- magnetic coupling between the lines
- **capactive coupling**
- electrical interaction between lines
Option 1 (case 1)

Option 2
\[ X_{012012,0,0} = 2.01 \text{ ohm/mi} \quad X_{012012,1,1} = 0.53 \text{ ohm/mi} \quad X_{012012,2,2} = 0.53 \text{ ohm/mi} \quad X_{0L1} = 2.01 \text{ ohm/mi} \quad X_{1L1} = 0.53 \text{ ohm/mi} \]

\[ X_{012012,3,3} = 2.04 \text{ ohm/mi} \quad X_{012012,4,4} = 0.52 \text{ ohm/mi} \quad X_{012012,5,5} = 0.52 \text{ ohm/mi} \quad X_{1L2} = 0.52 \text{ ohm/mi} \quad X_{0L2} = 2.04 \text{ ohm/mi} \]

Now for the zero sequence mutual coupling:

\[ Z_{M0} := R_{012012,3,0} + j \cdot X_{012012,3,0} \quad Z_{M0} = (0.27 + 1.13i) \text{ ohm/mi} \]

Case 1: Add a third line:
500 kV line currents
345 kV line current (unloaded prefault)

3 phase fault currents are in phase dominated by zero sequence current

- Now the system with 2 parallel lines:
Protection Solution

1. Use negative sequence directional element

2. If use ground directional

- comparison scheme

- supervise overcurrent element

$Z_{0n} \rightarrow R_{01-12} + jX_{01-12}$
If use 50G element

- Extensive short circuit studies
- SLG at remote bus
  - without ground connect
  - with parallel line in and out
  - at open end of parallel line

\[ I_{set} = 1.25I_{fL_{-\text{max}}} \]
Distance Elements

\[ \frac{V_A}{I_A + k_0 I_A} \]

\[ k_0 = \frac{Z_0}{Z_2} \]

AG

\[ V_A = mZ_1c (I_A + k_0 I_A) + mZ_0m \]

Underreach if \( I_0 \) & \( I_{om} \) in same direction

Overreach if \( I_0 \) and \( I_{om} \) in opposite direction
Zone 1 should never overreach
Zone 2 should never underreach

Some possible solution

- If have $I_{om}$ available as a measurement

$$V_A = m Z_{IL} \left( I_A + k_0 3I_0 + \frac{Z_{om}}{Z_{IL}} I_{om} \right)$$

Not widely used
Variable (Dynamic) \( k_0 \)

Parallel line: \( k_0 = \frac{Z_0 - Z_{lc} + Z_{om}}{3Z_{lc}} \)

( electrically coupled, when it is open \( k_0 = \frac{Z_0 - Z_{lc}}{3Z_{lc}} \))

what if open and ground at each end (magnetic coupling only)

\( k_0 = \frac{Z_0 - Z_{lc} - Z_{om}}{3Z_{lc}} \)

Use line current differential if have common change