Analytical investigation and experimental validation of Thermal & AC characterization of HTS Tape for modular superconducting fault current limiter

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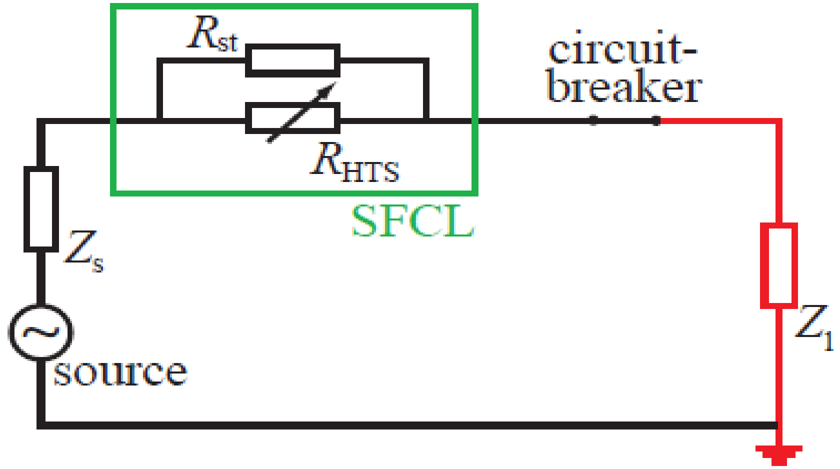
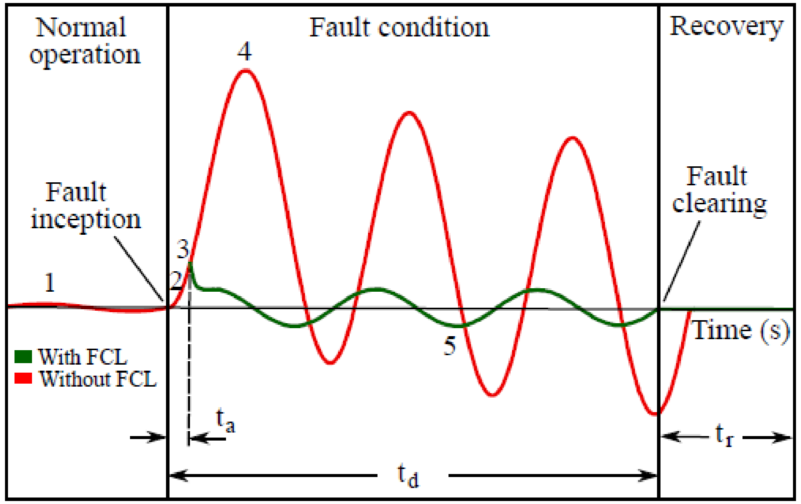
Fault Management Technique…….





Normal Operation, Current is less than the Critical Current of SC Tape : No Resistance across HTS

During Fault : Current is much more than Critical. HTS becomes Normal : Higher resistance : Reduce the Fault Current : Saves the online equipment

Present Study :

A. Development of a Fault Current Generator with different no of fault cycle (20 msec to 200 msec)

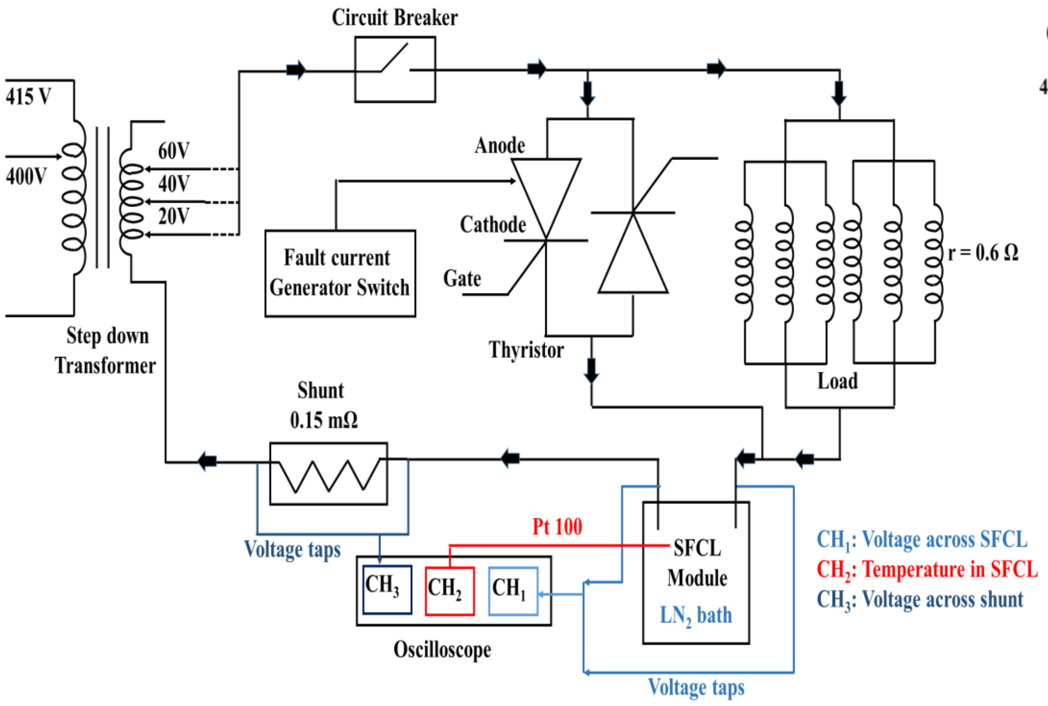
B. Experimental set up with load, fault current generator and HTS resistance type Fault Meter

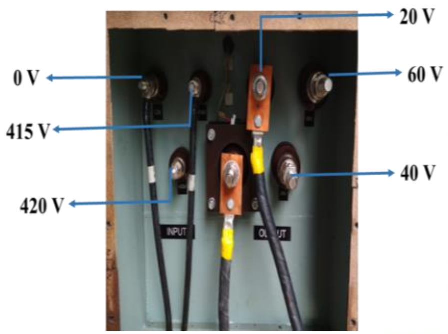
C. Measurement of Resistance, Fault Current, Temperature of HTS Tape

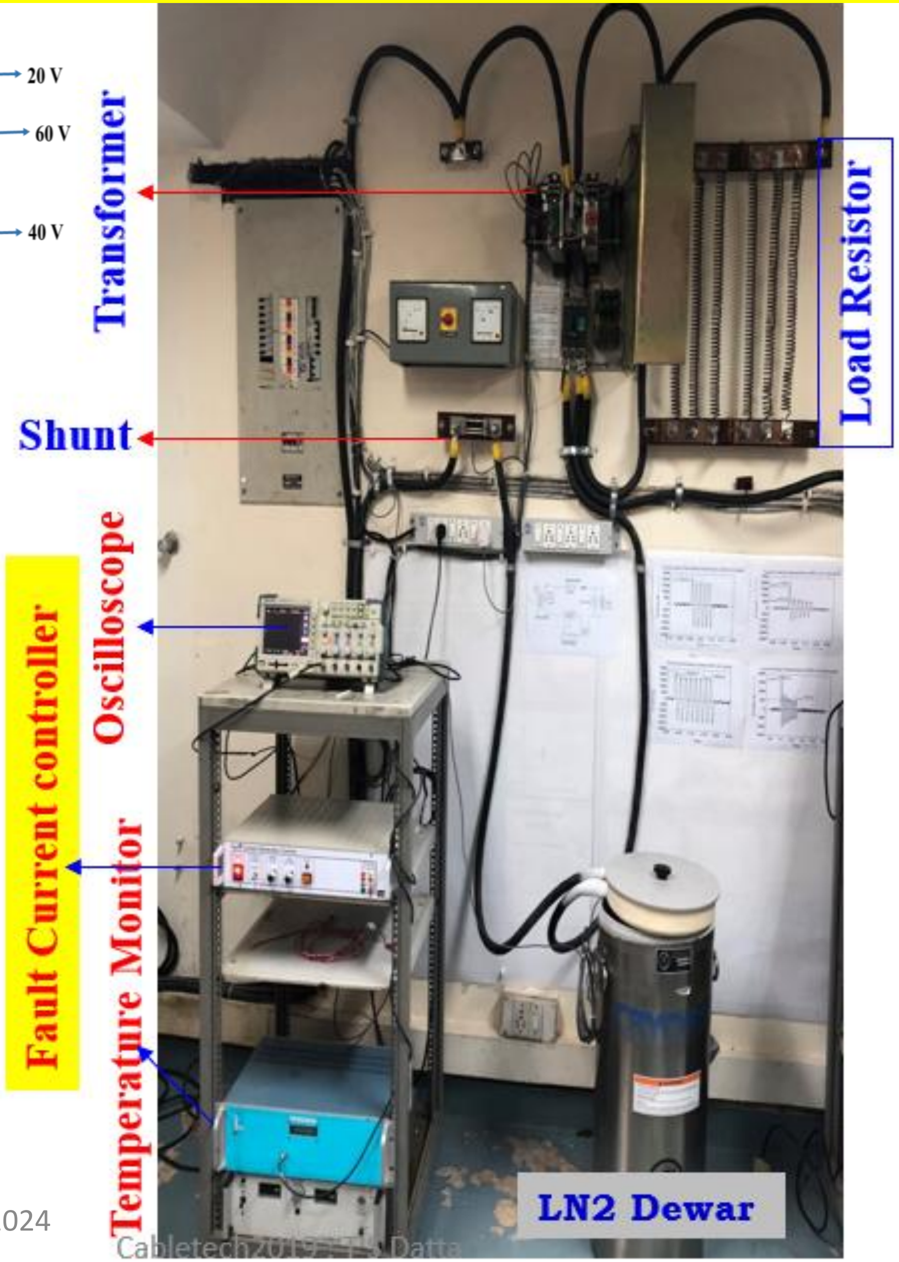
D. Analytical Calculation and Validation of Expt. Data on various length and type of HTS tape

UPGRADED FAULT CURRENT GENERATOR WIGH HIGHER RATING

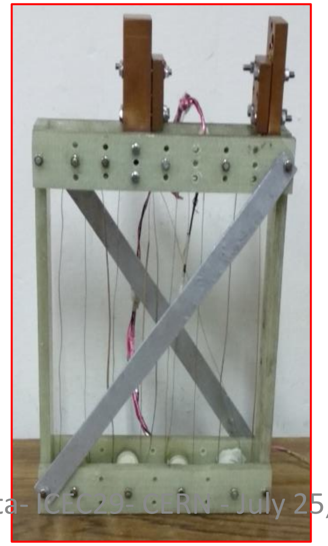
Experimental Test setup : AC characterization of 2G HTS tape at Fault Condition







SFCL MODULE with HTS TAPE (380/ 190 CM)

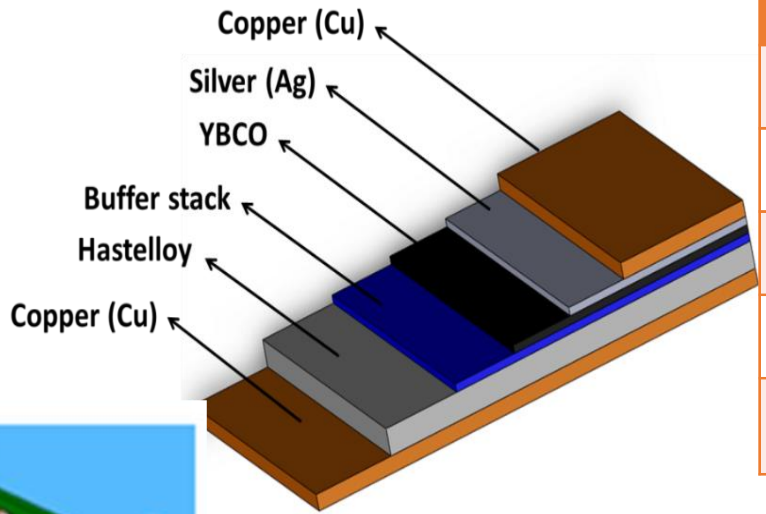


HTS TAPE : Two Types

2G HTS Tape (AMSC, USA)

A

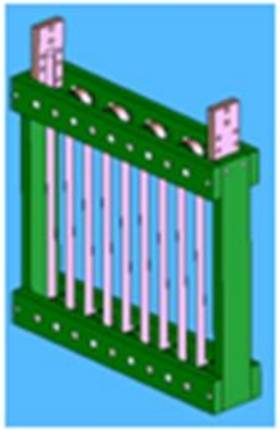
Parameters	Values
Thickness	0.17-0.21 mm
Width	4.8 mm
Lamination	Copper
Critical Current	100 A @77K
Critical Temperature	92 K

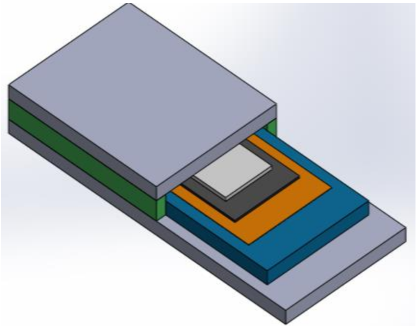


Material	Thickness
Copper	40 μm
Silver	2 μm
YBCO	1 μm
Buffer	75-77 μm
Substrate	50-75 μm

B

Description	Specifications
Superconductor	YBCO (Single Layer)
Lamination	SS-316L
Critical Current, I_c	> 200A @77K
Dimensions	12 mm x 0.24 mm



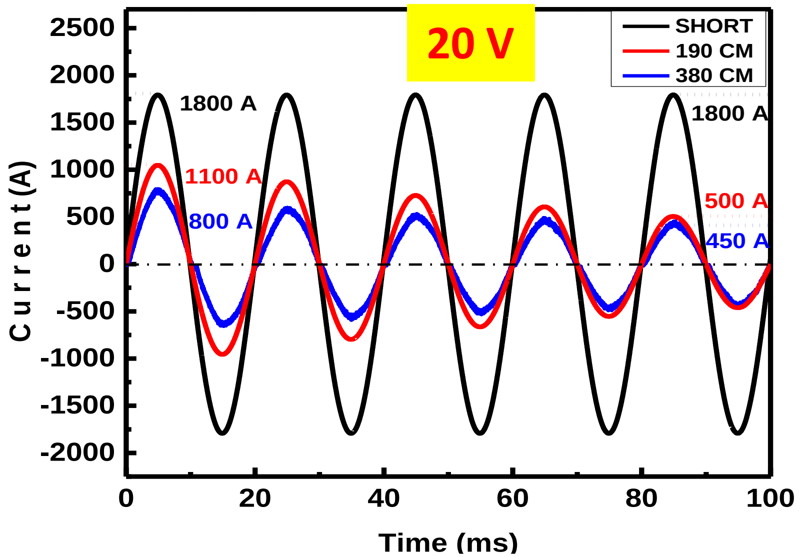


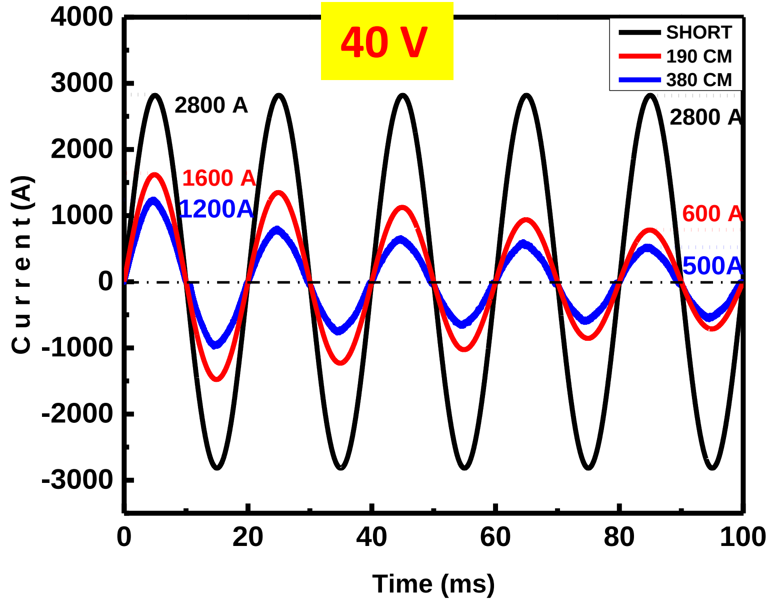
Higher Resistance at Room temperature. (Fault Current will be low compared to Copper)

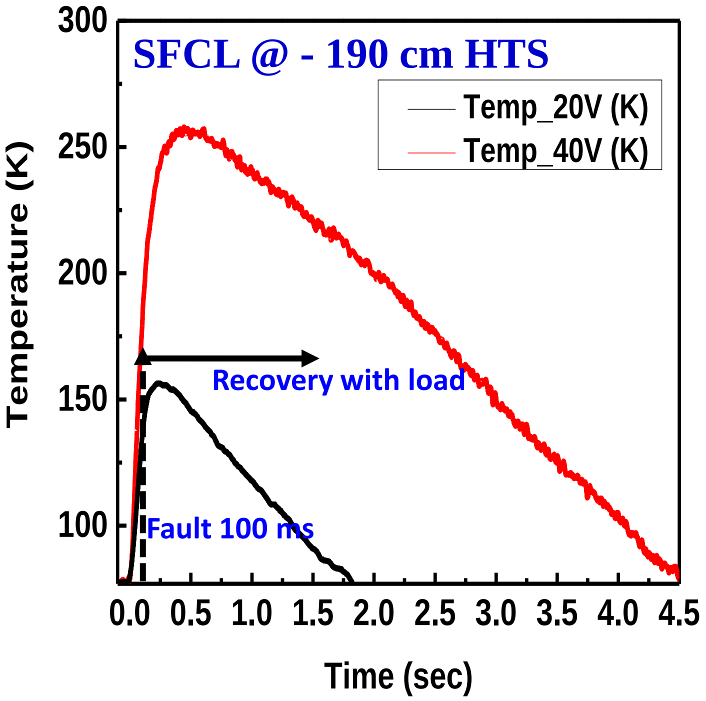
Higher Critical Current

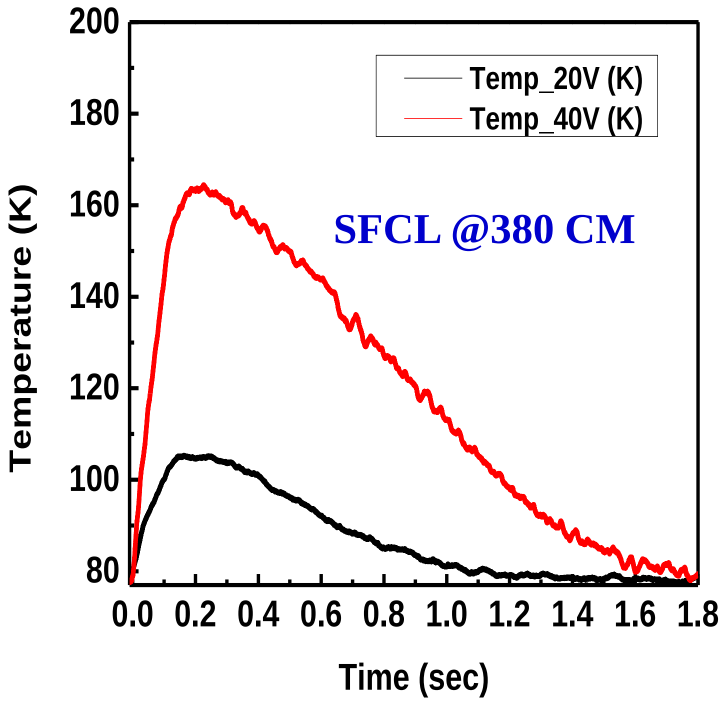
Higher Surface area (Heat Transfer Area)

Experimental plot on Fault Parameter of different length (Copper Laminated) at 20 V_{rms} and 40 V_{rms}





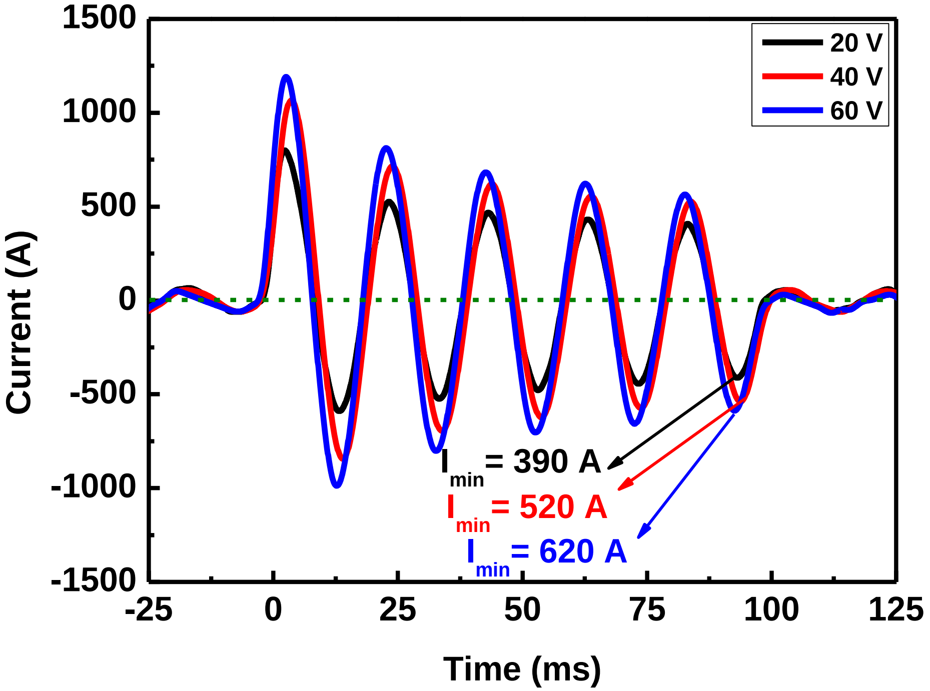


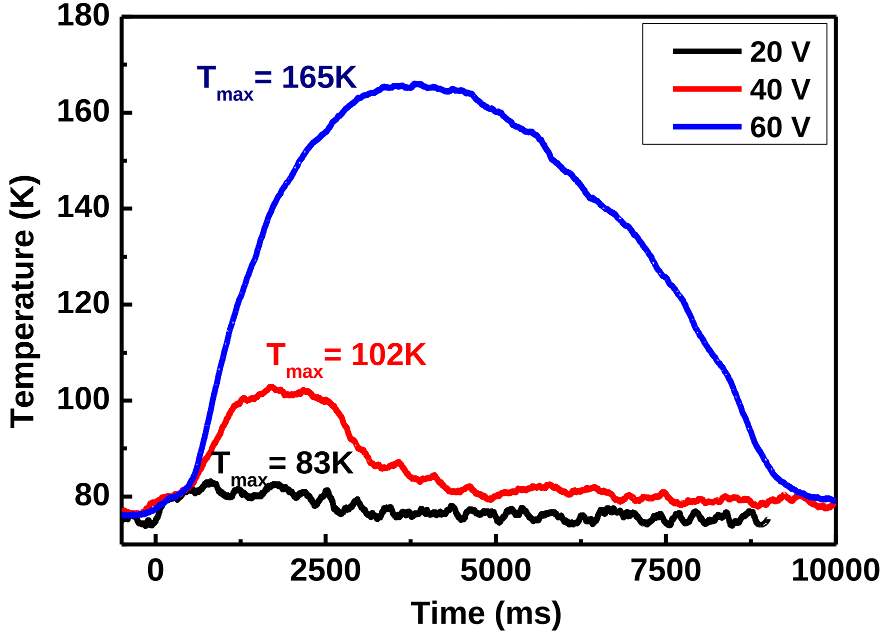


Temperature Profile during Fault and Recovery

Fault Current Reduced from 1800 A to 1100/ 800 A for a length of 190 and 380 CM respectively

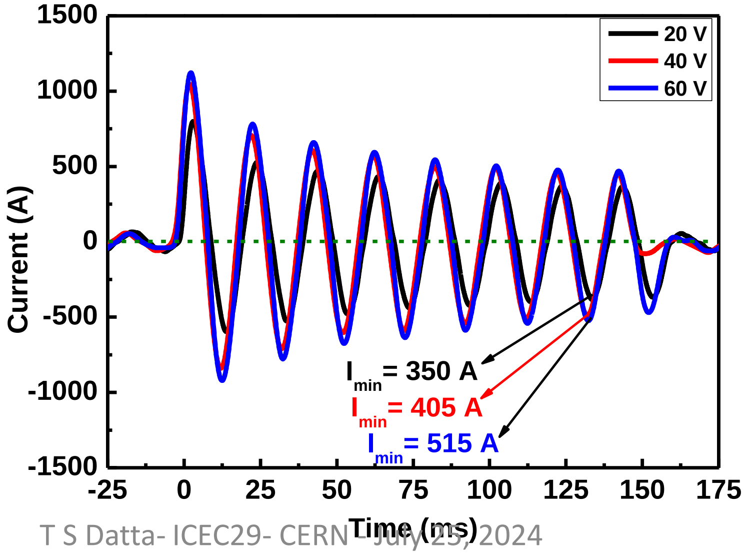
EXPERIMENT WITH SS LAMINATED TAPE (75 CM : 12 mm)

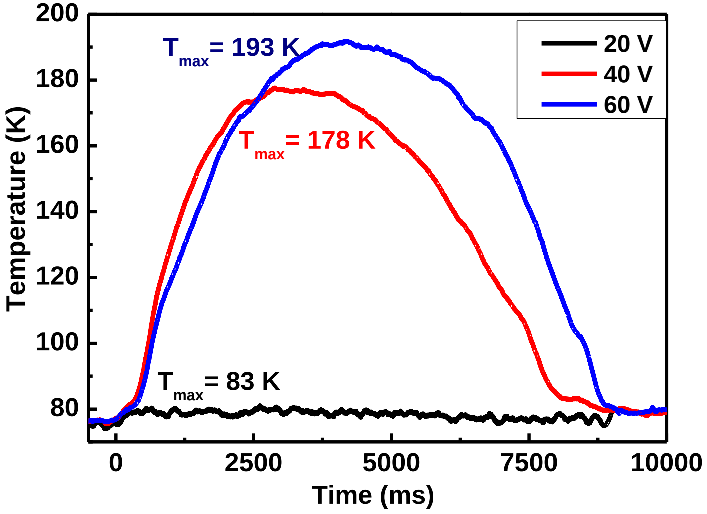




Note : For better comparison on SS and Copper lamination, we thought of using similar type of HTS Tape.

But ready availability forced us to have different dimension of tape





Analytical Calculation on Temperature/ Resistance of HTS Tape during Fault

$$Q_j = \int_{t=0}^{T/4} (I_0 \sin \omega t)^2 . R(t).dt \qquad (1)$$

$$\frac{1}{R_s} = \frac{1}{R_{Sup}} + \frac{1}{R_{Ag}} + \frac{1}{R_{Has}} + \frac{1}{R_{cu}} \qquad (2)$$

$$C_p = \frac{\sum m_i \, C_{pi}}{\sum m_i} \qquad (3)$$

$$dT = {Q_j}/{C_p \sum m_i} \qquad (4)$$

$$Q_C = 2.l.w.h.dT \qquad (5)$$

$$dT_{final} = {(Q_j - Q_c)}/{C_p \sum m_i} \qquad (6)$$

$$T_1 = 78.4 + dT_{final} \qquad (7)$$

At Normal Operation Current and Temperature at 78 K and I < I $_{C}$,

$$R_s = R_{HTS} = 0$$

During Fault , I > IC,

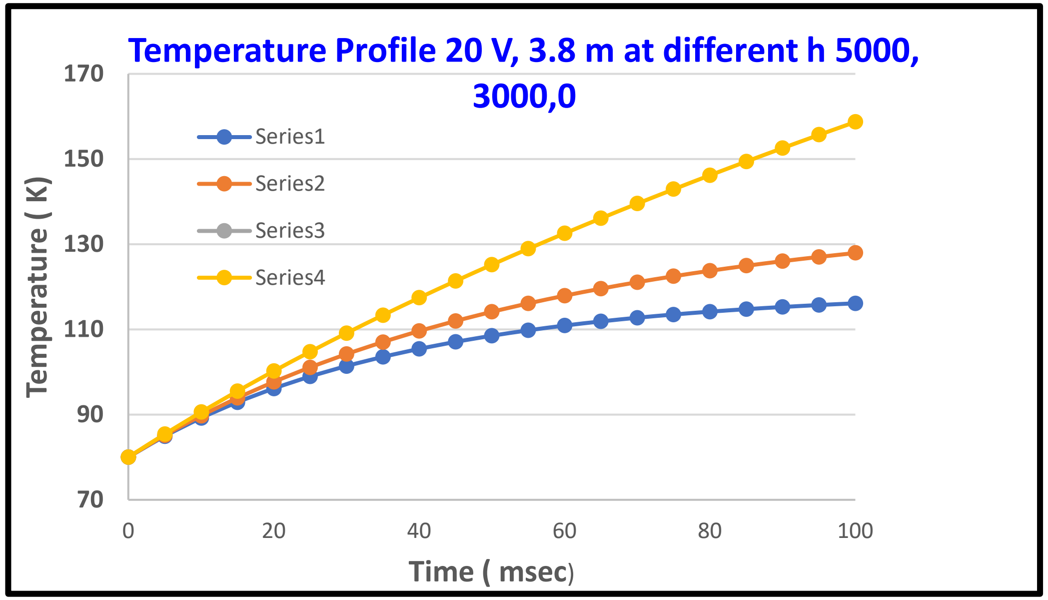
$R_S = R_{cu}$ or $R_s = R_{SS}$ **Function of Temperature**

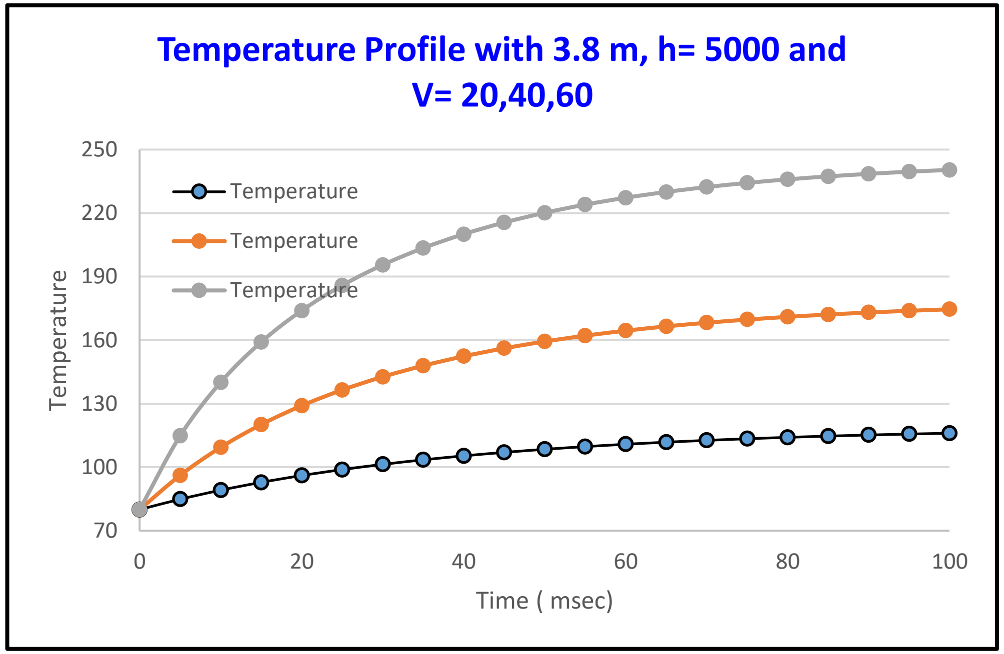
T_1 = Temperature of the Tape after first quarter Cycle (t= 5 milli sec)

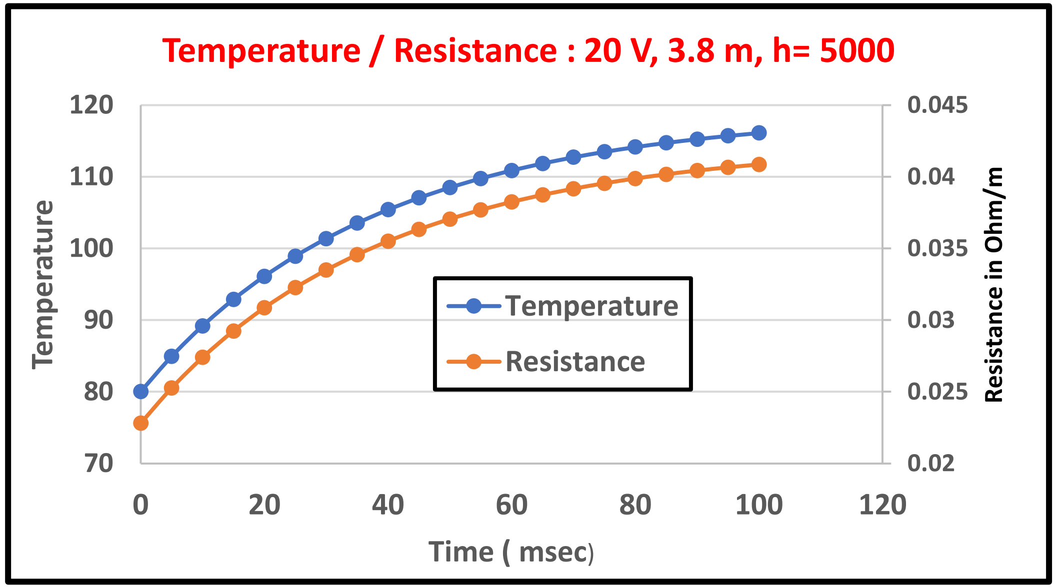
$$R_1 = R_{78.4}(1 + \alpha(T_1 - 78.4) \qquad (8))$$

Resistance and Temperature calculation is repeated for 2 nd quarter cycle and subsequently for 20 quarter cycle where the fault duration is 5 Cycle (100 milli sec)

Analytical Plot of Temperature and Resistance rise with time during fault



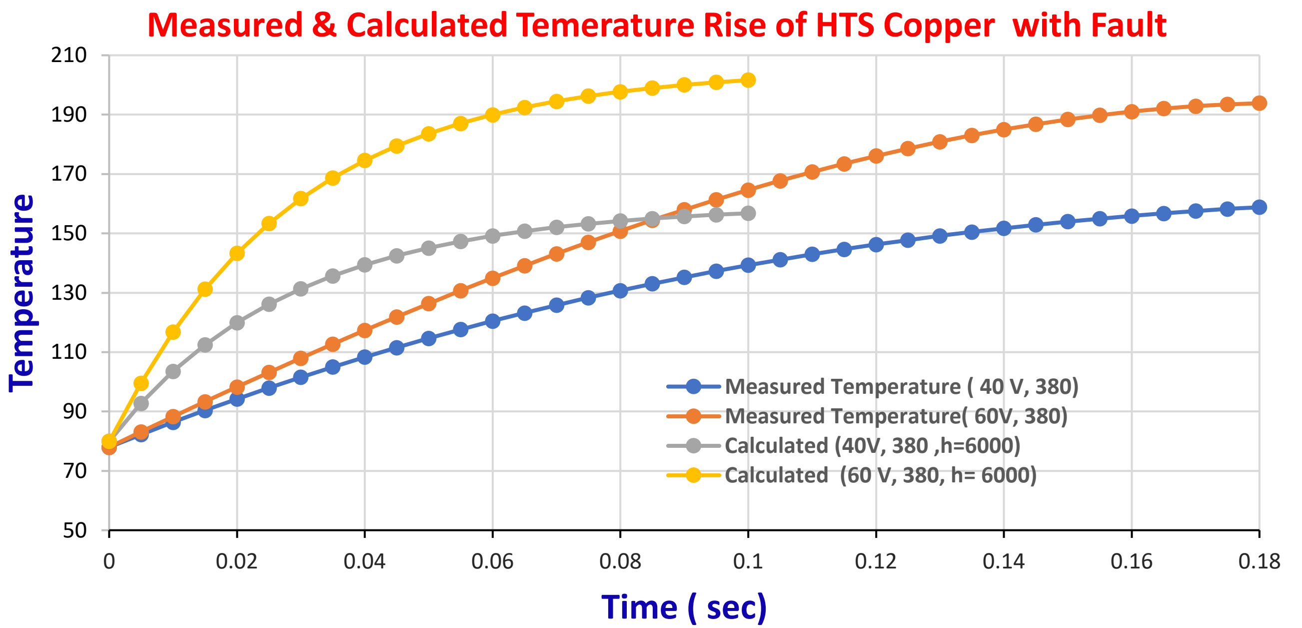




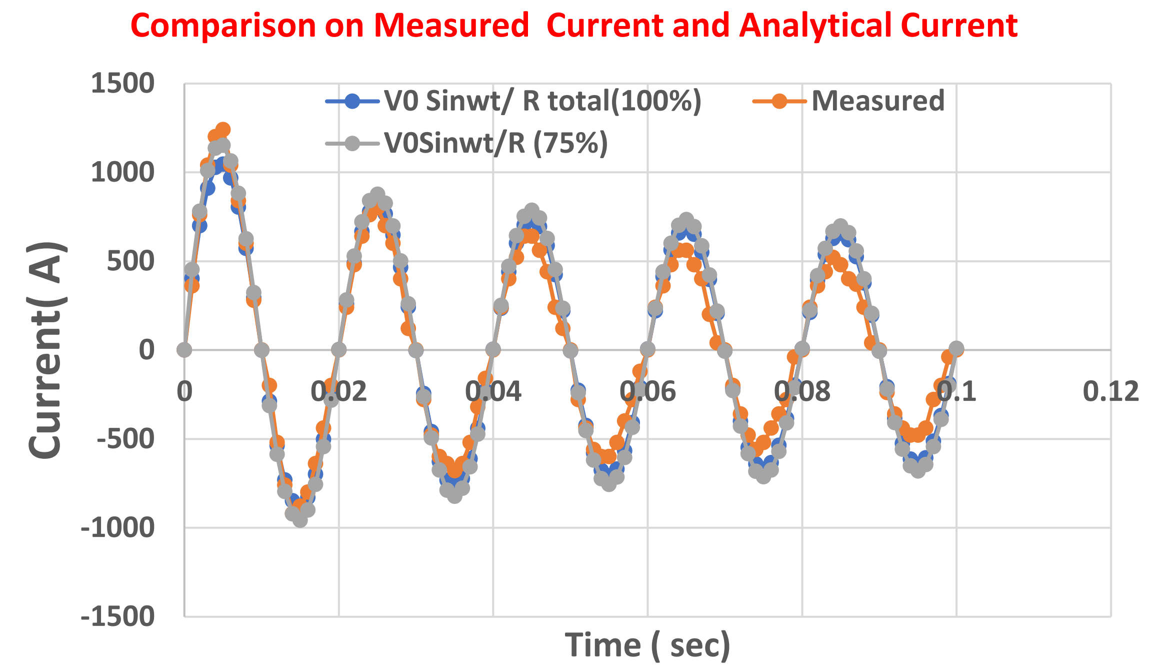
Assumption :

1. **Each quarter cycle (5 msec) resistance is constant**
2. **Resistance temperature Coefficient (is constant between 80 K – 200 K**
3. **Heat transfer co- efficient between Tape and LN2 is constant**

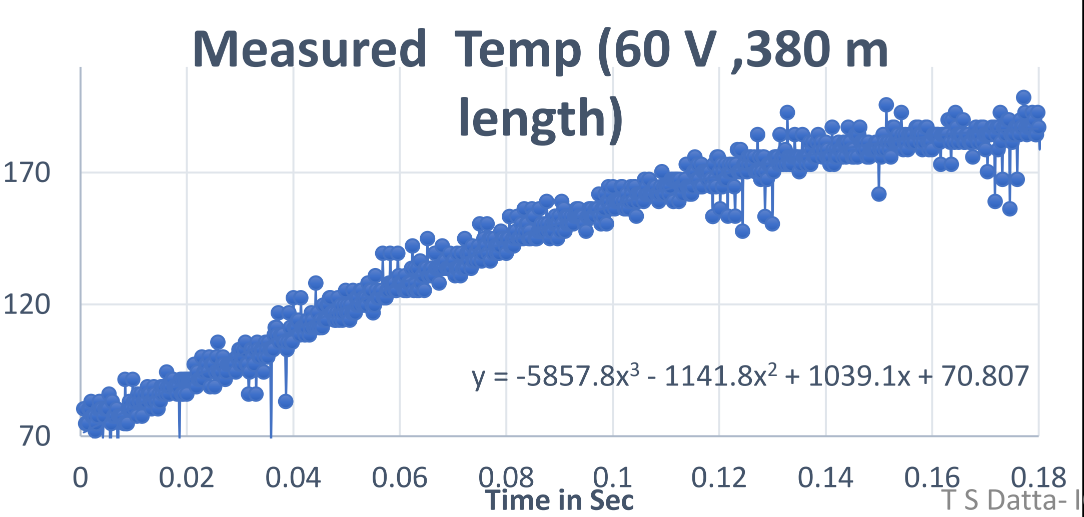
Comparison between Measured and Analytical Data



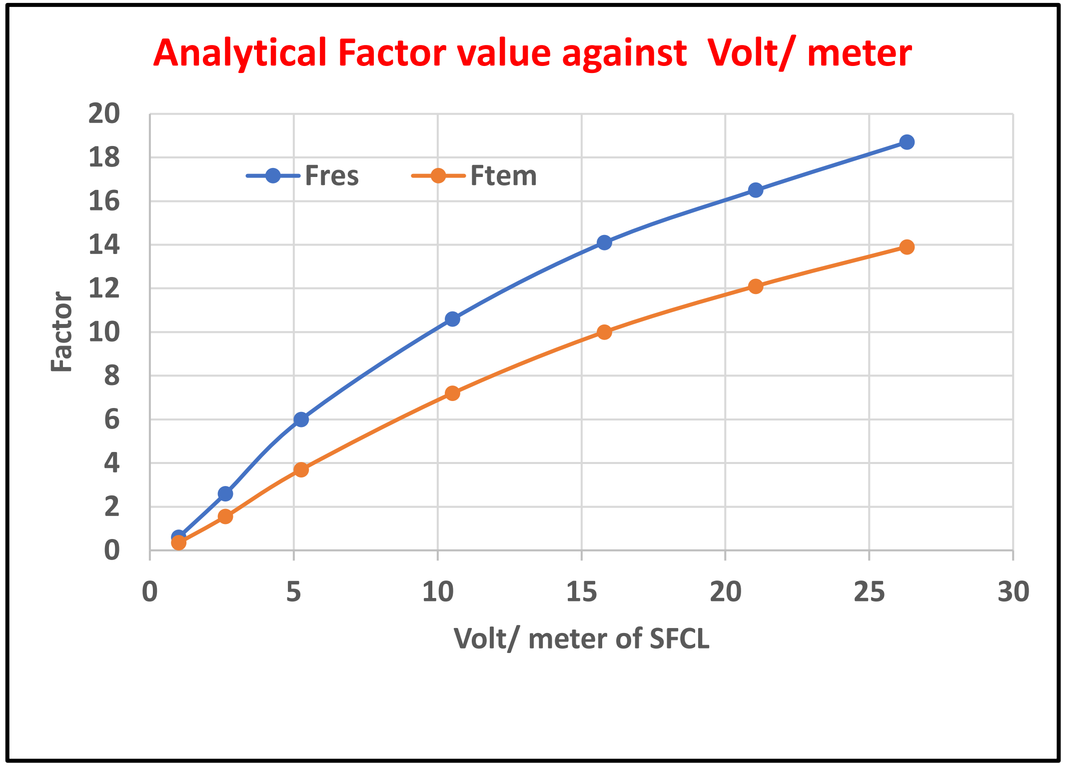
The best fitted curve from the measured data is drawn for comparison with Analytical curve

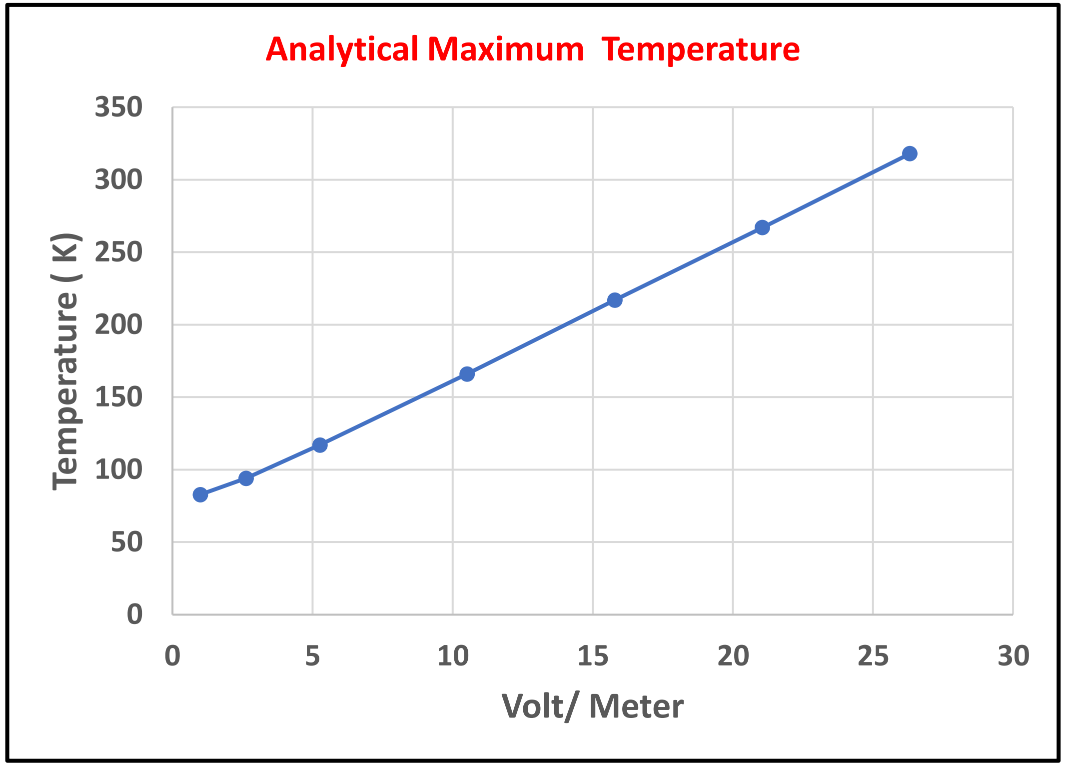


Fault circuit Impendence quality w.r.t resistance and Inductance is not known



There is time difference on Measured Temperature and Analytical because of finite value of Thermal diffusivity and response time of Sensor





$$R_t = R_{80} * t^{(R_{80} * \propto * Fre_s)}$$

$$T_t = 80 * t^{(\propto * Fte_m)}$$

$$F_{res} = 2.274 * (V/L)^{0.6352} \qquad (10)$$

$$F_{tem} = 0.0457 * (V/L)^{1.1078} \qquad (11)$$

, $R_{80} = r_{80} * L$

Where r $_{80}$ is the normal resistance per unit length

For a particular type of HTS, Both factors can be determined based on the design input parameter (V/ L) and then resistance, temperature and current profile can be generated analytically with this study

Summary and Conclusion

- Experiments were conducted on Fault Characteristics of HTS tape with variable voltage, Length and no of cycles

- It is noticed that Temperature and Fault Current remain same when V/L is the same

- Analytical Calculation was carried out and Validate with Experimental data on Copper laminated HTS tape. Agreed well
- With this data, analytical equation has been generated to predict temperature rise and fault current profile with time
- Yet to establish the model on SS laminated HTS Tape (Ongoing)
- Finally a generic model on Fault Characteristics will be developed for any type of HTS Tape

Thanks