Effect of Charge imbalance on a stack of Josephson Junctions

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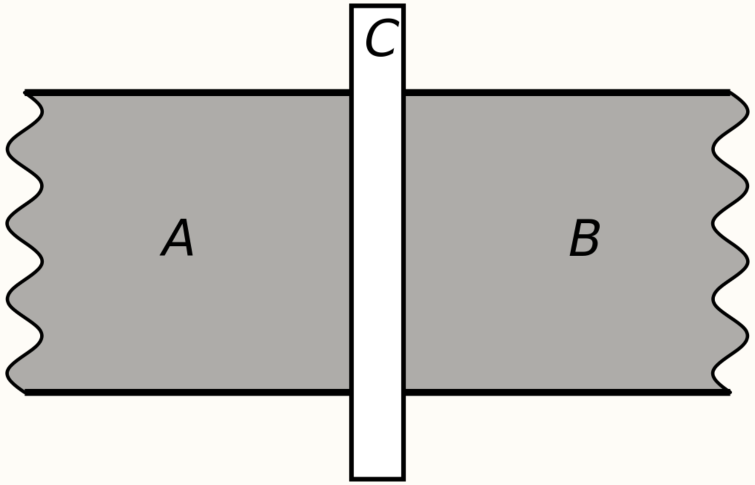
Josephson Junctions

– A Josephson junction is a **superconductor-insulator-superconductor device.**

$$\boldsymbol{\Psi_{\mathrm{A}} = |\Psi_{\mathrm{A}}| e^{i\theta_{\mathrm{A}}}}$$



$$\boldsymbol{\Psi_{\mathrm{B}} = |\Psi_{\mathrm{B}}| e^{i\theta_{\mathrm{B}}}}$$

DC Josephson Effect $I = I_o \sin\varphi$ **where** $\varphi = \theta_A - \theta_B$

AC Josephson Effect $\dfrac{\partial\varphi}{\partial t} = \dfrac{2eV}{\hbar}$

Resistively and Capacitively Shunted Junction Model (RCSJ Model)

– **An equivalent circuit** that can be used for most types of resistively junctions is shown in figure(2). **Here the Josephson junction (J) is shunted by a voltage independent resistor and a capacitor**

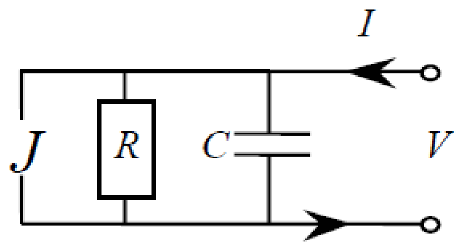


Figure 2. Equivalent circuit of a Josephson junction.

$$I = I_S + I_{Disp} + I_{qp}$$

$$I = I_o \sin\varphi + C\frac{dV}{dt} + \frac{V}{R}$$

$$I = I_o Sin(\varphi) + \frac{\hbar C}{2e}\frac{d^2\varphi}{dt^2} + \frac{\hbar}{2eR}\frac{d\varphi}{dt}$$

(Using normalized parameters)

$$\tau = 2\pi f_c t = \frac{2e}{\hbar} I_o R t \qquad \beta_c = 2\pi f_c RC = \frac{2e}{\hbar} I_o R^2 C \qquad \frac{I}{I_o} = i$$

$$i = \sin\varphi + \beta_c \frac{d^2\varphi}{d\tau^2} + \frac{d\varphi}{d\tau}$$

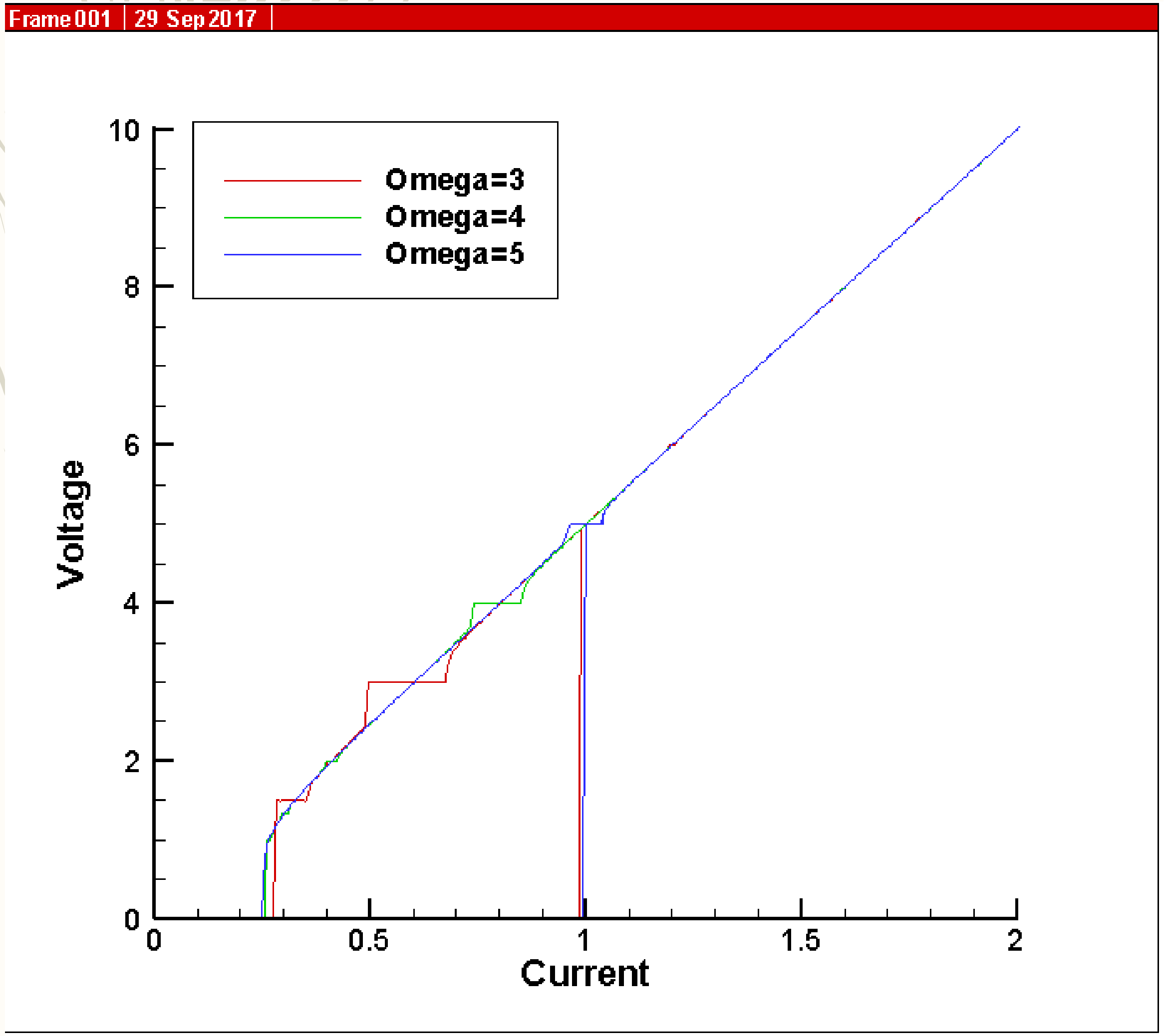
Where:-

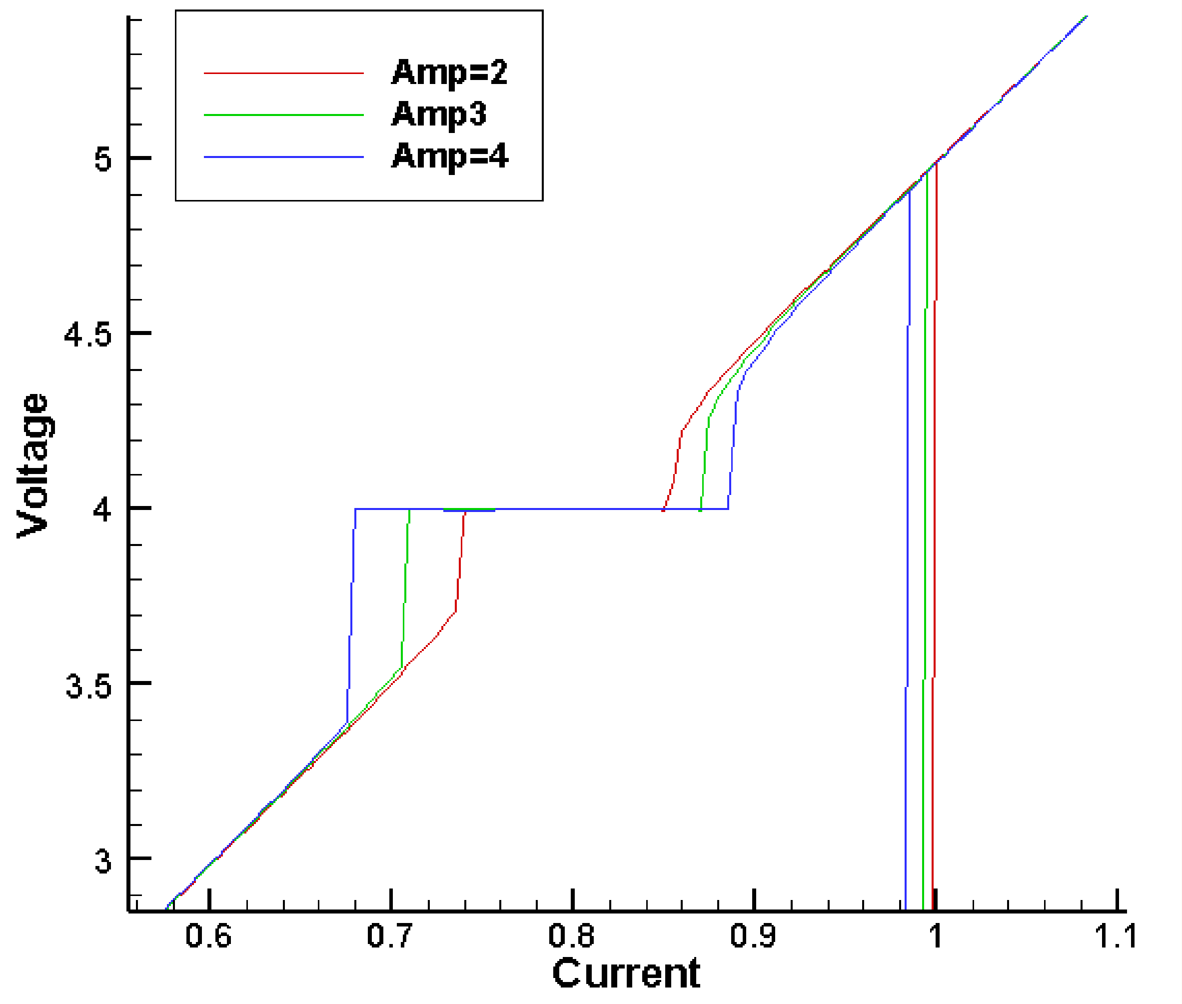
$$\omega = 2\pi f_c = \frac{2eI_o}{\hbar} R$$

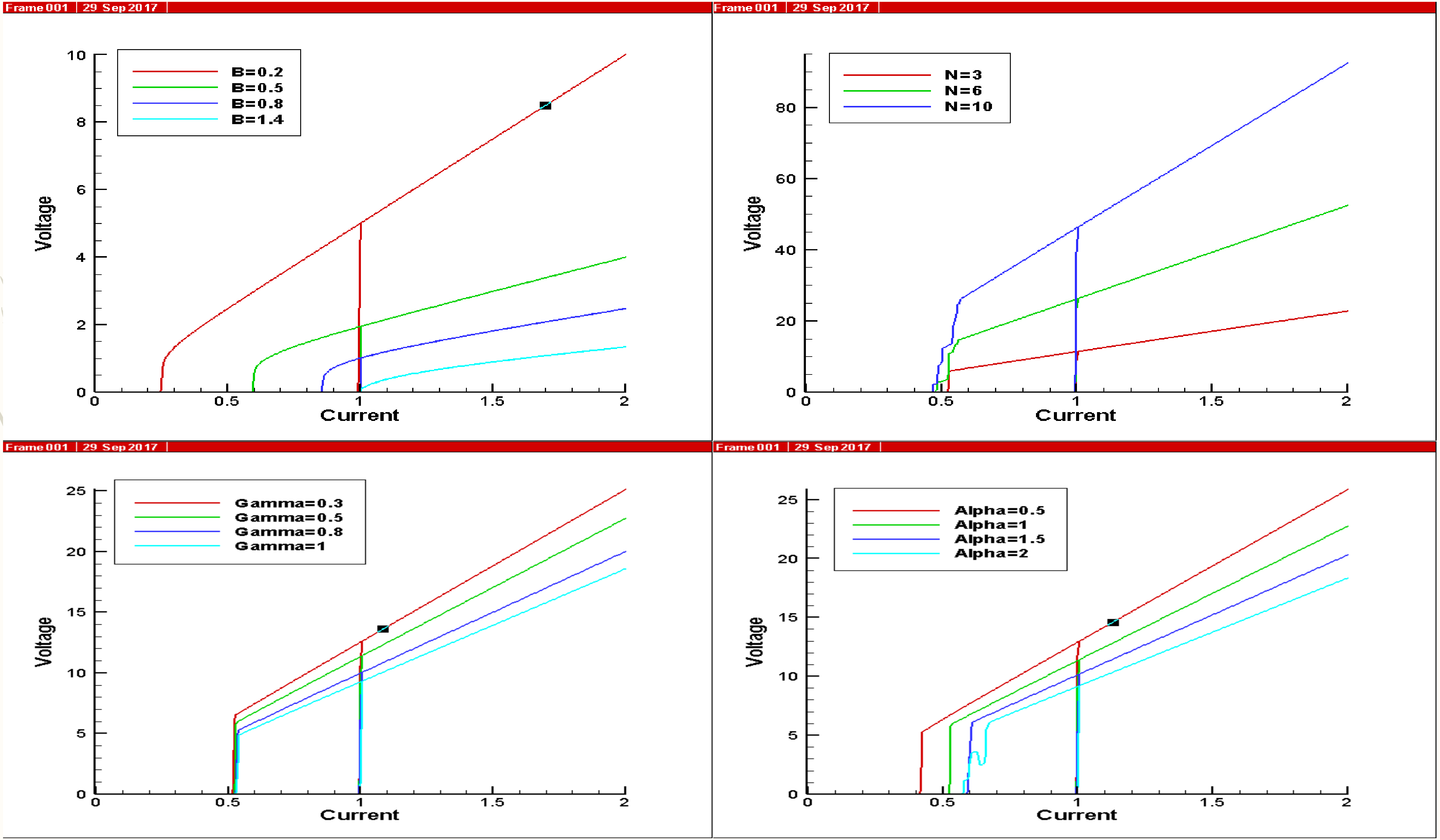
$$\beta^2 = \frac{1}{\beta_c}$$

Can’t be solved analytically, computer simulations are needed.

So **we changed some parameter to see how it would affect the Junction,** like exposing the junction to **external radiation (The appearance of Shapiro Step),** The dissipation parameter **(β)**, the coupling parameter **(α)**, the non-periodic boundary condition parameter **(γ)**

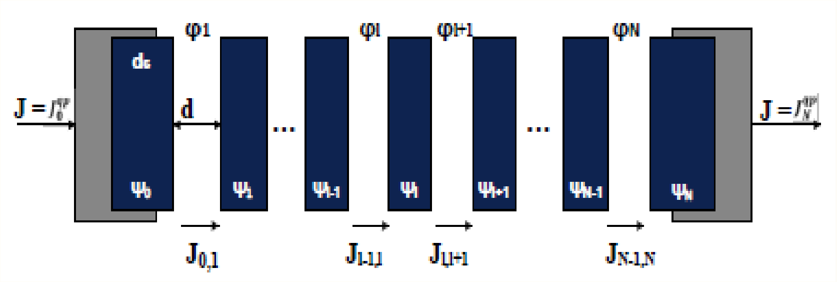






Frame 001 | 29 Sep 2017
B=0.2
B=0.5
B=0.8
B=1.4
Voltage
Current
N=3
N=6
N=10
Gamma=0.3
Gamma=0.5
Gamma=0.8
Gamma=1
Alpha=0.5
Alpha=1
Alpha=1.5
Alpha=2

Charge imbalance occurs between layers when one has more or less electrons, or holes, than the other. Injecting current from one end through the junction definitely causing charge imbalance. So we introduced new terms to the equations to be able to study the effect of charge imbalance.



$$\frac{\partial \varphi}{\partial t} = \frac{2e}{\hbar}\left(V_l(t) + \Phi_l(t) - \Phi_{l-1}(t)\right)$$

$$\frac{\partial \Psi}{\partial t} = \frac{4\pi r_D^2}{d_s^i}\left(I_l^{qp} - I_{l-1}^{qp}\right) - \frac{\Psi_i}{\tau_{qp}}$$

$$I = I_o \sin\varphi_l + C\frac{dV_l}{dt} + \frac{\hbar}{2eR}\dot{\varphi}_l + \frac{\Psi_l - \Psi_{l-1}}{R}$$

$$v_l^{\cdot} = \left[I - \sin\varphi_l - \beta\varphi_l + A\sin\omega\tau + \dot{I}_{noise} + \psi_l - \psi_{l-}\right]$$

$$\dot{\varphi}_l = v_1 - \alpha\left(v_2 - (1+\gamma)v_1 + \frac{\psi_1 - \psi_0}{\beta}\right)$$

$$\xi_0\dot{\psi}_0 = \eta_0\left(I - \beta\dot{\varphi}_{0,1} + \psi_1 - \psi_0\right) - \psi_0$$

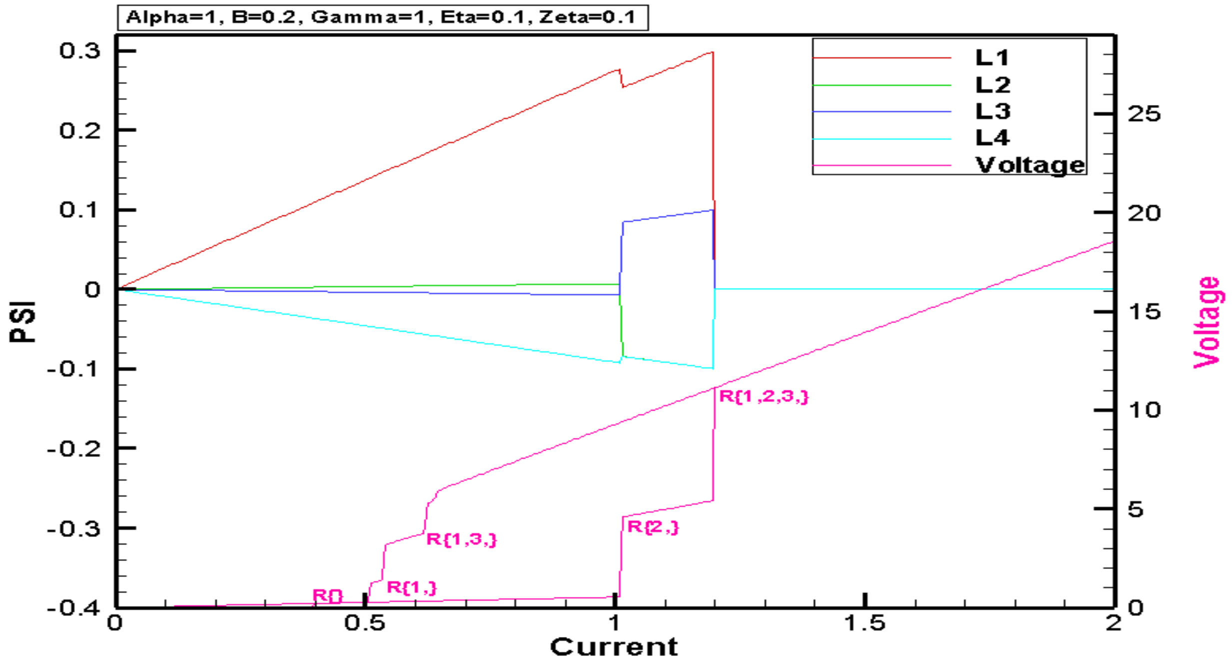
$$\dot{\varphi}_l = (1+2\alpha)v_l - \alpha(v_{l-1} + v_{1+1}) + \frac{\psi_l - \psi_{l-1}}{\beta}$$

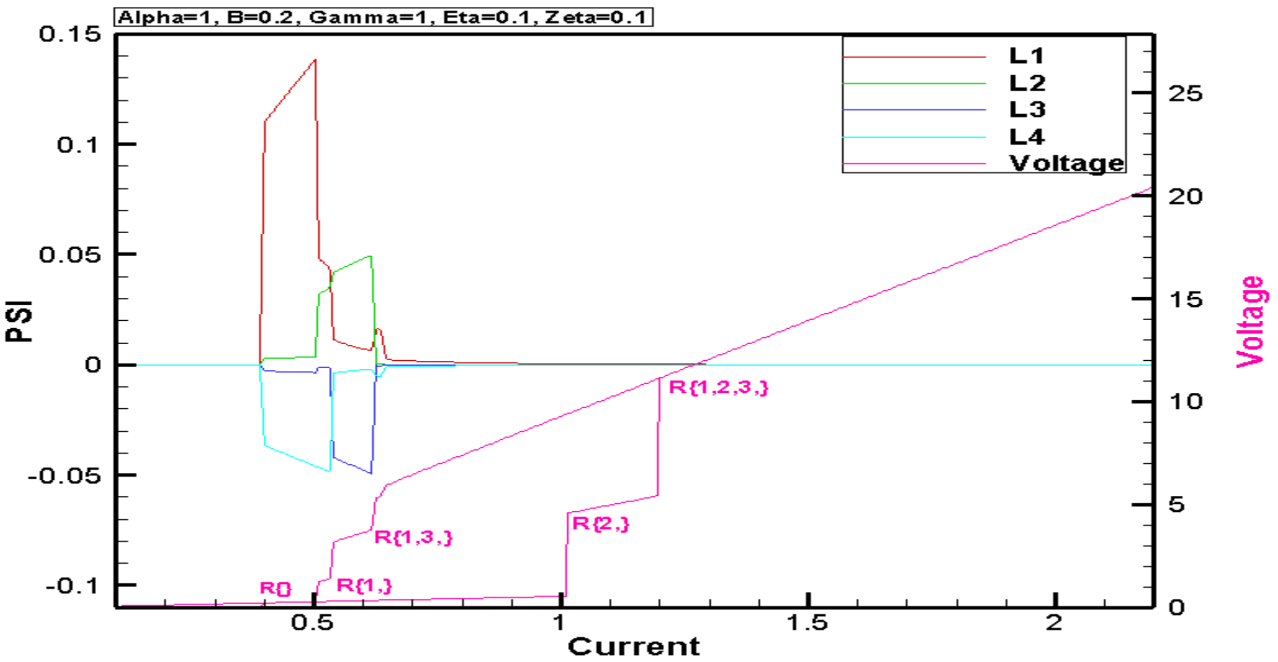
$$\xi_l\dot{\psi}_l = \eta_l\left(\beta[\dot{\varphi}_{l-1,l} - \dot{\varphi}_{l,l+1}] + \psi_{l-1} + \psi_{l+1} - 2\psi_l\right) - \psi_l$$

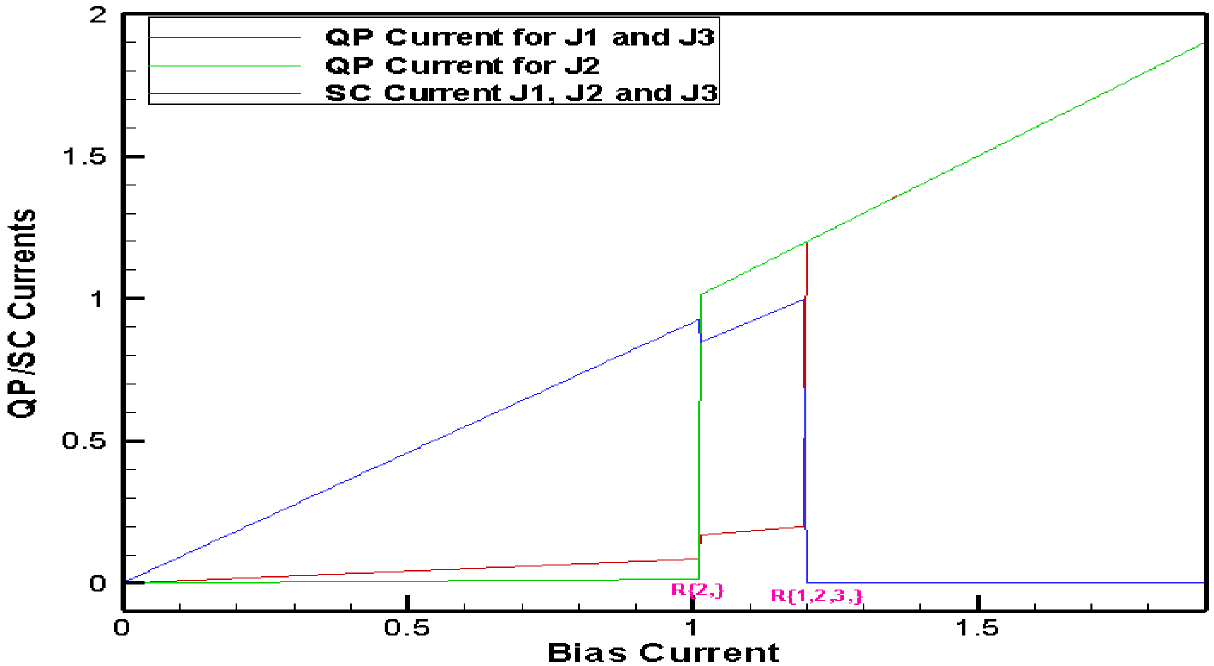
$$\dot{\varphi}_N = v_N - \alpha\left(v_{N-1} - (1+\gamma)v_N + \frac{\psi_N - \psi_{N-1}}{\beta}\right)$$

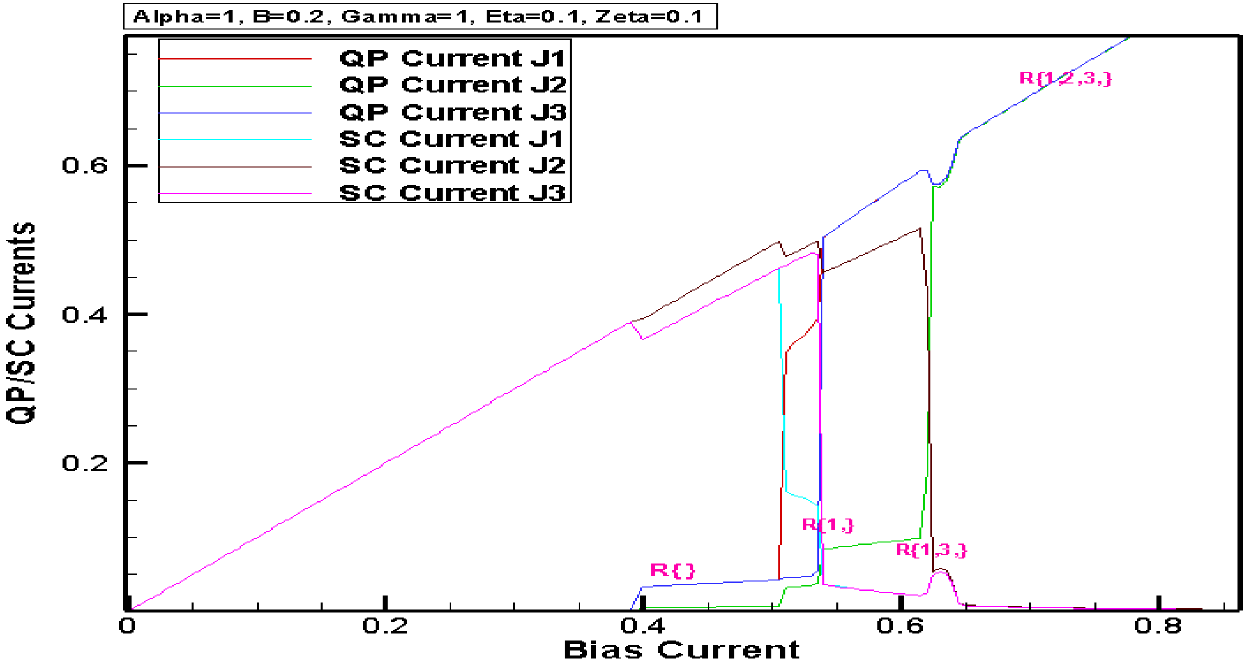
$$\xi_N\dot{\psi}_N = \eta_N\left(-I + \beta\dot{\varphi}_{N-1,N} + \psi_{N-1} - \psi_N\right) - \psi_N$$

Effect of **weak** charge imbalance**(η=0.1)** on a stack of Josephson junctions (N=3), β=0.2, Charge imbalance potential**(Ψ)** and **IVC, QP/ SC currents.**

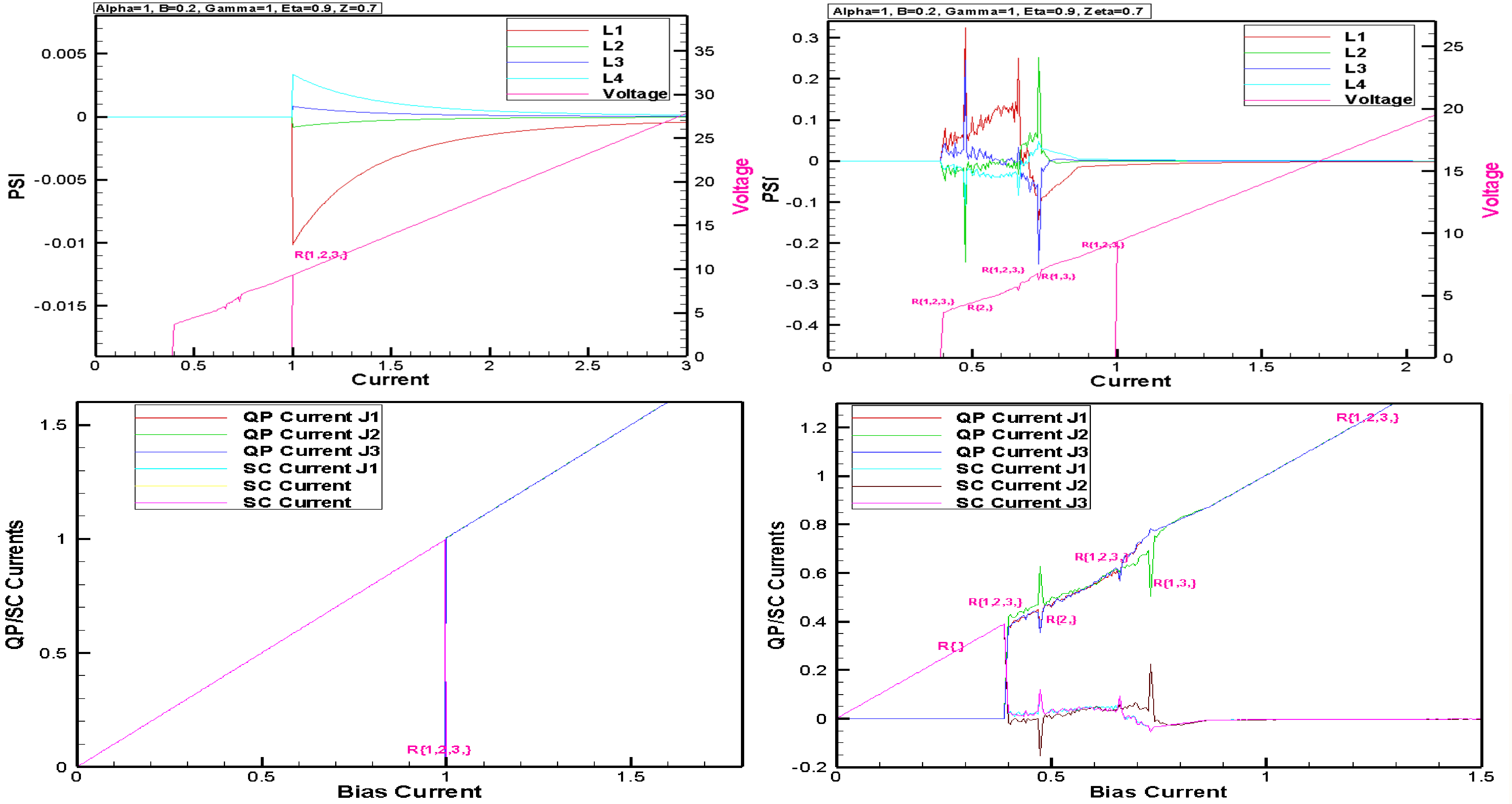




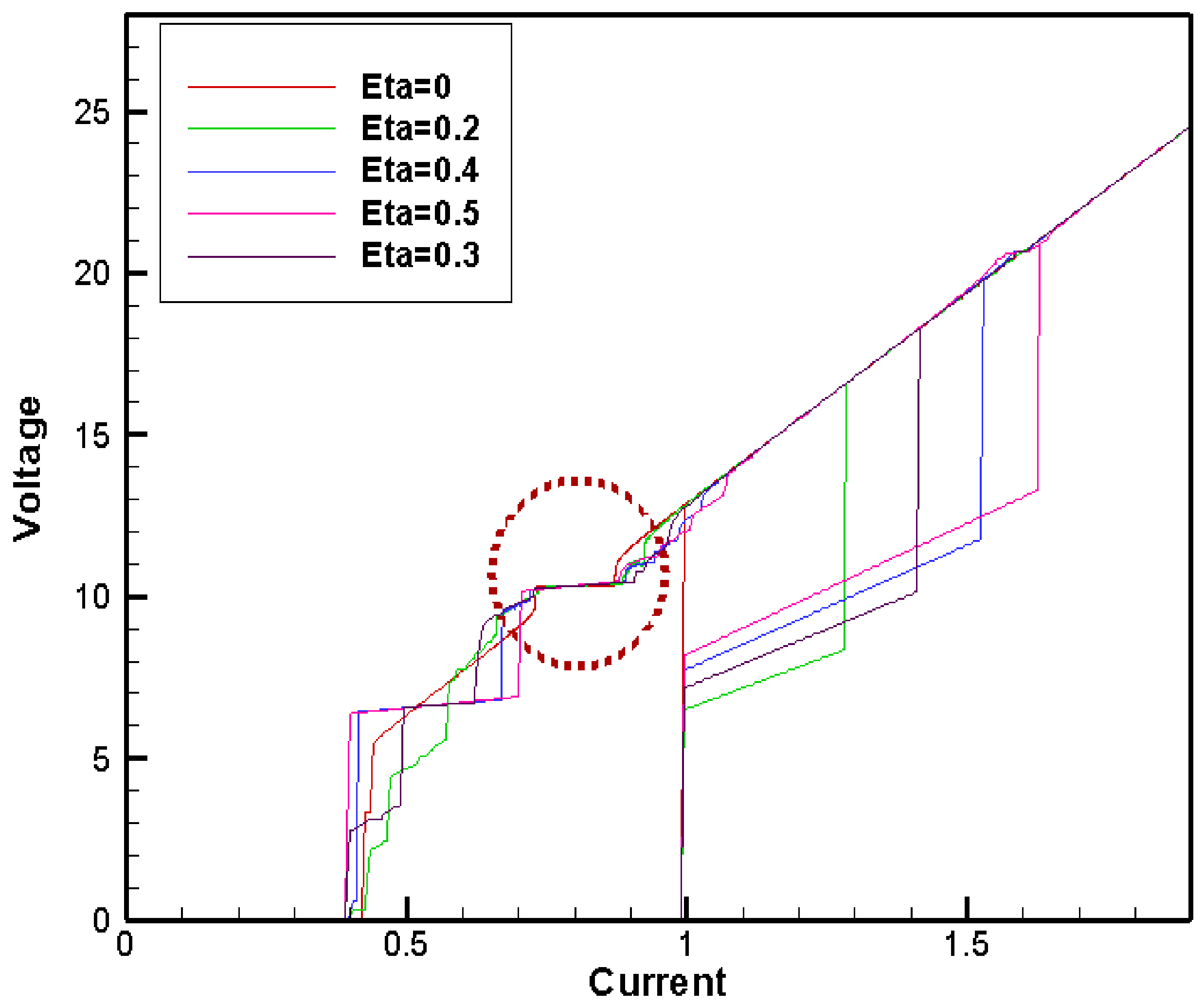


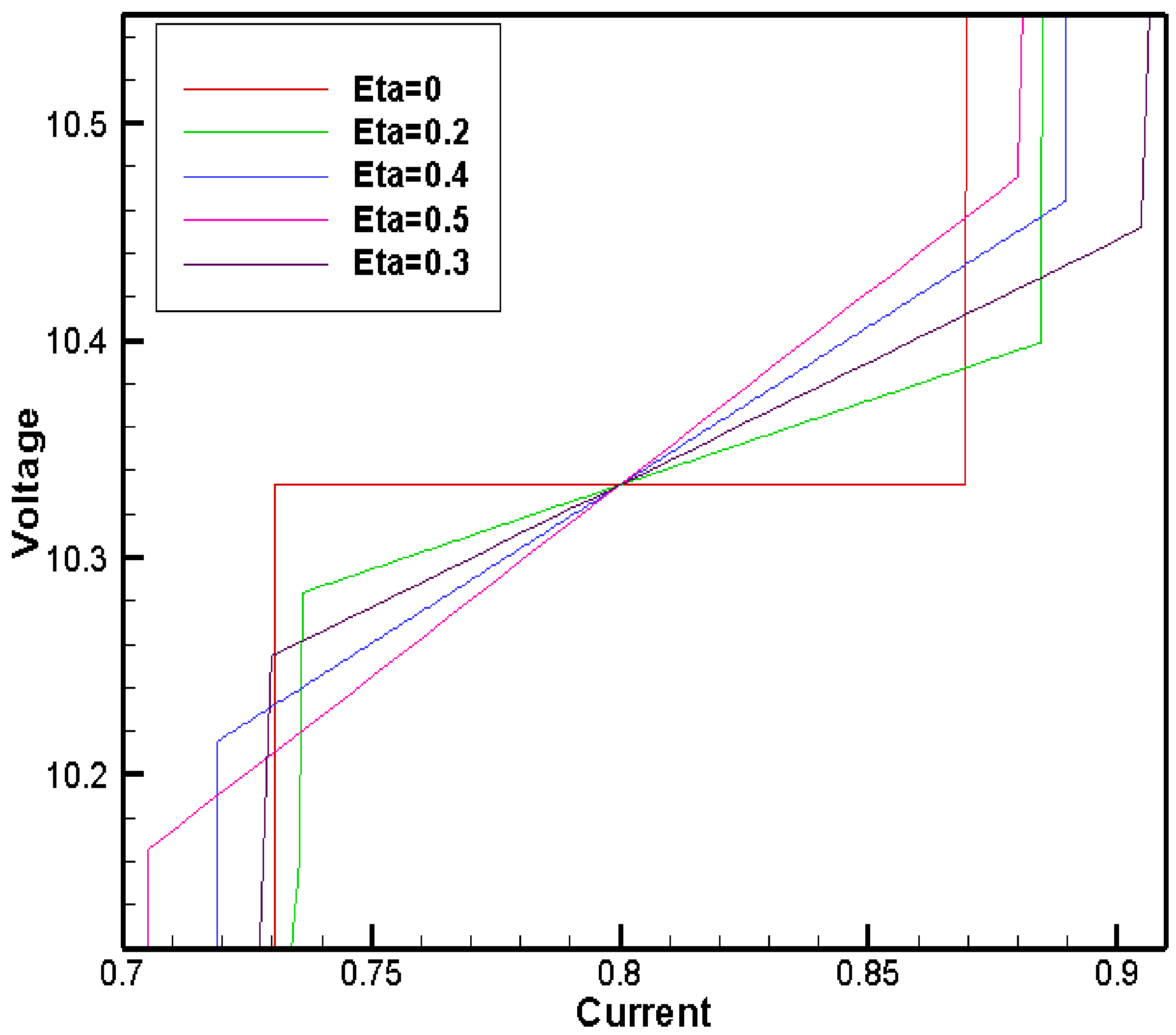


Effect of Strong charge imbalance(η=0.9) on a stack of Josephson junctions (N=3), β=0.2, Charge imbalance potential**(Ψ) and IVC**, **QP/ SC currents.**



Effect of **charge imbalance (η=0, 0. , 0.3, 0.4, 0.5)** on the **Shapiro Step**, B=0.2, External radiation frequency **ω =4, A=2**





Conclusion:-

- ❖ Studying the basics of Josephson Junctions.
- ❖ Studying the effect of :-
  - Some parameter like β, N, α, γ on Josephson junctions.
  - Charge imbalance on a stack of Josephson junctions.
  - Charge imbalance on Shapiro step