A SIMPLIFIED SEQUENCE FILTER CIRCUIT

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THEORY OF OPERATION

In an unbalanced three-phase system, the three vectors Q_A, Q_B and Q_C which may be with unequal magnitudes and/or with phase differences not equal to 120°, can be resolved into a system of three equal vectors known as zero sequence components, and two symmetrical or balanced three-phase systems known as positive and negative sequence components, i.e.,

$$Q_A = Q_0 + Q_1 + Q_2, \quad (1)$$

$$Q_B = Q_0 + \alpha^2 Q_1 + \alpha Q_2, \quad (2)$$

$$\text{and} \quad Q_C = Q_0 + \alpha Q_1 + \alpha^2 Q_2 \quad (3)$$

where the zero sequence component is

$$Q_0 = (1/3)\left(Q_A + Q_B + Q_C\right), \quad (4)$$

the positive sequence component is

$$Q_1 = (1/3)\left(Q_A + \alpha Q_B + \alpha^2 Q_C\right), \quad (5)$$

and the negative sequence component is

$$Q_2 = (1/3)\left(Q_A + \alpha^2 Q_B + \alpha Q_C\right), \quad (6)$$

$$\alpha = e^{j120°} = -(1/2) + j\sqrt{3}/2,$$

$$\text{and} \quad \alpha^2 = e^{j240°} = -(1/2) - j\sqrt{3}/2.$$

The letter Q may denote any vector quantity, such as voltage, current, or electric charge.

It is evident that the zero sequence [Equation (4)] component in a three-phase system can be detected by direct summing of the vectors Q_A, Q_B and Q_C. For positive and negative sequence detections one can begin by rewriting Equations (5) and (6) as follows:

From Equation (5):

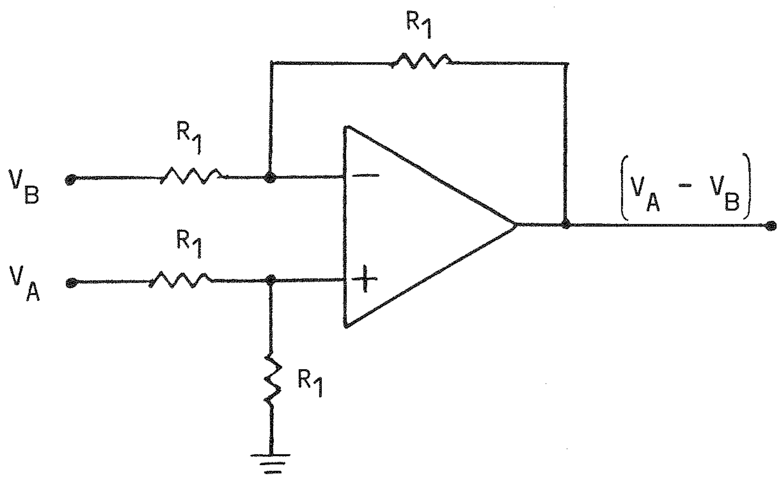
$$Q_1 = (1/3)\left[\left(Q_A - Q_B\right) - \left(Q_C - Q_B\right)e^{j60°}\right] \quad (7)$$

$$\text{or} \quad Q_1 = (1/3)\left[\left(Q_A - Q_C\right) - \left(Q_B - Q_C\right)e^{-j60°}\right]. \quad (8)$$

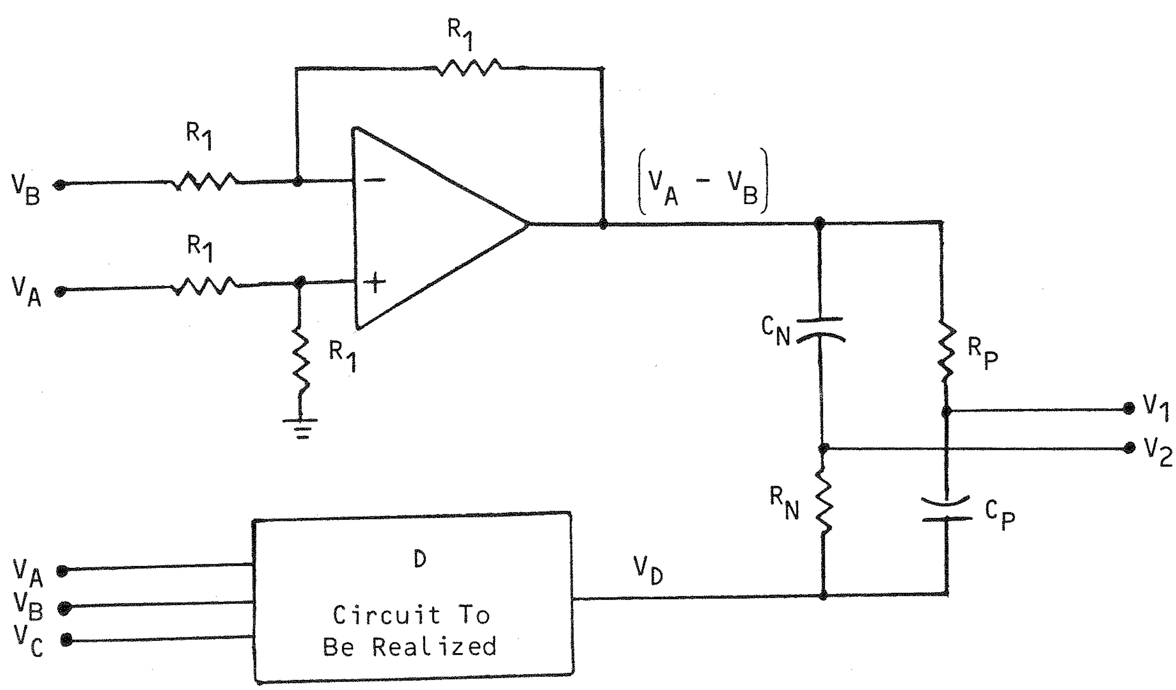
From Equation (6):

$$Q_2 = (1/3)\left[\left(Q_A - Q_B\right) - \left(Q_C - Q_B\right)e^{-j60°}\right] \quad (9)$$

$$\text{or} \quad Q_2 = (1/3)\left[\left(Q_A - Q_C\right) - \left(Q_B - Q_C\right)e^{j60°}\right]. \quad (10)$$



(a) $(V_A - V_B)$ Circuit



(b) Circuit Model Realizing Eqs. (13) and (16)

Figure 1. Circuit Model for Realization

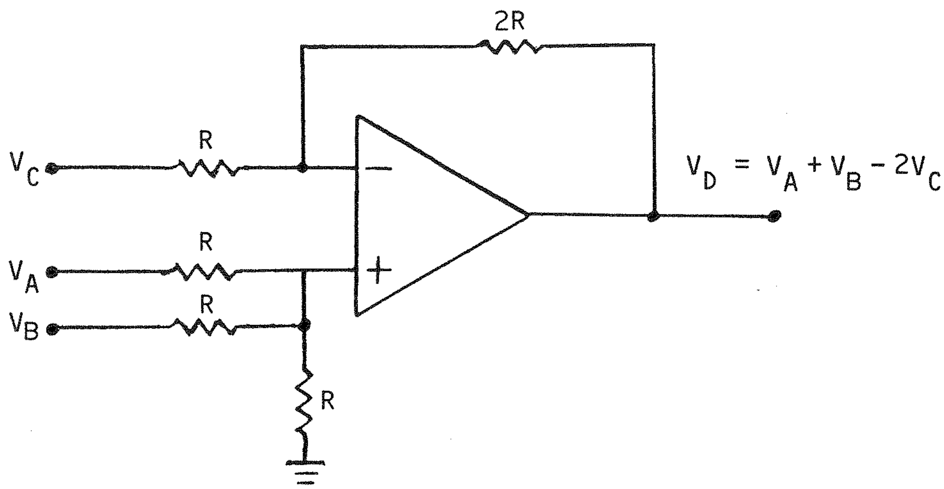


Figure 2. Realization of V_D

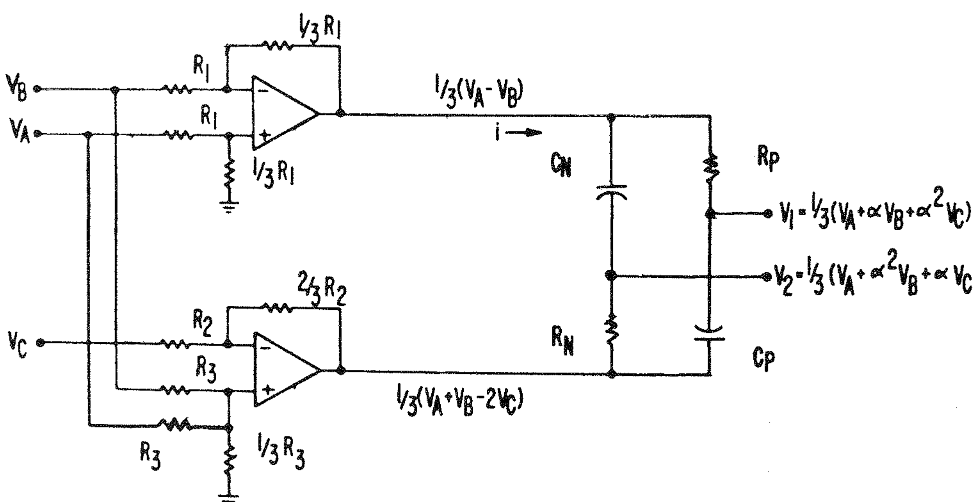


Figure 3. Overall Realization

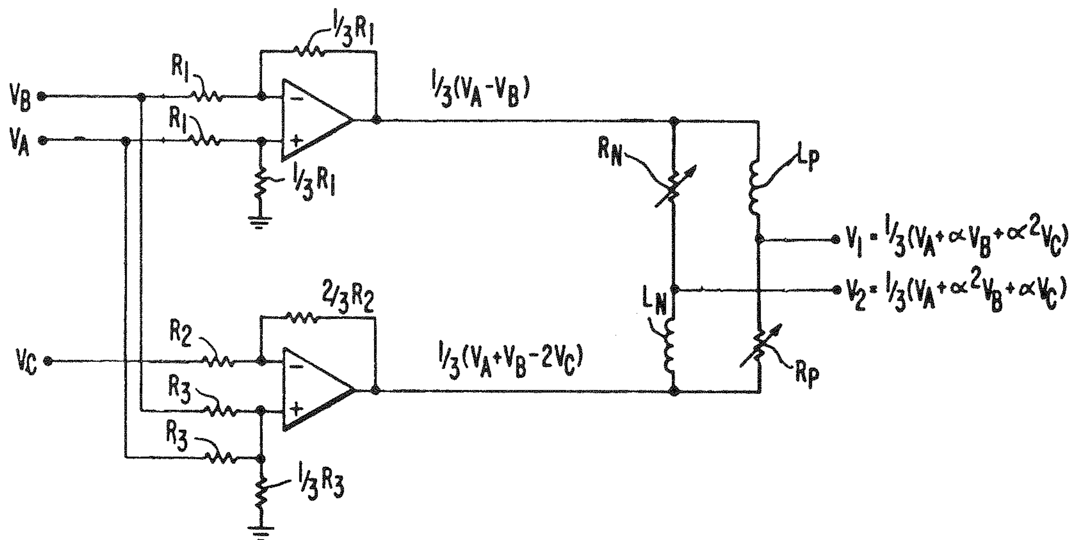


Figure 6. Realization Using Inductors

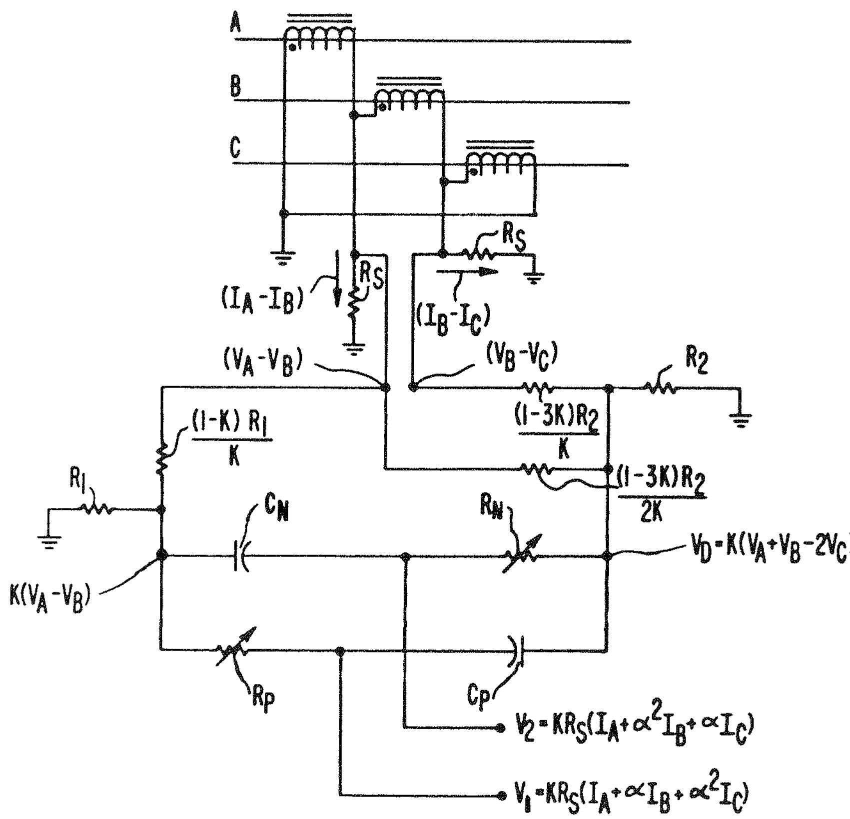


Figure 7. Current Sequence Filters-Passive Design

8 Reduce the magnitude of V_A - V_B - V_D from Step 6 by 1/2 and shift it 60 degrees in the positive direction to provide $(1/2)\ (V_A - V_B - V_D)\ ej60°$

9 Change the sign of $1/2\ (V_A - V_B - V_D)\ ej60°$ to provide $-1/2\ (V_A - V_B - V_D)\ ej60°$

10 Combine $V_A - V_B$ from Step 2 and $-1/2\ (V_A\text{-}V_B\text{-}V_D)\ ej60°$ which will be noted is equal to $3V_A$

11 Applying the scaling factor 1/3 to the result of Step 10 provides $1/2\ (V_A\text{-}V_B) - 1/2\ (V_A\text{-}V_B\text{-}V_D)\ ej60° = V_A = V_1$.

Figure 8B illustrates the positive sequence filter with a negative sequence input. Note that the vectors of the negative sequence have the relationship V_A, V_C, V_B instead of V_A, V_B, V_C as in the positive sequence. When the same steps outlined relative to Figure 8A are followed, it will be noted that $(V_A\text{-}V_B)$ developed in Step 2 is equal to and opposite in phase to $-\ (1/2)(V_A\text{-}V_B\text{-}V_D)\ ej60°$ developed in Step 9, and thus V_1 is equal to zero.

Figure 8C illustrates the positive sequence filter with a zero sequence input. The vectors V_A, V_B and V_C will all be equal to one another and in-phase. Thus, the terms $(V_A - V_B)$ and V_D will be equal to zero, resulting in V_1 being equal to zero.

The operation of the negative sequence filter can be similarly proven and therefore it is not repeated.

CONCLUSION

In summary, a new and improved symmetrical component sequence filter design has been described. The new design may be constructed of non-precision components while requiring only one single easily and quickly performed adjustment. If desired, precision components may be used in the phase shift circuits, and the adjustment will be eliminated. Further, it has been shown that the new design inherently rejects any zero sequence component in the input signal. Still further, the signal processing circuitry used in the new design is universally applicable to both the positive and negative sequences. The type of phase-shift circuit connected to the processing circuitry determines the nature of the sequence detection. With the implementation of two phase-shift circuits, both the positive and negative sequence detections can be obtained simultaneously.