PACIFIC GAS & ELECTRIC COMPANY

RECLOSING PRACTICES

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PG&E RECLOSING PRACTICES

INTRODUCTION

Historically, PG&E has used automatic reclosing schemes to restore power to its customers following circuit outages or substation outages. Schemes have been designed to suit various applications; distribution circuits, transmission lines and substations. Although reclosing design has varied with each application, the basic reclosing philosophy has been maintained: to improve customer service reliability, by restoring power in a systematic manner, in a minimum amount of time, and selectively control the restoration of tripped device(s) to minimize damage to equipment.

Over the years, the basic design of reclosing schemes has changed to take advantage of new technology for more complex station controls. The evolution of electromechanical relays into solid state relays enabled PG&E to expand on the basic principles of reclosing practices by introducing more features and logic functions. More recently, programmable logic controllers, due to their inherent flexibility, were adapted to accomplish complex automated reclosing functions for substations having more than one interrupting device. This has eliminated the need for external relays, reduced wiring required and greatly improved restoration times.

Today, PG&E is continuing the research and development of other alternatives, such as the use of microprocessor reclosing devices, and the use of existing SCADA (Supervisory Control and Data Acquisition) software with the goal of developing a more intelligent means of reclosing in order to meet the demands of quality service to our customers.

DISTRIBUTION SYSTEM

RECLOSING PHILOSOPHY

Much of PG&E's basic reclosing philosophy for distribution circuits has been derived from empirical data, and studies which reflect the probabilities of successful reclosure for various faults. Other features were added to improve the quality of service to customers and to address safety concerns.

Automatic line sectionalizing devices such as fuses, and line reclosers are used to reduce the number of customers interrupted by automatically isolating the faulted section. They also reduce the frequency of outages for customers on the source side of these devices.

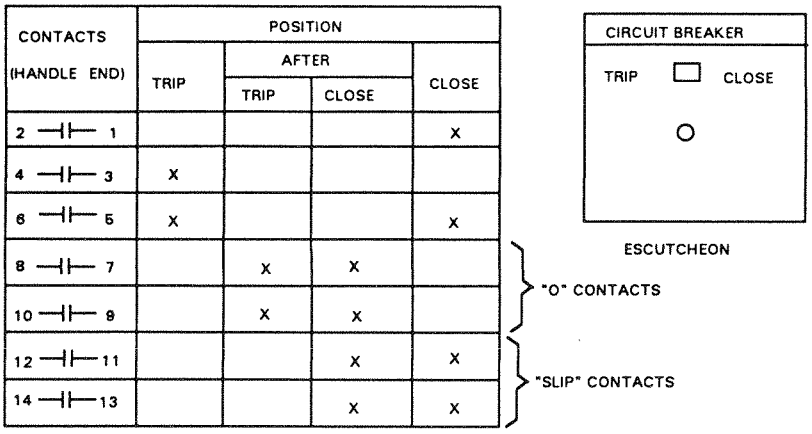
Typically, on overhead distribution circuits, PG&E allows for two line tests after the initial fault; experience has shown that the majority of faults can be restored with two line tests. The first test time is usually set for five seconds, but some consideration is being given to shortening this time to improve quality of service to customers. All reclosing is accomplished within thirty seconds to minimize hazards in case of a third party contact. The first test is sometimes extended to ten seconds, if a generating facility is tied to the distribution line, to allow enough time for their generator to trip off the line.

Reclosing is generally not permitted on underground distribution circuits unless a significant portion of the circuit is exposed to faults beyond overhead risers. A maximum of one test is allowed on any underground circuit to minimize damage to underground conductor.

RECLOSING CONTROL CIRCUITS

The reclosing relay for a distribution circuit breaker is controlled or supervised primarily by the breaker status contact and the manual control switch. If the breaker trips by protective relays, the breaker status contact will enable the reclosing relay to operate. A separate switch (RCO) is used to cut in or cut out the reclosing relay. (See Figure 2).

The "O" and "Slip", from the manual control switch are used to supervise the reclose circuit. If the breaker is opened by operating this control switch, both the "O" and "Slip" contacts are opened, thus preventing the reclosing relay from operating. The only condition when both contacts are simultaneously closed is when the manual control switch is returned to the center position after a close operation. For any other conditions, one of the two contacts will be in an open state and the other closed. This will prevent the breaker from reclosing automatically during manual operation. (Refer to Figure 1).



TYPICAL CONTROL SWITCH CONTACT POSITION
FIGURE 1

When load shedding schemes are employed on distribution circuits, underfrequency relays are used to supervise the reclosing relay's ability to reclose. The underfrequency relay has two trip frequency settings, high and low. The underfrequency relay will trip assigned feeder breaker(s) once the low set underfrequency condition is detected for a period of time. The feeder breaker's reclosing relay will be blocked until the frequency recovers above the high set point, then it will enable a reclose after a three minute time delay. The long block reclose time delay is required by WSCC (Western Systems Coordinating Council) to coordinate reclosing with other utilities in the WSCC.

If there is a cogenerator with stand alone capability on the circuit, an undervoltage relay connected to potential transformer devices on the line side of the circuit breaker will monitor the voltage on the circuit after circuit breaker opens. The reclosing relay is then blocked until the voltage drops below a low set value indicating that cogeneration is off the line.

PG&E is currently field testing the use of high speed reclosing, as a part of service reliability improvement. The basic principal of two line test intervals is maintained, but the first test interval is reduced from five seconds to one-half second. Since many customer complaints are the result of blinking displays on digital clocks and other modern electronic equipment, it is expected that customer service will be improved by reclosing the circuit before digital equipment can drop out. This change may also improve the chances of customers' motors staying on line through a momentary disturbance. This is an example of extending the reclosing scheme beyond its original intent.

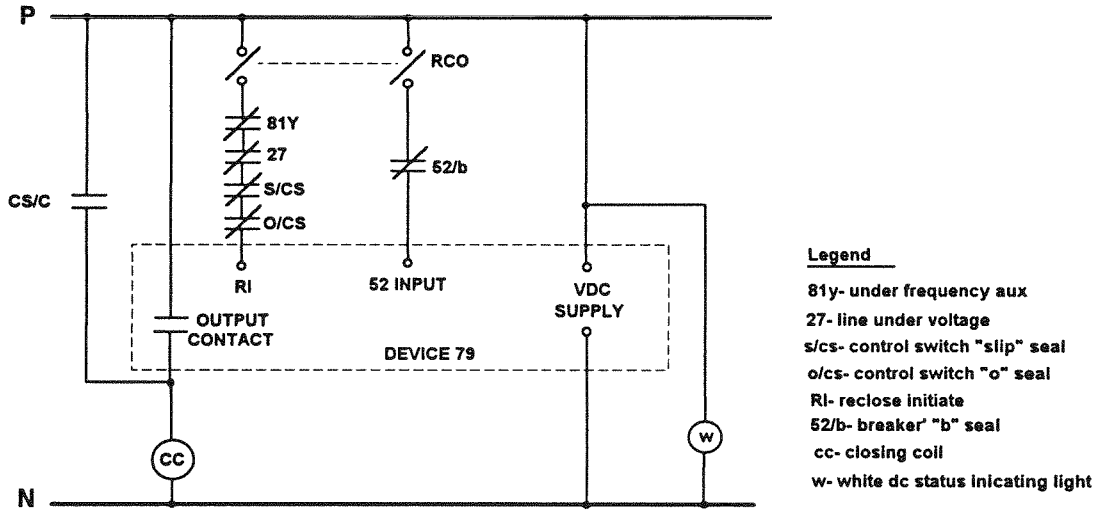
RECLOSING METHOD

MULTIPLE-SHOT RECLOSING RELAY

Multiple-shot reclosing relays are available in electromechanical, solid state and microprocessor designs. Most of these relays consist of one instantaneous and three delay timers. In addition to breaker status and reclose initiate inputs, and close and alarm outputs, they have all or some of the following input and output (I/O):

- Input to block instantaneous reclosers
- Input to drive to lockout
- Output to block instantaneous tripping
- Output to block load tap changer

Today PG&E uses a multiple shot reclosing relay with solid state and microprocessor designs. With the above described I/O s in mind, the functions of the relay is supervised by seals from various appropriate relays which fulfill the distribution reclosing philosophy, such as the scheme depicted in Figure 2.



TYPICAL DISTRIBUTION RECLOSER RELAY
FIGURE 2

TRANSMISSION SYSTEM

RECLOSING PHILOSOPHY

PG&E's transmission line reclosing practices vary and are based on the line configuration, voltage level and type of line protection. Automatic reclosing schemes for transmission lines are more complex than the reclosing for distribution circuits because the circuit breaker must do more than just automatically close to test the line. Our transmission substation automatic controls require continuous line and bus voltage information, via potential devices, and status inputs, from lockout relays and other circuit breakers in the station, in order to perform some output decision namely close or trip functions. (See figure 3.)

The automatic control scheme for transmission line breakers is designed to recognize five different conditions; four reclosing and one tripping. Each condition is wired to a separate feature switch in the control scheme logic. The following feature switches, located on front of the control panel, can be enabled and disabled separately to produce a flexible scheme:

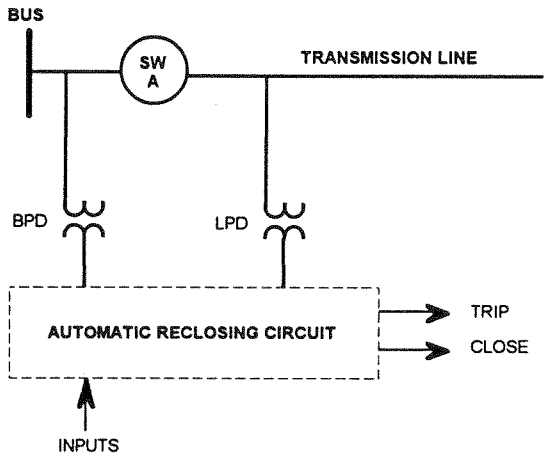
1. Line test (LT); the breaker will close after the reclosing timer times out if the breaker is open, the bus is energized and the line is deenergized.

2. Restore Power (RP); the breaker will close after the reclosing timer times out if the breaker is open, the bus deenergized and the line energized.

3. Parallel (PL); the breaker will close after the reclosing timer times out if the breaker is open, the bus energized, and line energized. For this feature, a synchronism check permission is required, usually from an external relay.

4. High Speed Reclosing (HSR); this feature is applied for a line breaker with pilot protection. The high speed reclosing will be blocked if a three-phase-fault is detected.

5. Power Failure (PF); the breaker will open after an undervoltage relay times out if the breaker is closed and the bus and line are deenergized. This feature is used to sectionalize a station or parts of the system when an area outage occurs. Transmission lines and substation loads can then be automatically restored in a controlled manner once power returns to the source stations.



TRANSMISSION LINE RECLOSING SCHEMATIC
FIGURE 3

Usually, a live voltage condition is defined to be more than 80% of the nominal value and a dead condition is defined as voltage of 50% or less. If a cogenerator is tapped on the line, the dead condition is when line voltage is less than 15 volts.

Whenever a circuit has paralleling capability, a synchronism check relay is added to supervise the reclose of the breaker. Use of this device insures that the breaker will close to parallel only when both bus and line sides potentials are live and the phase angle between potentials is within an acceptable value, usually 30 degrees.

Any of the reclosing can also be disabled or blocked automatically with the use of interlocks from lockout relays or other breakers in the station. Reclosing can be stopped or blocked at any time if the conditions which allow reclosing are no longer satisfied.

In addition to the above criteria, careful coordination of reclosing and tripping times is required so that unwanted tripping or simultaneous reclosing to the same bus, line or transformer does not occur. For example, the line test reclosing times should not be identical at both ends of a transmission line.

HIGH SPEED RECLOSING

High speed reclosing is a feature that is used primarily on bulk transmission lines to immediately return a transmission line to service following a relay operation and thereby maintain the integrity and increase the transient stability of the transmission system. High speed reclosing requires that the transmission line have a pilot protection scheme in service. Reclosing is initiated by breaker status and line relay inputs without checking bus and line voltages or synchronism. Reclosing is one-shot only, multiple recloses are not allowed.

500 KV LINES

All 500 KV lines were originally designed for three pole tripping and high speed reclosing in one-half of a second. Experience has shown that reclosing faster than one-third of a second may result in re-strike of the arc due to the existence of ionized gases from the original fault.

Selected intertie lines have recently been converted to single pole tripping to improve system stability. The high speed reclosing times for these lines has been extended to one second to allow time for extinction of the secondary arc on the open phase. This time was selected after staged fault tests on a 500 KV line demonstrated that the arc would extinguish within 45 cycles. Only one breaker at each end of the line closes by high speed recloser (breaker-and-a half or ring bus arrangement.)

High speed reclosing is initiated by the primary line protective relays which operate via a pilot communications channel. The same relays also block reclosing for multiple-phase or three-phase faults and out-of-step conditions.

If a transmission line is connected to a generating station, the high speed reclosing of the breaker at the generating station is cut out and the parallel feature is cut in. Thus, for a line fault, the breaker at the other end of the line will high speed reclose and the end near the generator will close by parallel feature.

230 KV LINES AND BELOW

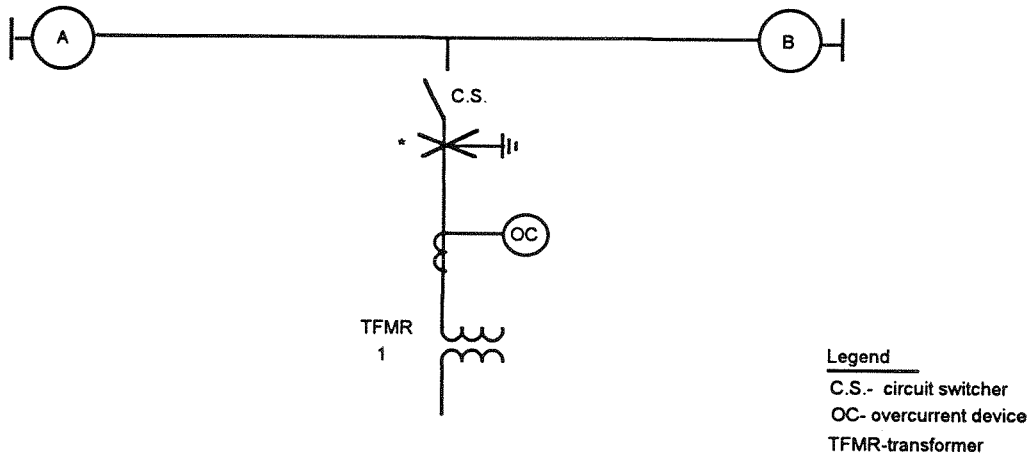
In general, these lower voltage lines have features for high speed and time delay reclosing. The high speed reclose is set for 30 cycles and it is cut in only if the pilot relay scheme is in service. High speed reclosing is blocked for three phase faults. The time delay reclosing is cut in if the high speed reclosing is not in service.

TIME DELAYED RECLOSING

In general, one time delay reclose is used for a transmission line with non-pilot protection. However, some line configurations can require two time delay recloses. The following examples illustrate the reclosing requirements for substation configurations requiring two time delay reclose operations on the circuit breakers:

SINGLE TAPPED STATION

Single transformer substations are commonly tapped on the line through a circuit switcher. Since the circuit switcher has no current transformers (CT), the transformer protective relays are connected to the transformer 's bushing CTs. Thus the area between circuit switcher and the transformer bushing relies on remote terminal relaying for protection. For this type of the configuration, the remote breakers at A and/or B may be equipped with two time delay line tests, or the feature selections and the reclosing times of breakers at A and B may be coordinated to allow two time delay tests. The first circuit breaker to close tests the line with the circuit switcher closed; if the line relays again, the second line test is delayed to allow time for the circuit switcher to open by power failure feature. If the first or second line test is successful, the breaker at the second remote line terminal will automatically parallel. (See Figure 4)



SINGLE TAPPED TRANSMISSION LINE WITHOUT BUS PROTECTION
FIGURE 4

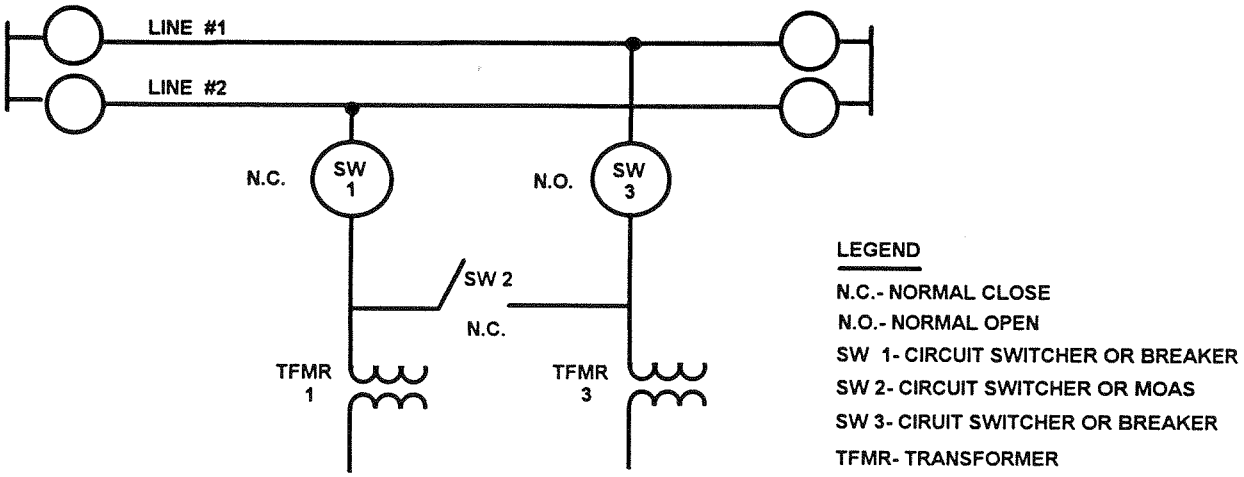
FLIP FLOP STATIONS

To improve service reliability, a station may be switched to either of two separate transmission line sources. In this case, the station is operated with the breaker to the preferred source normally closed and other breaker open as an alternate source. Figure 5 shows this station arrangement. Usually the automatic scheme for the breakers consists only of Power Failure and Restore Power features.

Following system trouble, such as trip of Line #2, SW 1 will open on power failure, and wait for the preferred source to return. If Line #2 returns, SW 1 will restore the station. If the preferred source does not return, SW 3 will restore the station from the alternate source.

On a two transformer station, for a sustained transformer fault, the circuit switcher will remain open and the unfaulted transformer will be restored from the preferred or alternate source depending on the location of the fault.

Care must be taken when applying this scheme to flip flop stations with circuit switchers. Proper coordination between the flip flop station's switches and remote breaker timers are essential, since it is possible to lock out both transmission lines for a permanent station fault.



FLIP FLOP RECLOSING APPLICATION
FIGURE 5

MULTIPLE TRANSFORMER LOOPED STATIONS

The design of multiple transformer stations varies depending on the number of transformers and the voltage level. A typical three transformer station can consist of:

A. Two breakers, and two Motor Operated Air Switches without fault interrupting capability.
B. Two breakers, and two Circuit Switchers with fault interrupting capability (see Figure 6).
C. Four circuit switchers with fault interrupting capability.

In general, the A and B substation configurations are designed with line, transformer and bus protection, while the C configuration has only transformer protection. Configuration B (see Figure 6) will be used to illustrate operation of the station automatics for the following system conditions:

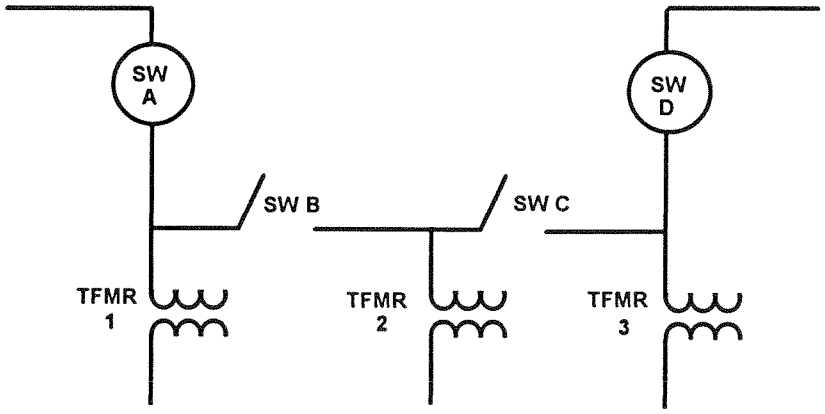
LINE FAULT: For a line fault, the associated breaker will open and reclose back either by line test feature or parallel feature if the remote breaker closes first.

BUS FAULT: The two breakers and two switchers will open by bus tripping relay, then station automatics will test one section at a time until the station is restored. For a sustained fault, the faulted section will be isolated and unfaulted section will be restored. Note that a station with four circuit switchers does not have bus protection, therefore, the automatics will function the same as for system trouble described above.

SYSTEM TROUBLE: Breakers A and D will open by power failure feature. After normal line voltage returns from one of the remote stations, the breaker with a hot line will restore power and the second breaker will close by parallel feature or line test depending on system conditions.

For a station with four circuit switchers, all switchers will open on power failure, and upon power return, they will close one at a time. It is necessary to split up the station in this manner, because it is not known whether the remote breakers have tripped due to station bus trouble, line trouble or system trouble.

TRANSFORMER FAULT: The associated breaker and/or circuit switcher(s) for the faulted transformer will open if the circuit switcher(s) are not overstressed. (Note: an overstress condition occurs when the fault current is above the circuit switcher's interrupting rating as detected by fault detectors in the CT circuits of each of the circuit breakers). If overstress is detected, the fault detectors will block tripping of the circuit switchers and direct tripping to the circuit breakers instead. The appropriate circuit switcher(s) will open once the fault has been cleared by the breakers.



LOOPED STATION RECLOSING APPLICATION
FIGURE 6

The following example will illustrate the operation of this station for a fault on Transformer #2.

For a fault on Transformer #2, circuit switchers B and C will be tripped by transformer protection and the reclosing relay on each of these circuit switchers will start timing. The circuit switcher with the shorter time setting will reclose by restore bus feature and the other one will reclose by the parallel feature. But, if the first circuit switcher has closed into a sustained fault, it will be tripped and both circuit switchers will stay open.

If the circuit switchers are overstressed for a fault on Transformer #2, breakers A and D will open first to interrupt the fault and then circuit switchers B and C will open.

- For a momentary fault, breakers A and D will each close by restore power feature, then the circuit switcher with overall shorter time will restore Transformer #2. The remaining circuit switcher will close by parallel feature.

- For a sustained fault, the first circuit switcher restoring Transformer #2 will cause the two breakers to trip again. The two circuit switchers will remain open and the breakers will restore Transformers #1 and #3.

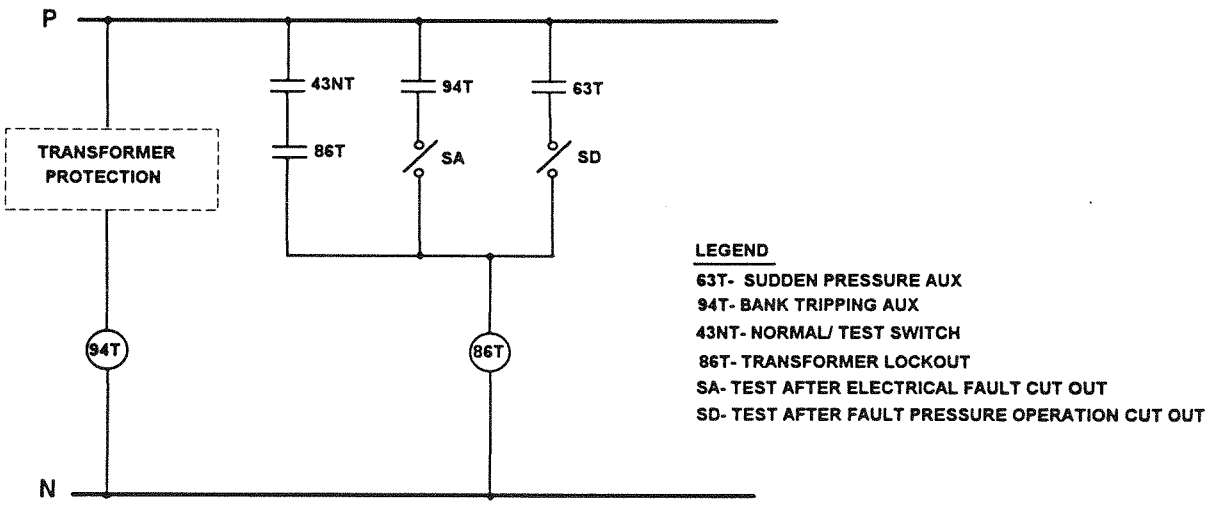
RECLOSING CONTROL CIRCUITS

TRANSFORMER TEST

All substation automatic reclosing is designed to automatically test a transformer after an electrical fault, or a fault pressure relay operation. Feature switches allow reclosing to be selected or blocked for different types of transformer faults. (See Figure 7 below.)

Protective relays trip the circuit breaker and circuit switcher via transformer auxiliary tripping relay 94T. Reset of 94T will permit the automatics to close a circuit breaker to test the transformer. If the fault is detected on reclose, the reclosing relay will run to lockout and other breakers in the station will be prevented from reclosing through interlocks.

Features "SA" and "SD" when open (cut in), will not allow the 86T relay to pick up. This will allow the automatics to test the faulted transformer. If the "SA" and/or "SD" features are closed (cut out), the 86T relay will pick up and the automatics will be blocked from testing the faulted transformer.



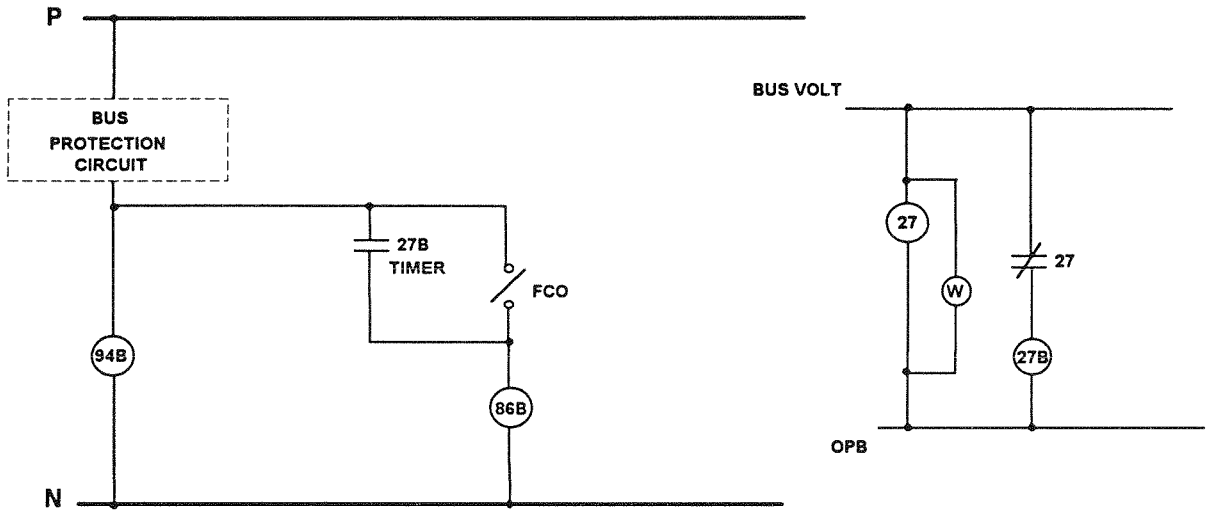
TRANSFORMER RECLOSE APPLICATION
FIGURE 7

BLOCKING TEST OF BUSES

All buses can be selected to be tested once after an electrical fault or the reclosing relays can be allowed to go directly to lockout. Since more than one breaker may have the restore bus feature cut in, the scheme is designed to block reclosing on all other breakers once the first breaker has closed to test the bus and the fault is sustained. (Refer to Figure 8 below).

Bus test feature cut in (FCO open):
When the fault first occurs, the bus protection will operate the 94B relay tripping all bus breakers. Automatic reclosing relays will start timing to close one or more of the circuit breakers. Before the first breaker closes to test, the bus undervoltage relay (27) will time out and pick up the undervoltage timer (27B). If a permanent fault exists when the breaker is closed, the bus protection will again trip the breaker, and the lockout relay (86B) will be picked up through the 27B contact to block any further reclosing. See Figure 9 for an example of how a contact of the 86B is used to block reclosing.

Bus test feature cut out (FCO closed):
The 86B relay will pick up by the 94B relay on the initial fault, and all reclosing will be blocked.



LEGEND
27B- BUS UV TIMER DELAY
86B- BUS LOCKOUT
94B- BUS TRIP
27- BUS UV RELAY

BUS RECLOSE BLOCKING CIRCUIT
FIGURE 8

RECLOSING RULES:

The automatic scheme should function properly regardless of the system's configuration. Some possible system configurations are:

- The system is operating with a breaker open at one of the remote substations.
- One of the breakers or circuit switchers is open at the local station.

The following rules are useful when setting up an automatic reclosing scheme:

- If testing is allowed for a transformer fault, the faulted transformer should not be tested more than once. This is true from one or both sides of the transformer.
- Do not start automatic timing until the auxiliary trip relay (94T or 94B) has dropped out.
- If a lockout relay of one of the transformers is picked up, go through the automatic cycle to restore the other sections, but prevent reclosing of the breaker and circuit switcher associated with that transformer.
- Careful coordination of reclosing times is required to prevent both sectionalizing devices from energizing the same transformer or bus at the same time.
- Power failure times on a station without bus protection should allow remote breakers to trip and test back for a fault on the line.

RECLOSING METHODS

MULTIPLE SHOT RECLOSING RELAYS

As described in the Distribution Reclosing Method section, these relays are available in electromechanical, solid state and microprocessor designs. In the PG&E system, an electromechanical repeat cycle timing relay is the most commonly used device for transmission substation automatic schemes. This relay is used to perform line test (LT), restore power (RP) and parallel reclosing functions. The timing of different functions is determined by "cam" settings on the rotating drum which control the output contacts. The number of functions and timing between them is limited by the number of cams and a fixed timing cycle. This scheme requires one synchronism check relay and several auxiliary relays in addition to the reclosing relay.

For high speed reclosing one single shot reclosing relay is required.

For the power failure (PF) function, one auxiliary relay and one time delay voltage relay are required.

RECLOSING RELAY WITH VOLTAGE AND SYNCH CHECK RELAY BUILT IN

These relays are available in both solid state and microprocessor designs. The operating principle of these relays is similar to the mechanical repeat cycle timer in which various operations are permitted as the cam rotates; the difference being that timing functions are done electronically. Voltage sensing is included to monitor bus and line voltage magnitudes.

To achieve the required versatility, the following features are included:

- Test line features
- Two separate restore power features
- A parallel feature
- A high speed reclose feature
- A power failure feature
- A reclose memory feature

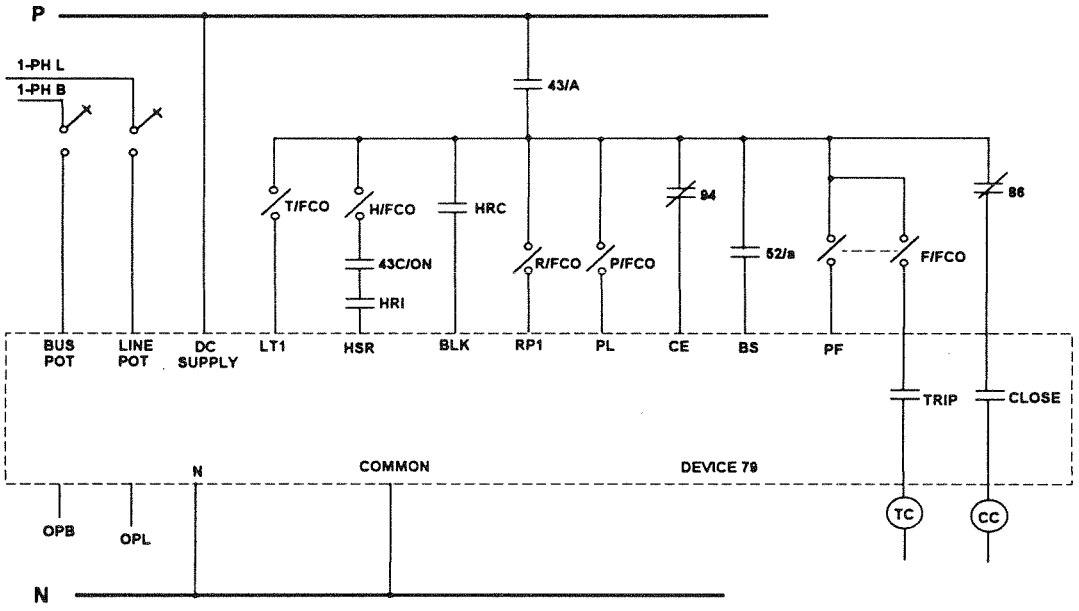
This relay is used most commonly on transmission line breakers which perform the following functions:

- Line test
- Restore power
- Parallel
- High speed reclose
- Power failure

This full package reclosing relay eliminates the following individual relays that were required with previous designs:

- One multiple-shot reclosing relay
- One single-shot reclosing relay
- One time delay undervoltage relay
- One synchronism check relay
- Two auxiliary relays

Use of this relay also simplifies the external wiring. Figure 9 shows the typical wiring connections required for the multiple shot reclosing relay package with all features built-in.



LEGEND
LT1- FIRST LINE TEST ENABLE
HRS- HIGH SPEED RECLOSE ENABLE
BLK- BLOCK HIGH SPEED RECLOSE
RP1- FIRST RESTORE POWER ENABLE
RP2- SECOND RESTORE POWER ENABLE
PL- PARALLEL ENABLE
CE- MASTER TIMER ENABLE
PF- POWER FAILURE ENABLE

MULTIPLE-SHOT RECLOSING RELAY PACKAGE
FIGURE 9

USE OF PROGRAMMABLE CONTROLLER FOR RECLOSING

Automatic reclosing schemes using electromechanical relays or discrete solid state reclosing relays on multiple transformer stations became cumbersome to work with due to the elaborate logic and the amount of components and wiring required. These schemes became very expensive to design, wire, and install. In addition, numerous man days were required to check out all of the connections between auxiliary relays and to prove that the relay logic worked properly. Concurrent with the available technology of the eighties, programmable controllers were seen as a possible solution to simplifying the amount of hardware used since most of the reclosing logic could be accomplished in software. This soon lead to the development of our first design for substation automatics using a programmable controller.

Presently, the programmable controller is being applied at new installations and replaces existing multiple transformer automatic reclosing schemes when a substation is expanded.

The programmable controller has many attributes which have improved the design and operation of station automatics:

- Standardization - In house designed standard reclosing programs which, once proven, can easily be used at several substation locations. A standard programming format can be followed to create standard designs for various substation configurations.

- Flexibility - Some functions inherent to the program can be readily modified to operate the automatics as required. For example, the reclose timer settings can easily be changed without the need to bench test a relay. A standard design can easily be customized for a new substation configuration by changing the software; and the external connections to the programmable controller may remain the same.

- Monitoring - The operating panel displays for each circuit breaker (or circuit switcher) has indicating lamps to display the status of the reclosing circuit for that breaker - whether the recloser is timing to reclose, has already closed, or has locked out. The processor in the programmable controller has continuous self-monitoring which will produce an alarm if the processor has failed, or lost a power supply.

- Operator Interface/Testing - A test panel allows operators and technicians to run a functional test, simulating station automatics, without the need to clear station switches. A mimic bus is provided to show simulated breaker and line potential status during testing.

- Documentation - The software provides means for documenting the logic with labels and annotations so that it can be easily followed. The documentation can also be printed to hard copy to save as a reference.

- Upgrade Additions - The programs are planned and designed for future station expansion, such as the addition of a transformer, so that any required program changes are minor. All that is required is to install additional I/O and wire.

- Maintenance - Minimal hardware maintenance is required since the program is self-monitoring. There are fewer external auxiliary relays to test. Only a periodic functional test is required.

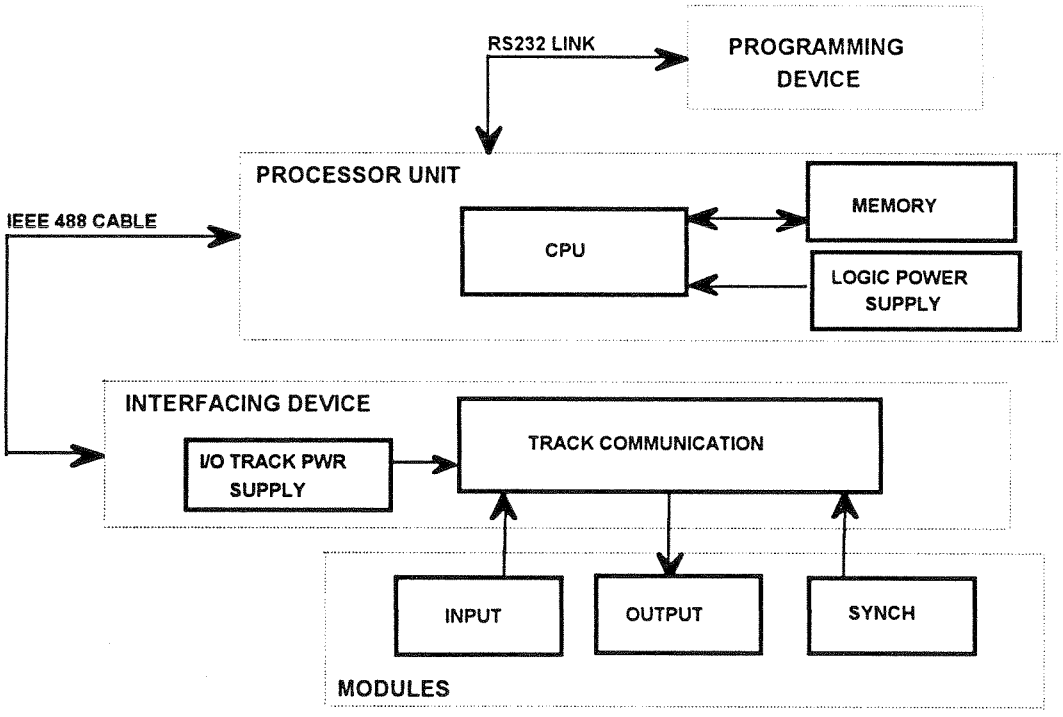
- Installation - Installation and testing is simplified because of fewer components, and because the logic has already been proven. The amount of work required to create and check out wiring diagrams and DC elementarys has been reduced significantly.

Since the processor currently being used is designed for industrial applications, it has had its share of problems operating in a substation environment because of induced switching transients. Many of the problems have been solved. Improvements on the processor hardware's ability to withstand the substation environment are presently being developed.

The following characteristics and features of the programmable controller make the reclosing functions possible:

HARDWARE

A basic programmable controller consists of three parts, the processing unit and the interfacing devices and the modules. The processing unit is comprised of a CPU, Central Processing Unit, Memory, and CPU power supply. The interfacing device consists of the track which houses the modules and serves as a communication link between the processor, modules, and the I/O supply which supplies station DC power to the modules. The modules are the VAC/VDC discrete input modules, used to for input of analog and digital status signals from the substation to the CPU, and VDC discrete output modules used to send status and control signals from the CPU to indicating lights and station switches. The controller may have communication ports available for connecting with programming devices for the purposes of programming the CPU or interrogating the processor's network. Overall, the processor's main function is to gather external information and respond to the information as programmed in the software. (See Figure 10)



PROGRAMMABLE CONTROLLER ARCHITECTURE
FIGURE 10

The following further details the programmable controller in the reclosing system.

Processing Unit

CPU Unit-
The central processing unit uses a 6502 8-bit processor which has up to 6k of user memory for ladder logic software. It continually examines I/O status and user program and calculates the proper responses for the outputs. The CPU performs several self-check routines and tests the I/O tracks and module communication.

Logic Power Supply-
115/230 VAC @ 60 HZ or 48/125 VDC which is converted to supply internal logic voltage to the controller. RAM is backed up by 2-D size alkaline batteries.

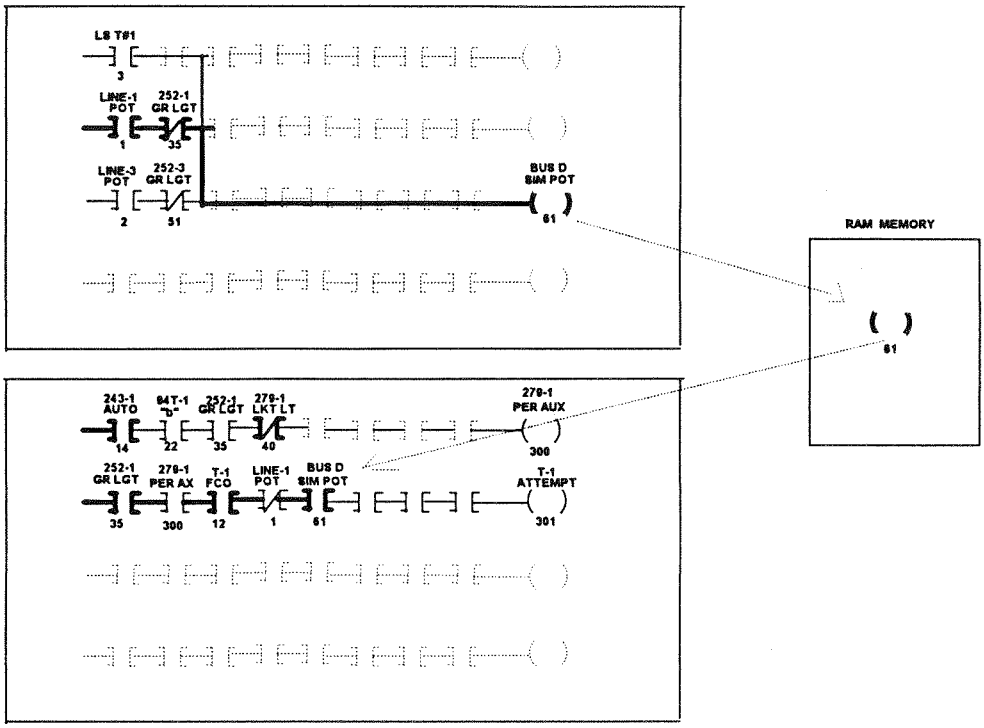
Memory-
User memory consists of CMOS RAM with battery backup, and user non-volatile memory EAROM.

Discrete I/O points-
The processor can handle up to 256 maximum discrete I/O points. This is equivalent to 4 full tracks of modules (8 inputs per module, 8 modules per track). A typical reclosing program requires a maximum of two full tracks.

Internal Relay Coils -
Up to 240 logic output coils can be programmed. The maximum logic output coils used in the reclosing program requires about 95 internal relay coils.

Timers/Counters-
Up to 64 timers/counters can be programmed to count up or down. The maximum number of timers used in the reclosing program require 25 timers.

Scan Speed-
Varies with how the system is programmed and which sections of logic are active or non active. The processor scans the entire program sequentially, page by page. Each page is scanned from left column (8 maximum) until the right most coil column is met. The results of the coil column of each page are then stored in RAM memory and are immediately available for use as contacts on following pages. Then on the next scan, all data pages which hold logic registers which are used to process timers and latch hold logic, are then read line by line which instructions are activated. (Refer to Figure 11.) Average scan time can be minimized by manipulating the ladder logic's architecture. The typical scan time can range from a minimum of 25 msec to 150 msec. Our programs requires no more than 50 msec total scan time. Newer model controllers, running at a faster clock rate, can reduce the scan time by a factor of four.



PROCESSOR'S METHOD OF SCANNING PROGRAM
FIGURE 11

Interfacing Device

One to 4 tracks can be tied to one processor. Each track has a voltage supply interface, and is connected to the processing unit via IEEE 488 cables (GPIB). Newer models use twisted pair wires, thus reducing the CPU's exposure to voltage transients produced via tracks during switching or faulted conditions.

Modules

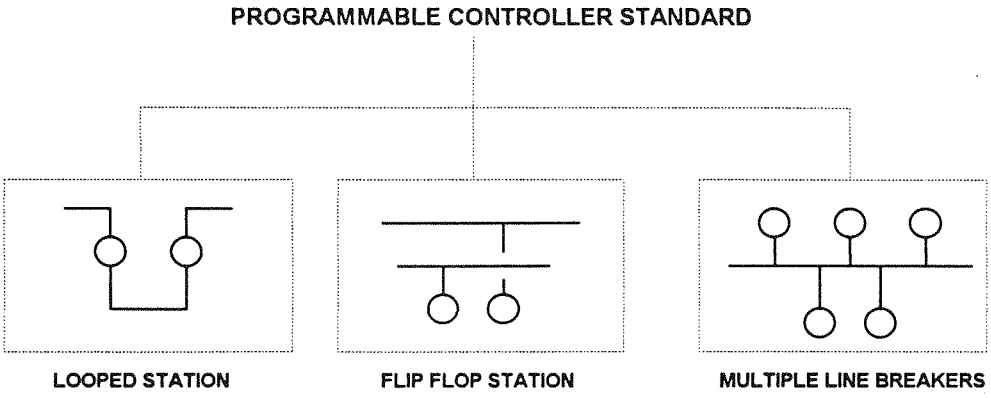
High density input/output modules - (8 points per module) of the following types: 48 VDC or 125 VDC input modules, 48 VDC or 125 VDC output modules, and 120 VAC input modules.

Synchronism Check Card, is a special module made for paralleling reclose application. It is capable of checking synchronism between a pair of potentials, two sets on one card. The card includes measurement of four voltage magnitudes and two phase comparators, and LED indicators. This card was custom developed for this application by one PLC manufacturer. Other manufactures may require an external synchronism check relay. Standard programs are designed to allow the option for use of an external synchronism check relay.

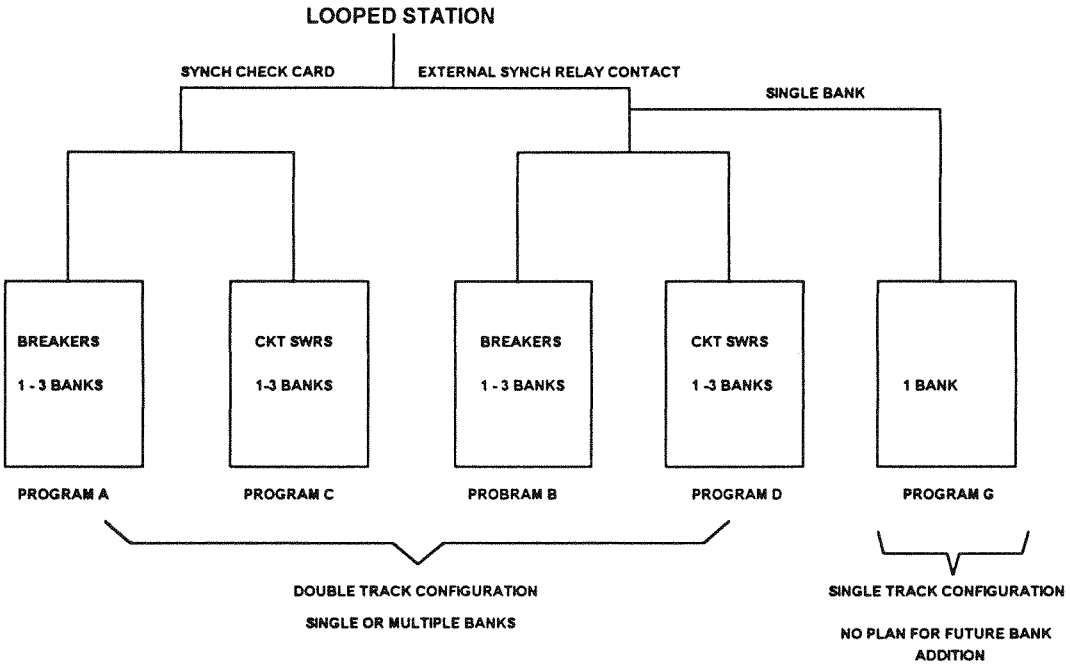
SOFTWARE

A variety of programs were written to be used as a basic architecture which can be easily modified to meet any station configuration, and maintain a consistent style of logic format and nomenclature. The following figures illustrate the various standard programs created (Refer to Figures 12, 13, 14, and 15). Programs are categorized into three station type configurations, namely looped, flip flop and multiple line

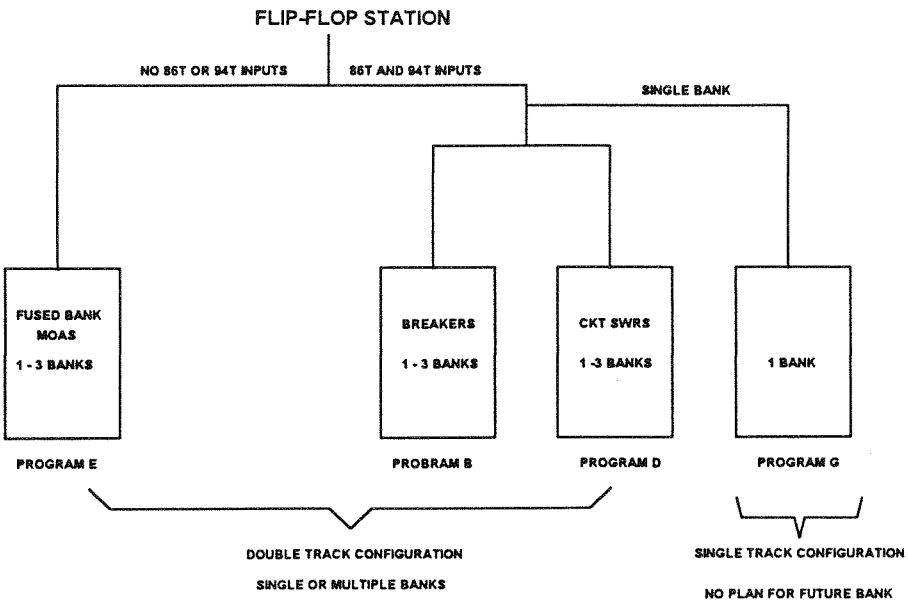
breakers. With each station type, programs were tailored more specifically to reduce the need for modification.



SOFTWARE IS DETERMINED BY TYPE OF STATION
FIGURE 12



LOOPED STATION SOFTWARE
FIGURE 13

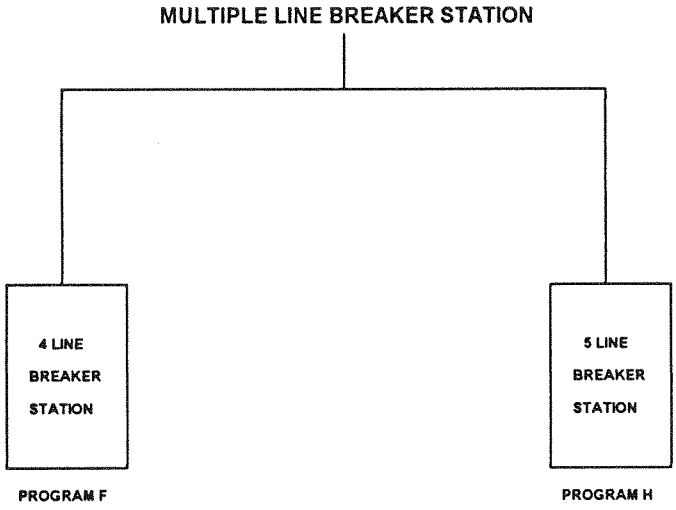


NOTES:

THE FOLLOWING FEATURES ARE NOT REQUIRED FOR FLIP FLOP STATION-
(UNLESS THERE IS PLAN FOR RUNNING STATION LOOPED)

TEST LINE FCO
SECOND LINE TEST FCO
PARALLEL FCO- SYNCH CHECK RELAY INPUT IS NOT NEEDED.

FLIP FLOP STATION SOFTWARE
FIGURE 14



MULTIPLE LINE BREAKER SOFTWARE
FIGURE 15

TEST PANEL FOR ROUTINE AND MAINTENANCE TESTING OF AUTOS

A test panel was designed to provide a means of testing the programmable controller's automatics without tripping and closing the breaker and circuit switchers. These tests verify the controller logic and wiring up to and including the trip and close output relays.

Additional design went into the wiring of the scheme, so that whenever a routine function check is being performed, the station will remain protected with appropriate fault tripping relays. Transformer tripping is transferred to a bus tripping auxiliary while the controller is in test mode, therefore transformer tripping still exists during test mode but is less selective. During the test mode, the controller output is used to drive the auxiliary relays which serve as dummy breakers, and run appropriate indicating lights.

The test panel contains the following features:

- Line potential switches and indicating lights.
- Bus section potential indicating lights
- Test-normal transfer switch.
- Breaker and circuit switcher control switches and indicating lights.
- Bus fault push buttons.
- Transformer fault push buttons.
- Recloser target lights (PF, T, R, P).
- Recloser status lights. (Reset, Timing, Lockout.)

A blue light was added to supervise the auxiliary test relay contacts, and is on the front panel marked as transfer under test. It provides means of indication, for the tester, that the transfer (switch is in TEST position) is complete and safe to proceed.

Bus faults can be simulated by use of the bus-1 and bus-3 buttons. The bus-1 push button is used for faults fed from line-1. The bus-3 push button is used for faults fed from line-3

Both push buttons are used for a fault fed from both lines. To simulate a permanent fault, the push button must be pressed a second time when the faulted bus section is re-energized.

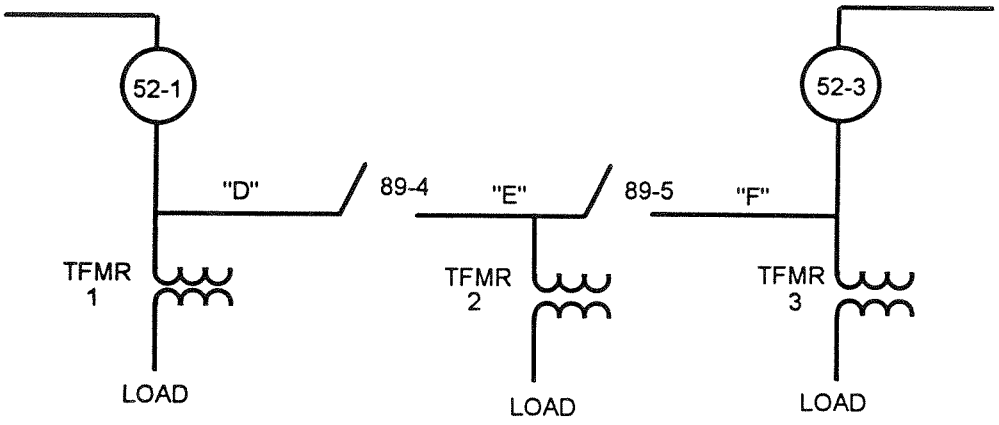
Individual fault push buttons are provided to simulate faults for each transformer. These work through the fault pressure scheme. Since the fault pressure relay may have a closed period of only two cycles, a rapid button motion should be used to simulate this relay.

To simulate a permanently faulted transformer, the push button is pressed a second time after the transformer has been re-energized.

Power failure can be simulated by opening one or both line potential switches depending on whether the bus is closed or split.

PROGRAMMABLE CONTROLLER USED FOR TRANSMISSION STATION RECLOSING

PG&E has developed programs which can be used for a single tapped station, a double tapped station or a looped station with one, two, or three transformers. The following information is for a three transformer station as shown in Figure 16. This station configuration has the most elaborate software ladder logic program.



THREE TRANSFORMER STATION CONFIGURATION
FIGURE 16

INPUTS

The inputs used by the program (via input modules) are as follows:

Line Potentials-
Buses D, E, and F potentials are developed internal logic from line potentials 1, and 3 and switch positions 1,3, 4, and 5.

43/A-
Manual/auto feature switch for each position (1, 3, 4, 5)

FCOs-
Feature cutout switches of the following:

- Test LT-1, LT-3, LT-4, LT- 5
- Restore RP-1, RP-3, RP-4D, RP-4E, RP- 5E, RP-5F
- Parallel P-1, P-3, P-4, P-5
- Power Fail PF-1, PF-3
- Preferred Source N-1, N-3, N-4, N- 5

The N feature is only available through this program's ladder logic scheme, and is very important for flip-flop stations, because it allows to restore the station to its preferred source first before transferring to the alternate source. The N feature is cut in for the switch that it is to operate open.

Parallel is always cut out on all switches when it is desired to operate a switch open in the station.

For a full three transformer station, switches 4 and 5 will have two restore features. The program allows a restore attempt from either direction of the looped station. In this case switches 4, and 5 can restore from either buses adjacent to them, bus sect. E and their respective end bus sections D and F.

52/b or 89/b-
Circuit breaker or circuit switcher's "b" seal 1, 3, 4, 5 (or an "a" seal from their auxiliary relays)

25a-
External Synchronism Check Relay e.g. IJS contact ("25a") which is not required if a synchronism check module is used.

43T/N-
Normal/Test mode switch

CS/T-and CS/C-
Test Panel's control switches to trip and close 1, 3, 4, 5 under test mode.

94T-
Output from transformer tripping auxiliary relay (transformers 1, 2, 3) "b" contact

94B-
Output from bus tripping auxiliary relay 1, 3, "b" contact

86T-
Output from transformer tripping lockout auxiliary relay (transformers 1, 2, 3) "b" contact

OUTPUTS

One benefit of using a programmable controller is that outputs can be readily programmed to provide more than the expected trip, close, lockout, and reset capabilities of a reclosing scheme. PG&E programs are written to also contain logic which produce outputs listed below:

30XC- Controller failure alarm indicates a controller malfunction, or dc loss. Along with the alarm, all outputs are set to be disabled.

30PF- Power failure disagreement alarm indicates that their is a disagreement between the controller trip output and the breaker position, and is supervised by an electromechanical undervoltage relay.

30LB- Low battery alarm used to indicate that the processor's batteries are weak and needs to be replaced.

Recloser Target Lights- (PF, T, R, P)

Recloser Status Lights- (Reset, Timing, Lockout)

Synchronism output- to be provided for external synch check relay.

TIMERS

The largest reclosing software program requires the use of twenty-five of the controller's internal timers. Additional timers not standard with any other relaying schemes are used for coordinating the program with external hardware that it is tied to; e.g. during closing of a breaker or parallel.

Each switch's features are assigned a timer; Test, Restore, Parallel, Preferred Source, and Power Fail, as described under FCO inputs. Timers start timing, when the appropriate conditions exist to produce a trip or close output, and reset if voltage conditions change. Timer settings can be easily monitored and changed by a peripheral device via an RS232 cable.

In addition to feature timers, the following timers are included: Reset, Lockout and Close output duration. Reset and lockout logic is written to simulate a typical reclosing scheme. A sufficient amount of delay is assigned to the Close Output Duration timer to assure the close output is long enough for breakers without an anti-pumping mechanism to operate. This timer resets when the associated interrupting device closes.

PROGRAMMABLE CONTROLLER USED FOR 500 KV RECLOSING

Programmable controllers were first applied in 500 KV stations where the transmission lines had been converted to single-pole tripping. This was seen as an ideal application for the programmable controller due to the complexity of different reclosing times and control actions required for one pole and three pole schemes.

For 500 KV breakers, programmable controllers are used to provide single pole, three-pole and parallel reclosing. Inputs to the controller are from breaker seals, protective relays (Reclose Initiate and, Reclose Block), selector switches, test push-buttons and line potentials. Outputs energize external auxiliary reclosing relays and target lights.

High Speed reclose time is set for 60 cycles for single-pole operation and 30 cycles for three-pole operation. The reset timer is set for 10 seconds and parallel timer is set for 11 seconds after a successful line test. The lockout timer is set for 15 seconds following an unsuccessful reclose.

Selector switch inputs

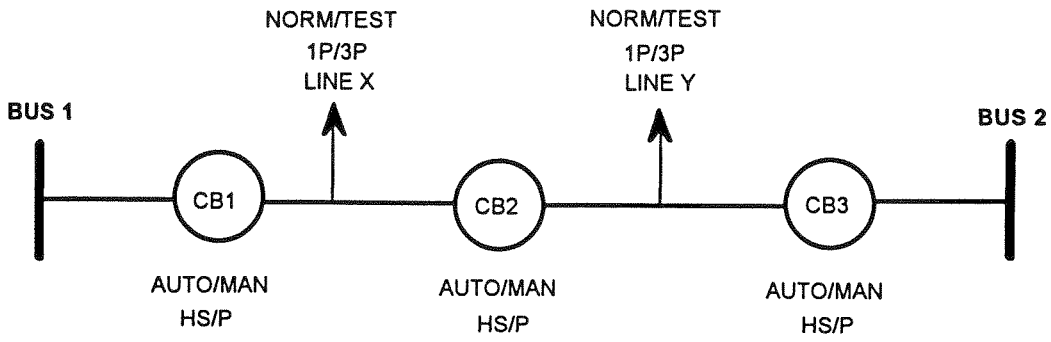
AUTO/MAN (Automatic/Manual) - One Selector Switch per breaker. This is the main control for the reclosing; it functions as a reclose Cut-out Feature switch. When this switch is in the "MAN" position, reclosing is disabled and breaker can only be closed manually. In "AUTO", the breaker will reclose only when no reclose block (RB) signal is present and a reclose initiate (RI) signal is received from the primary relays.

HS/P (High Speed/Parallel) - Feature Select - one Switch per breaker. With the switch in the "HS" position, the breaker recloses High Speed (single-pole or three-pole). In the "P" position, the breaker will trip three-pole for any type of fault and will be allowed to Parallel when conditions permit.

1p/3p (Single pole/Three pole) - Pole Select, one Switch per line. With the switch in the "1P" position, the line breakers will operate single-pole or three-pole depending on fault type; with the switch in the "3P" position, the breakers will trip and reclose three-pole.

NORM/TEST - Programmable Controller Selector, one Switch per line. The station is operated normally with the switch in the "NORM" position. In the "TEST" position, the switch disables reclosing; it also ties phase A, B and C trip wires together so that in case of a fault, the breakers trip three-pole.
This avoids a time delay three-pole trip by pole disagreement relay in the event of a single phase fault.

Only one breaker per line terminal has high speed reclosing cut in, the other has parallel. Thus for single-pole tripping, the breaker that is selected to high speed reclose will trip and reclose single-pole. If the test is unsuccessful, the breaker will open three-pole and further reclosing will be blocked. If the test is successful, the other breaker will parallel.



500 KV LINE RECLOSING SELECTOR SWITCHES
FIGURE 17

RECLOSING PROGRAM:

The present design uses one processor for three adjacent breakers (bay). (See Figure 18).
The salient features of the programs are described in the following paragraphs

- As soon as a RB signal from any line relay reaches the controller, it seals in and prevents reclosing. The RB seal-in circuit can be reset from the RESET button on the switchboard.

- Opening of a breaker pole (52b made) or operating a test trip push button (PBT) will pick up a Green target light. This Green light is used, instead of a 52b, in all program logic to indicate a tripped pole.

- A pole discrepancy logic has been developed for each breaker. At present this logic is used for reclosing tests only, but it can provide an output to trip the breaker for pole disagreement.

- Permissive conditions for Line Test are set up separately for single-pole and three-pole reclosing. The logic for a single-pole reclose output requires pick up of a minimum timer, set for 40 cycles, and a Test timer, set for 60 cycles. When the single-pole reclose timer completes its time, an internal "Test single-pole" relay is picked up for 0.5 seconds which in turns picks up the reclose output relay 79. The timer for three-pole reclosing is set for 30 cycles; it picks up an internal "Test/Parallel" relay which picks up all three 79 output relays.

- The program also includes logic for the special arc monitoring module which is still being evaluated. The module is designed to detect when the secondary arc on the faulted phase has extinguished, and the recovery voltage has returned to a nominal 60 hz value. The module will allow a faster single-pole high speed reclose time if it detects that the arc has extinguished sooner than 40 cycles.

- Permissive logic for paralleling, the timer is set for 11 seconds.

- An anti-pump logic has been included in the program. Together with the Line Test relay, an internal Test Lockout relay is picked up and sealed in; it prevents additional reclosing until the reset timer times out (if the breaker trips within 10 seconds after the first reclose, it goes to lockout).

CONTROLLER OUTPUTS:

Ten target light outputs are provided on the operator's control board to show the status in the TEST condition for each breaker as listed below:

• POLE A OPEN	GREEN
• POLE B OPEN	GREEN
• POLE C OPEN	GREEN
• 3-POLES CLOSED	RED
• RESET	WHITE
• LINE TEST 1-POLE	AMBER
• TEST 3-POLE	AMBER
• PARALLEL	ORANGE
• LOCKOUT	BLUE
• RECLOSE TIMING	YELLOW

The following alarm outputs are provided:

- Alarm for controller failure and for track power failure.

- Indicates low voltage of target lights power supply (the target lights have a 24 VDC power supply).

TEST FEATURES:

Ideally the tests should check the reclosing circuits and components without a service interruption or a need for a "clearance":

1. Check the condition of the Input and Output modules, and verify that the processor runs the program correctly.

2. Check the selector switches and the switchboard wiring.

3. Check the operation of line relays RI and RB contacts and the related switchboard wiring.

4. Check the breakers seals (52b) and the wiring to the seals and to the closing coils.

Tests covered under items 1 and 2 above can be performed with the line energized (breakers closed) and with no need for a line clearance. Tests covered under items 3 and 4 can be performed one breaker at a time, whenever a primary line relay is under test (with provisional clearance). The idea is to trip and reclose only one of the two line breakers while the other line breaker remains closed and the line carries power.

The condition of the target lights can be checked at any time using the LAMP TEST push-button on the switchboard.

SECURITY:

Failure of the controller, or testing of the reclosing features will not produce a trip or reclose output (it cannot cause a breaker operation). If the protective relays operate because of a line fault while testing is in progress, the breakers will trip three-pole and will not reclose.

CONCLUSIONS

When properly designed and applied, automatic reclosing schemes can be counted on to maintain power system integrity and to provide more reliable service to the customer. Automatic reclosing in the station can restore power in a systematic and logical manner independent from supervisory control systems (SCADA) that are dependent on reliable remote communications.

While we continue to apply many of the existing designs, PG&E is looking for new technology to improve the substation automatic reclosing schemes and to make the controls smarter and more reliable. One goal is to develop an automatic reclosing program that will run in the local station's existing SCADA RTU (Remote Terminal Unit), and use the substation status data to provide circuit breaker automatic control. This is another step in using new technology towards a totally automated or "smart" substation.

ACKNOWLEDGMENTS

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