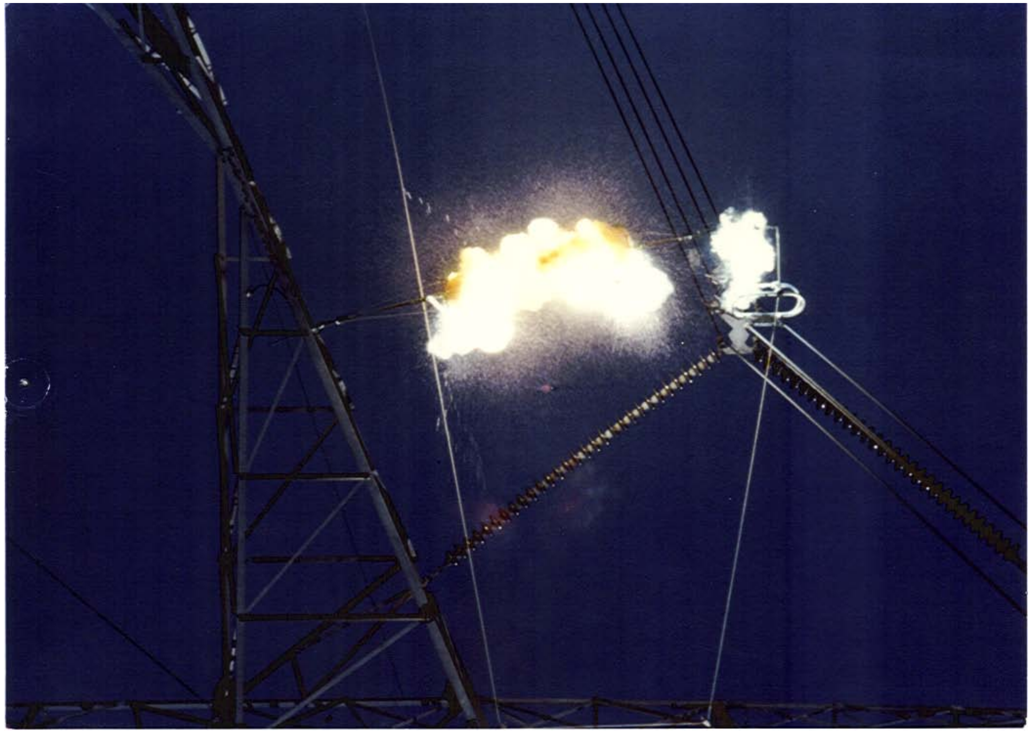
Double Ended Fault Location using PMUs



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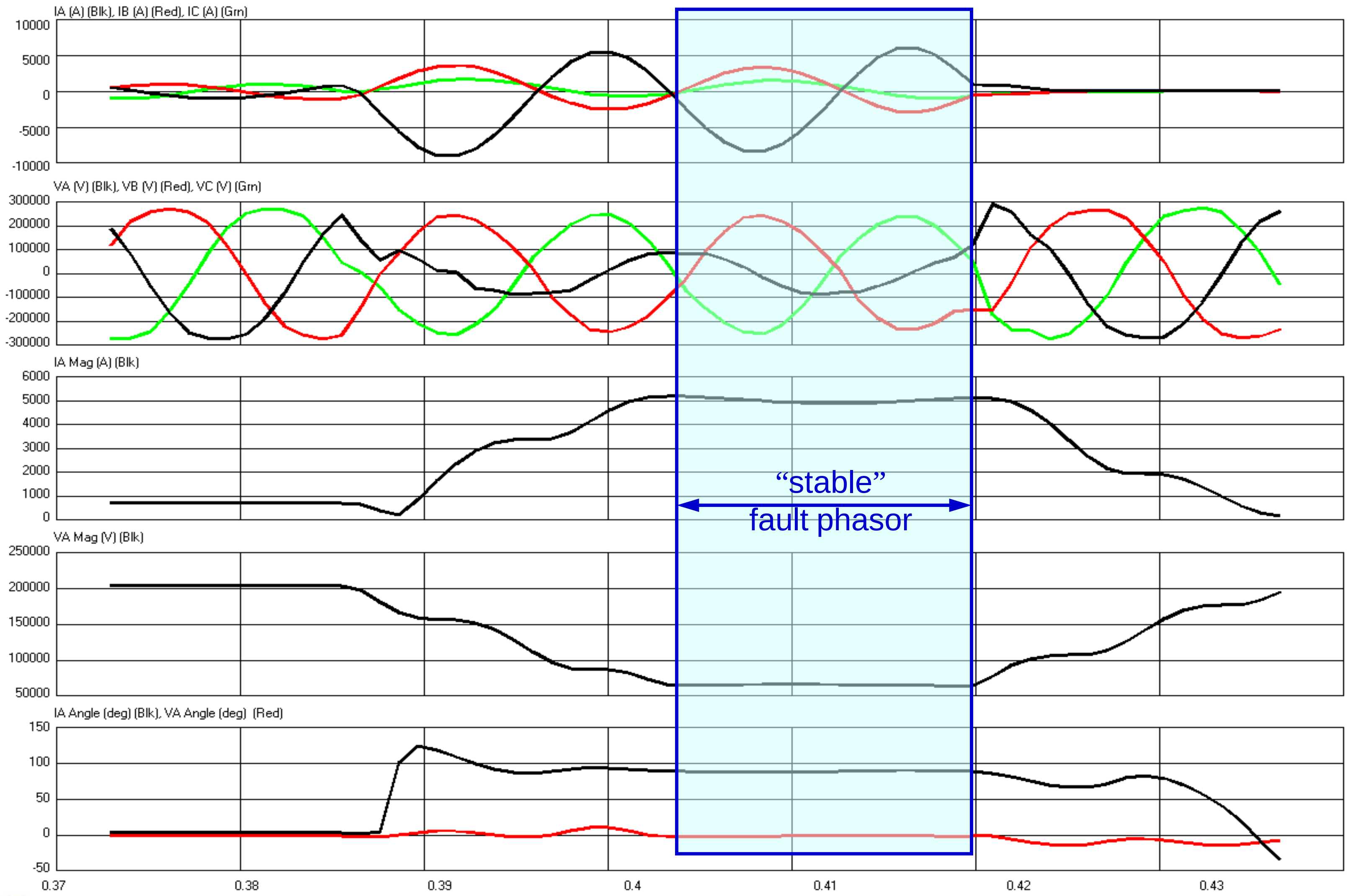
Single Ended Fault Location

Affected by:

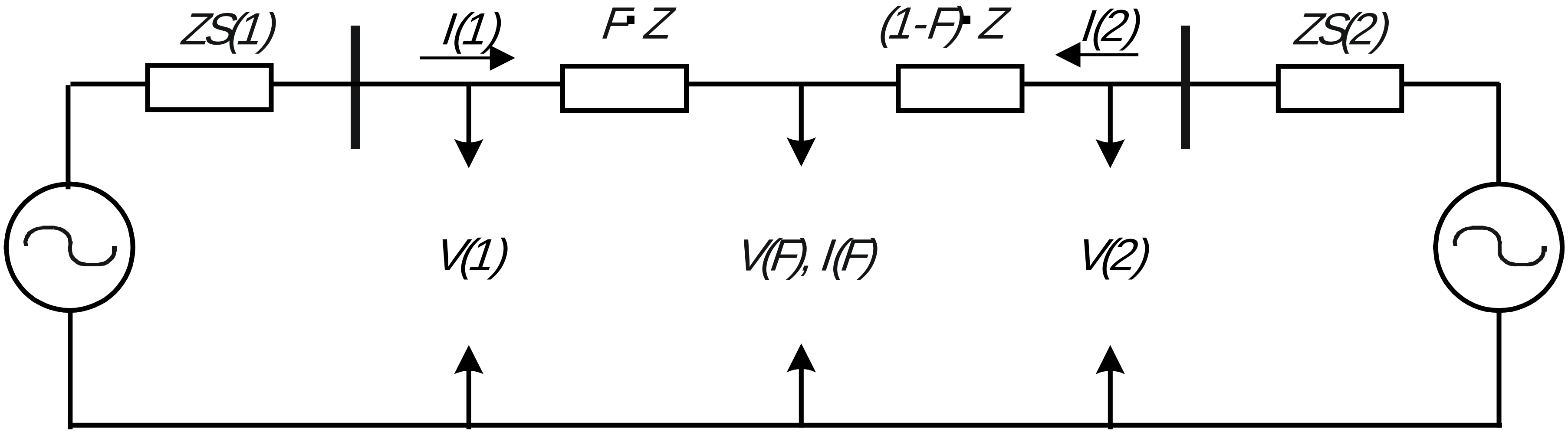
- Non-homogeneity of voltages at line ends
- Fault Impedance
- Zero-sequence coupling / Mutual Impedance
- Application issues on 3-terminal lines and weak infeeds

Synchrophasor Dynamic Response



Need for high-rate P-Class Synchrophasors

Sequence View of a Line



The composite signal is created using Clarke transform in such a way that regardless of the fault type, there is a disturbance in the composite signals.

$$V = \frac{2 \cdot VA - VB - VC}{3}$$

Traditional Clarke transform has a weakness of zeroing out currents for BC faults-not good to represent the fault under all circumstances

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Modified Clarke Transform

$$V = \frac{2 \cdot VA - b \cdot VB - b^{*} \cdot VC}{3}$$

Modified Clarke transform

Both phase currents (IA,IB,IC) and voltages (VA,VB,VC) at all the points of interest are converted into the composite signal such as the generalized Clarke transform using the same transformation method throughout the network of interest.

$$b = 1 + j \cdot \tan(\alpha) \qquad b^{*} = 1 - j \cdot \tan(\alpha) \qquad \alpha = pi/4$$

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Fault Location Calculation

The fractional fault location is given by:

$$F = \mathrm{Real}\left[\frac{\dfrac{V(1)-V(2)}{Z}+I(2)}{I(1)+I(2)}\right]$$

- **Takes advantage of redundancy in the data.**
  - **more equations than unknowns,**
- **Equation is independent of faulted phase, fault type, fault resistance, and zero-sequence (ground current) coupling to an adjacent transmission line, if any**

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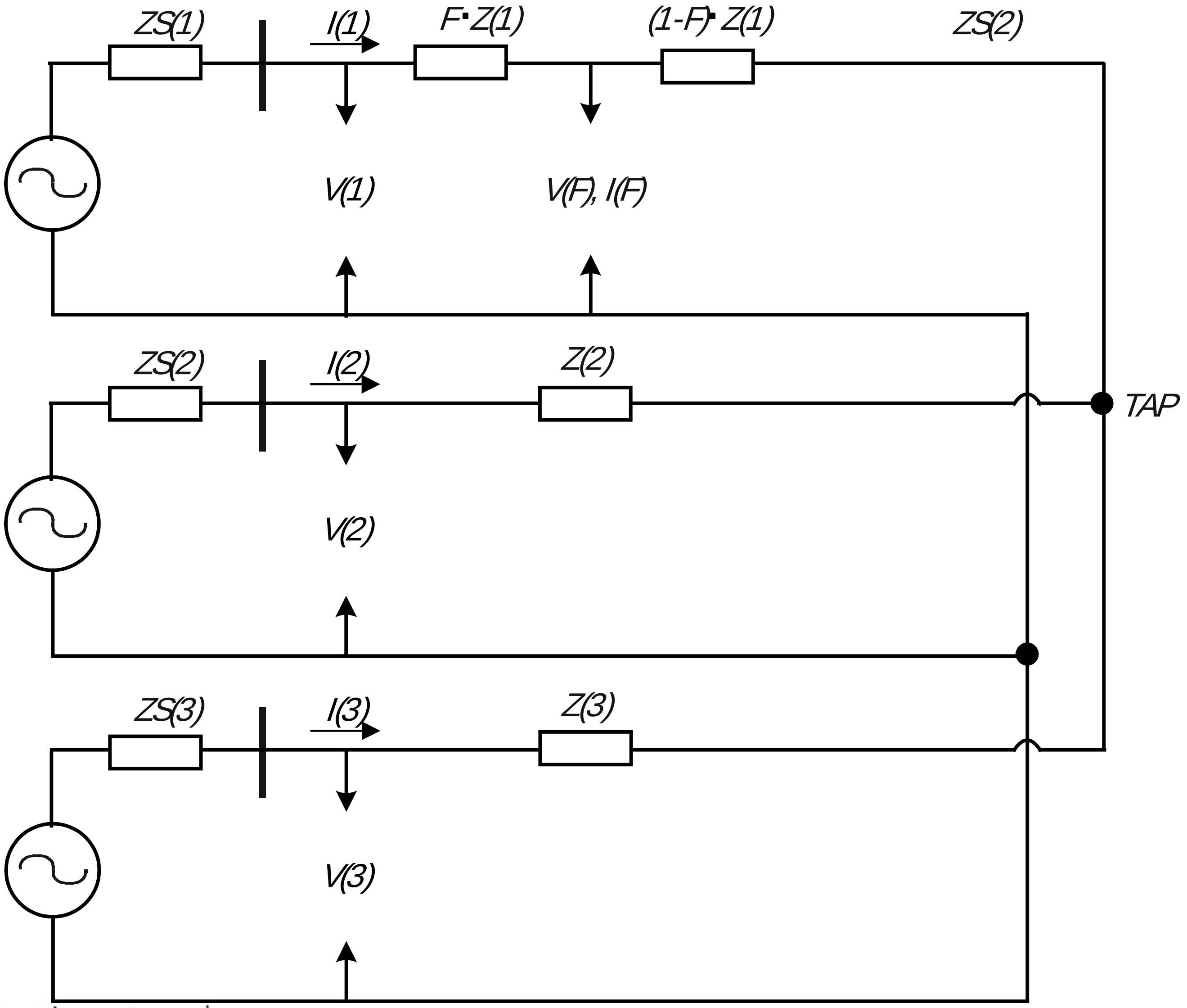
3-Terminal Solution



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Solves Voltage Loops to Tap Point

Fault Impedance Calculation

For a phase to ground phase A, first the voltage at the fault from local relay is estimated.

$$V_A(F) = V_A(1) - F \cdot \left(\left(I_A(1) - I0(1)\right) \cdot Z1 + I0(1) \cdot Z0\right) - F_m \cdot I0_m \cdot Z0_m$$

Then phase A current at the fault location can be computed:

$$I_A(F) = I_A(1) + I_A(2)$$

Fault resistance is:

$$R_A(F) = \mathrm{Real}\left(\frac{V_A(F)}{I_A(F)}\right)$$

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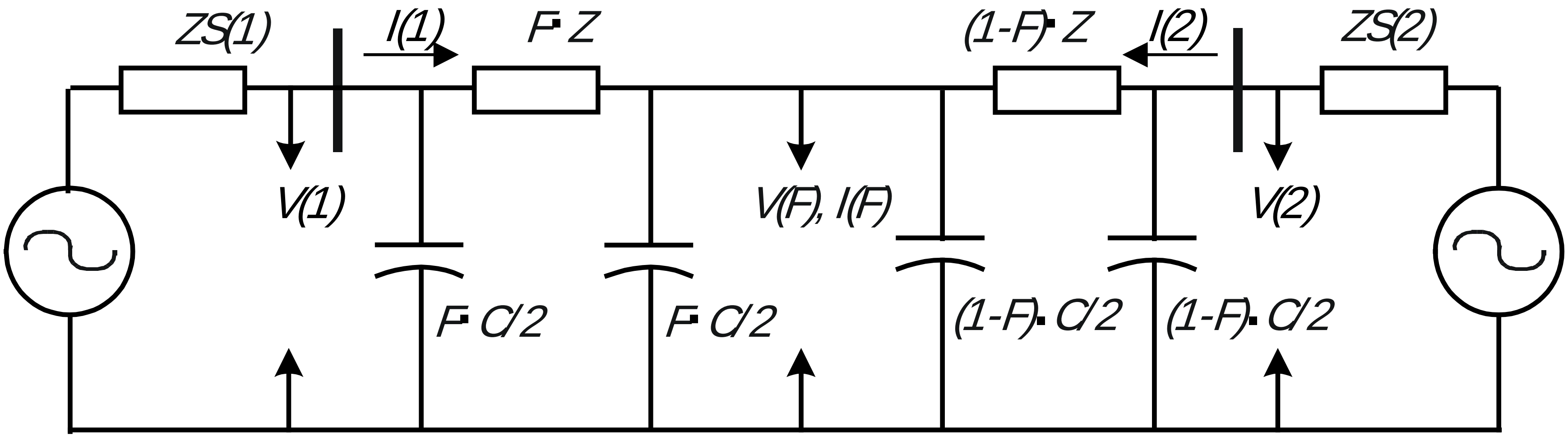
Charging Current Compensation

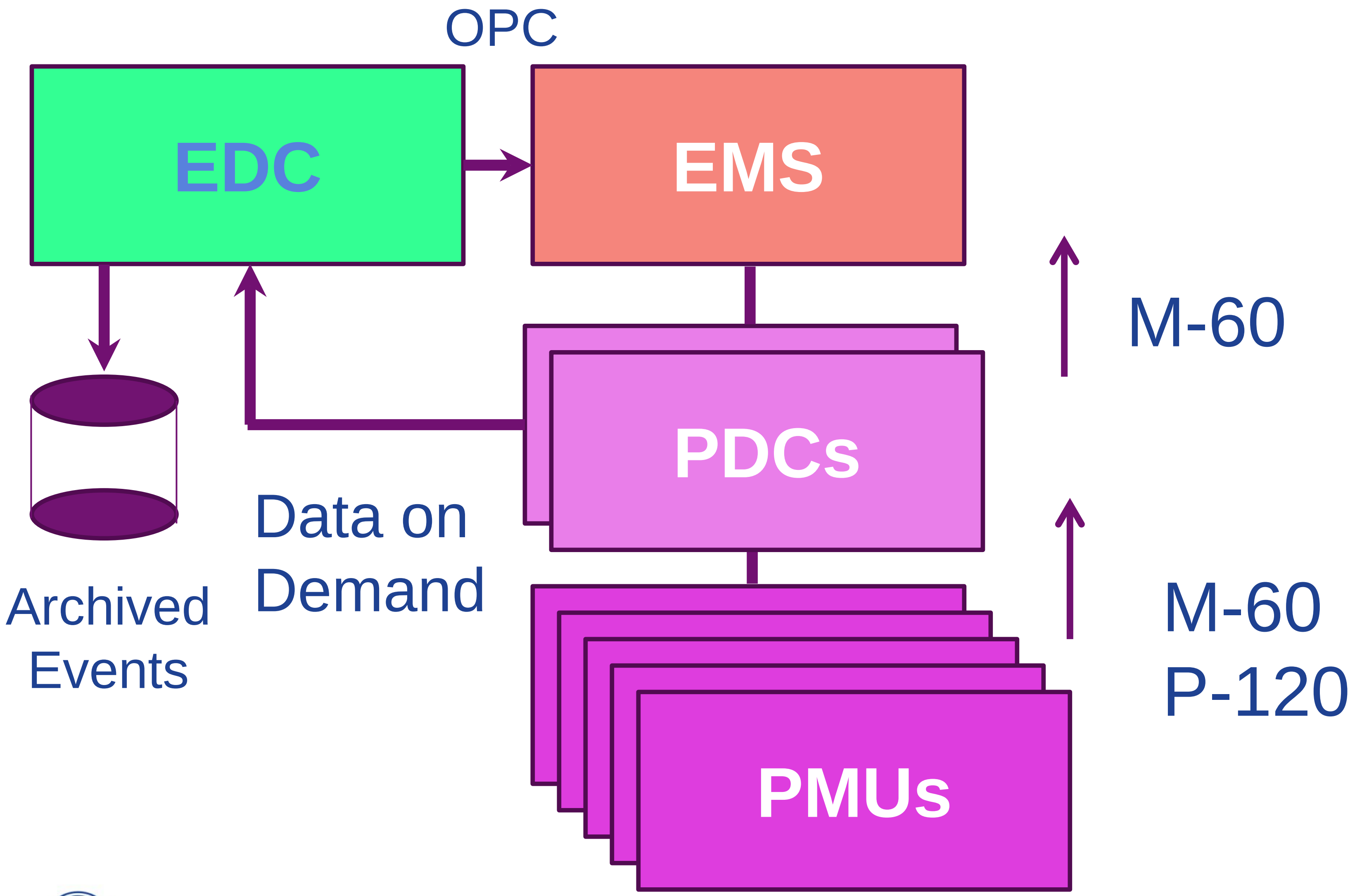


In Steady State:

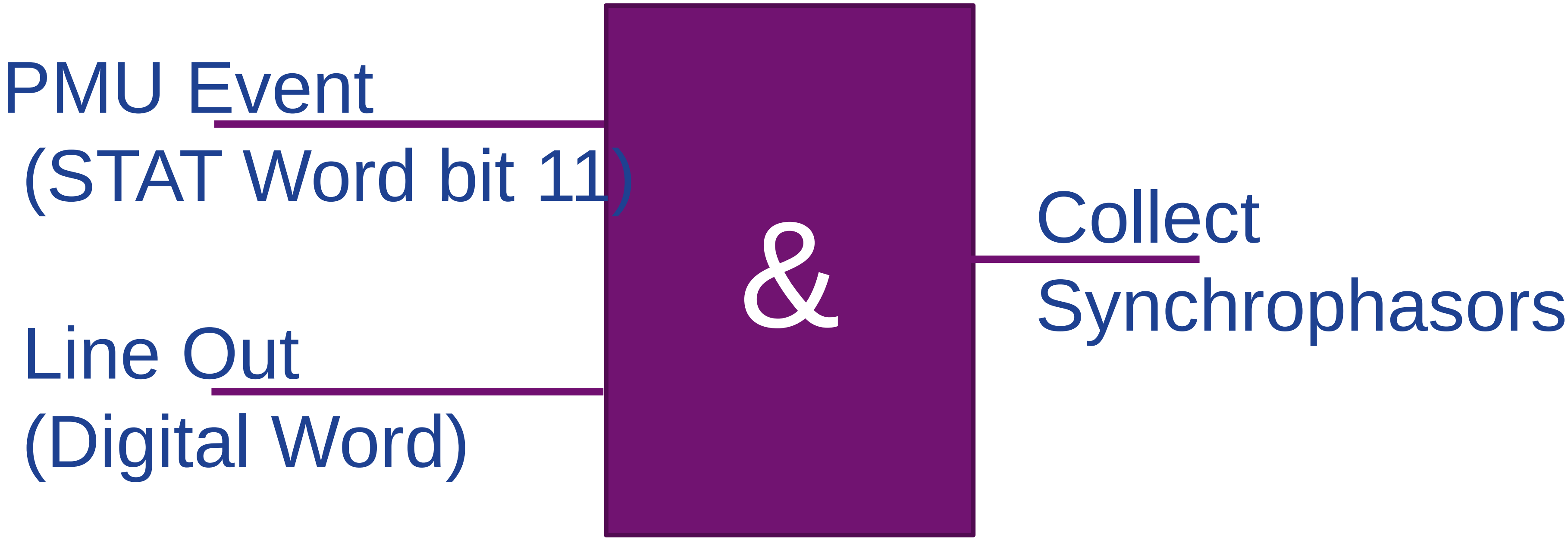
I1 – I2 = Total Charging Current

Compensate Each end by ½ of Total

Typical Synchrophasor Data Path

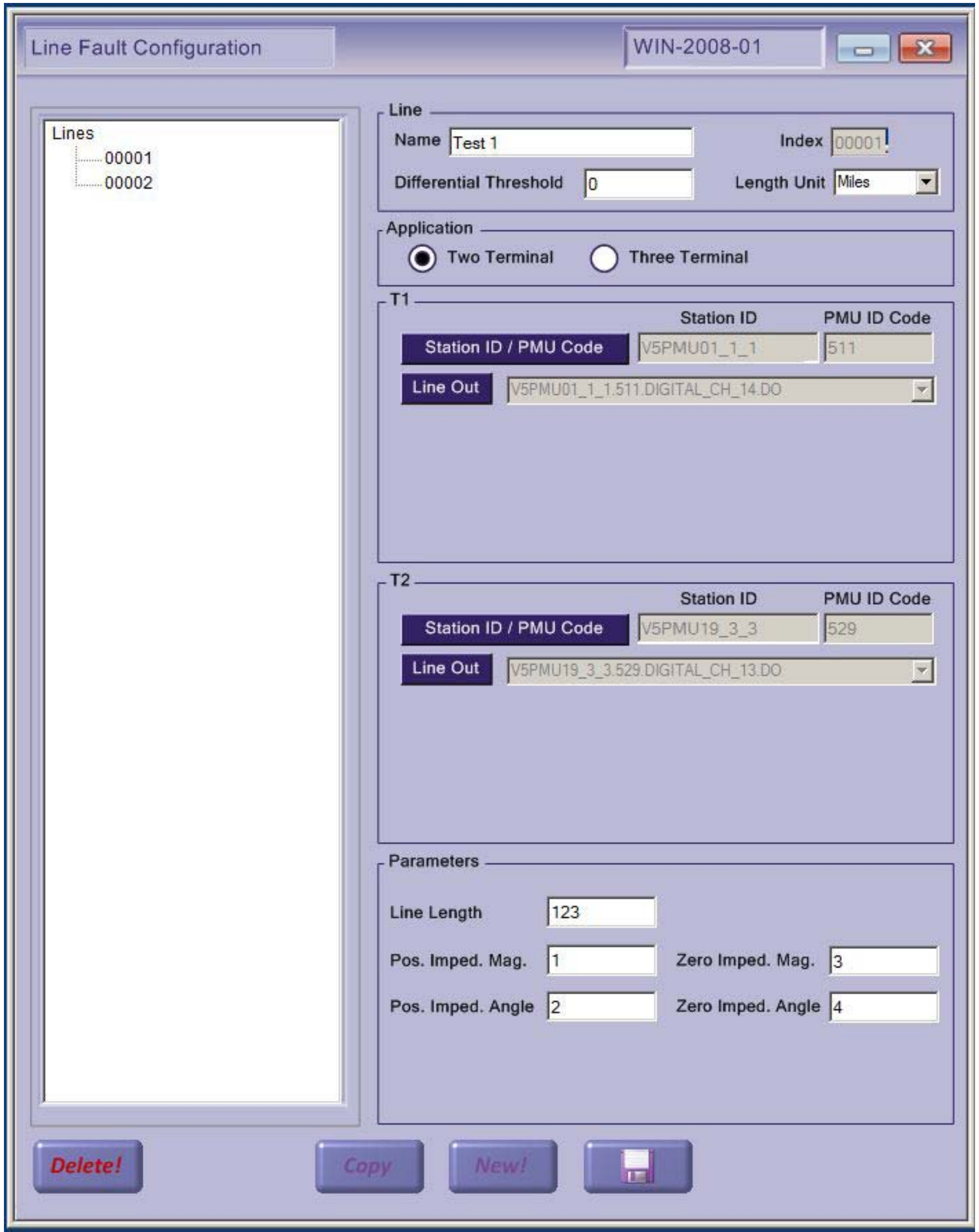


Data Capture Criteria



Collect 200ms before and after event

Line Fault Parameter Configuration



Fault Time Detection via Current Differential

T1	I1	I2	ΔI < Charging
T2	I1	I2	ΔI < Charging
T3	I1	I2	ΔI < Charging
T4	I1	I2	ΔI > Charging
T5	I1	I2	ΔI > Charging
T6	I1	I2	ΔI > Charging
T7	I1	I2	ΔI < Charging

Fault Data Located
Line Impedance Estimated
Fault Location Calculated

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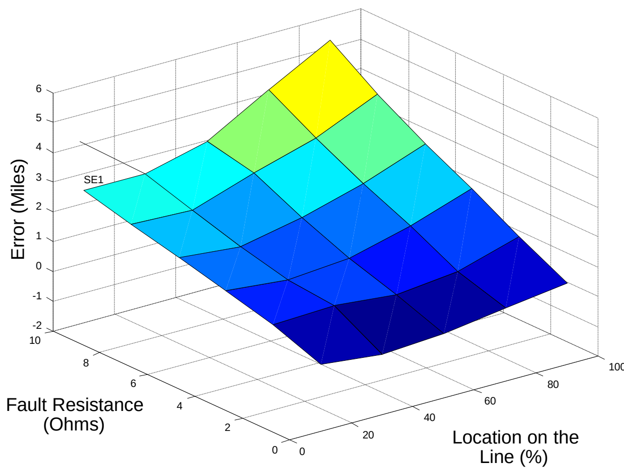
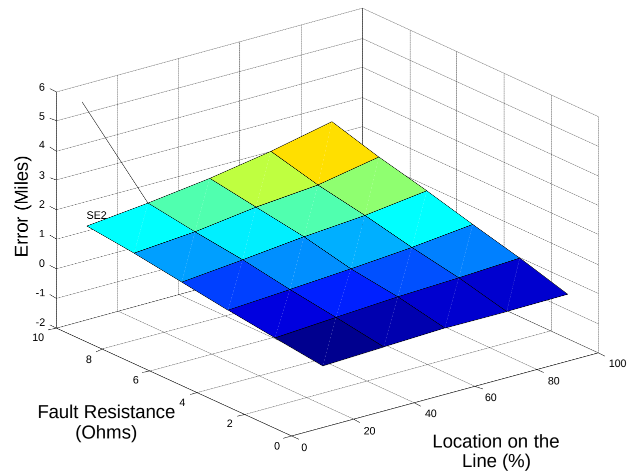
Comparative testing with single-ended methods

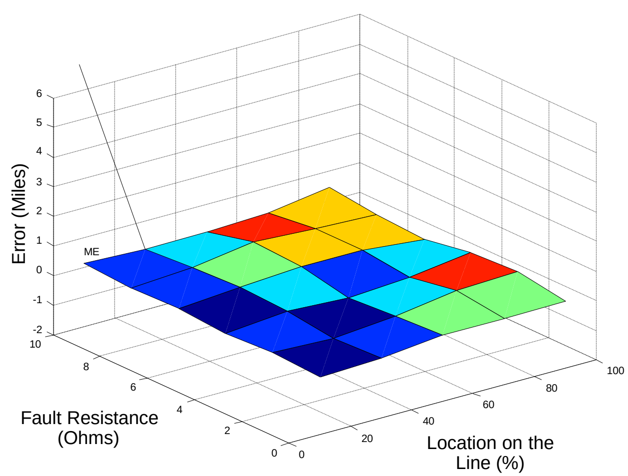
- **Error for variable fault resistance for fault along the line**
- **0.66pu export power**



Single Ended Fault Location R1



Single Ended Fault Location R2



Multi-ended Fault Location

RTDS Testing:

- 0.3% accuracy achieved

Conclusions

- **Multi-ended Fault Location provides immunity to fault type, fault resistance, power flow, voltage homogeneity, weak infeed and operates on on 3-terminal lines**

- **High-speed P-Class Synchrophasors can provide visualization of the fault waveforms**

- **Faulted Synchrophasors can be effectively identified**

- **Performance validated over a range of fault locations and fault impedances**

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