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Power System Protection

LOAD CONSERVATION

LOAD CONSERVATION BY MEANS OF UNDERFREQUENCY RELAYS

by

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GENERAL ELECTRIC

LOAD CONVERSION BY MEANS OF UNDERFREQUENCY RELAYS

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The term load conservation is an attempt to express the necessity which faces the power system engineer when the load on his system suddenly exceeds the available generating capacity. Traditionally, it has been called "load shedding," with the implication that some reduction in load was needed. However, that is not the real crux of the matter -- what the power system engineer has been doing is saving or conserving as much of the load as possible, and selecting what he was able to carry.

That is what the term load conservation is intended to convey. Beyond simple semantics, it is an attempt to shift the emphasis to a more positive approach. And the purpose of this paper is to review the means that can be employed to conserve essential load and at the same time to keep intact as much of the power system and its interconnections as possible under the emergency condition.

THE PROBLEM

The references at the end of this paper document the problem very fully, but basically it may be summarized as follows. Any portion of a power system, whether it is an independent system or one with interconnections, will begin to deteriorate if there is an excess of load over available generation. The prime movers and their associated generators begin to slow down as they attempt to carry the excessive load. As the speed slows, the frequency decreases below normal and, neglecting for the moment the effects of automatic correction devices, the system voltage decreases.

The decreases in voltage and frequency have a certain corrective effect in that both tend to reduce the load. Thus, on a system with a preponderance of resistive load, voltage reduction alone would be the most effective in reducing the total load. On the other hand, on a system with a preponderance of motor load, the best response for reducing load is obtained with a reduction in both voltage and frequency.

Most systems today employ some automatic means to maintain voltage constant. There is a definite advantage to the power system in maintaining a relatively high or near normal system voltage, since this provides a higher level of system stability. This is important in system behavior under excessive load, for it eliminates, or tends to do so, the load reduction which might be expected from a reduction in voltage. And the total load will not be significantly reduced by a reduction in frequency alone.

Further, the drop in frequency may endanger generation itself. While a hydro-electric plant is relatively unaffected by even a ten per cent reduction in frequency, a thermal generating plant is quite sensitive to even a five per cent reduction. The power output of the thermal plant depends to a great extent on its motor-driven auxiliaries, such as boiler feedwater pumps, coal pulverizing and feeding equipment, and draft fans. As system frequency decreases, the power output of the auxiliaries begins to fall off rather rapidly, and this in turn further reduces the energy input to the turbine-generator. The situation thus has a cascading effect, with a loss of frequency leading to a loss of power which can cause the frequency to deteriorate further, and the entire plant is soon in serious trouble.

Most of the reference papers state that on a 60-cycle system, a frequency of 56 to 58 cycles per second is low enough to endanger thermal plant auxiliary equipment. Further, a serious underfrequency condition can develop in only a few seconds on a heavily overloaded plant.

OVERLOADS - EFFECTS AND CONTROL

An underfrequency condition due to an excess of load over available generation can occur in several ways. In any given system or interconnected system, the loss of a major source of generation or the loss of an interconnection carrying incoming power can produce the condition. The basic cause of most of these disturbances usually results from a short circuit. The short circuit either directly causes instability because of the shock to the system or, because of inadequate or slow relaying, indirectly causes instability by prolonging the reduction of the power transmission capability. Hydroelectric generating sources are usually located at some appreciable distance from the load areas they serve. Their long transmission tie lines on the same right-of-way are more vulnerable to multiple outages and thus may leave some load areas severely deficient in generation.

The higher the ratio of load to remaining generation in a separated system, the faster the system frequency will drop. Figure 1 shows typical frequency vs time curves for a representative steam turbine generator which is subjected to various per unit excess loads. The initial load is assumed here to be 1.0 per unit. The curves are approximations based on a typical inertia constant, a constant torque load, and no change in steam pressure. They give a reasonable indication of the initial rate of change of frequency.

It is evident that, assuming a critical frequency of 56 cycles for a given generating plant, there may be only a fraction of a second time, depending upon the excess load, in which to act to prevent the plant developing a really severe emergency. Corrective measures must therefore be taken quickly and automatically to remove the load and avoid a shutdown. It is quite possible that in the case of a small generator subjected to a very severe overload, the rate-of-change of frequency might be so great that no automatic protection would be effective to avoid a shutdown.

Underfrequency relays can be used to drop non-essential load in accordance with a predetermined schedule in order to balance generation and load in the affected area. Such action must be taken promptly and must be of sufficient magnitude to

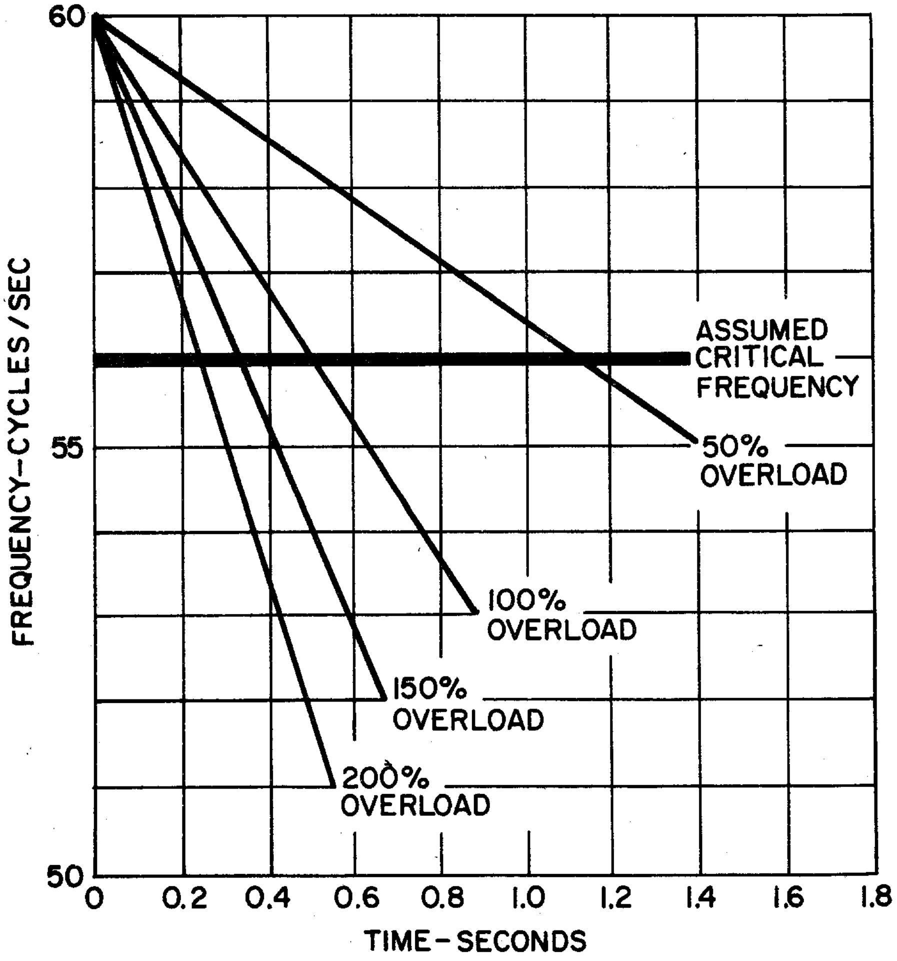

Figure 1. Frequency vs Time Characteristic for Steam-Turbine Generator with Overload

conserve essential load and enable the remainder of the system to recover from the underfrequency condition. Also, by preventing a major shutdown of the system, restoration of the entire system to normal operation is greatly facilitated and expedited.

PAST EXPERIENCE AND PRACTICES

Programs of load conservation have been in use for 35 years as recorded in the literature. The idea is therefore not new. Such schemes have not been widely applied in the United States, apparently because of a feeling that the additional complexity and the risk of misoperation are not warranted in view of the strong system interconnections that exist across the country. This would be particularly true in areas where it is deemed that spinning reserve capacity is held at an adequate level. On the other hand, some type of load conservation program could function to provide a less widespread customer outage or even prevent a system shutdown.

Many large industrial plants across the country that have some local generation have adopted some form of load conservation program. Normally, they depend on a tie line with a utility for a part of their power needs. A typical one line diagram is shown in Figure 2. If the tie breaker at the utility end should open, the industrial plant generation would be overloaded especially if it is also attempting to pick up utility load which is tapped on the tie line. This will produce an underfrequency condition on the industrial system. The industrial power system designer usually uses underfrequency relays to open the tie to the utility system, Breaker T, and to drop the plant non-essential load, perhaps Loads 1 and 2. Essential Load 3 can therefore be maintained to the limit of the generation capability.

This was exactly the situation that occurred recently at our Schenectady plant. The underfrequency relay separated the plant from the utility and dropped all plant non-essential load. Three classes of critical load were not interrupted at all, and the plant operator then picked up other loads on a preselected priority basis to the limit of his local generation capability.

A point to be made here is that the necessary decisions must be mutually agreed to and converted into relay connections and settings before the emergency occurs. There is just not enough time left for communication and accurate decision making when the emergency does occur.

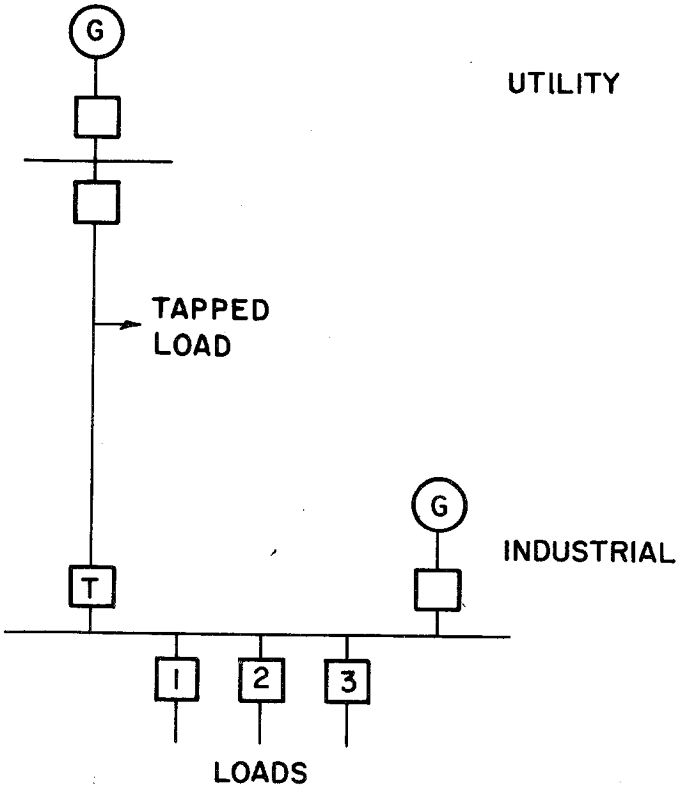

Figure 2. Industrial with Local Generation and Tie Line to Utility

There are also applications of load conservation programs which use directional power relays in conjunction with underfrequency relays. The power relay may be used with a time delay auxiliary which stores the information on the direction of power flow before a disturbance began. Then, through the control circuits when an underfrequency condition develops, the decision is already made as to what breakers should be tripped.

For example, consider the interconnection between two utilities shown in Figure 3. In this case Utility A normally furnishes power to Utility B, which has an excess of load over available generation. If this is the situation before the disturbance, then the control circuits are already arranged by the directional power relay and its auxiliaries so that an underfrequency condition would cause a trip-out of Load 1, assumed inter-

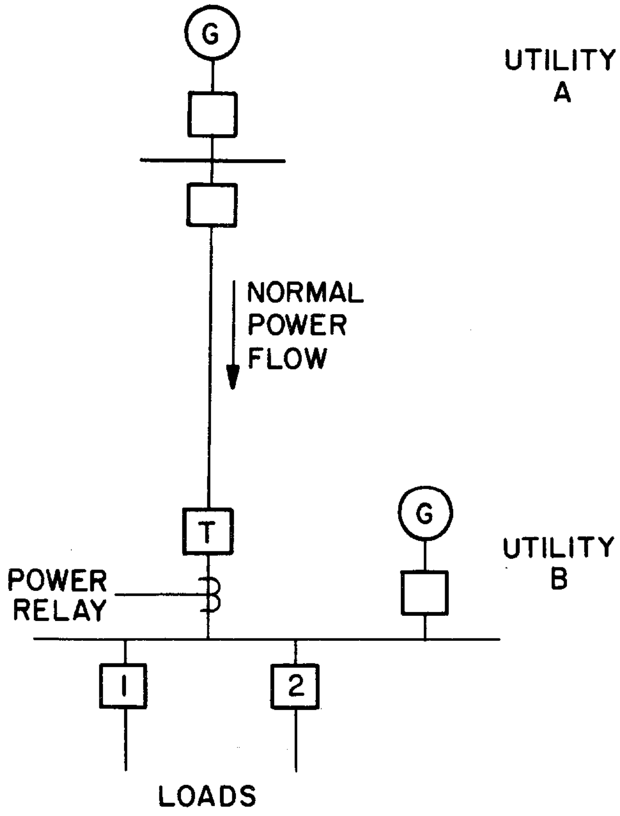

Figure 3. Tie Line with Power Relay

ruptible on Utility B's system. If Load 1 was of sufficient size to relieve the overload condition on the two interconnected systems, they could both recover. The tie breaker T is usually not tripped until the last possible moment to retain the value of the interconnection for the mutual benefit of both utilities. Similarly, if before the disturbance power flow was into Utility A, then any load conservation program should probably be initiated in the Utility A system.

Interconnection agreements are of course negotiated, and the methods and plans for operation during system disturbances and emergencies are thus predetermined. The scheme of operation just described, however, does seem to be an equitable one in that the utility or area which has an excess of load over generation should initiate the overall load conservation program by dropping part or all of its interruptible load. It is widely recognized, however, that all of the members of an interconnection or pool must have similar coordinated programs for load conservation in order to keep the entire interconnected system intact.

Most automatic load conservation schemes use underfrequency relays as the sensor units. These relays are then applied to trip off preselected feeders or groups of feeders, to drop non-essential or interruptible load in a variety of ways:

1. Trip off blocks of load in several steps with several relays set at successively lower frequency values
2. Trip off one large significant block of load, such as an industrial customer, at one level of frequency
3. Trip off blocks of load in several steps on a time basis, at or below one level of frequency, so that as each time step is reached, additional load is dropped. If the frequency recovers between steps, the scheme resets and further load tripping ceases.

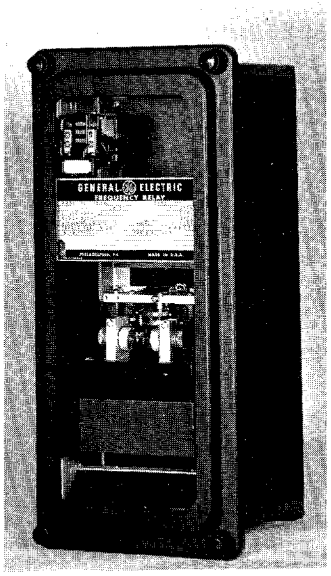

Figure 4. Type CFF relay

HIGH SPEED UNDERFREQUENCY RELAY

The basic principle of a frequency relay circuit was patented by Mr. Charles Steinmetz in 1900. Frequency relays of the slow speed, induction disk type were commercially available in 1921, and the high speed, induction cup relay, Type CFF, was put into use in 1948. For most present day installations of a load conservation scheme, the induction disk relay is too slow. We shall therefore concern ourselves only with a discussion of the high speed induction cup relay, Type CFF, shown in Figure 4.

The relay operating time is an important factor, since the underfrequency condition will develop as a rate-of-change of frequency. Therefore the relay operating time is plotted against a constant rate-of-change of frequency in Figure 5. While a constant rate-of-change of frequency on a power system is seldom experienced, it is believed that these time curves offer a more realistic way of analyzing the problem.

The solid curve of Figure 5 shows the relay operating time for the Type CFF12A relay, including a fixed auxiliary time delay of six cycles. This relay has been frequently applied in load conservation programs. The time delay is added to prevent relay misoperation when voltage is suddenly removed or applied.

The dotted curve of Figure 5 shows the relay operating time for a Type CFF13A relay, which is approximately 0.1 second faster. Tuned circuits are employed in this version which control the transient response of the relay under system fault conditions, thus removing the necessity for the auxiliary time delay. The relay is insensitive to the sudden application of voltage but may misoperate on the sudden opening of the coil circuits, as when switching to an alternate voltage source or on a blown potential transformer secondary fuse. It should be emphasized that the faster CFF13 relay should not be used unless the 0.1 second faster operating time is definitely needed and the limitations of its application are definitely recognized and appreciated, or compensated for by using a power directional relay for supervision.

The time curves of Figure 5 show relay operating time only. In applying a load conservation program to a system it must be recognized that a low frequency condition does not begin to be corrected until a circuit breaker operation occurs to disconnect some interruptible load. The family of curves shown in Figure 6 are therefore constructed to show frequency vs time after the disturbance starts for a number of different rates-of-change of frequency. They include (1) an

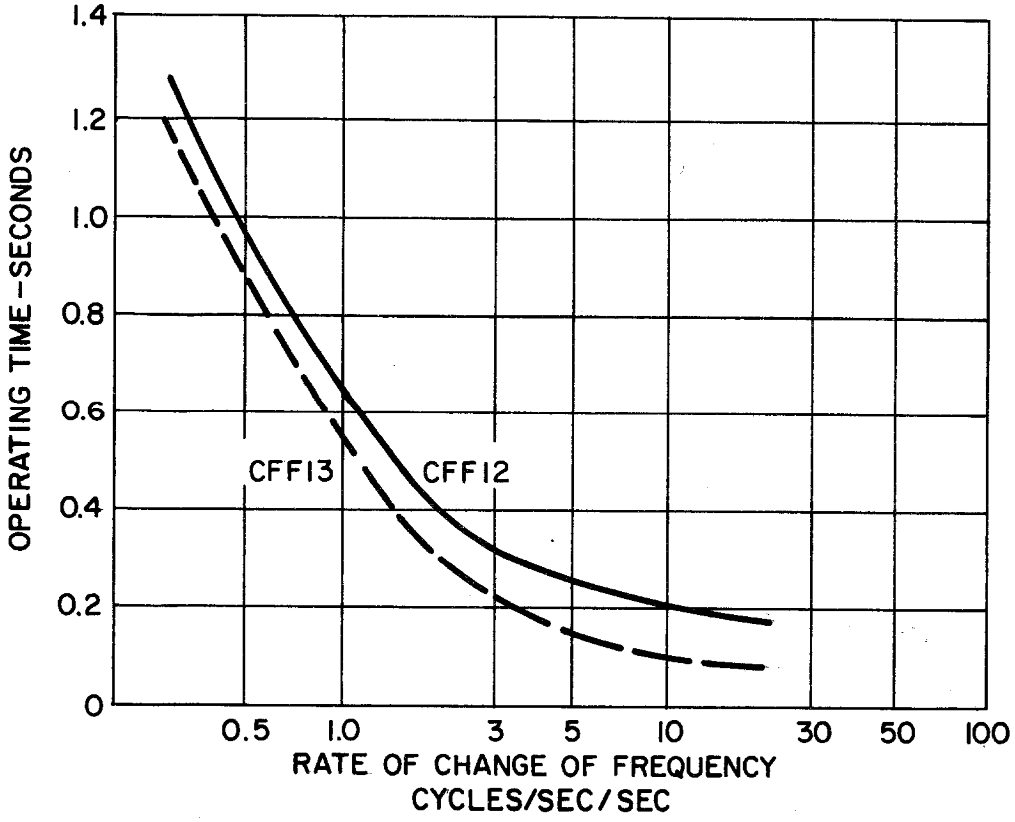

Figure 5. Time Frequency Characteristics – Operating Time After System Frequency Reaches Relay Pickup Setting

allowance of six cycles for total breaker clearing time, (2) the frequency relay auxiliary time delay of six cycles, and (3) various frequency pickup settings on the relay. The curves show that the relay will operate to start load conservation before the assumed critical frequency is reached, up to a rate-of-change of frequency of ten cycles per second per second.

A serious underfrequency condition on a system is likely to be accompanied by low voltage. The voltage response of a frequency relay is therefore important. This characteristic for the CFF12A relay is shown in Figure 7. The variation in pickup over the range of 40 to 140 volts is only 0.6 cycle/sec with the pickup frequency decreasing with decreasing voltages.

The stability of the relay characteristic with respect to temperature is also important. With the relay continuously energized, its frequency pickup will vary ± 0.2 cycles over the ASA Standards ambient temperature range of -20 to +40C. The relay, when first energized, exhibits a self-heating characteristic which decreases the frequency pickup by about 0.3 cycle within the first ten minutes. It is for this reason that a maximum pickup setting of 59.5 cycles is recommended. The repeatability of operating frequency of the relay is ± 0.05 cycles with all other conditions stable.

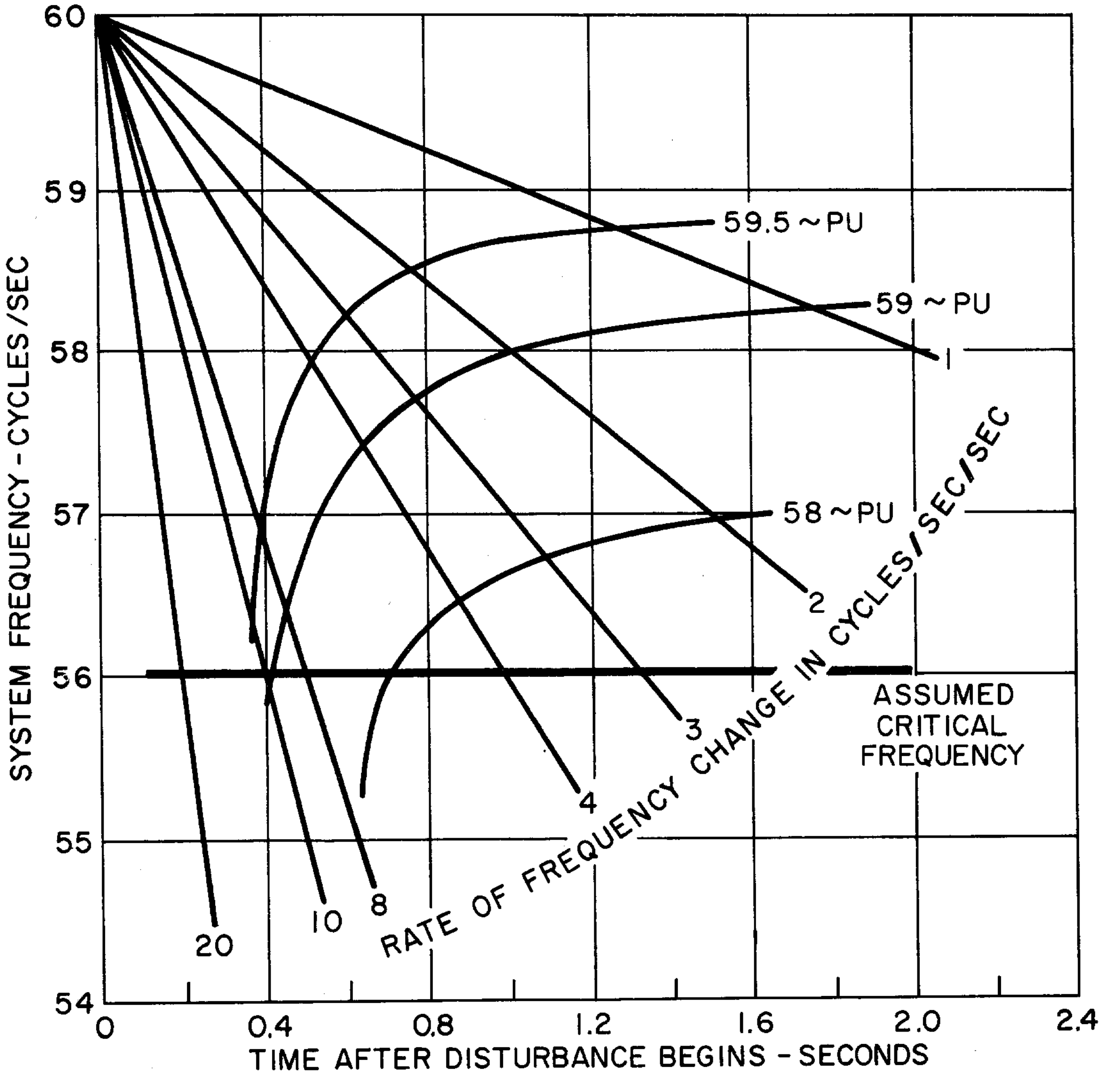

Figure 6. Frequency vs Time Characteristics for Total Clearing Time

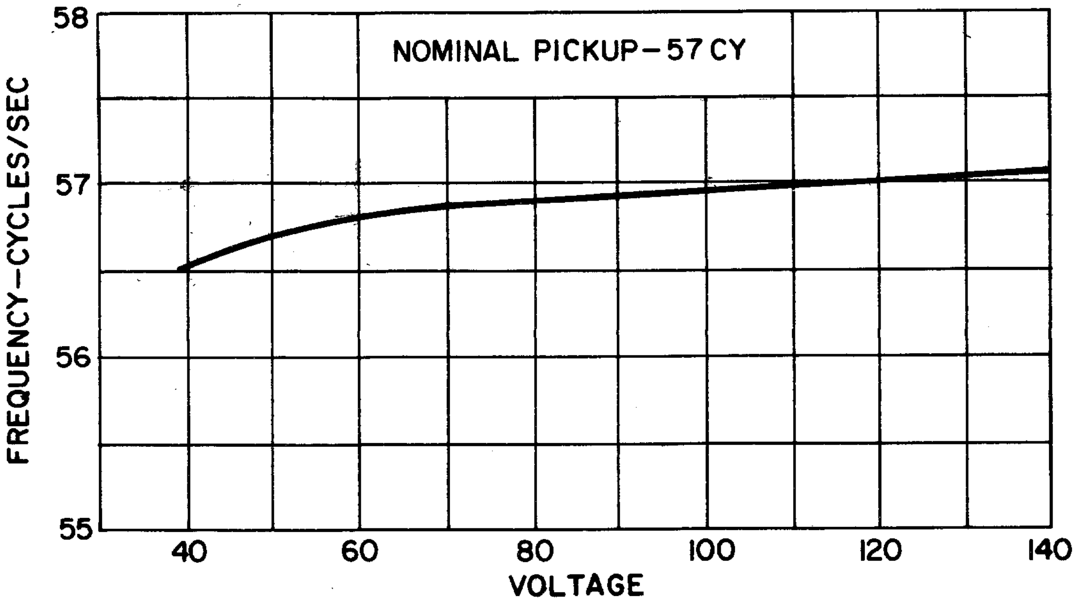

Figure 7. Variation in Frequency Relay Pickup with Applied Voltage

MOTOR LOADS

A tapped subtransmission or distribution substation which has a heavy preponderance of motor loads may present a problem of time coordination in the application of the standard high speed underfrequency relays. If the transmission sources to such a substation were tripped out for any reason, the motor loads would tend to maintain the voltage for a short time while the frequency decreased as the motors were slowing down, especially if the line capacitance keeps the motors excited. This slow decay of voltage may last longer than the six cycle delay of the high speed underfrequency relay, and the relay may trip and lock out breakers undesirably. In an unattended installation, restoration of the load would not then be accomplished by simply reenergizing the transmission line. One solution that has been applied is to further delay the operation of the underfrequency relay from 6 cycles to 20 cycles, and this has apparently been adequate for most cases.

RESTORATION OF LOAD

The difficulty of restoring load that has been dropped during a system disturbance, particularly at unattended stations, has been somewhat of a deterrent in the application of load conservation programs. Supervisory control of such unattended stations, of course, has overcome many such objections where it is available. For the remainder of such unattended installations, the underfrequency relay can be applied to restore the load automatically when the system frequency has returned to a value near normal. This relay, Type CFF14, has two frequency calibrations; the first calibration is the low frequency setting, at which point the preselected non-essential load is tripped; the second calibration is then automatically made within the relay to a higher frequency setting at which the relay will reset. Thus the relay can be used to restore load automatically when the frequency has returned to a value near normal.

The circuit connections for this relay are shown in Figure 8. The 81/A device is a six-cycle-delay auxiliary which is energized by the main relay element 81/UF at the low-set frequency condition. The 81/A contact shorts out the resistor and recalibrates the relay so that it resets at a higher frequency, which is usually close to normal frequency. In the control circuits (Figure 9), the A auxiliary contact is used for direct tripping the non-essential load. When the frequency relay resets to the higher level, the A unit drops out again to initiate reclosing supervised by the breaker "b" switch, the breaker control switch, and any other supervising contacts as in usual automatic reclosing schemes.

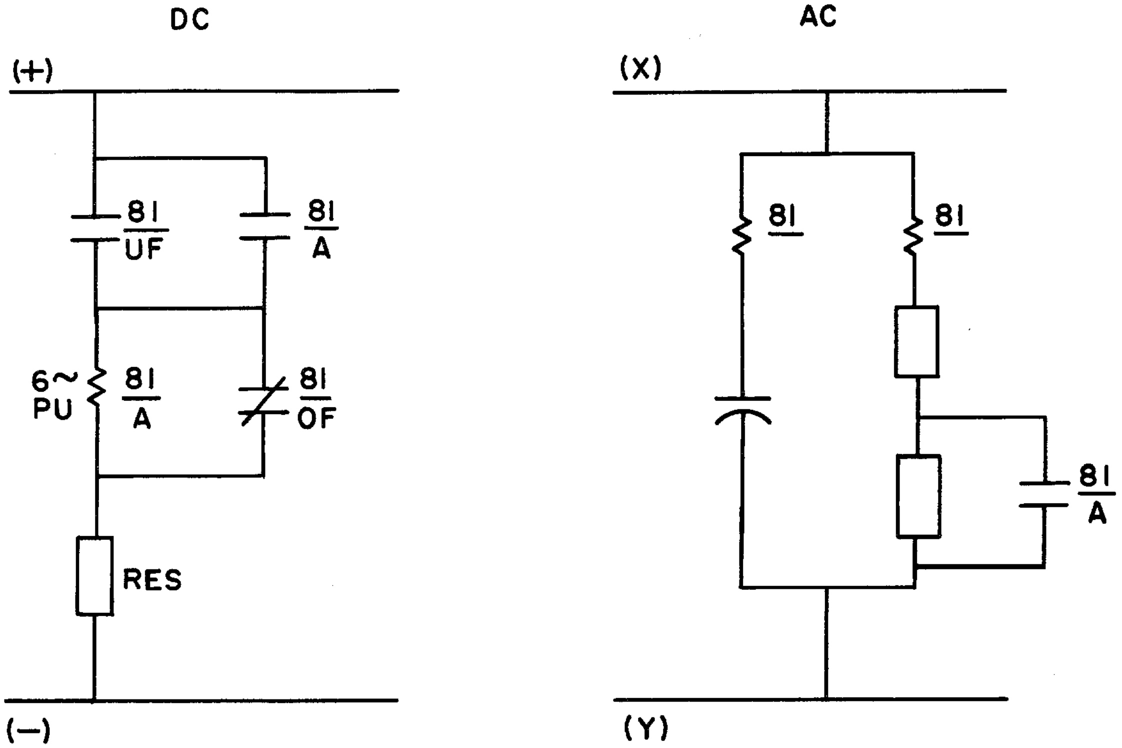

Figure 8. Circuit Connections – Frequency Relay with Recalibration Feature

It should be noted as a caution that widespread automatic restoration of load may cause the underfrequency condition to reoccur if the system is not ready to accept the load. Some means of staggering the restoration of load, either on a frequency or on a time basis, could be employed for these situations.

CONCLUSIONS

A load conservation program using underfrequency relays as the primary detector can be an effective means of preserving the basic integrity of a power system, permitting it to continue to carry the essential load and facilitating the rapid restoration of the system to a normal condition even under extremely adverse conditions. The implementation of a load conservation program, particularly on larger systems and with system interconnections, can be quite complex, and will frequently involve network analyzer or computer studies for proper evaluation.

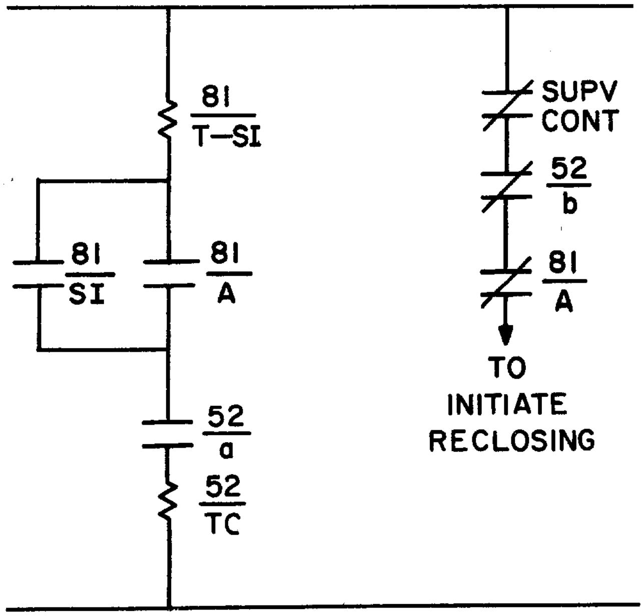

Figure 9. Control Circuits – Tripping and Reclosing

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