Effects of surge voltage on electrical machines

Day 25

Effect of Surge on Motors

ILOs – Day25

- List the effects of switching surge on motors
- Explain the nature of distribution of surge voltage inside motor winding
- Draw various motor winding models for surge studies
- Discuss the needs and ways for protection of motors from switching surges
- Give examples of surge protective devices used in motors

Effects of switching surge on motors

Effect of switching surge on motors

- A nominal switching surge is defined by a 250/2500 μs impulse, with a front time of 10 μs and above
- This will usually cause no harm to the terminal equipment (motor, or generator, or transformer etc.)
- But a switching sequence, involving a **restrike** of the arc in the circuit breaker or isolator gives rise to steep fronted transient voltages of up to 3– 5 p.u.
- These switching surges may exist on the system for not more than a 0.5 to 1.5 cycles of the power frequency, and can have a front time *1 μs* or less
- In extreme cases, it can even reach a low of *0.2 μs* and become capable of causing severe damage to the terminal equipment
- All such waves are termed as ***steep front of waves***

Effect of switching surge on motors

- When such a surge penetrates electrical equipment such as an induction motor's winding, most of its stress may appear only across a small part of the windings (the line end coil or the first coil)
- The front of the surge will become less steep as it penetrates the windings, due to:
  - Lumped capacitances *C* of the winding insulation
  - Partial reflections and damped refractions from the discontinuities of the windings
  - Eddy current losses
- *The inter-turn voltage stress due to switching surges will thus be higher* for the line end coil of the windings than the subsequent coils

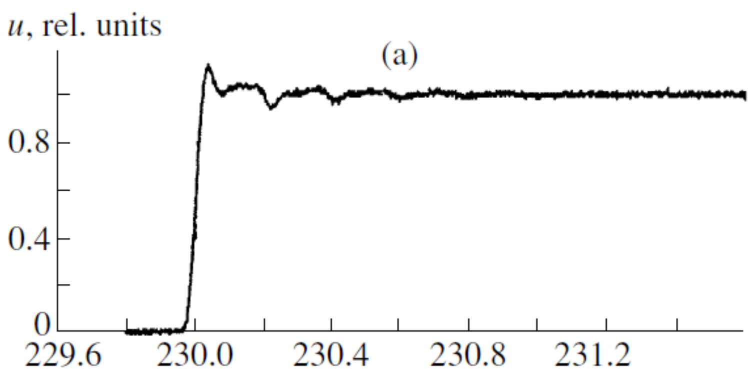
Effect of switching surge on motors

- The voltage stress across the first coil alone may be as high as 70–90% of the total transient voltage across a motor windings
- The first few turns of the line end coil of a motor or transformer will be rendered vulnerable to damage by such steep fronted transient voltages
- On the other hand, not-so-steep fronted switching surges (≈ front time 1 μs) may travel through a greater length of the winding and more evenly distributed over the entire length of windings

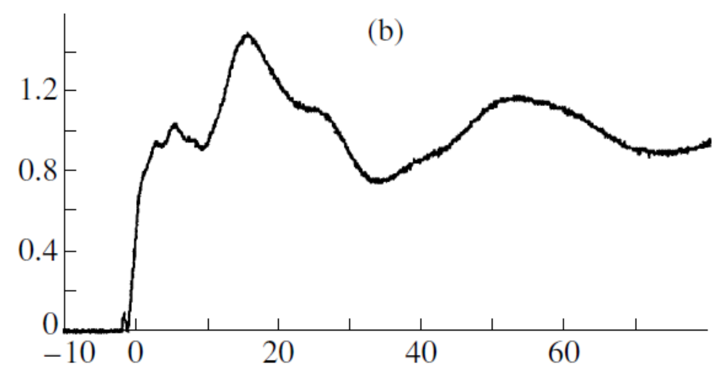
Surge distribution inside motor winding

Surge distribution inside motor winding

- Generally, it is the steepness of the surge that has a greater severity on inter-connecting cables and machine windings
- The travelling waves and their partial reflections at the discontinuities of the windings influence the surge's amplitude and distribution over the length of the windings
- The windings' length, shape, inductance *L* and leakage capacitance *C* and speed and size of the machine are vital parameters that play a significant role in determining the surge amplitude and its distribution over the length of the windings



Voltage surge at entrance to the motor winding

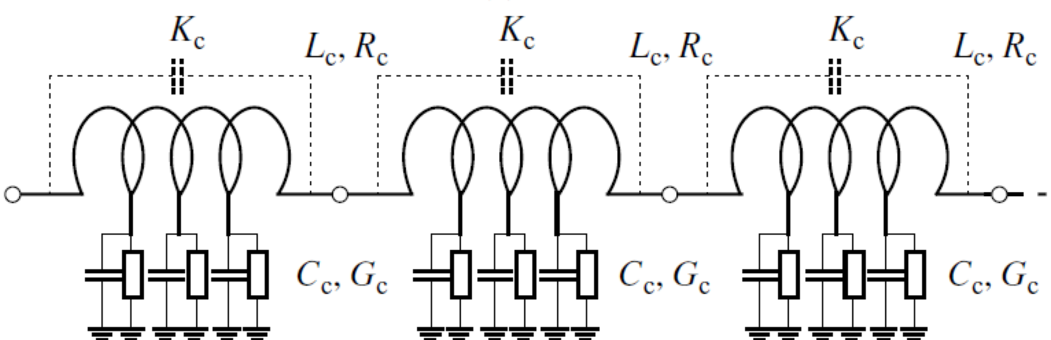


Shape of the same surge at the end of 1st coil group

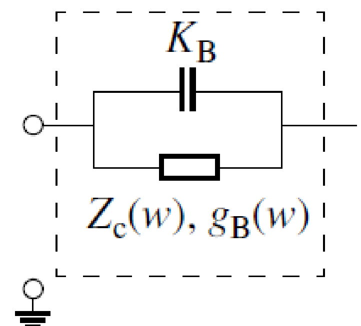
Motor winding models for surge studies

Motor winding models for surge studies

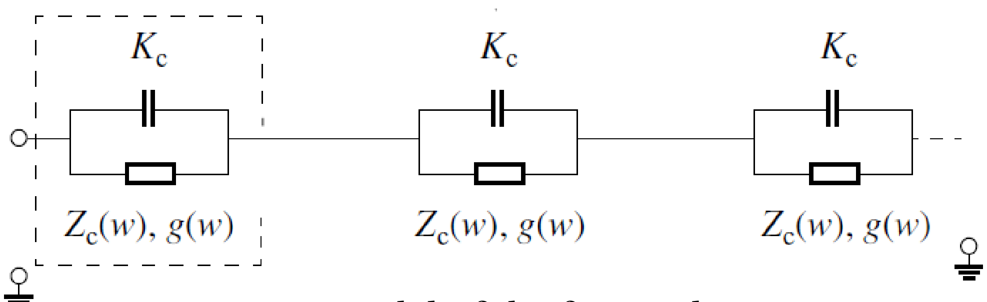
- Various researchers have proposed different forms of winding models for surge propagation studies in induction motors
  - [1] Proposed model of a coil to represent the winding as a line with distributed and lumped (DL) parameters



DL model of the whole winding



DL model of a turn

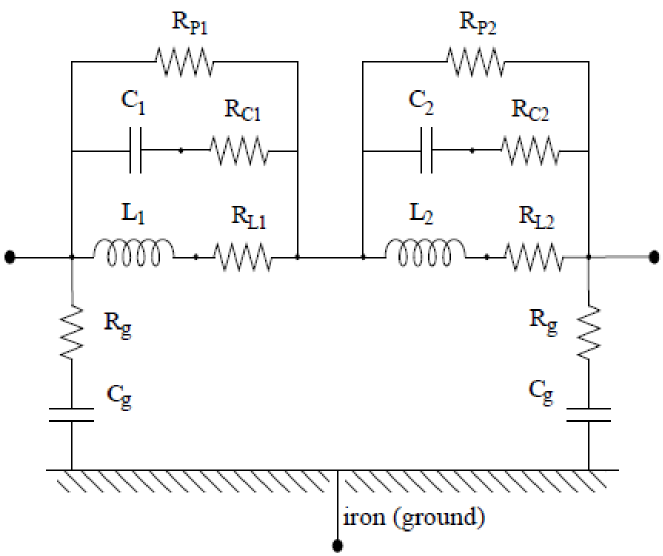


DL model of the first coil

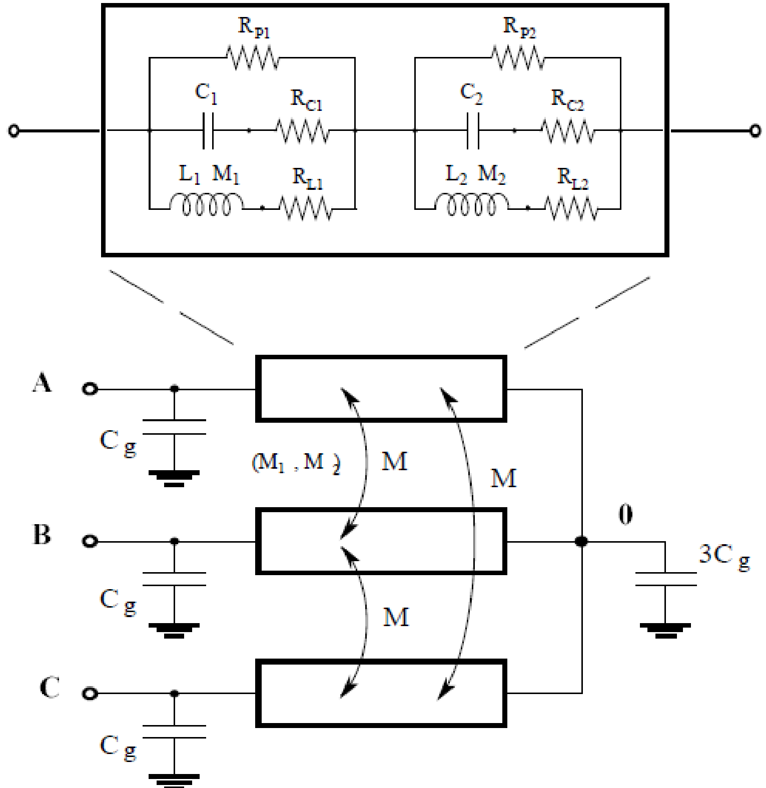
[1] V. E. Kachesov, "Studies of Voltage Surges in a High-Voltage Electric Motor and Adjustment of a Winding Model", *Russian Electrical Engineering, 2007, Vol. 78, No. 6, pp. 322–331*

Motor winding models for surge studies

- [2] Proposed a lumped parameter HF circuit model of a coil that considers both turn-to-turn and turn-to-iron capacitances.
- Also additional dissipative phenomena such as skin and proximity effects in the wires, dielectric and iron losses are taken into account



HF equivalent circuit of coil

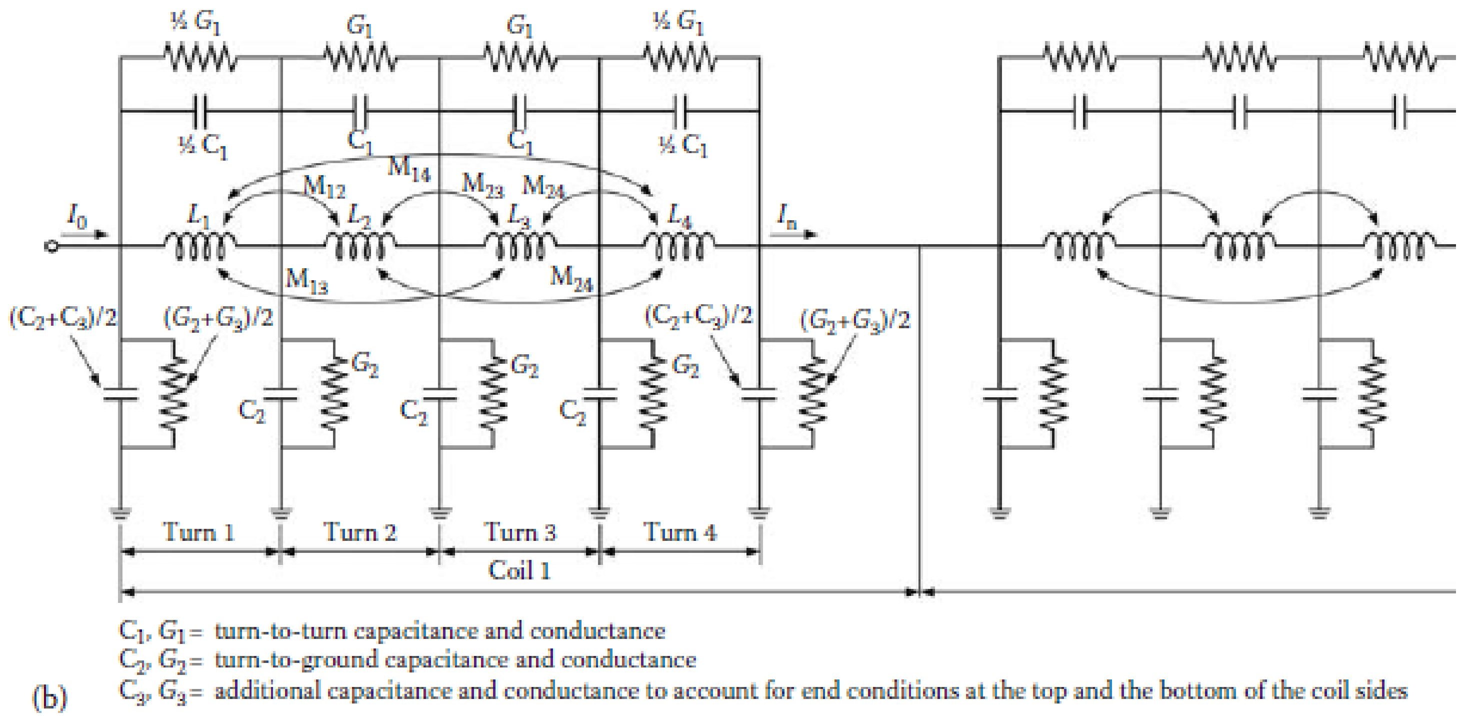


Scheme of the three-phase winding model

[2] Gabriele Grandi, D Casadei, A. Massarini, "High frequency lumped parameter model for AC motor windings", *[https://123doc.net/document/4301194-high-frequency-lumped-parameter-model-for-ac-motor-windings.htm]1997*

Motor winding models for surge studies

- In [3], a machine winding is represented by a lumped-parameter equivalent circuit
- The circuit parameters are grouped to form a circuit with nodes between adjacent turns at the coil connection end and at the entrance and exit from the coil



Lumped-parameter equivalent circuit of a machine winding

[3]Juan A. Martinez-Velasco, Ed "Power System Transients : Parameter Determination", *CRC Press, 2010, pp. 327 - 328*

Protection of motors from switching surges

Protection of motors from switching surges

- Protection against surge is recommended in motors above 3.3 kV
  - To prevent motor damage
  - To prevent process shut down
- Motors are more prone to switching surges than lightning surges
- For adequate protection of the machine it is essential to know the amplitude, V_t, and the rise time of the severest voltage surge (FOW) that may occur on the system
- Each high voltage machine is thus tested in the laboratory under simulated (hardware) conditions to check adequacy of winding insulation

Surge protecting devices in motors

- Since the standard insulation level (BIL) of a machine or a system is already defined during its design and manufacturing, the machines are accordingly designed for this basic insulation (BIL) only
- When the prospective surges are expected to be more severe than this, separate protection becomes imperative
- This is particularly important for a rotating machine which, besides being a dry equipment, also has only a limited space within the stator slots and hence has the smallest BIL of all

Surge protecting devices in motors

- The following aspects therefore must be kept in mind while attempting to protect a rotating machine
  - The surge protective device (SPD) must be suitable for absorbing energy of the long duration (250/2500 μs) switching surge at the commencement of arc interruption
  - The SPD must offer a low residual voltage (V_{res}) *to* protect the machine adequately from over-voltages
  - The SPD must have capability to sustain FOWs should they arise during switching operations
    - That means they should also be able to see the high frequency surges rather than high amplitude surges only

Surge protecting devices in motors

- **Protection of major insulation area**
  - This is the winding insulation to the body, which is more vulnerable to prospective surge voltage peaks
  - When the surge voltage exceeds the BIL of the machine, it can be damped to a safe limit with the use of a surge arrester
  - The selection of the arrester will also depend upon the method of star (neutral) formation of the stator's star connected windings
  - If it is solidly grounded, the reflections will be less severe, as the incident surge will be discharged through the ground and cause less reflections
  - But when the star point is left isolated, it may cause severe voltage stresses to the end turns of the coil due to repeated reflections

Surge protecting devices in motors

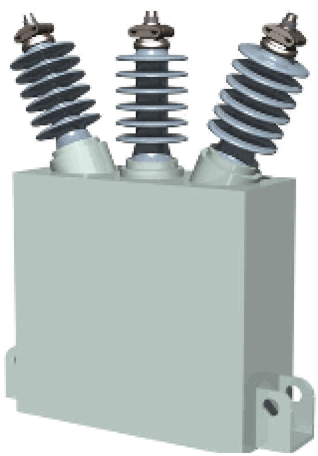
- **Protection of minor insulation area**
  - This means the turn to turn insulation, which is more vulnerable to the steepness of a surge
  - A surge arrester can only reduce the amplitude of the surge, but not its steepness
  - Very fast-rising waves can be tamed with the use of surge capacitors or surge suppressors
  - Surge capacitors possess a good energy absorption capacity and can reduce the amplitude and the steepness of a fast-rising wave (FOW) to a safe level, less than the turn-to-turn impulse withstand level of the coil
  - Normal practice is to tame it to 10 μs so that the surge is uniformly distributed over the entire windings and a normal surge arrester in association with a surge capacitor, can protect it safely
  - Surge capacitors in the range of 0.1–0.25 μ F (generally 0.25 μ F) are ideal for neutral grounded machines and twice this level for the neutral isolated machines

Surge protecting devices in motors

- **Surge arresters**

Metal oxide LV surge arrester

Medium voltage surge arrester



Surge capacitor

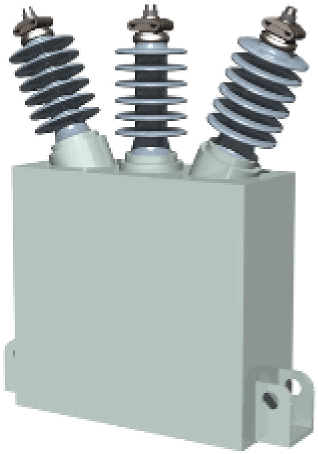
Surge suppressors

Surge protective devices

- ***Surge arresters***
  - A conventional gapped distribution class arrester will not offer adequate energy absorption capability, particularly for the long duration switching surges
  - The residual voltage (*Vres*) of such arresters is also usually high for the chosen arrester rated voltage (*Vr*) and may not offer adequate protection to the machine
  - For this purpose therefore a gap-less distribution class surge arrester, also known as metal oxide varistor (MOV) possessing high energy absorption capability (J) may be used for motor protection
  - These arresters too are able to see only the amplitude and not the steepness of the surge
  - A surge capacitor in association with the MOV can overcome this drawback

Surge protective devices

- ***Surge capacitors***
  - A surge capacitor offers a near-open circuit during normal operation (at or near the power frequencies) and a near short-circuit to the arriving surges at surge frequencies, f_s
  - While the inductance of the motor windings ($\propto f_s$) rises rapidly and offers a near-open circuit to the arriving surge
  - It thus attracts an arriving surge and reduces its steepness as well as amplitude due to high '*C*' in the circuit parameters
  - The basic use of surge capacitors is to absorb only the FOWs and reduce their steepness and magnitude to make them safe for the turn insulation of the machine



Surge protective devices

- ***Surge suppressors***
  - A surge capacitor reduces the steepness and damps the amplitude of a surge
  - The use of a surge arrester is to damp the amplitude of the surge, in association with a surge capacitor, may require more space, besides being a more expensive arrangement
  - A compact and economical alternative is found in a surge suppressor, which makes use of a low-value damping resistance *R in* series with the surge capacitor *C*
  - The resistance can now absorb a part of the energy of a high-amplitude surge, damp it to a desired level and make the *C–R* unit suitable for taming as well as damping an FOW surge
  - The combination of C and R is appropriately termed a surge suppressor

Surge protective devices

- ***Surge suppressors***
- The damping resistor R of the surge suppressor provides a means of absorbing the excess energy of the surge
- While the surge capacitor *C* absorbs bulk of the energy and arrests the steepness of the surge to a desired level
- A C–R suppressor also helps to reduce the surge impedance, Z_s of the circuit thereby limiting the surge voltage reflection
- These suppressors can be mounted on the switching device itself