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College of Engineering

ECE 528 – Understanding Power Quality

http://www.ece.uidaho.edu/ee/power/ECE528/

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Lecture 8

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Today…

- Fuse/trip-saving
- Time-current curves
- Voltage sags
  - Motor starting
  - Motor starting mitigation

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Fuse saving tradeoffs

- What are the advantages of using fuse saving?

- What are the disadvantages?

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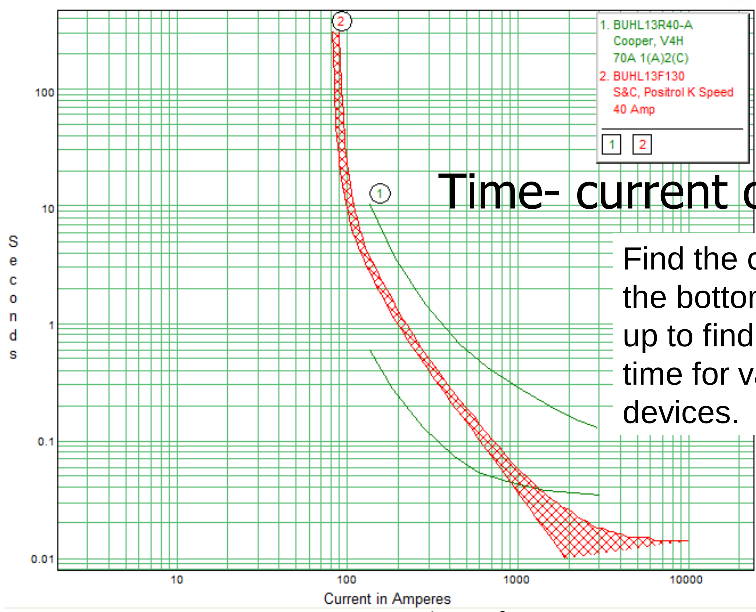
Time- current curves



Find the current at the bottom, then go up to find the trip time for various devices.

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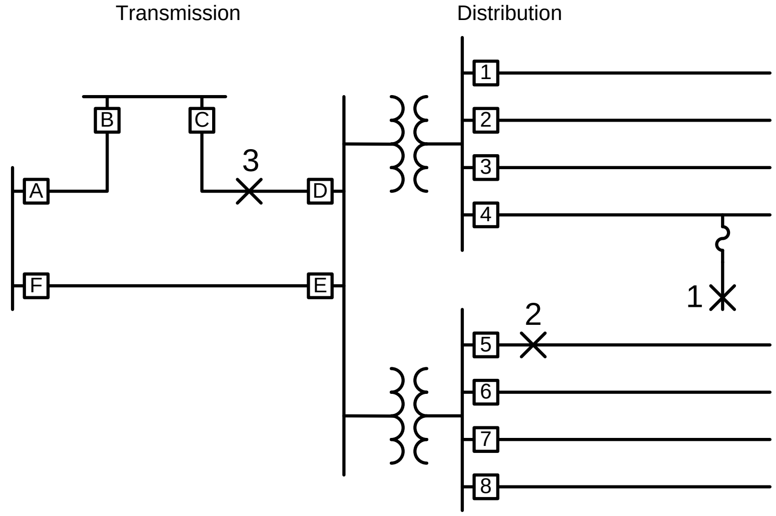
Voltage Sag Impacts



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Motor starting

- Motors may start and stop frequently or only occasionally.
- Common cause of voltage sags in industrial facilities – the facility's own large motors may cause voltage sags.
- Power systems are typically designed for the peak steady-state load or "demand", not the motor-starting demand.

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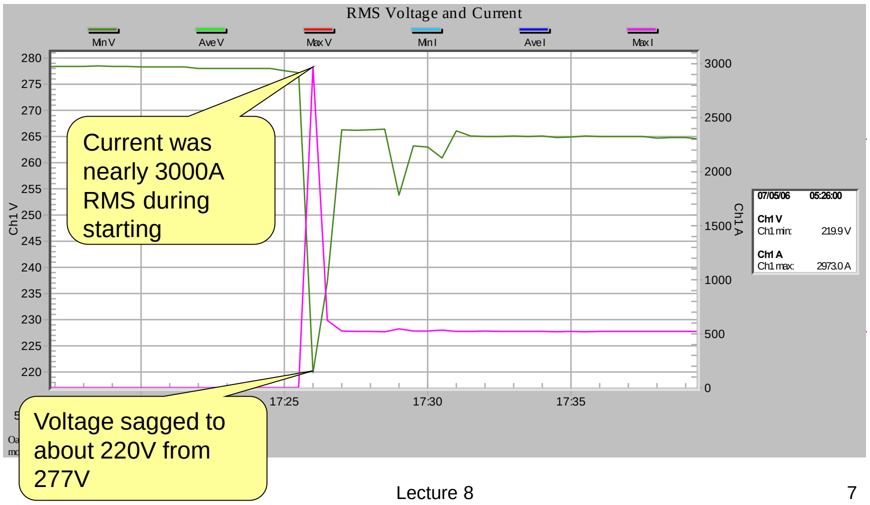
Motors – starting 500Hp



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Motor Starting

- "Across the line" or full voltage starting
  - Typically 6 to 8 times normal running current
  - Inexpensive
  - Fast acceleration
  - Results in largest voltage sag or flicker compared to using a "soft starting" system.

See FPQ, pp 113-131 for motor starting examples.

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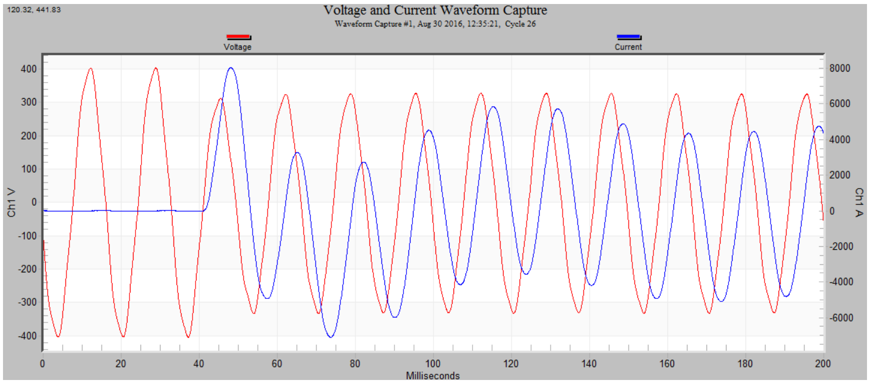
Motor starting – 3 stages



Stage 1 – Transient inrush current – note initial offset and low frequency oscillation

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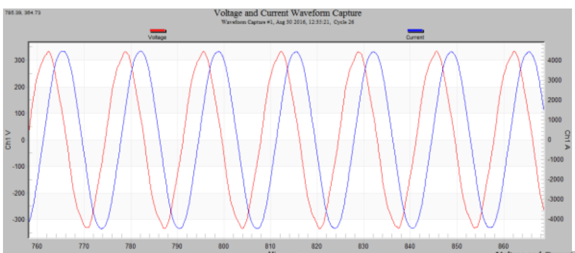
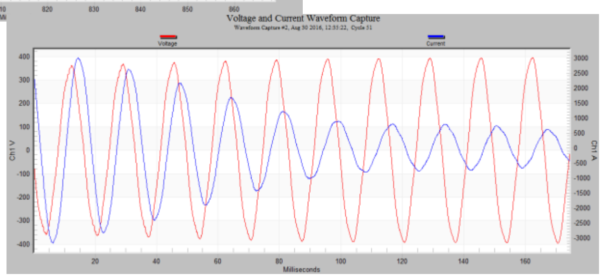
Motor starting – 3 stages



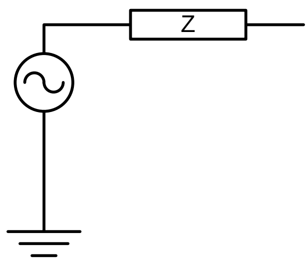
Stage 2 – steady current during acceleration – This is what is usually considered the “starting current”



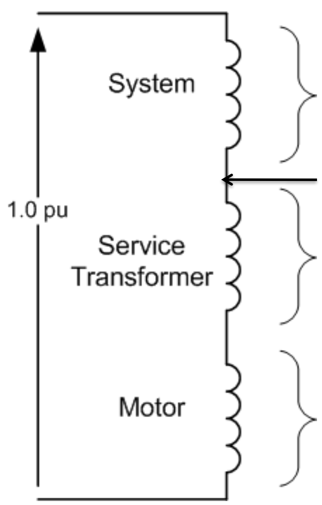
Stage 3 – Current drops and voltage recovers as motor reaches operating speed

Thevenin equivalents

- We can reduce the upstream system to a voltage source in series with an impedance, or maybe a few impedances so we can determine the voltages at different locations.



Motor starting analysis: voltage division



Xs: determines short-circuit MVA at primary side of service transformer

Other customers are connected here

Xt: with Xs, determines short-circuit MVA at the motor terminals

Xm: with Xs and Xt, determines magnitude of voltage sag when motor starts

Reactances and kVA or MVA

- Can solve problem using reactance or the KVAsc or MVAsc values
- Working in per-unit we can convert back and forth between reactances and short-circuit kVA or MVA.

$$\frac{V_{base}^{2}}{Z_{base}} = MVA_{base} \qquad \frac{(1pu\ voltage)^2}{1pu \cdot impedance} = 1pu \cdot Power$$

- The system fault capacity in MVA is based on 1pu voltage and 1pu impedance. So the fault capacity is the base MVA of the primary system.

Basic calculation example:

Using reactance:

$Xs := 0.05 \cdot pu$ $\qquad Xt := 0.06 \cdot pu$ $\qquad Xm := 0.5 \cdot pu$

$$Vmin := \frac{Xm}{Xs + Xt + Xm} = 0.82\,pu \qquad Vmin = 81.967\,\%$$

Basic voltage division…

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Same example using MVA values

- Motor draws 3MVA starting at rated voltage.
- System can deliver 30 MVA to a 3-phase fault at transformer primary.
- Transformer is 1.5MVA, 6% impedance.

$MVA := MW$ $\quad kVA := kW$ $\quad pu := 1$

$kVAs_{sc} := 30MVA$ $\quad kVA_{LR} := 3MVA$ $\quad kVAt_{sc} := \frac{1.5MVA}{0.06} = 25\,MVA$

$$kVAst_{sc} := \frac{1}{\frac{1}{kVAs_{sc}} + \frac{1}{kVAt_{sc}}} = 13.636\,MVA$$

$Vmin := \frac{kVAst_{sc}}{kVAst_{sc} + kVA_{LR}} = 0.82$ $\quad Vmin = 81.967\,\%$

Same result…

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Converting reactances and fault capacities

- First, pick a base MVA – One of the existing ones makes things easier – I'll use the transformer rating:

$pu := 1$ $\quad kVAt := 1.5MVA$ $\quad kVA_{base} := kVAt$

- System short circuit MVA, and motor starting MVA both imply 1pu impedance on their own bases. We'll convert to the transformer base:

$kVAs_{sc} := 30MVA$ $\quad kVA_{LR} := 500hp \cdot 6\frac{kVA}{hp} = 3\,MVA$

$Xs := \frac{kVA_{base}}{kVAs_{sc}} = 0.05\,pu$ $\quad Xt := 0.06 \cdot pu$ $\quad Xm := \frac{kVA_{base}}{kVA_{LR}} = 0.5\,pu$

Motor and transformer data

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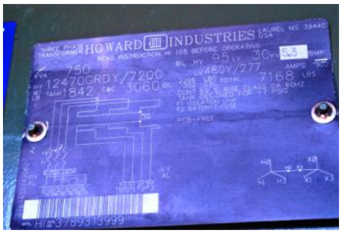

Transformer:
12.47kV:480V (L-L) Wye-wye
750kVA
X = 5.3%

Motor:
460V (L-L) 3-phase
100HP
NEMA Code letter G
Full-load Amps: 117

Primary system data

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Results from computer simulation

Result	A/AB	B/BC	C/CA	Bal/Tot
Ft Away	---	---	---	27631
Ft Into	1031	1031	1031	1031
Emer Reserve	0	0	0	0
Cont Reserve	0	0	0	0
MAIFI	0.0	0.0	0.0	0.0
SAIDI (min)	0.0	0.0	0.0	0.0
SAIFI	0.0	0.0	0.0	0.0
Ph-Ph	---	---	---	1034
Max LG	---	---	---	868
Min LG	---	---	---	288.7
3 Phase	---	---	---	1193
ZS Into	R,X,Z	4.215	7.278	8.410
Z1 Into	R,X,Z	3.392	5.090	6.117
Z0 Into	R,X,Z	5.861	11.653	13.044

Primary System:
12.47 kV (L-L) 3-phase
3-phase Fault duty: 1193A

Note that this software also reports sequence impedances

$$12.47\text{kV}\cdot\sqrt{3}\cdot 1193\text{A} = 25.767\,\text{MVA}$$

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Motor starting mitigation
(See FPQ pg. 113-131)

- Autotransformer starters
  - Reduce voltage applied and corresponding current and starting torque
    - Starting current and torque are reduced to 25%, 42.25%, or 64% of full voltage values.
- Resistance or Reactance starters
  - Insert a series impedance which reduces the voltage applied to the motor.
    - Starting current and torque reduction varies.

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Motor starting mitigation

- Part-winding starters
  - Lower voltage level is applied to one of two parallel windings during starting.
    - Starting current and torque are reduced to 50% of full voltage values.
- Wye-delta starters
  - Stator connected in wye for starting, then changed to delta.
    - Starting current and torque reduced to 33% of full-voltage values.

Motor starting mitigation

- All of these methods reduce the starting current drawn by the motor and result in reduced starting torque.
- What if we apply a delta-wye starter in our example?

$$Vmin := \frac{kVAst_{sc}}{kVAst_{sc} + 0.33 \cdot kVA_{LR}} = 0.932 \qquad Vmin = 93.231\,\%$$

Impact of "soft starting" the motor

- In our example, a voltage sag to 82% of nominal voltage is reduced to a "voltage fluctuation" or flicker of about 6.8%.
- How much flicker is acceptable?
  - Energy providers usually limit the maximum system fluctuation, or how much one can flicker the neighbor's voltage.
  - Providers usually also consider flicker when sizing service transformers and conductors.

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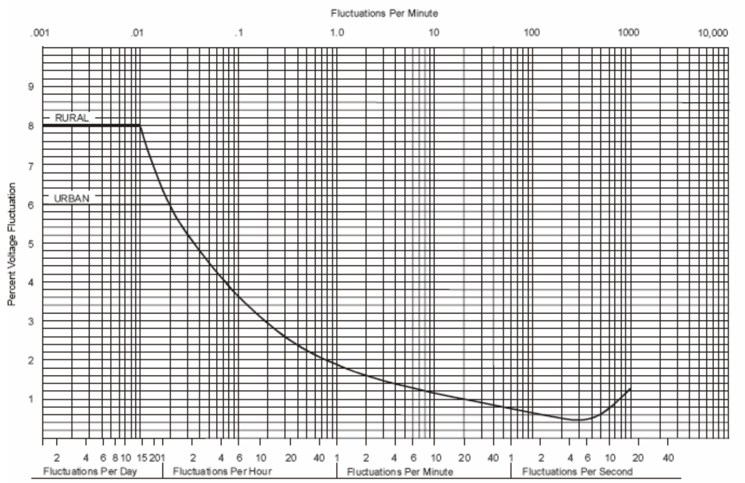
Allowable flicker – see PSQ p. 347, 512-519



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Next time, and things to do:

- Next time: Equipment impacts – rectifier-based loads
- Things to do:
  - Homework 2 – Problems 2 and 3; distribution protection and motor starting
  - Download the paper: *Troubleshooting induction motors,* by W.R.Finley, IEEE, 2000. Read section V; "Motor Instantaneously Taken Off Line" for information on the impact of the initial DC offset in motor starting current.