OUT OF STEP RELAYING SYSTEM SELECTION

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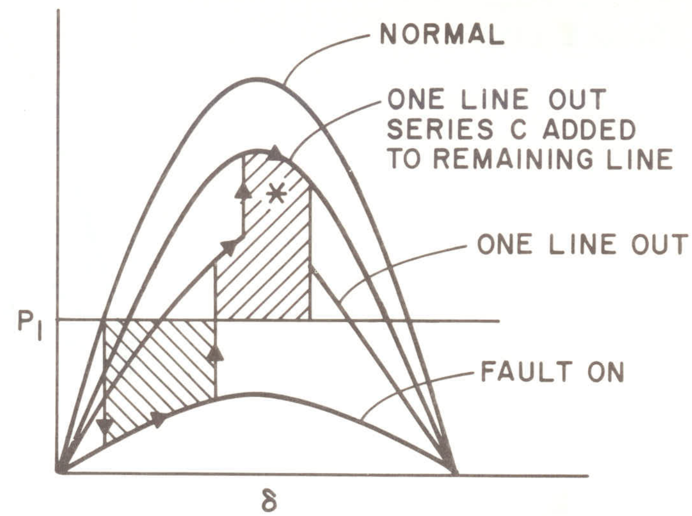
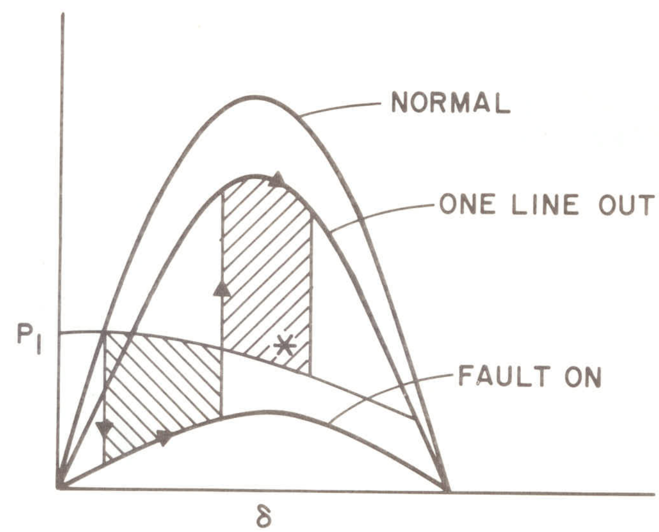
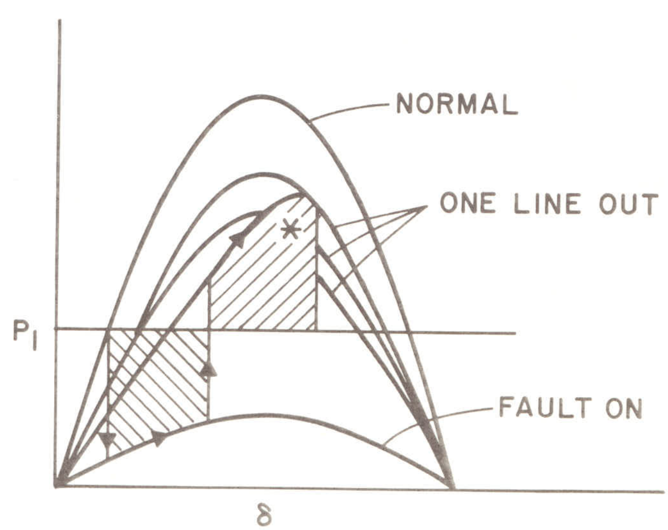
d) SERIES CAPACITOR INSERTION



e) FAST VALVING



f) FAST EXCITATION SYSTEM



EFFECT OF INSTABILITY ON RELAYING SYSTEMS

Some representative relaying systems are shown on the resistance-reactance diagrams of figure 1. Points A and B represent transmission line terminals, and the circles are phase distance relay characteristics. Several possible trajectories of swing ohms are shown with the resulting relaying systems action that will naturally result without os control. These trajectories are described in Appendix I.

ZONE 1

In figure 1A, only the zone 1 relay characteristic for terminal A is shown. Comparable effects would occur to the relay at B as those shown for the relay at A. Whether tripping occurs or not is dependent, in the absence of any os controls, only on whether or not the apparent ohms enter the characteristic circle of the zone 1 phase relay. Instability involves balanced currents, and, therefore, only those relays or units that are responsive to 3-phase faults can operate (desirably or undesirably) during an out of step condition.

It is reasonable to assume that instability will follow when a swing produces operation of a zone 1 relay. This occurs because the swing angle between sources required to produce such operation is very large, usually greater than 120 degrees.

DIRECTIONAL COMPARISON BLOCKING

Figure 1B shows that an unstable swing can produce tripping at one, both or neither terminal, depending on where the trajectory of the ohms goes. Tripping occurs when the tripping relay (21P) operates, and at that same moment, the starting relay (21S) at the remote terminal is not operated.

UNBLOCKING OR OVERREACHING TRANSFER TRIP

These systems are similar to the directional comparison blocking system, but the fact that blocking-carrier is always transmitted except when 21P (or the ground relay, in the general case) operates, restricts tripping on an os condition to only those cases where *both* 21P's (at A and B) operate.

PHASE COMPARISON

Phase comparison systems compare the phase relationship of current(s) in one end of the line with current(s) out the other. Since current "in" and "out" are essentially identical for an os condition, no tripping action will take place when the swing ohms pass through the line (figure 1d) for any phase comparison relaying system except the "combined-scheme." That scheme is effectively a directional comparison scheme for other than ground faults. Pilot wire relaying is unresponsive to os swings in a manner similar to the phase comparison system.

OS SENSING

Figures 2 and 3 show the prevalent os related schemes, the functions they provide, and where each would be most effectively applied.

PROBLEMS

BREAKER DAMAGE

Os tripping may have to be controlled critically to avoid breaker damage or transmission line thermal damage. Breaker damage may occur as a result of the high recovery voltage that appears across the breaker contacts when interrupting with the two system segments approximately 180 degrees out of phase. ANSI standard C37.079-1973 states as a guide that breakers rated for out-of-phase switching must be able to interrupt a current of 25 percent of rated interrupting current with a recovery voltage of 3.53 per unit of rated line-to-neutral voltage without damage. Figures 4 and 5 show how such large recovery voltages are produced during os tripping. Recovery voltage is the critical quantity for controlled trip coil energization where swing rates are comparatively fast, and tripping can be delayed until a favorable angle between systems exists. If it is delayed until the two system segments are nearly in phase, "current zero" occurs approximately at "voltage zero," and the recovery voltage is insignificant.

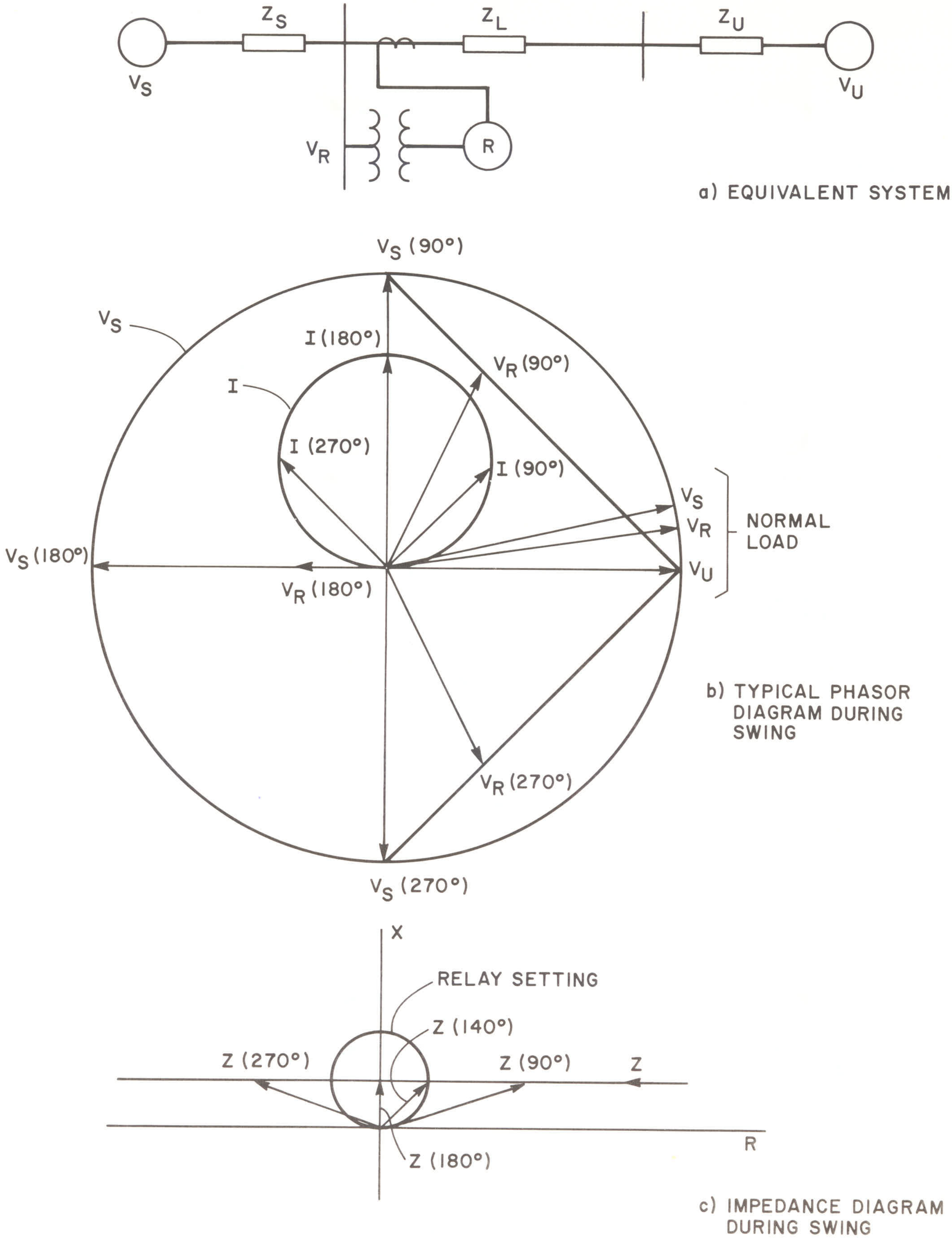


FIGURE 9. RELAY QUANTITIES FOR OS CONDITION

CONCLUSIONS

Optimum system operation entails taking every action economically justifiable to avoid instability such as single or combinational use of high speed relaying, high speed breakers, generator braking resistors, generator dropping, series capacitor insertion, fast turbine valving, fast excitation system, single pole tripping and independent breaker mechanisms to downgrade faults from 30 to 00 etc., Appendix II and figure 10 show the reasons these actions are effective in improving transient stability. Where instability cannot be avoided, the out of step relaying systems described here can be used to provide an orderly separation.

REFERENCES

1. "Electrical Transmission and Distribution Reference Book," chapter 13 Westinghouse Elec. Corp., E. Pgh, Pa.
2. Crary, S. B. Power System Stability Volume II, a book, John Wiley, & Sons.
3. Kimbark, E. W., "Power System Stability," Volume I, a book, John Wiley & Sons.
4. Kimbark, E. W., "Improvement of Power System Stability by Changes in the Network," IEEE Transactions on Power Apparatus & Systems 1969, pp 773-781.
5. Cushing, E. W. et al, "Fast Valving as an aid to Power System Transient Stability," IEEE Transactions on Power Apparatus & Systems 1972, pp 1624-1636.

APPENDIX I

Figure 9a has a simplified schematic diagram with line impedance ZL and source impedances ZS and ZU. The phasor diagram of figure 9b demonstrates how the voltage and current at an intermediate point in a system varies as instability develops. One can see how VS advances, with VU assumed fixed, to the 90°, 180°, 270° points and finally back in phase. Meanwhile, I adjusts itself to a magnitude sufficient to produce the required voltage drop between the two sources and to an angle lagging this voltage drop by the power factor angle of the total impedance (ZS + ZL + ZU). Note that, at the 180 degree point, the voltage at the relay is very low, the current at the relay is very high, and the current lags the voltage by the total impedance angle.

The impedance diagram of figure 9c shows the manner in which the apparent impedance varies as it is viewed from the relay location. The distance relay with the particular setting shown would respond to this condition, when the swing angle advances to approximately 140 degrees and enters the operating area. If tripping were initiated by this relay, it is evident that the angle between the two source voltages *at interruption* would be greater than 140 degrees and opening, producing a very high recovery voltage across the breaker contacts for this case.

The trajectory of the ohms on the R-X diagram is determined by the relative impedances in the system. The lower ZS is with respect to ZL and ZU the closer VR stays to VS, for example, and the closer the swing ohms will come to sourse S. As drawn, the impedances were assumed equal and pure inductances. For this assumption, the impedance center of the system is at the center of ZL. With equal source voltages, this is also the electrical center. The swing ohms progress to within ZL/2 of the relay location. With the relay set to reach farther than ZL/2, operation would be expected.

APPENDIX II

Any good book on power system stability describes the equal area criterion, 1, 2, 3. These texts should be referred to for more detailed description. The criterion simply states that the integral of decelerating power with respect to torque angle must equal the integral of accelerating power with respect to torque angle in order for transient stability to be retained, when a large disturbance occurs. This criterion gives no clues to dynamic stability, the response of a system to small disturbances, and it is generally accepted that those things which assure transient stability may be detrimental to dynamic stability.

The areas below the P1 (pre-fault power) line such as A1 in figure 10a represent accelerating power areas, and the areas above represent decelerating power areas.

Figure 10 shows in graphical form, the effect of different devices and controls on stability. The asterisks indicates the area where beneficial results are particularly noticeable from the action described.

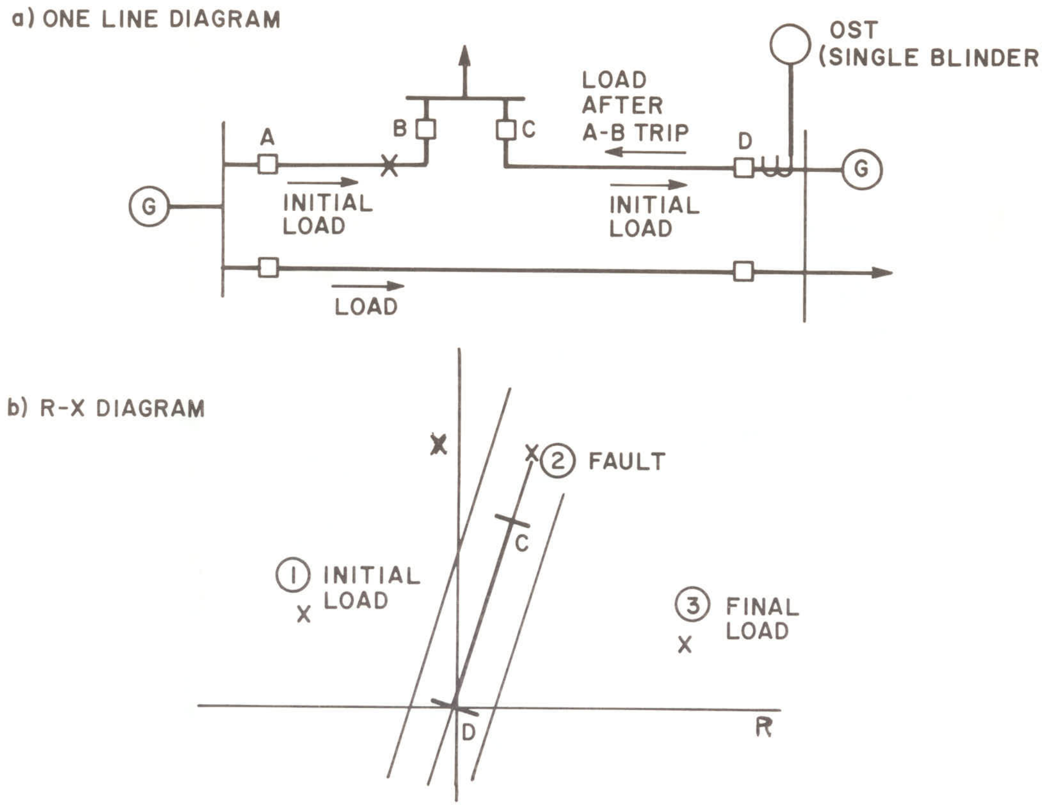


FIGURE 7. FALSE TRIP CAN RESULT FROM LOAD REVERSAL WITH SINGLE BLINDER SCHEME

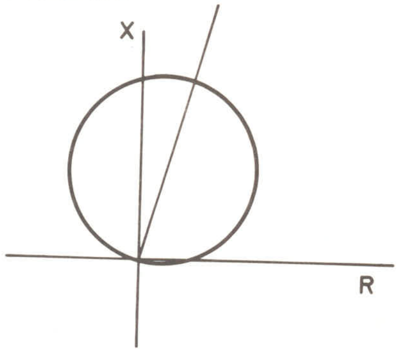
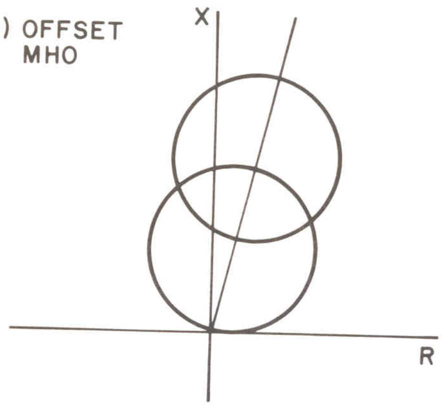
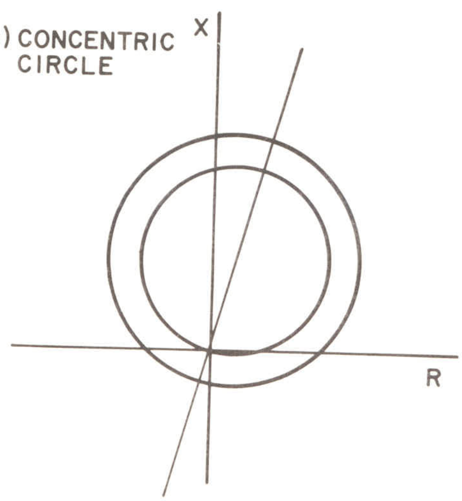
OS SENSING	FUNCTIONS PROVIDED	RELAYS	WHERE TO APPLY
a) LINE RELAYS 	OST	SKDU KD-10	MODERATE LENGTH LINES WHERE I ON OS LESS THAN 25% OF BREAKER IC.
b) OFFSET MHO 	RT	KD-10 KD-3	LONG LINES WHERE I ON OS LESS THAN 25% OF BREAKER I.C.
c) CONCENTRIC CIRCLE 	1. OSTB 2. OSRB 3. OST (WHEN EQUIPPED WITH RESET SEQUENCE LOGIC OR ZONE I MEMORY	SKSU SKDU KS KD-10 KST KD-10	OSTB WHERE OS TRIP PRODUCES UNDESIREABLE SYSTEM SPLIT POINT. OSRB WHERE LINE RELAYS TRIP ON OS. OST ON MODERATE LENGTH LINE OR GENERATOR WHERE NO LOAD REVERSAL.

FIGURE 2. OS SENSING

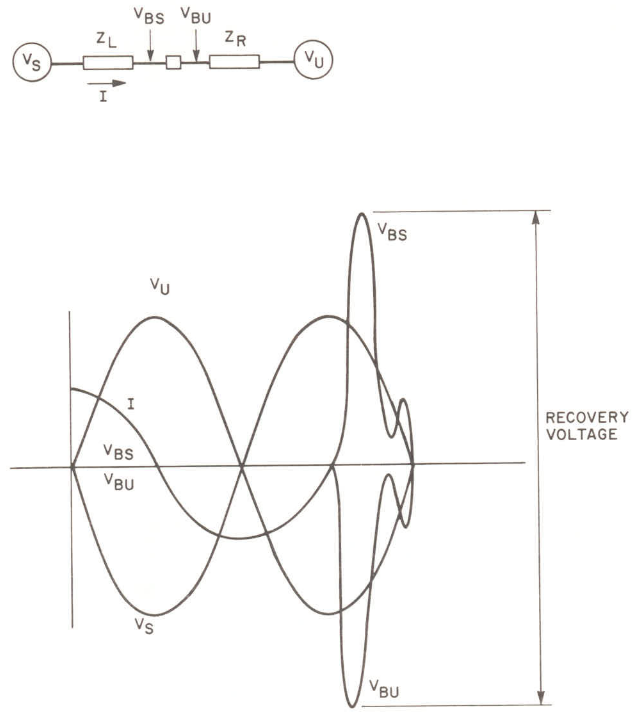


FIGURE 4. MAXIMUM RECOVERY VOLTAGE ON OS TRIP WITH BREAKER AT ELECTRICAL CENTER

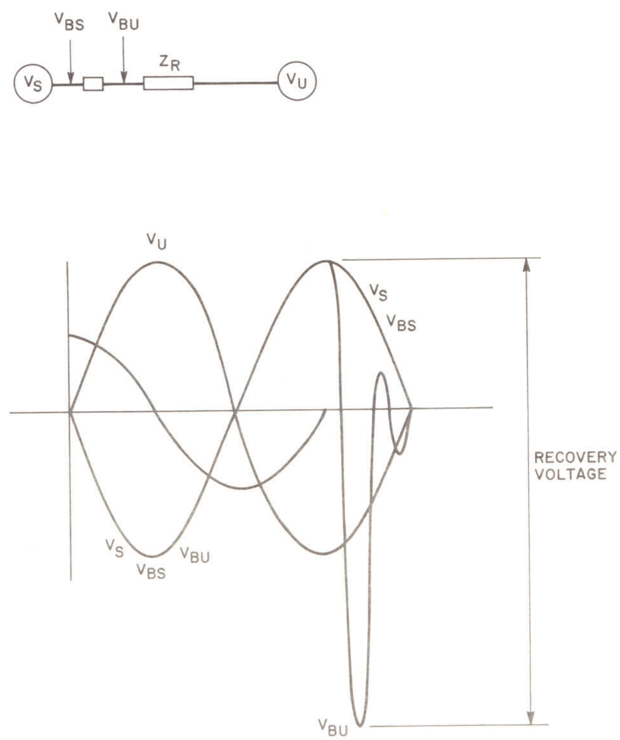


FIGURE 5. MAXIMUM RECOVERY VOLTAGE ON OS TRIP WITH BREAKER AT SOURCE