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Influence of Dynamic Resistance on Current Distribution of HTS DC Cable Conductor for Feeder Lines and Large Scale Magnet

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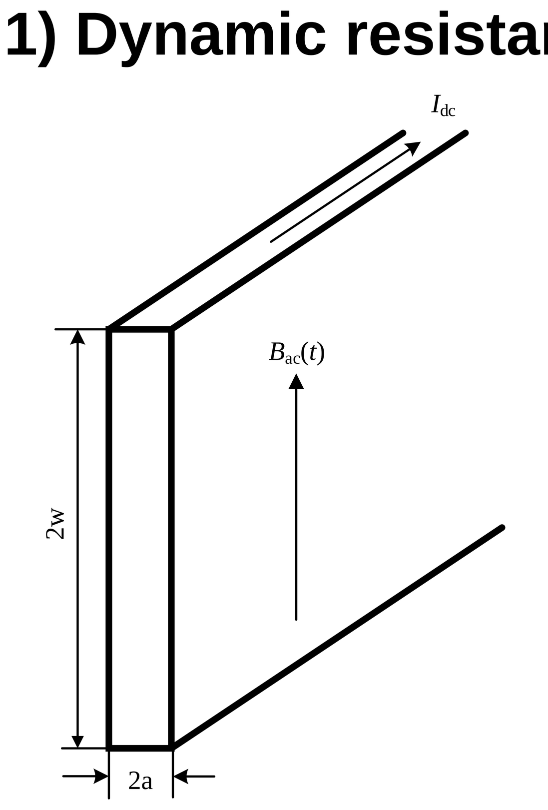
Introduction

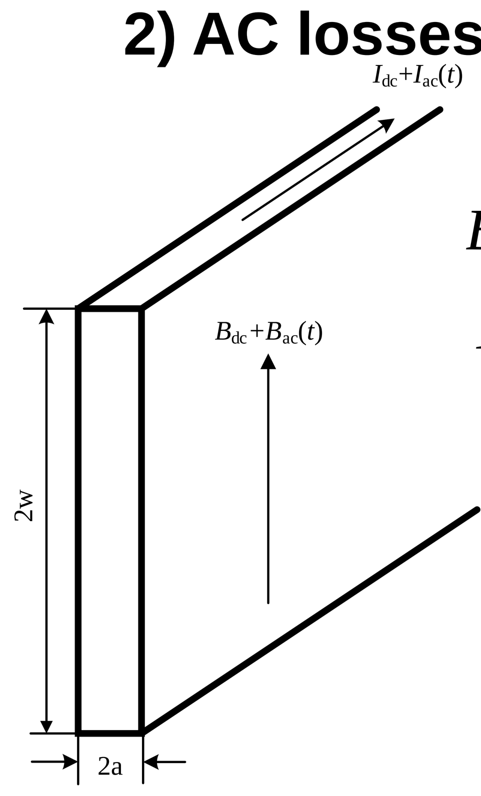
- HTS DC cable with high current capacity promising in feeder and transmission lines, electrolysis plants, large scale magnets
- AC current are Unavoidable fluctuation ripple current from AC/DC converter.
- Conventional design method with uniform current principle without fully transposition among layers
- Effect of dynamic resistance due to ripple current not only on AC losses but also significant on current distribution which seldom considered in design conventional method
- Essentially exploring new design principles with high current capacity

Dynamic resistance and AC loss of superconducting slab

1) Dynamic resistance



2) AC losses



$$B_{ac}(t)=B_m\sin(\omega t)$$
$$I_{ac}(t)=I_m\sin(\omega t)$$

$$B_{ac}(t)=B_m\sin(\omega t)$$

$$R_{dyn}=\frac{4af}{I_c}\left(B_m-B_{th}\right)$$

$$B_{th}=B_p\left(1-\frac{I_{dc}}{I_c}\right)$$

$$B_p=\mu_0 J_c a=\mu_0 I_c/(4w)$$

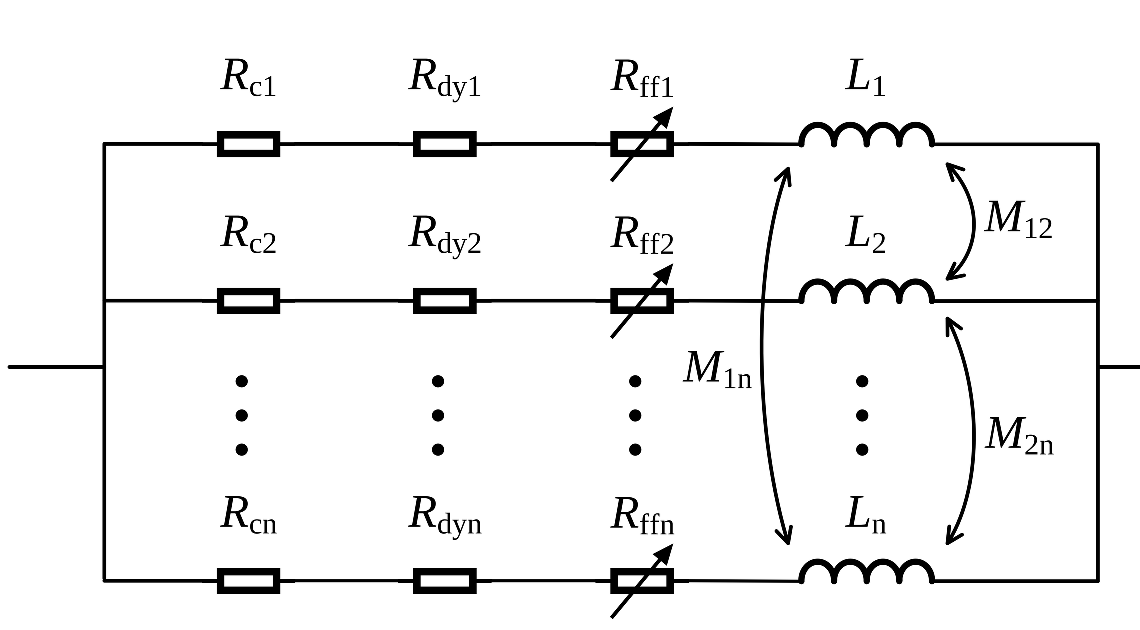
$$i_{ac}=\frac{I_m}{I_c};\ b_{ac}=\frac{B_m}{B_p}$$

$$i_{dc}=\frac{I_{dc}}{I_c};\ b_{dc}=\frac{B_{dc}}{B_p}$$

AC loss Equation see Reference [1]

Conventional principle of HTS DC cable

1) General AC circuit for uniform current design



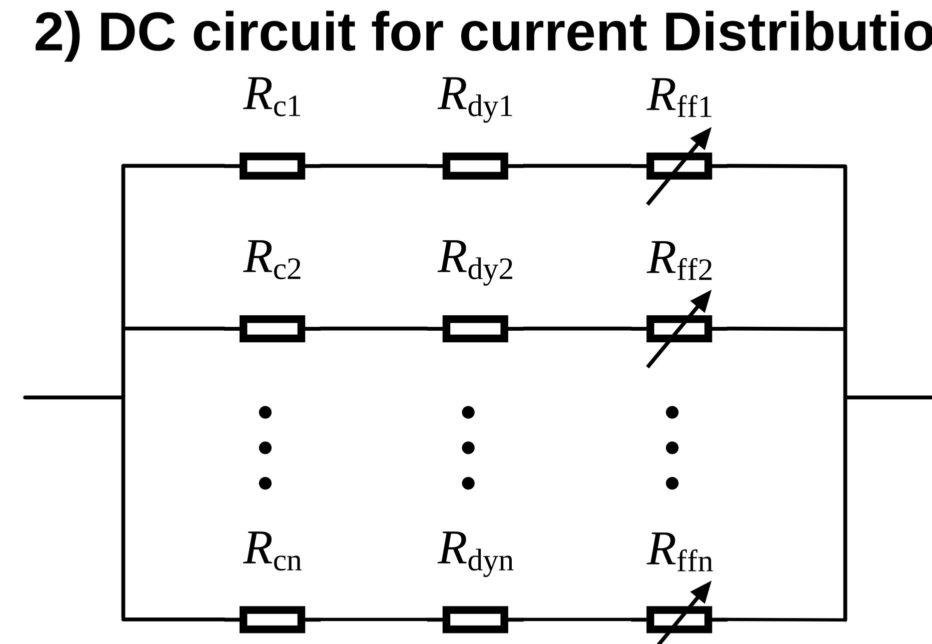
R_{ci} ith-layer terminal resistance (~0.01μΩ),
L_0 is length of the cable conductor
θ_i is winding angle
Tan $(\theta_i)=2\pi r_i/L_{pi}$

$$R_{dyni}=\frac{4af}{I_{ci}(B_{dci})}\left(B_{mi}-B_{th\text{-}i}\right)\frac{L_0}{\cos\theta_i}\qquad R_{ffi}=\frac{E_c}{I_{ci}(B_{dci})}\left(\frac{I_i}{I_{ci}(B_{dci})}\right)^{n_i-1}\frac{L_0}{\cos\theta_i}$$

$$\begin{bmatrix}(R_{c1}+R_{dy1}+R_{ff1})I_{m1}\\(R_{c2}+R_{dy2}+R_{ff2})I_{m2}\\\vdots\\(R_{c2}+R_{dyn}+R_{ffn})I_{mn}\end{bmatrix}+j\omega L_0\begin{bmatrix}L_1&M_{12}&\cdots&M_{1n}\\M_{21}&L_2&\cdots&M_{2n}\\\vdots&\vdots&\ddots&\vdots\\M_{n1}&\cdots&L_{nn}&L_n\end{bmatrix}\begin{bmatrix}I_{mm}\\I_{m2}\\\vdots\\I_{mn}\end{bmatrix}=\begin{bmatrix}V_{m2}\\V_{m2}\\\vdots\\V_{mn}\end{bmatrix}$$

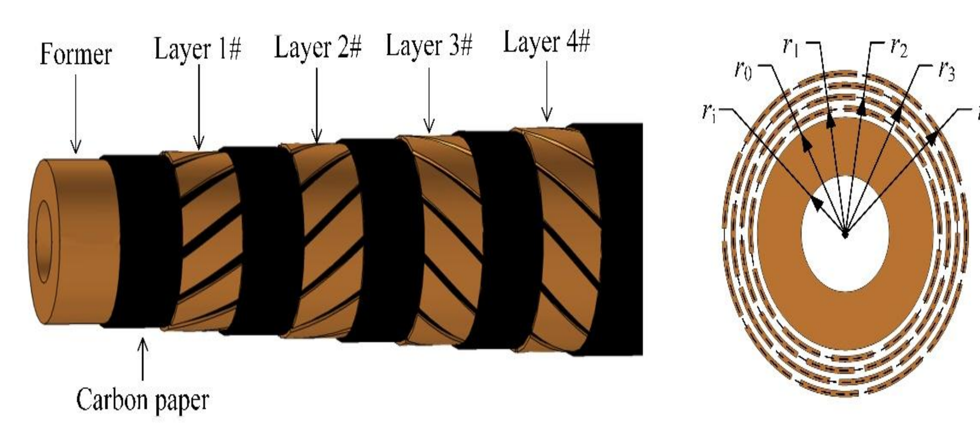
[1] Y.S.Wang, Fundamental Elements of Applied Superconductivity in Electrical Engineering. Wiley, 2013, Equations (5.8)-(5.15), pp146-147

2) DC circuit for current Distribution



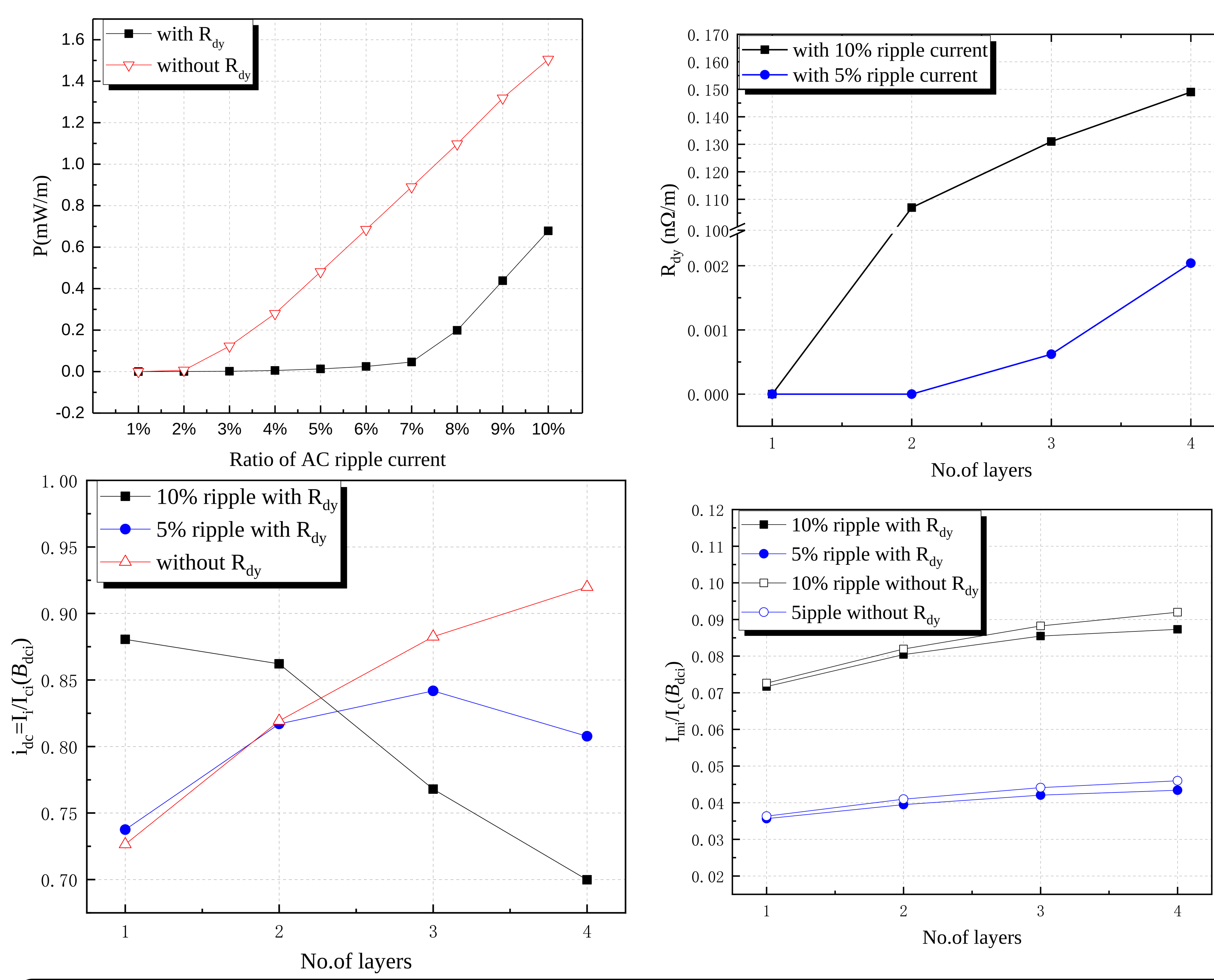
$$\begin{bmatrix}(R_{c1}+R_{dy1}+R_{ff1})I_1\\(R_{c2}+R_{dy2}+R_{ff2})I_2\\\vdots\\(R_{c2}+R_{dy2}+R_{ffn})I_n\end{bmatrix}=\begin{bmatrix}V_{dc1}\\V_{dc2}\\\vdots\\V_{dcn}\end{bmatrix}$$

5 kA HTS CD cable conductor



Items	Value
r_i /mm	5.4
r_o /mm	8
r_1 /mm	8.18
r_2 /mm	8.4
r_3 /mm	8.63
r_4 /mm	8.85
L_{pi}/mm	147, 382.5, 280, 90.5
Winding directions	-1, -1, 1, 1
Tapes per layers	11, 11, 11, 11

Results



New possible design principles?

1) Equal DC margin principle

$$\frac{I_1}{I_{c1}(B_{dc1})}=\frac{I_2}{I_{c2}(B_{dc2})}\cdots=\frac{I_n}{I_{cn}(B_{dcn})}\qquad\text{(I)}$$

2) Equal AC margin principle

$$\frac{I_{m1}}{I_{c1}(B_{dc1})}=\frac{I_{m2}}{I_{c2}(B_{dc2})}\cdots=\frac{I_{mn}}{I_{cn}(B_{dcn})}\qquad\text{(II)}$$

3) Equal DC + AC margin principles

$$\frac{i_{ac1}}{i_{dc1}}=\frac{i_{ac2}}{i_{dc2}}\cdots=\frac{i_{acn}}{i_{dcn}}\qquad\text{(II)}$$

Summary

- Dynamic resistance affects on DC current distributions and can adjust the distribution.
- AC current distribution adjusted by inductances and DC current distributions by Dynamic resistances.
- Equal AC, DC or (AC+DC) equal margin principles possibly beneficial to optimal design of HTS DC cable conductors with high current capacity