchronous operation is the important point here.



- The high Eo of LS-PMSM 2 makes it generate reactive power at rated voltage, so this increases as the supply voltage falls. (this can be understood by consideration of two a.c. sources connected by an inductance and resistance)

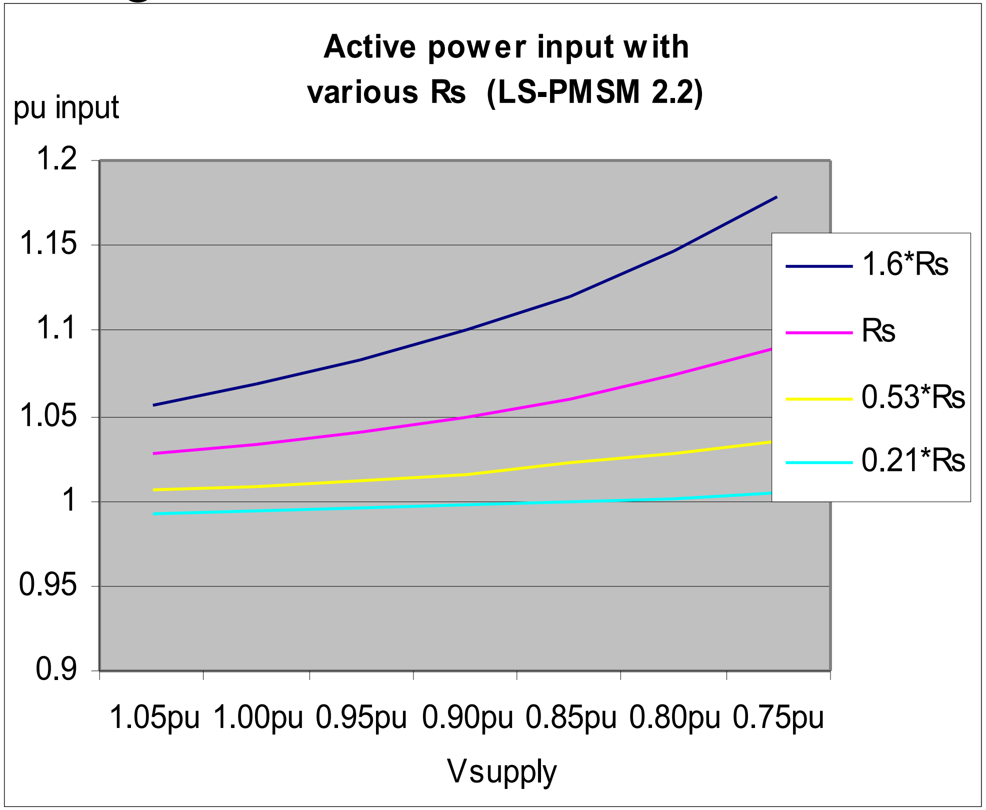


Parameter variations

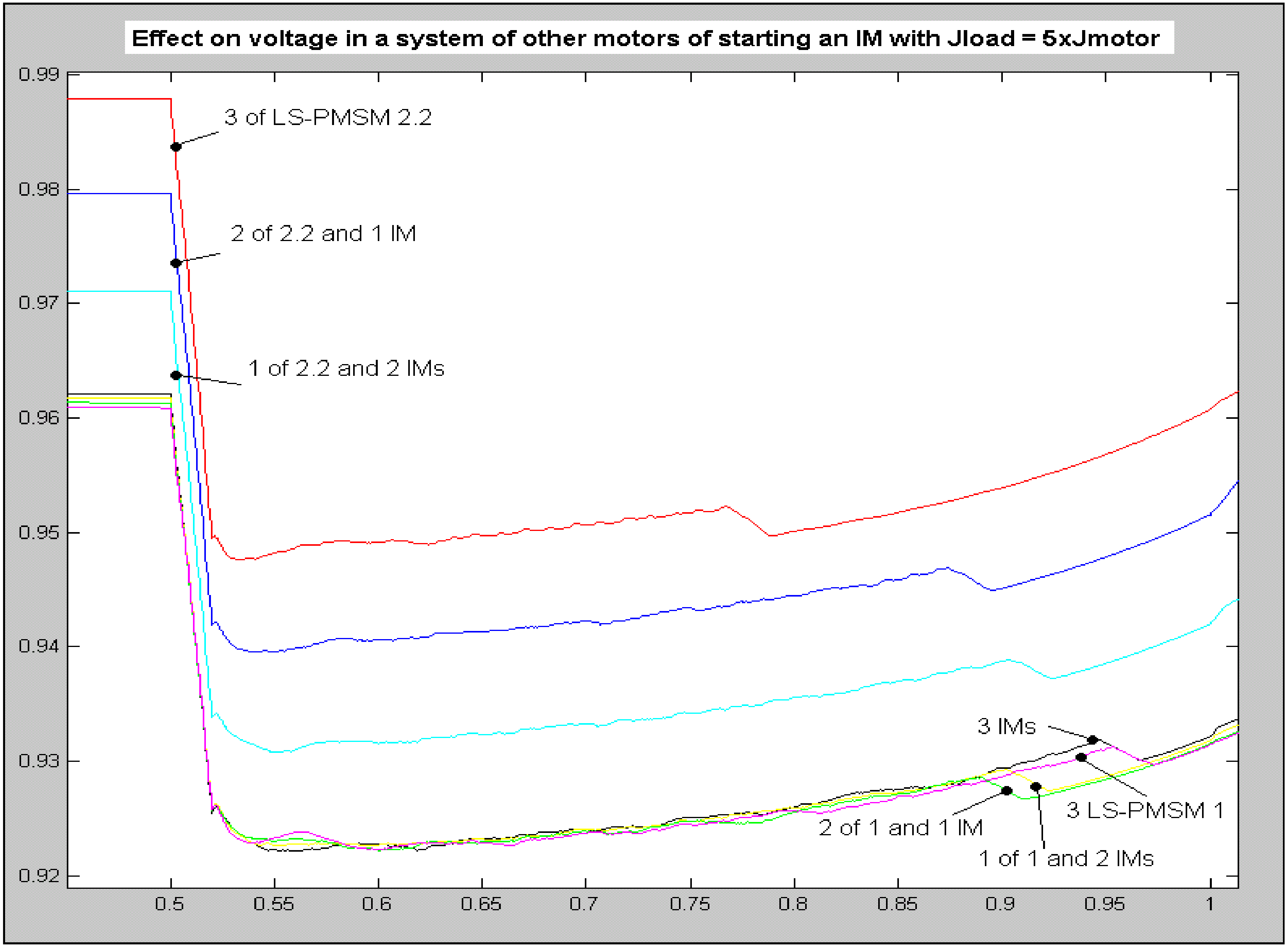
Eo has a great effect on the reactive power consumption or generation. By this parameter, a motor can be designed to produce reactive power at nominal voltage, thus it helps a typical system.

Reduced voltage results in increased generation (or reduced consumption)

The stator resistance is responsible for all extra active power consumption when the voltage is reduced.



System voltage with supply impedance and several machines



Other interesting features

- More regeneration into the system (if supply is cut off)

note that an IM can regenerate briefly, due to decay of rotor currents

- More transfer of load <-> supply disturbances

- The effect of harmonics has not been simulated as the lack of iron loss and skin effect modelling would make a study of harmonic losses almost worthless with these models. These extra effects could be added to the models, but at considerable extra complexity.

Conclusions

- Very favourable reactive power consumption and response of reactive power to voltage changes
- Possibility of harm to the motor from excess currents when the voltage drops and active power consumption increases, especially if the motor was initially generating reactive power
- The increased active power consumption with reduced voltage could be a problem to the supply system if many motors are installed
- The SM style regeneration will raise the fault level on buses with large proportions of IM load replaced by LS-PMSMs
- Starting transients can be expected to be worse than for IMs, so there is more need for a strong supply. However, the presence of parallel LS-PMSMs already synchronised could be helpful in providing more reactive power during the start
- Effect of voltage harmonics needs more study

Overall:

- A suitably designed LS-PMSM can be expected to have a favourable effect on the local system, except in cases of simultaneous starting of many such motors, or if fault levels are already near their limit.
- On the large-scale system, the increased fault level could be important, and the increased active power with decreasing voltage could have a bad effect if voltage reduction is used as a means of reducing power consumption in emergencies (brownout)