IEEE PES conference on Innovative Smart Grid Technologies

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Innovative Electromagnetic Dynamic Fault current Limiter operating at Ambient Temperature for Smart Grid

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Relevance of Fault current limiters to Smart Grid

An important feature of the smart grid is stability and reliability achieved through inherent responses of components and supervisory controls.

Short circuits are major destabilizers for the grid both in magnitude and transient effects. They can lead to progressive and permanent damage to network components as also cascading failures including blackouts.

Fault current limiters (FCL) prevent high short circuit currents thus reducing the electromagnetic and thermal stresses while limiting network disturbances.

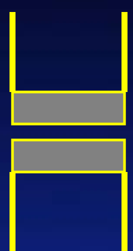
Dynamic FCL (DFCL) presented here is an inherently smart device as it responds to the varying fault or source impedances to keep the short circuit current limited to safe values and still prevent fault hanging.

Hazards due to High short circuit currents –

- *Excessive electromagnetic stresses - $F_{max} \alpha I_{peak}^2$*
- *High thermal stress due to quick temperature rise – $I_{sc}^2 * t$*
- *High voltage drop in the network - $VD = I_{sc} * Z_{source}$*
- *Large arc energy in the fault leads to fire hazards – $E = I_{sc}^2 * r * t$*
- *Large arc energy on the fault clearing switchgear – $E = ½ L * I_{sc}^2$*
- *Cascade tripping and Black outs*

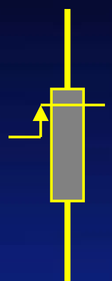
Limiting the short circuit current is very Important for smart grid

Some of the fuse-less Fault current Limiter Technologies -

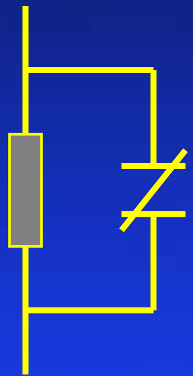


Isolating Transformer With high p.u. impedance X p.u.

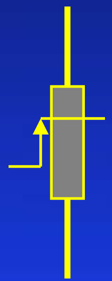
Fixed Inductor L



Saturable Inductor Ls / Ln



Fixed Inductor with Superconducting switch L // 0 to L // Rt



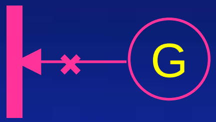
Superconducting Cable

R0 / Rt

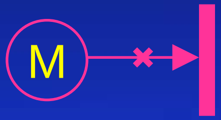
Incremental Permeability Dynamic FCL
L α I
At ambient Temperature

Reasons for High short circuit currents

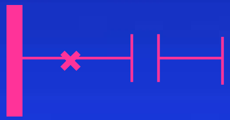
- *Large source capacity*
- *Interconnected networks for redundancy and reliability*
- *Distributed Generation*



- *Contribution to fault from large motors*



- *Large PF correction capacitors on Line*



The ideal Fault current limiter -

- *Fast response time*
- *Limit the first peak as well as rms short circuit current*
- *Should operate in wide ambient variations without external cooling or controlled atmosphere*
- *Should respond directly to the short circuit current without depending upon separate supply or signal*
- *Very good reliability and repeatability*
- *Should limit current to low value and still allow discrimination and relay coordination. Avoid " Fault Hanging"*

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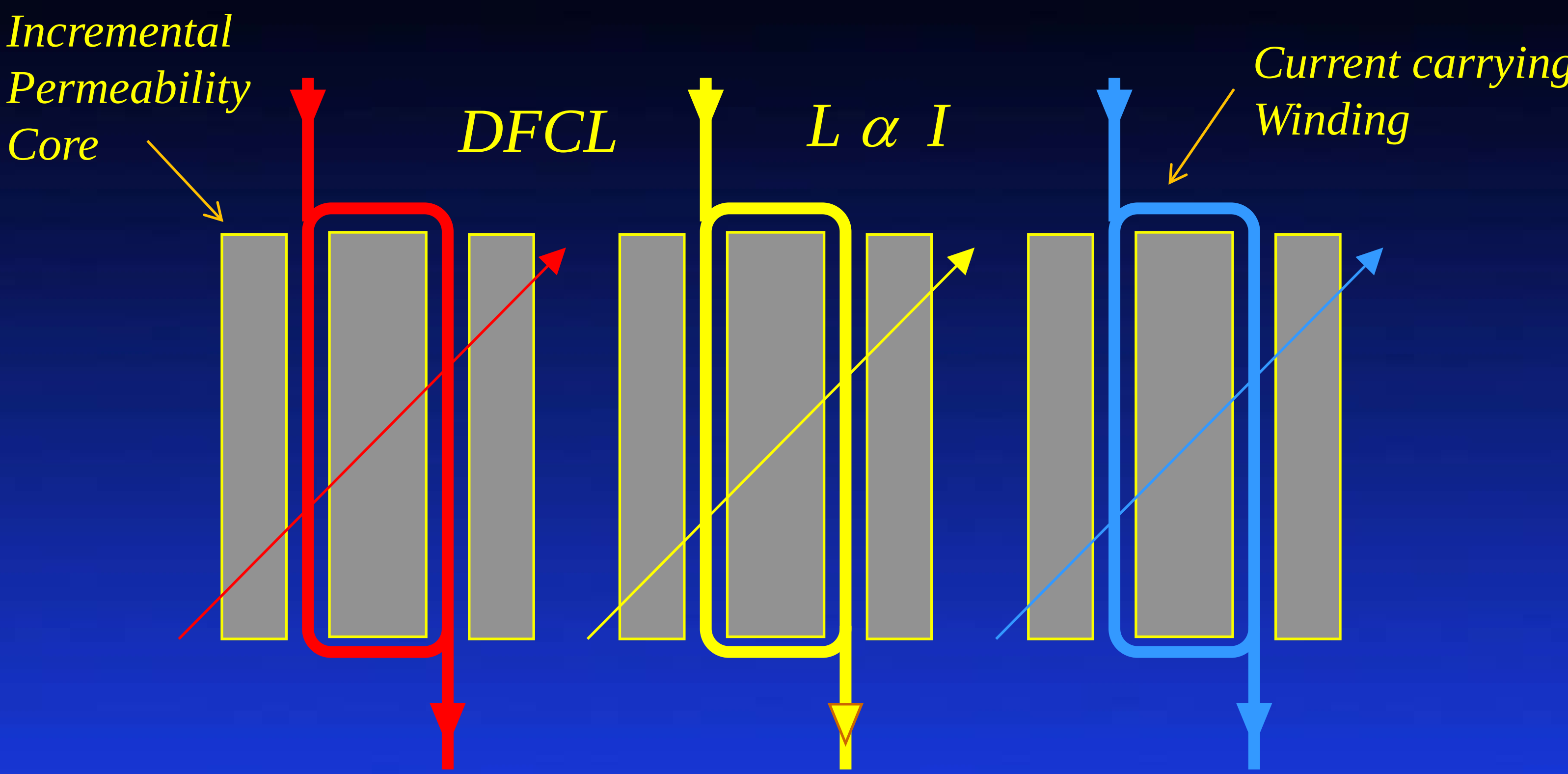

3 phase schematic construction of the Dynamic fault current limiter

Present status of Dynamic FCL –

1. Voltage range - 15 KV tested and installed commercially
   138 KV under validation
2. Nominal current – 1000 amps tested and installed commercially
   4000 A under validation
3. Short circuit limiting ratio – Reduction Achieved 7 max. (14% of
   (rms) prospective short circuit current)
4. 1st peak limiting – similar to rms reduction ratio
5. Response time – Less than quarter cycle – Set ON
   Less than 1 cycle Auto-Reset
6. Short circuit withstand – 3 short circuits of 3 second duration
   consecutive.
7. Cooling – Air Natural at normal ambient -20 deg C to + 50 deg C
   (- 4 deg F to + 122 deg F)
8. Epoxy Resin cast dry type design
9. Connection options – Cable Box , Flanged bus duct

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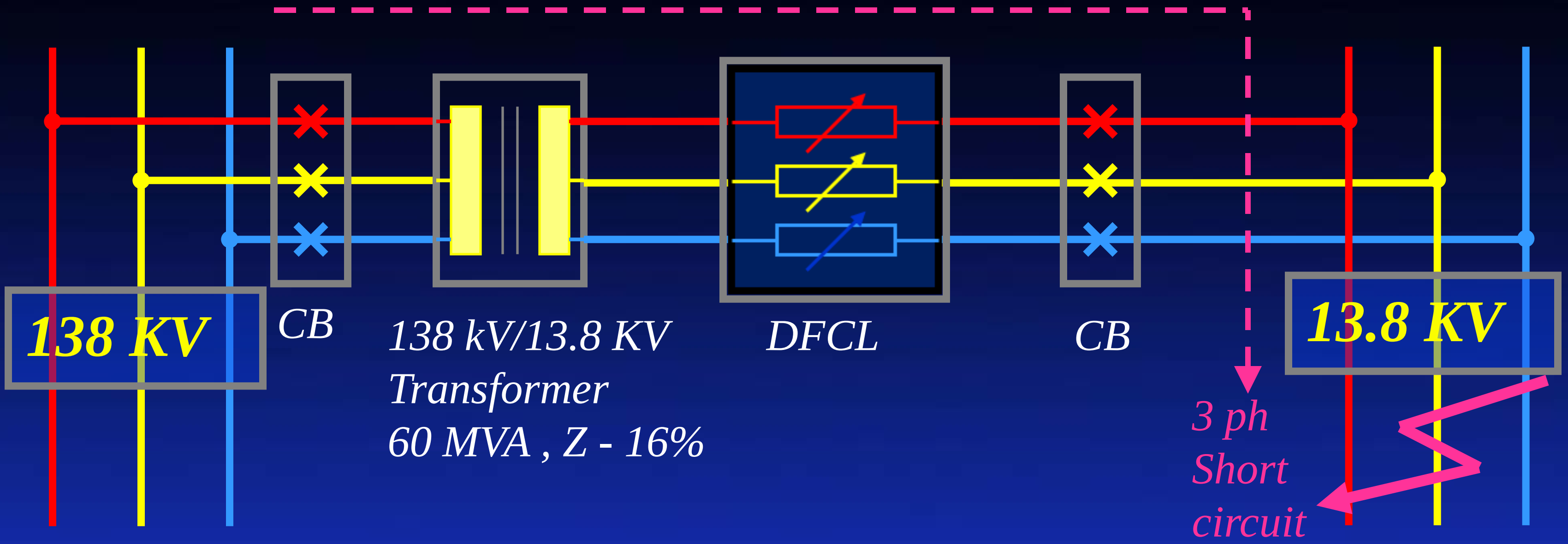
16 KA rms to 6 KA rms with DFCL



Case 1 – Single transformer 138 / 13.8 KV , 60 MVA Z - 16%

Down stream 3 ph fault - 45 KA peak , 16 KA rms without DFCL

- 16 KA peak , 6 KA rms with DFCL

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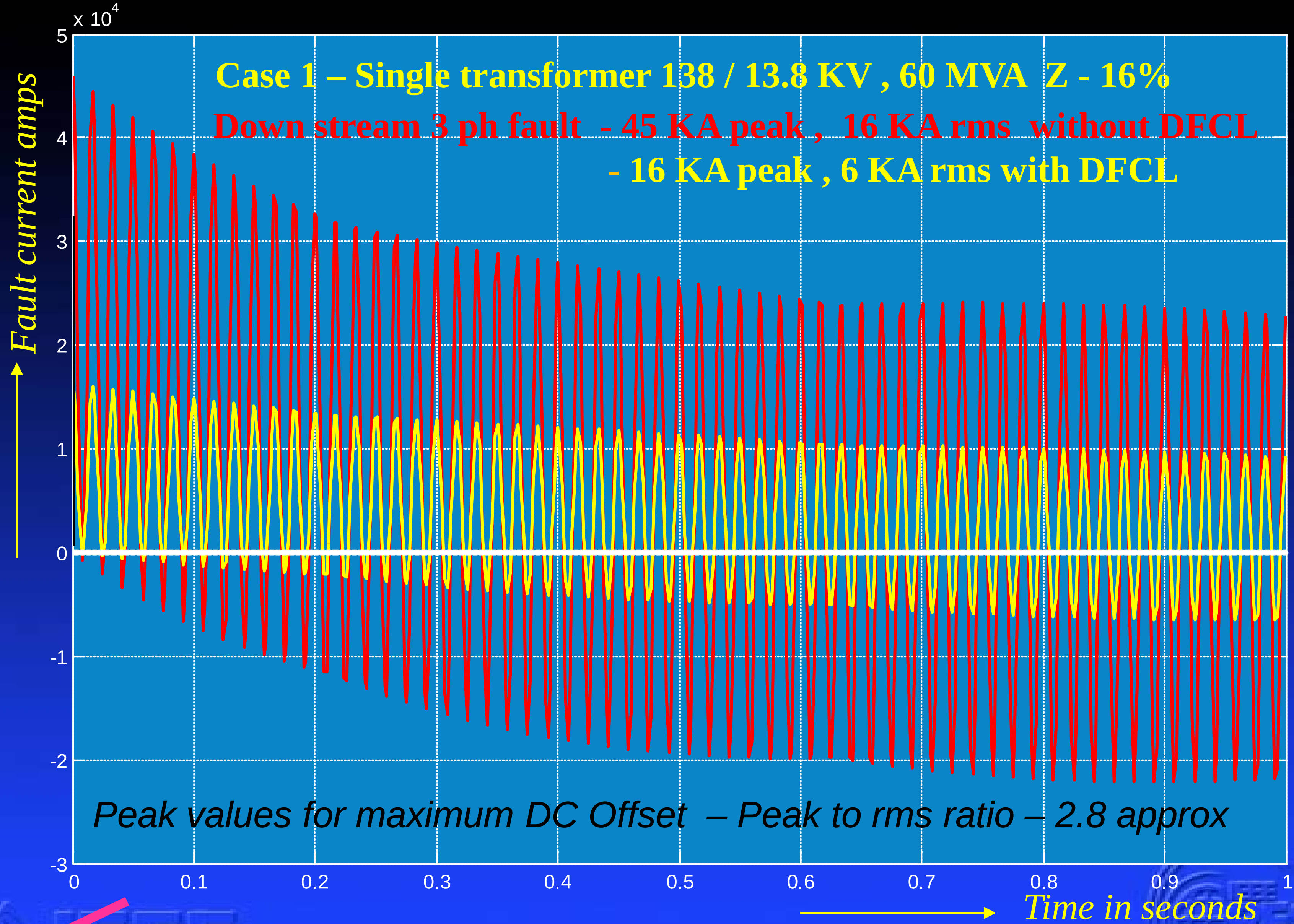

Prospective and limited fault current waveforms

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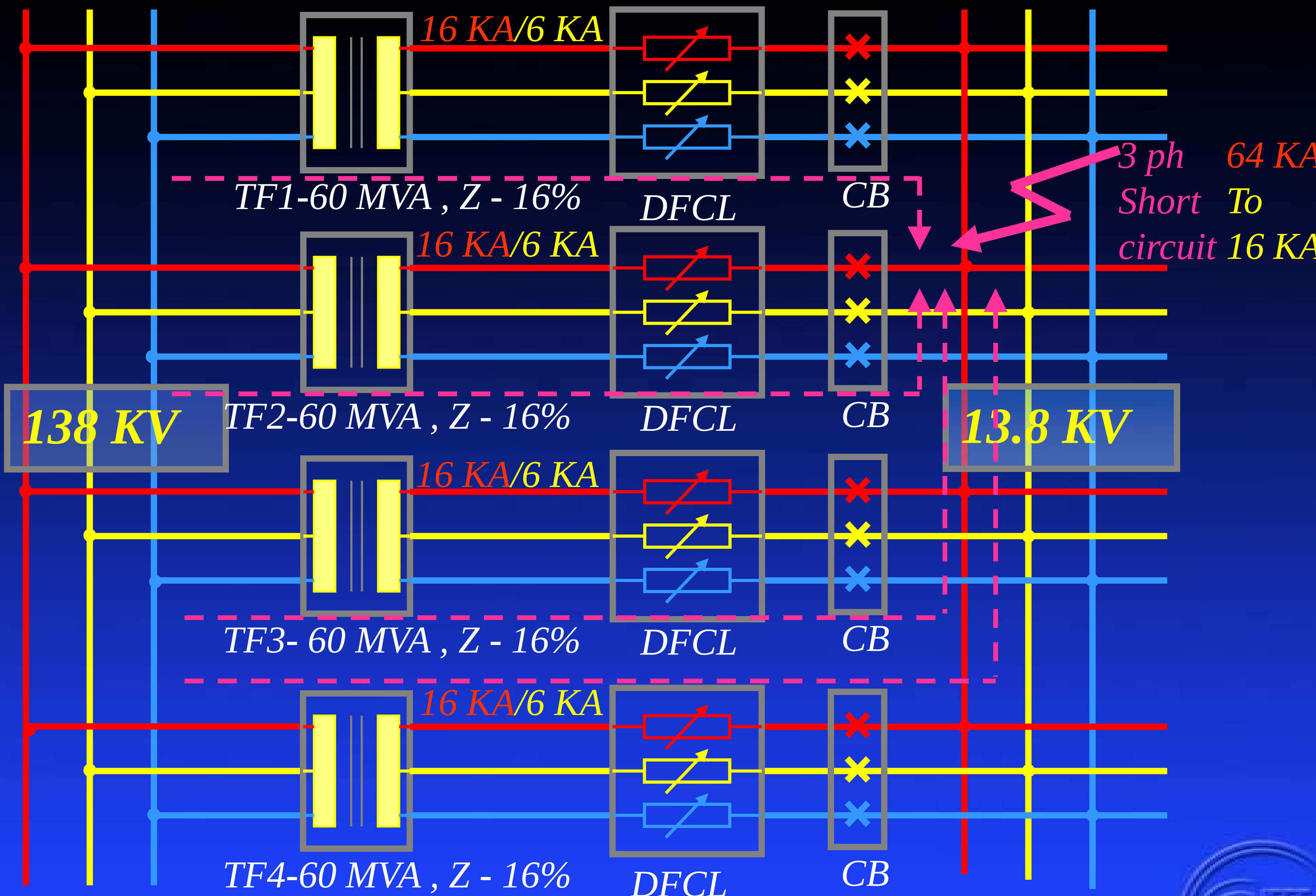
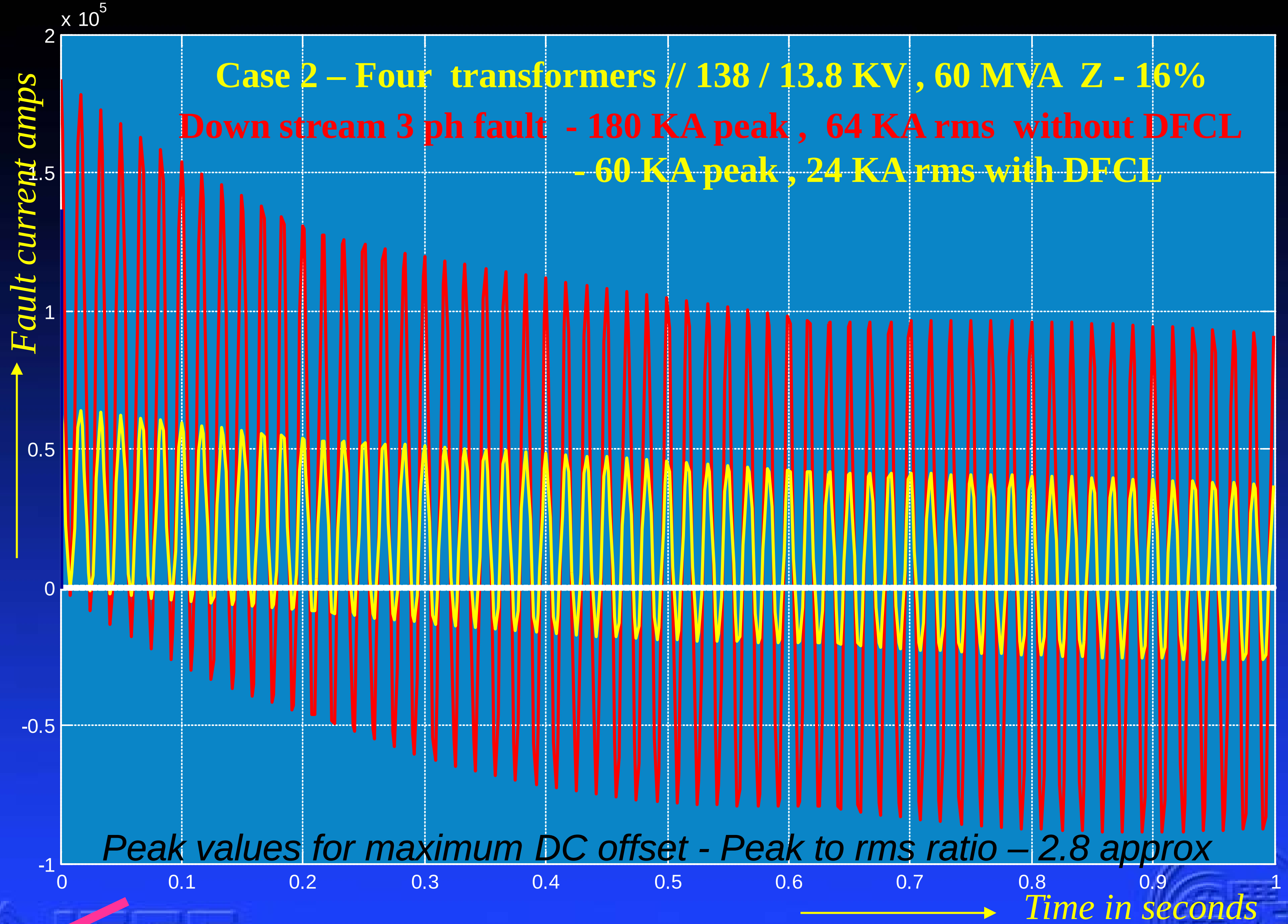
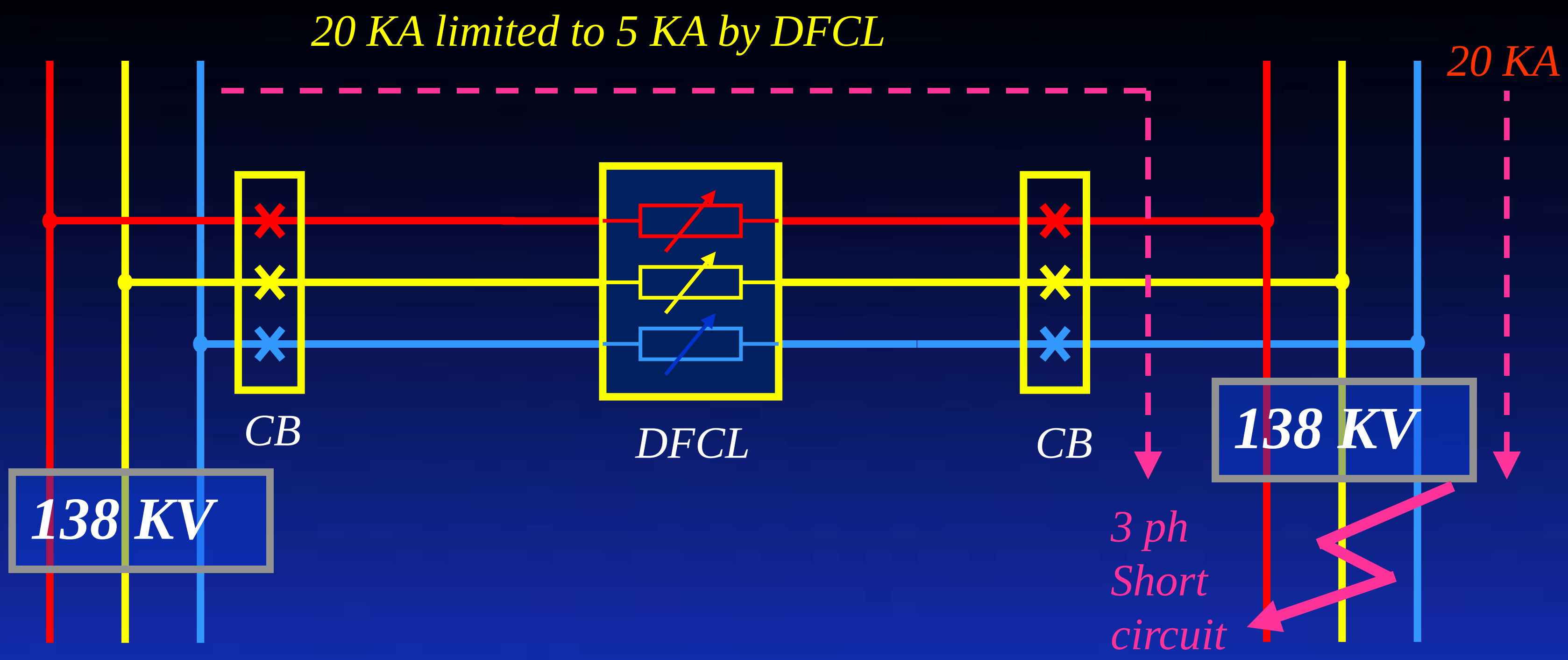


Case2 – 4 transformers in parallel



Prospective and limited fault current waveforms



Case 3 – DFCL on 138 KV bus tie for bi-directional current limit

Down stream 3 ph fault - 100 KA peak , 40 KA rms without DFCL

- 55 KA peak , 25 KA rms with DFCL for fault on either supply line

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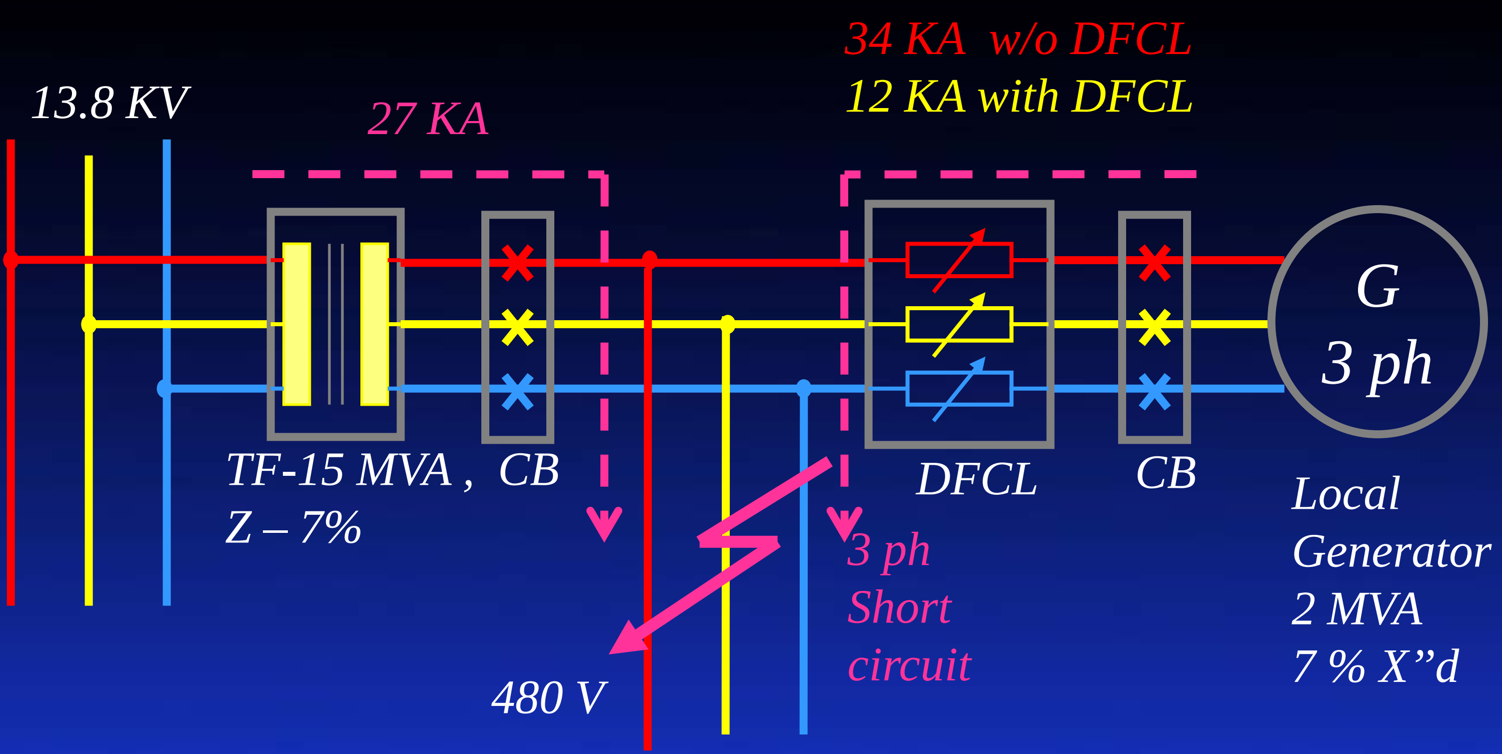

Case 4– Distributed generation . Local Generation in parallel with Utility

Down stream 3 ph fault - 150KA peak , 61KA rms without DFCL

- 100 KA peak , 39 KA rms with DFCL

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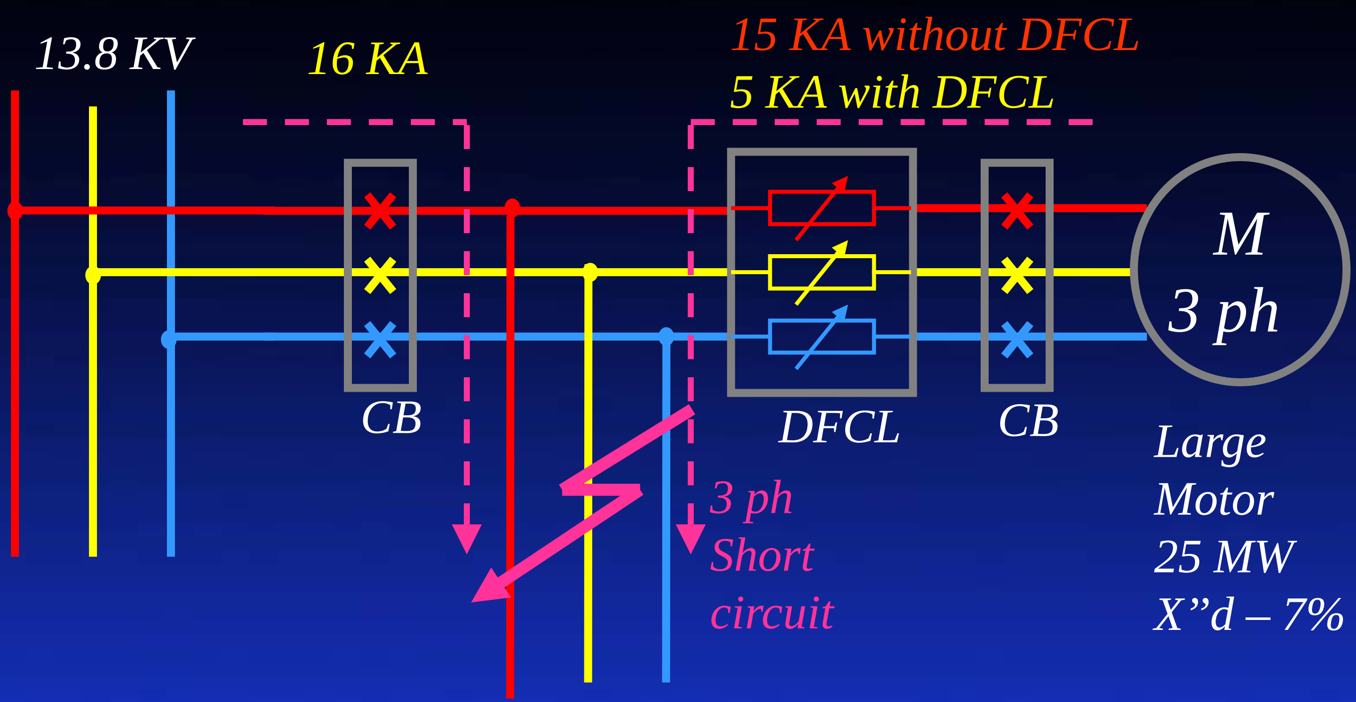
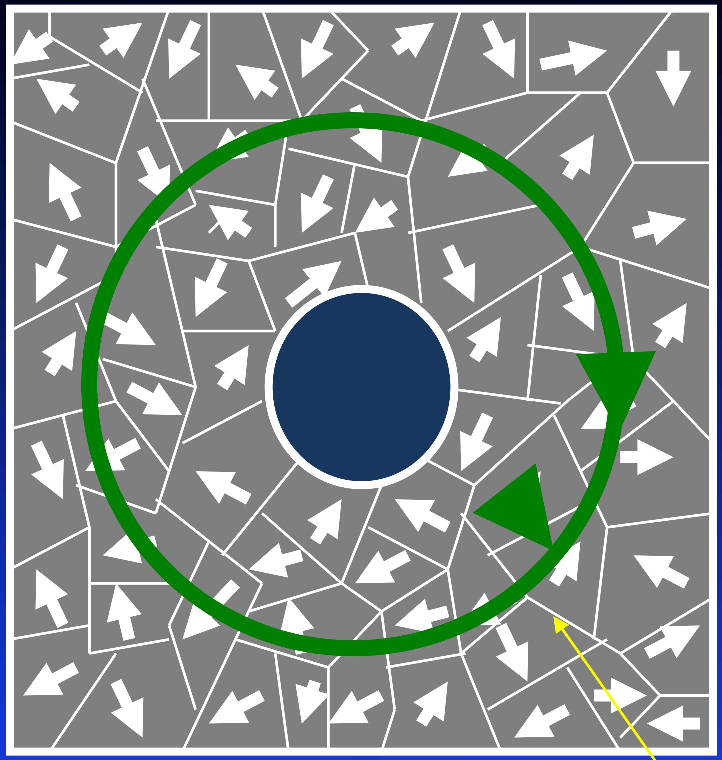


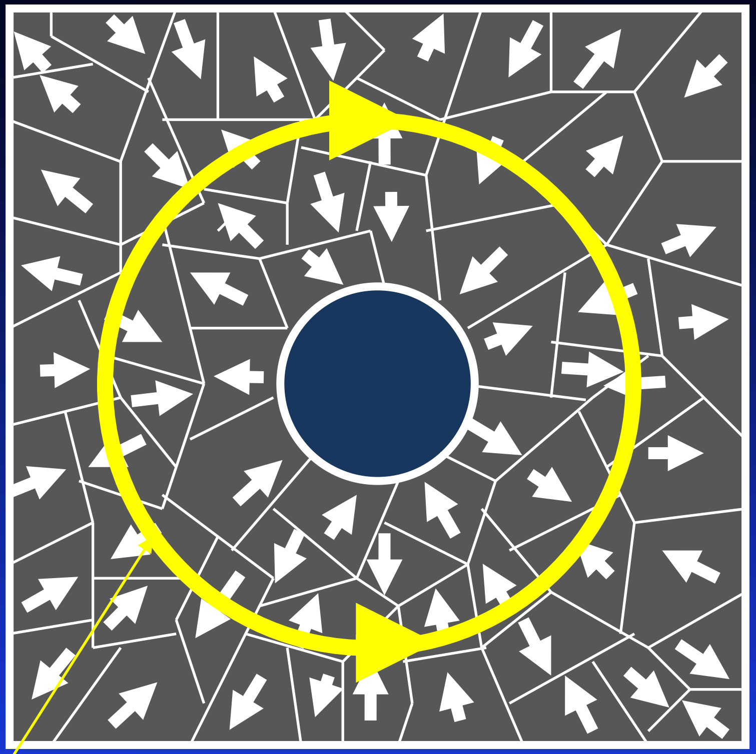
Case 4– Reduction in Fault contribution from Large motors

Down stream 3 ph fault - 70 KA peak , 31 KA rms without DFCL
- 46 KA peak , 21 KA rms with DFCL

Unprocessed core

DFCL core

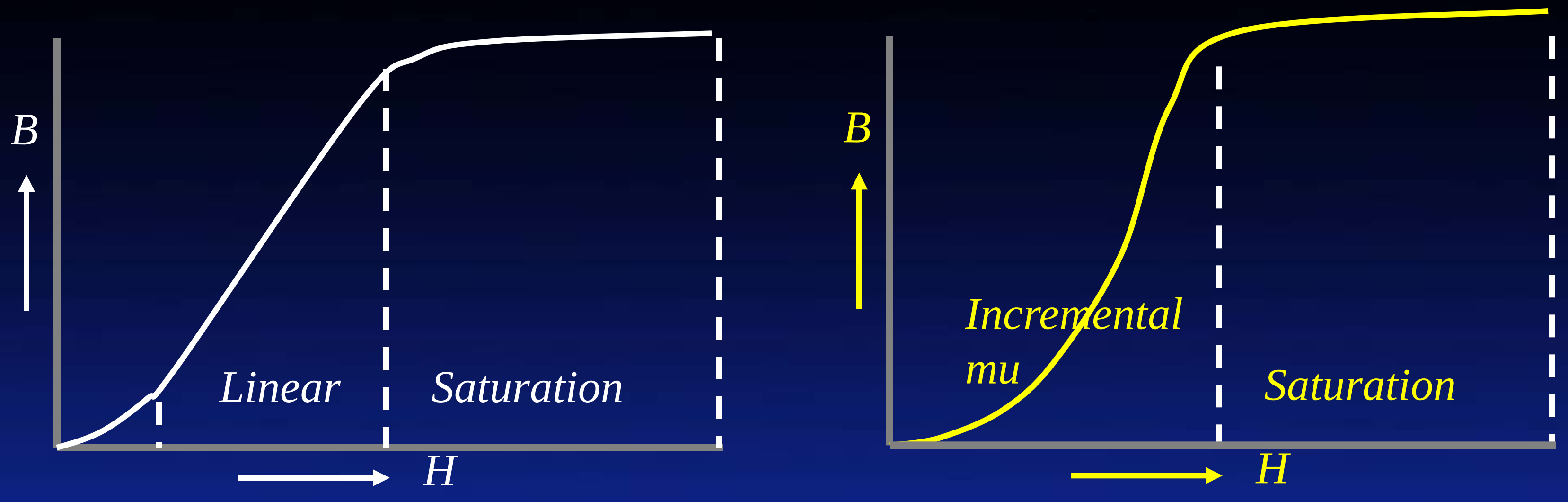




Randomly aligned domains in the unprocessed core

Circumferential Flux

Radially pre- aligned domains in the processed core

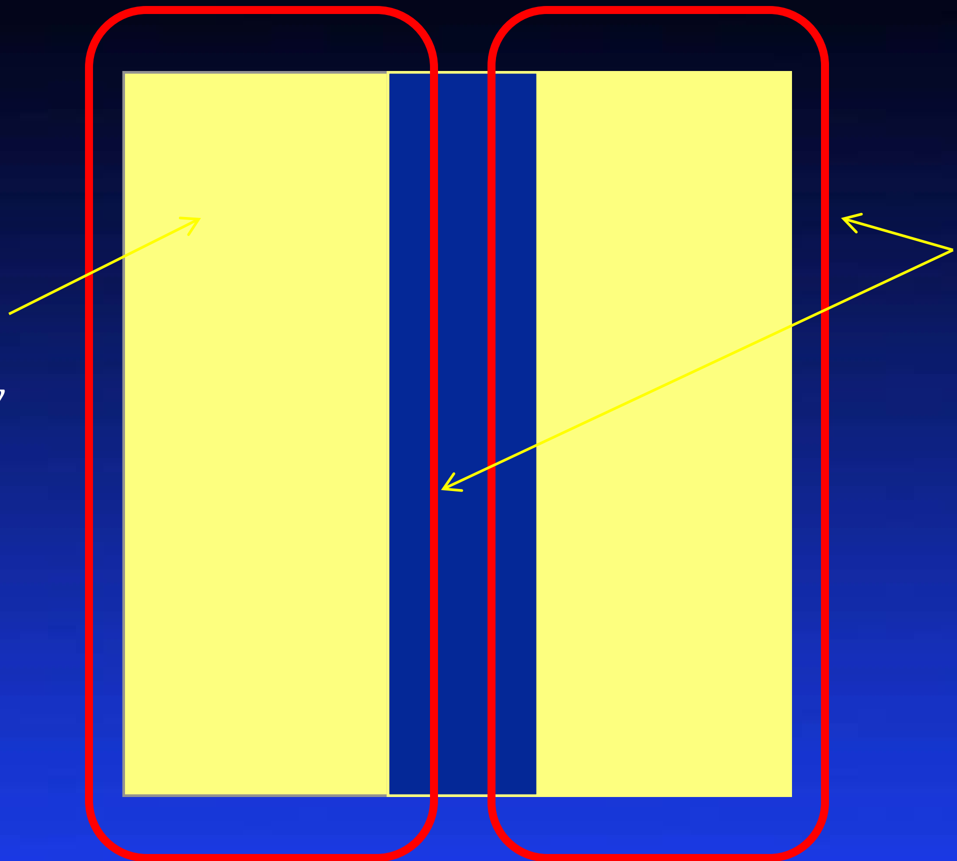


Near constant permeability of conventional core

Incremental permeability of DFCL core

Magnetization curves for the DFCL core

Toroidal per phase winding of the Electromagnetic DFCL



Sectional view

Salient Features of the incremental permeability Electromagnetic DFCL

- *Impedance increases with fault current. Thus short circuit current is limited in a narrow band for different fault and source impedances*

- *Can work with Air natural cooling. No requirement of cryogenic cooling*

- *Simple and rugged in construction.*

- *Failure if at all to high impedance mode which will increase the normal voltage drop and is easily detected*

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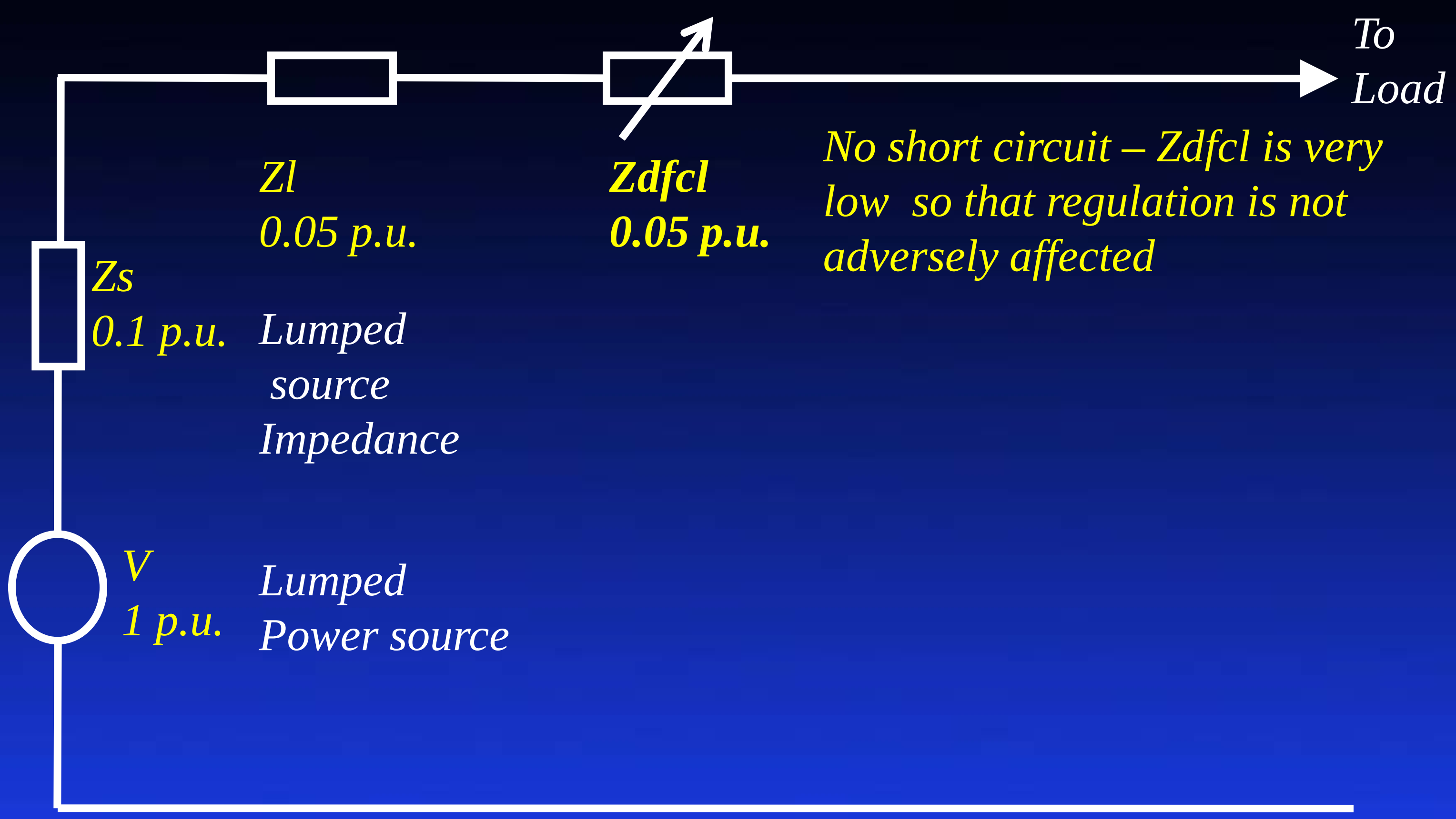

Impedance behavior of DFCL for healthy network pre-fault or post fault-clearance

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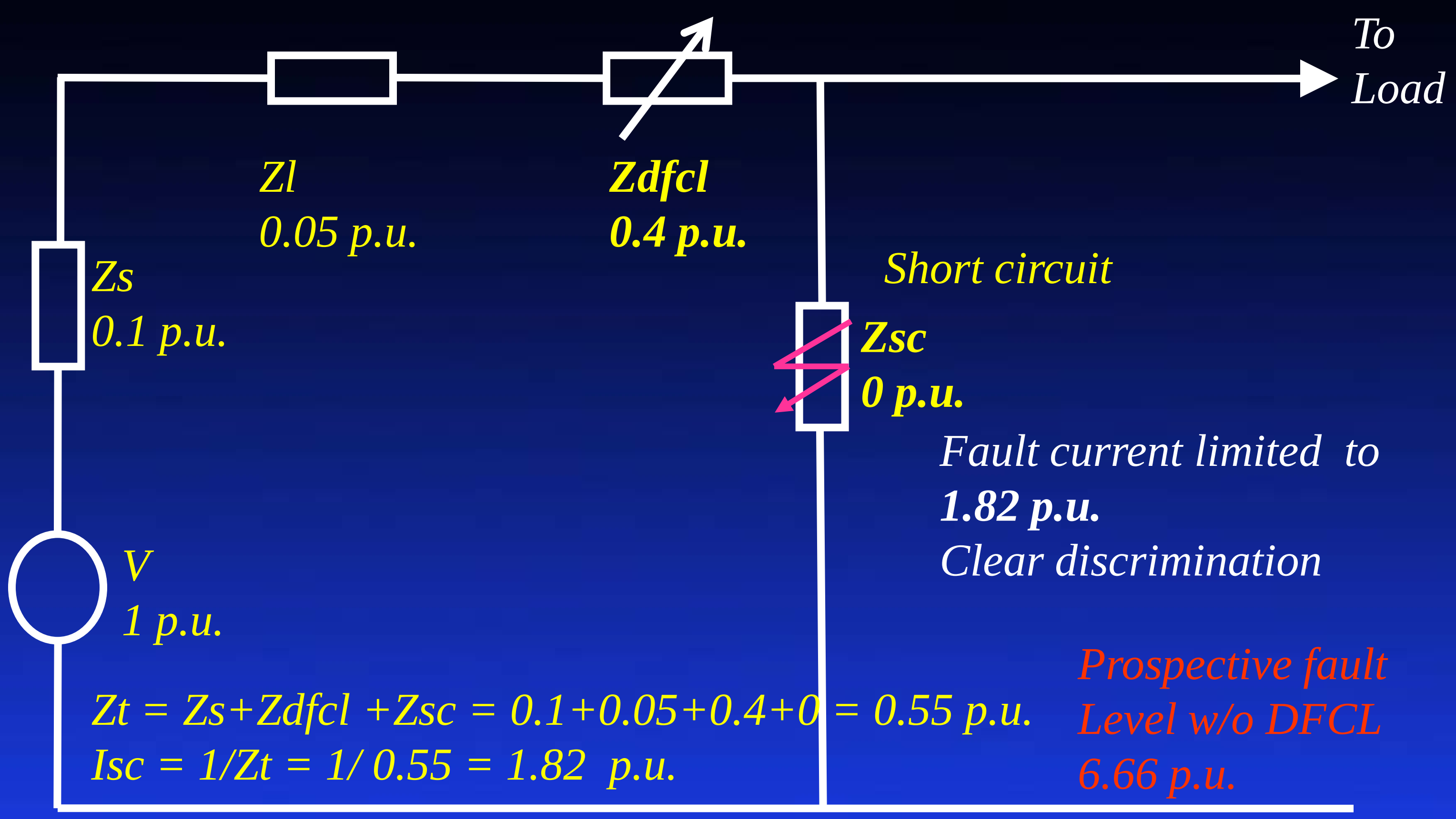

$Zt = Zs+Zdfcl+Zsc = 0.1+0.05+0.4+0 = 0.55$ p.u.

$Isc = 1/Zt = 1/0.55 = 1.82$ p.u.

Impedance behavior of DFCL with a low impedance fault – bolted short circuit

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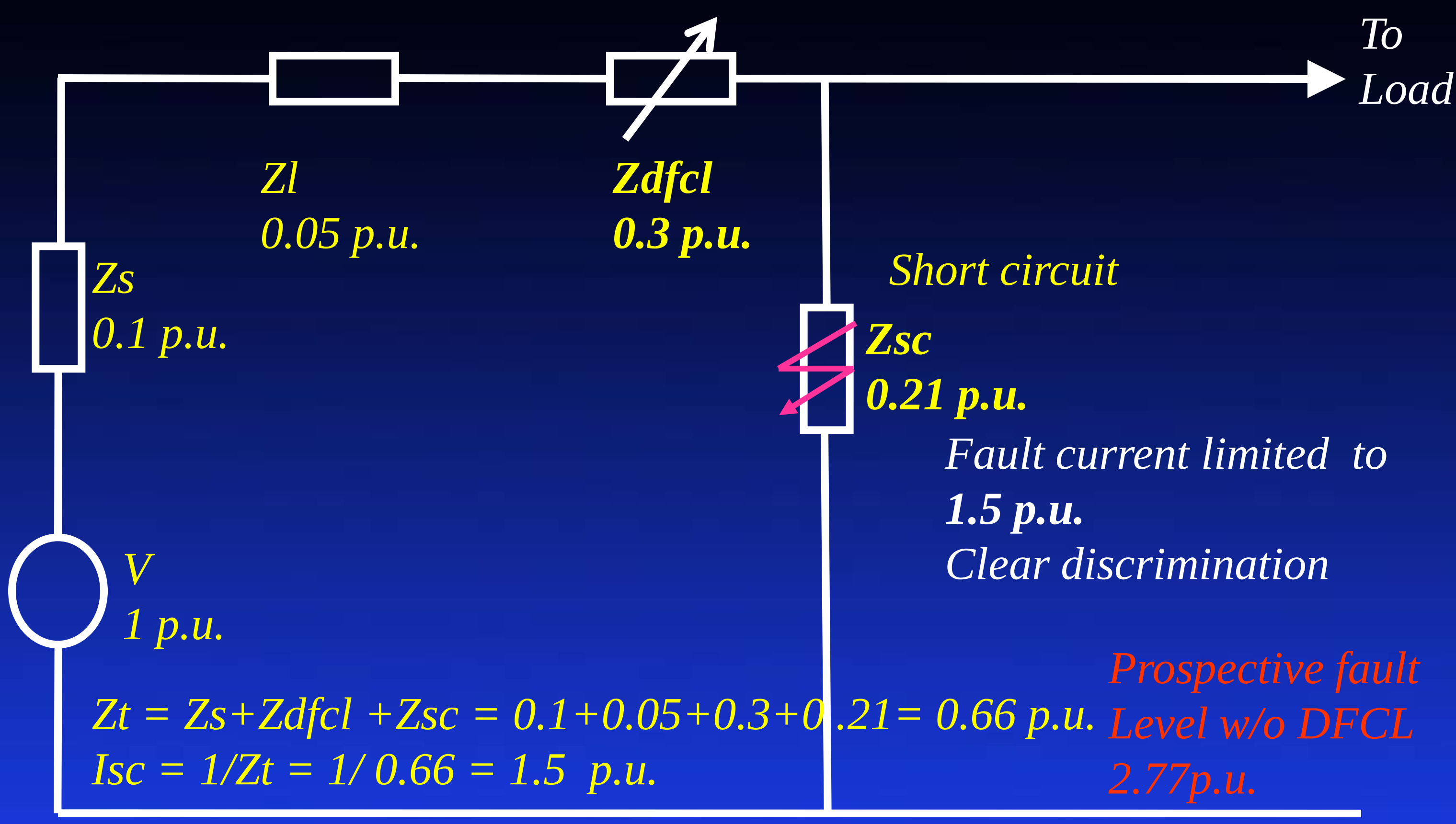
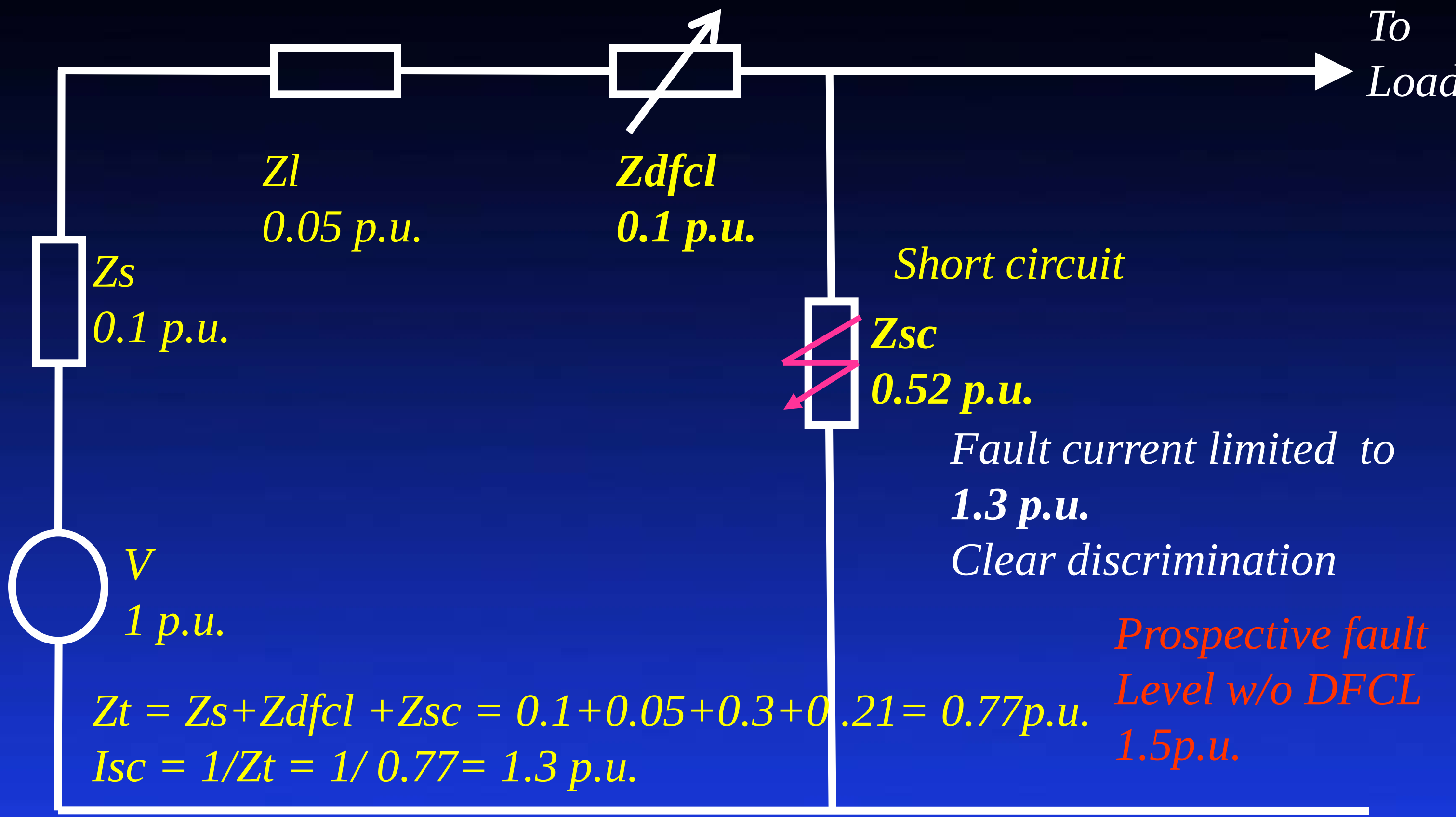


Impedance behavior of DFCL with a medium impedance fault



Impedance behavior of DFCL with a high impedance fault

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Zsc	**Zdfcl**	**Fault currents in p.u. Zs – 0.1 p.u. Zl – 0.05 p.u.**						**Isc with no Limiter**
		DFCL current limit	Impedance of fixed inductor with or without Superconducting switch					
			0.07	0.15	0.2	0.25	0.3	0
0	**0.4**	**1.82**	4.55	3.33	2.86	2.5	2.22	6.67
0.2	**0.3**	**1.54**	2.38	2	1.82	1.67	1.54	2.86
0.3	**0.25**	**1.43**	1.92	1.67	1.54	1.43	1.33	2.22
0.4	**0.18**	**1.37**	1.61	1.43	1.33	1.25	1.18	1.82
0.5	**0.1**	**1.33**	1.39	1.25	1.18	1.11	1.05	1.54

Illustrative example of Fault currents with DFCL & with fixed impedance Inductor with our without Superconducting switch

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Thank you