MINIMIZING REFINERY UPSET DURING POWER INTERRUPTIONS USING PLC CONTROL

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Robert A. Hanna
Senior Member IEEE
Petro-Canada Products
Oakville, Ontario,
Canada

Peter Bulmer
Member IEEE
Stone & Webster
Toronto, Ontario
Canada

Rasul Kohistani
Senior Member IEEE
Stone & Webster
Boston, Mass.
U.S.A.

ABSTRACT

When a refinery electrical distribution system experiences severe voltage dips or short duration power interruptions, on-line starters de-energize and motors stop resulting in plant upset. To minimize the impact of momentary power disturbance, it is highly desireable that motors used for critical services be restarted automatically and sequentially. This paper presents typical utility incoming power disturbance investigation, criteria for selecting critical motors, main frame computer studies to determine the system optimum re-acceleration load, and development and design of Programmable Logic Controller (PLC) programs. The reporting functions to verify re-acceleration system performance are described and field measurements are presented.

INTRODUCTION

A refinery continuous process operation is very vulnerable to severe voltage dips lasting few cycles or momentary loss of incoming power supply. Motors trip at random depending on the severity of voltage disturbance and this causes process unit upset, safety hazard, environmental problems and loss of production.

To avoid complete plant shutdown and minimize process disturbance, motors used for critical services must be re-accelerated quickly and sequentially. Traditionally, hard wired time delay under voltage relay schemes have been used for this purpose [1], [2]. Today's generation of inexpensive small PLC's offer many advantages over relay systems including:

- protection against high transient shaft torques caused by the re-application of line voltage before the motors internal voltage has decayed to safe limits.
- Restriction of motor starts per hour.
- Flexibility in motor sequential starting.
- Generation of historical data verifying the performance of the system under disturbance conditions.

This paper is a case study for the re-acceleration system installed at Petro-Canada, Lake Ontario Refinery, Mississauga Plant. The work was commissioned because the refinery's incoming power supply is subjected to an average of six severe voltage disturbances per year. This paper covers typical incoming power disturbance investigations, basis for selecting critical motors, computer studies for motor re-acceleration and development and design of PLC programs.

OVERVIEW OF REFINERY ELECTRICAL DISTRIBUTION SYSTEM

Petro-Canada, Lake Ontario Refinery, Mississauga Plant is fed from two overhead incoming lines at 27.6 KV voltage level. Fig. 1 shows simplified single line diagram for electrical distribution system. The two 27.6KV overhead lines designated as 67M9 and 67M2 originate from Ontario Hydro Lorne Park Substation approximately 5 miles away. Additionally eight 27.6KV overhead lines originate from same Hydro Substation and feed other customers in the area. Both lines 67M9 and 67M2 are dedicated to the refinery and each line is capable of carrying the total refinery demand load upon loss of the other line. Total refinery demand load is approximately 19 MW. The refinery has two main substations, "A" built in 1965 and "B" built in 1978, and power is distributed to unit substations via underground cabling at 4160V and 2300V levels. Incoming power to substation "B" is controlled by incoming breakers 52-1 and 52-2 together with a normally open bus tie circuit breaker 52-T. The incoming breakers are electrically interlocked with the bus tie in order that if one line is lost the bus tie automatically closes. Approximately 1.6 second time delay is applied between line breaker opening and tie breaker closing to prevent nuisance breaker operation and tie breaker fast closing. Ontario Hydro does not permit paralleling of two incoming lines using tie breaker 52-T. The automatic transfer scheme for substation "A" is similar to that of substation "B".

The major cause of refinery electrical supply problems are not attributed to the actual long time loss of a line, but rather due to lightning strikes on the Hydro's overhead lines and faults on lines feeding other Hydro customers. The area experiences on the average 20 thunderstorms in a year.

In order to quantify the quality of incoming power supply an advanced on-line power monitor was installed in August 1990 [3] to record the waveforms of voltage and current fluctuations for the two incoming lines as well as the breakers status. Figures 2 and 3 show momentary loss of voltage on line 67M9 for 900 msec caused by breaker tripping and reclosing as a result of line to ground and line to line faults respectively.

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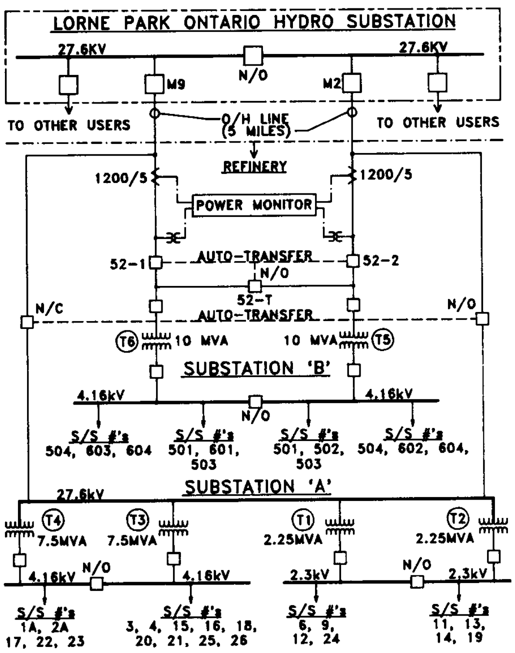


FIG. 1 – SIMPLIFIED SINGLE LINE DIAGRAM
LAKE ONTARIO REFINERY – MISSISSAUGA PLANT

CRITERIA FOR SELECTING MOTORS FOR RE-ACCELERATION

Two aspects required evaluation to specify the basis of the re-acceleration system.

1) Process considerations.
2) Electrical considerations.

PROCESS CONSIDERATIONS

Of primary concern is to maintain the operation of the utilities services, such as steam, air, water and equipment lubrication since without these the plant will shut down. Therefore only a minimum time can be tolerated before restarting after a power interruption. Refining processes are comparatively less critical as they can ride through interruption of longer durations.

The general criteria used by the process engineers to establish priority ratings was as follows:

a) Avoid operation of Relief Valves.
b) Protect Process Heaters.
c) Protection of catalyst and runaway reactions.
d) Personnel safety.
e) Environmental considerations - Maintain Sulphur Plant incineration, Asphalt Plant charcoal filters, sand filter charge pumps and waste water phenol pumps.

These considerations led to the selection of the following priorities:

Priority #1: Utilities - steam, air, water, lubrication.
Priority #2: Hydrobon platformer.
Priority #3: Lubes manufacturing units.
Priority #4: Crude Unit, Hydro Desulfurization Unit (HDS) & Isomerization Unit.
Priority #5: Distillate Desulfurization Unit (DDS).

The situation where critical drives had both an electric motor and a steam turbine prime mover with an "auto" start interlock between them, was addressed as follows. In the case of a utilities service the electric motor would be included in the re-acceleration system. For other process applications, the steam turbine would be relied upon to maintain flow.

ELECTRICAL CONSIDERATIONS

Whereas reciprocating compressors perform critical process functions, investigation into the automatic re-starting of such machines was found to be not practical.

Under normal starting conditions a reciprocating compressor driven by an induction or synchronous motor is started unloaded. Once the machine is up to rated speed, the compressor is then loaded with the use of both manually and electrically operated loading valves.

Upon severe voltage dip or momentary loss of power, the motor will trip and the loaded compressor will come to a standstill very quickly, namely in few revolutions. If an attempt to restart the motor is made while the compressor is still in the loaded condition, the motor starting torque is not sufficient to overcome the load and it will stall. The compressor would therefore have to be first manually unloaded before starting the motor. Consequently, it was agreed to exclude the reciprocating compressors from the re-acceleration scheme. Motors driving centrifugal compressors, pumps and fans can be automatically re-accelerated and were included in the study. In this particular refinery the only use of synchronous machine is to drive reciprocating compressors.

SURVEY OF EXISTING MOTORS

In order to facilitate motor data review by the process engineers, prioritize on individual critical motors and to carry the data needed for computer studies it was decided to produce a spreadsheet format as shown in Fig. 4.

The motors are grouped by substation which also identifies the process unit. This together with the drive name and tag was sufficient to facilitate process priority selections. For computer study, actual locked rotor current were required for motors above 100 HP, below 100HP default values were used.

The survey listed a total of 950 motors out of which 169 motors were identified by process engineers for critical services and require automatic re-acceleration. The total re-acceleration load is 15,000 HP.

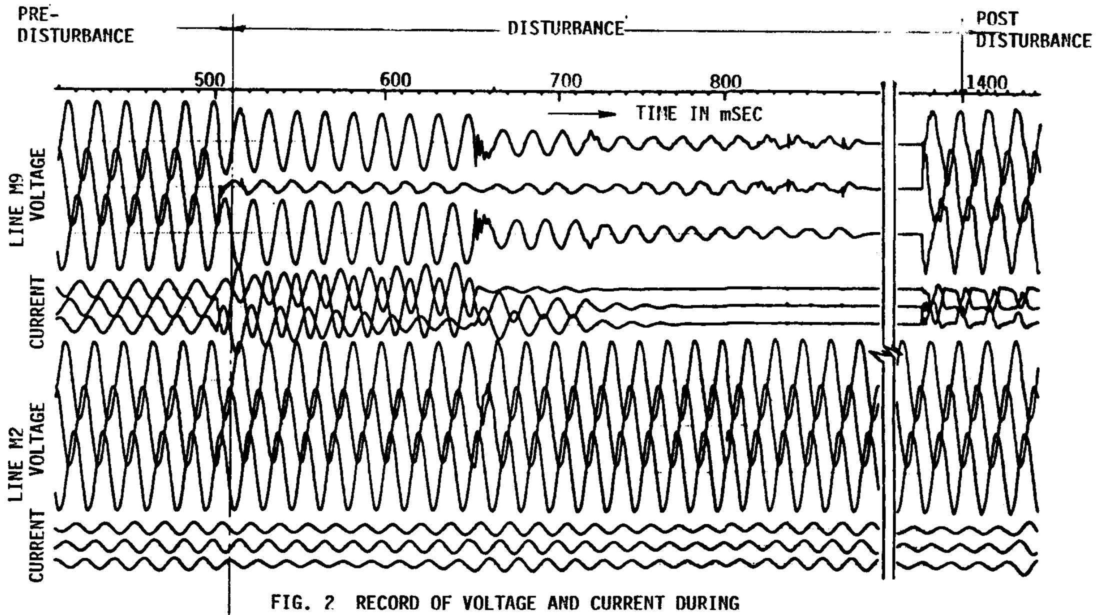


FIG. 2 RECORD OF VOLTAGE AND CURRENT DURING MOMENTARY LOSS OF POWER ON INCOMING LINE M9 (GROUND FAULT ON PHASE B)

EVENT DATE: APRIL 7, 1992 AT 15:14:16.510

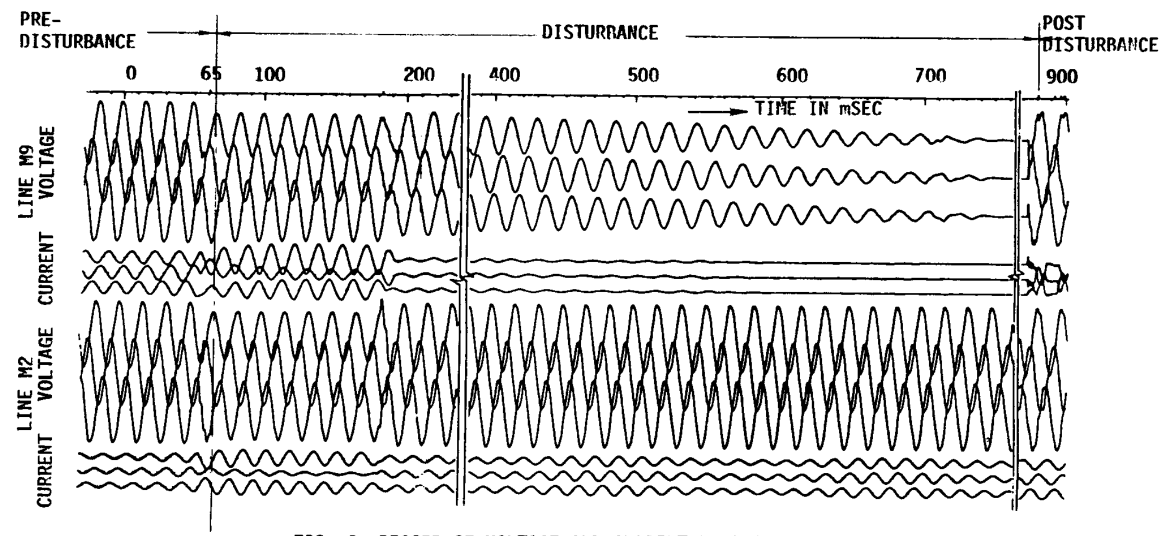


FIG. 3 RECORD OF VOLTAGE AND CURRENT DURING MOMENTARY LOSS OF POWER ON INCOMING LINE M9 (LINE TO LINE FAULT)

EVENT DATE: APRIL 8, 1992 AT 15:14:47.065

PRIORITY DEFINITIONS 1) UTILITIES 4) CRUDE, HDS & ISOM 2) HYDROBON 5) DDS 3) LUBES SYSTEM									
EQUIPMENT	EQUIP	RE-ACCEL. PRIORITY 1	2	3	4	5	SUB. #	HP	VOLT
CHARGE PUMP SOUTH	031965	*					1A	75	575
HDS FEED PUMP	P-109				*		16A	125	575
DDS CHARGE PUMP	1-J					*	21A	350	4000
HYD. CHARGE PUMP E	PM 1A		*				23A	350	4000
LP SOLVENT PUMP	MP-102			*			502	350	4000

FIGURE 4: ABRIDGED EXAMPLE OF SPREADSHEETS AFTER PROCESS REVIEW. FOR CLARITY ONLY 1 MOTOR PER PRIORITY IS SHOWN.

COMPUTER SIMULATIONS

When normal power supply to a group of running motors having various types of driven loads, such as pumps, fans and compressors is interrupted, fast re-energization of the motors is essential to retain process integrity and minimize safety risk. The choice between fast transfer of all the motors to an alternate supply source as well as sequential re-acceleration of groups of motors depends on the following main factors:

1. Duration of unavoidable power interruption.
2. Stiffness and capacity of the alternate supply source.

During the time when motors are separated from their source of power interchange of energy takes place among them. Motors with high inertia loads, such as fans, act as generators (similar to dynamic breaking) while motors with low inertia driven loads keep on motoring, but with increasing slip. Due to this interaction phenomena residual voltages of motors could not be determined from motor open circuit time constants. If the magnitude and phase angle of the residual voltages are not known, it could not be ascertained that upon transfer to the alternate source, the magnitude of the resultant voltages at the motors, in volts per hertz, be kept below the recommended value of 133%, of nameplate voltages, so as to prevent damage to motor shaft and windings. [4], [5].

Furthermore, if the entire group of motors is re-accelerated under this condition, the magnitude of inrush currents might be excessive and result in collapse voltages in the healthy portion of the electrical distribution system of the refinery.

It is possible to determine the magnitudes and phase angles of the residual voltages by modelling motor mechanical transients including behavior of driven loads versus speed, motor stator and rotor electrical transients. Such modelling, however, is very data intensive and the accuracy of the result depends on the availability of accurate data, some of which may not be available, especially for existing systems.

In view of the above considerations, it was concluded that fast re-restart not be considered, and instead, a sequential re-acceleration of motors be analyzed.

The first step in analyzing such a scheme was to develop a priority list for critical motors to be re-accelerated. Based on this list, it was found that re-acceleration loads resulting from loss of feeder 67M9 imposed more severe duty on the alternate supply source than that resulting from the loss of 67M2. About 15,000 HP for loss of feeder 67M9 and 4,600 HP for loss of feeder 67M2.

The computer simulations focussed on determining the voltage response of the system under static conditions i.e., voltages at the instant of motor startings. To be able to assess the performance of the system certain modelling methodologies and acceptability criteria were established:

- Running motors were modelled as constant MVA loads.
- Motors being started were modelled as constant impedance loads, based on their locked rotor currents.
- Under steady-state running conditions, motors required a minimum of 90% of their rated voltage.
- Motors require minimum 80% of rated voltage for successful starting.
- Maximum voltage drop at 27.6KV not to exceed 3%.
- To prevent running motors from stalling when other motors are being started, the terminal voltages of the running motors should not dip below 75% of nameplate voltage.

Using the above methodology and acceptability criteria as a guide, a series of load flow simulations was made, with the objective of determining a sequential motor re-acceleration scheme that would satisfy the voltage drop criteria and preferably, result in shortest overall acceleration time.

The first step in the computer load flow simulations was to assess the response of the system to the five-step motor re-acceleration priority list developed by the process group. The results of these load flow simulations showed that, except for priorities 2 and 5, the voltages were unacceptable. Even though the results of these simulations showed that the initial five-step re-acceleration priority would not work, they did provide insight about where the weaknesses and the strengths of the electrical distribution system were. This insight was then used to shuffle the motors in the initial priority list, with due consideration for process and environmental needs, and then imposing the reordered re-acceleration priorities on the electrical distribution system. After several trials a modified six-step re-acceleration sequence, which satisfied the voltage drop criteria, was developed. Using empirical motor acceleration times for each group of motors (though time is not used to determine whether motors have reached full speed after re-energization) it was estimated that the entire group of motors would be re-accelerated in about eighty seconds.

APPLICATION OF COMPUTER STUDIES

The computer studies showed that the maximum horsepower which could be applied to the system at one stage and maintain the required voltage drop at the incoming feeder was approximately 4600 HP. In order to present the computer generated data to the process engineers for their review, a bar chart was produced as shown in Fig. 5. This chart shows the critical load against priority and time. Empirical values were employed for motor acceleration periods.

The restart times used were 5 sec. for 600V motors, 8 sec. for 4KV motor/pump and 12 sec. for 4KV motor/fans. Accurate accelerating times can be calculated provided that motor torque/speed characteristic, rotor inertia and driven equipment load characteristics are known.

SYSTEM DESIGN CONSIDERATIONS

The areas requiring definition are summarized below:

1) Time window for re-acceleration system operation.
2) Motor open circuit time constant allowance.
3) Permissible motor starts per hour.
4) Limitation of grouped motor starting.
5) Sequence starting methodology.
6) Locations selected for PLC control.
7) Use of central PLC or distributed small PLC's.

Each of these areas is discussed as follows:

1) TIME WINDOW FOR RE-ACCELERATION SYSTEM OPERATION

To meet the criteria set by Process Engineering all drives must regain rated output within 1 minute after a power interruption. Examination of the distribution system switching arrangements shows that if one feeder is faulted and power is not re-established on that feeder, the bus tie breaker will close in 1.6 seconds. If supply at the associated loads is still absent after 1.6 seconds it would indicate that the second feeder has failed and that the time frame for the return of supply to the refinery is uncertain. Under these conditions the system should be disengaged to prevent unwanted restarting. To provide a margin of timing error a time of 5 seconds was selected to reset, or disengage the system.

2) MOTOR OPEN CIRCUIT TIME CONSTANT ALLOWANCE

To minimize high transient motor shaft torques caused by the re-application of power prior to the decay of the motor internal voltages it is necessary to delay the reconnection of supply to motors. This time delay should be initiated by the detection of power outage. In order to accurately simulate motor behavior the largest motor in the system was considered and is an 1,100 HP, 4 pole machine. From standard data the motor open circuit time constant is 1.68 seconds. A time value of 2 seconds was chosen.

3) PERMISSIBLE STARTS PER HOUR

Two starts per hour are permitted to comply with EEMAC and NEMA standards.

4) LIMITATION OF GROUP LOAD STARTING

Examination of the loadings associated with some priorities indicated that cases existed at the 600V level, where the combined locked rotor currents of motors to be restarted would trip the associated local MCC main circuit breaker. Therefore, the applied HP at any one switching step should be limited. After study of the various MCC main circuit breaker protective relay characteristics, a conservative figure of 200 HP per MCC was selected. This value will result in limiting the locked rotor currents and voltage drop at the bus, thus enhancing re-acceleration time.

5) SEQUENCE STARTING METHODOLOGY

As noted earlier, the total load to be reaccelerated is 15,000 HP and the maximum permissible load that may be applied at one step is 4,600 HP subsequently, sequence starting must be applied.

Three basic methods of sequencing were examined:

(A) initiate starting on a fixed time base or

(B) to use bus voltage recovery as a trigger

(C) a combination of (A) & (B).

(A) FIXED TIME BASE

Not all drives in the system can be guaranteed to be running at any point in time, Therefore a fixed time base would introduce unnecessary time delays.

Acceleration time of motors is a function of their driven load. To assign a fixed time base successfully would require that the worst condition be assumed for each drive. As flow rates in most processes vary depending on production requirements, a fixed timing sequence would need to be conservatively derived and thus longer than actually required.

Motors for both the primary and standby drives are included. Under normal operating conditions only one machine would run. However, there are process conditions where both machines may be running. Again a fixed time sequence could overload the system if the design had dictated that only one machine should run, and extend the time if allowance for both motors to start had been stipulated.

(B) BUS VOLTAGE RECOVERY

This method provides the minimum total re-acceleration time. Upon starting a group of motors, the voltage is initially depressed due to the combined locked rotor currents. When these currents settle to running values, the voltage rises to its steady state level. Under these circumstances the motor driven load variables are automatically compensated and time is not lost in allowance for motors which are not running.

The effectiveness of this method is dependent on the monitoring of voltage at a single point, (the incoming feeder location) and the use of a central switching control programmed to start motor groups in sequence.

(C) COMBINED FIXED TIME & BUS VOLTAGE RECOVERY

If the central control point be substituted with distributed control locations, each having independent voltage detection and control it would not be recommended to apply voltage recovery alone as the voltage may recover at all locations simultaneously thus causing system overload. If however, a time factor is introduced the overall system loading can be controlled.

6) LOCATIONS SELECTED FOR PLC CONTROL

Critical drives are distributed throughout the refinery and are connected at thirteen different substation/load centres, these locations are typically 1,000 ft. to 1,500 ft. distance from main substations "A" & "B". At three locations however, only one or two critical drives were identified and in each case all drives were assigned to priority #1. As no sequencing was required, conventional time delay under voltage relaying was used. At the remaining 10 locations the motor count ranged between a minimum of 5 and a maximum of 60 with process priorities varying between 1 and 5. Therefore, at these 10 substation/load centres voltage detection and PLC control was provided.

7) USE OF CENTRAL PLC OR DISTRIBUTED SMALL PLC's

Two alternatives were considered to implement the re-acceleration system and are presented here.

I - Central PLC Methodology [6]

a) measure the feeder voltage to detect interruption and monitor re-acceleration progress.

b) provide a central PLC at one of the main substations, programmed to control all critical motors.

c) furnish each unit substation with remote I/O modules which are hardwired to medium voltage starters and 600V MCC for status and control functions.

d) install a communications link between the central PLC and remote I/O.

Study of the practical aspects of applying this methodology to the particular refinery case revealed certain drawbacks. Firstly, existing spare underground raceways were not available to every unit substation. Secondly, where spares existed, they are in close proximity to high voltage cabling, therefore to establish reliable communication, fibre optic transmission would be desirable. After close scrutiny, the potential installation difficulties and associated cost invalidated this approach.

II - Distributed Small PLC's Methodology

This concept was developed to replace the central voltage detection and PLC, with local voltage detection and small modular block type PLC's at each of the 10 unit substations.

The main features of the PLC selected are:

- analog capability
- enhanced instruction set
- expandable I/O capacity
- data storage capability

Examination of this design shows that detection of a plant feeder voltage interruption will affect all associated unit substations equally. The measurement of restored voltage is enhanced as readings are taken closer to the relevant busses.

As no communications link is provided between PLC's, the restoration of voltage only cannot be used for the initiation of sequence start commands. If this were to be attempted, uncoordinated switching between PLC's could lead to system overload.

Therefore time must be used as a secondary control. To address this concern and optimize the overall time performance of the system, the data shown in Fig. 5 was reviewed. It can be seen that the first 10 seconds are load critical and after this period the load drops significantly.

The bar chart shown in Fig. 6 was then developed and two levels of time constraint applied. Firstly a 10 second delay was given to all groups of motors not designated for immediate restart (Priority #1). Secondly a delay of 2 seconds was imposed between the starting of each group of motors. By this means the overall re-acceleration time is improved.

The 2 second time delay is triggered by the restoration of bus voltage following the voltage drop caused by the preceding motor group starting. If the preceding group of motors restarts in less than the empirical re-acceleration time allowed, the next group is effectively moved forward.

It should be noted that by applying an initial 10 second delay to all but Priority #1 motors, there is no risk of uncoordinated motor restarting causing system overload.

DEVELOPMENT OF PLC CONTROL SYSTEMS - PRACTICAL CONSTRAINTS

From initial equipment surveys, space was not available to house the PLC equipment in existing enclosures, therefore separate PLC cabinets had to be provided. All tie-ins to existing equipment had to be completed during a planned refinery shut down. The implementation of PLC work was divided into three phases.

1. Pre shut down activity: this included mounting the PLC cabinets and installation of raceways and wiring to starters.
2. Shut down activity: this consisted of modifications to starters and termination of wiring.
3. Post shut down activity: this comprised the programming and testing of the system.

At the outset of the design it was decided that any scheme employed should be an operations aid rather than a supervisory control. A start command only would be given to critical motors, whilst stopping and other control functions would remain unchanged. Work at the starters was limited to wiring system outputs across the "start" terminals and the provision of auxiliary relays to provide isolated motor status information to the system. PLC cabinets were factory prewired and housed the CPU, I/O modules, interposing PLC output relays. Fused terminal blocks are used for incoming status monitoring circuits and disconnecting terminals used for output signals. The interposing relays are required with this type of PLC, as isolated outputs were not available. The fuse terminals protect the PLC control voltage against external wiring faults. These together with the disconnecting terminals were employed to isolate the system until programming was completed. A small UPS is provided in each PLC cabinet to power the system during a interruption. A pilot light was installed at each cabinet and wired to provide common indication of interruption of supply to the PLC, failure of the substation incoming voltage detection and CPU fault. Bus voltage monitoring was achieved by the use of voltage/mA transducers which were generally connected to the unit substation incoming switchgear P.T's. Transducers were 150V AC input with a 4-20 mA DC output. The power supply to the transducers was taken from the associated PLC cabinet UPS.

PLC PROGRAMMING PHILOSOPHY

The re-acceleration system employed must fulfill the following requirements:

a) Detect incoming feeder voltage dip.
b) Monitor the running status of all critical motors.
c) Freeze the record of the running critical motors only.
d) Prevent the re-application of voltage to the motor's terminals until the machines internal voltage has decayed to safe limits.
e) Limit the motor starts per hour.
f) Make allowances for the possibility of a second power dip during the re-acceleration period.
g) Provide flexibility in motor starting sequence.
h) Ensure that line voltages have recovered to acceptable limits prior to starting motors of a lower priority or position in a sequence.

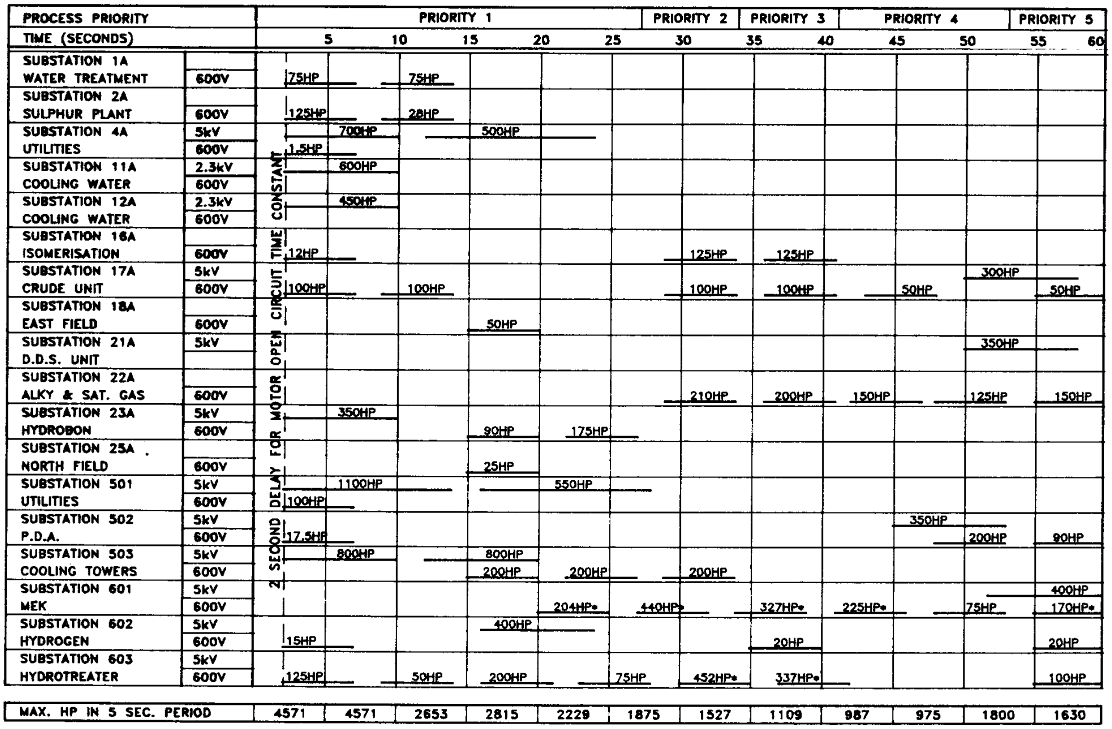
It was decided to divide the program into two main elements - an "arming" sequence and a "starting" sequence.

The "arming" sequence is designed to recognize all inputs which would cause an initiation of the re-acceleration system. These include detection of voltage drop, simultaneous motor stops, prior "re-acceleration" motor starts and voltage dips occurring during an ongoing re-acceleration program. It also controls the motor open circuit time constant which is set at 2 sec.

The "starting" sequence covers all starting and recording functions after the system has been "armed". This includes measurement of restored voltage, applying motor group time delays, sequencing of primary and standby motors within a group (if required) and generation of information to the records registers.

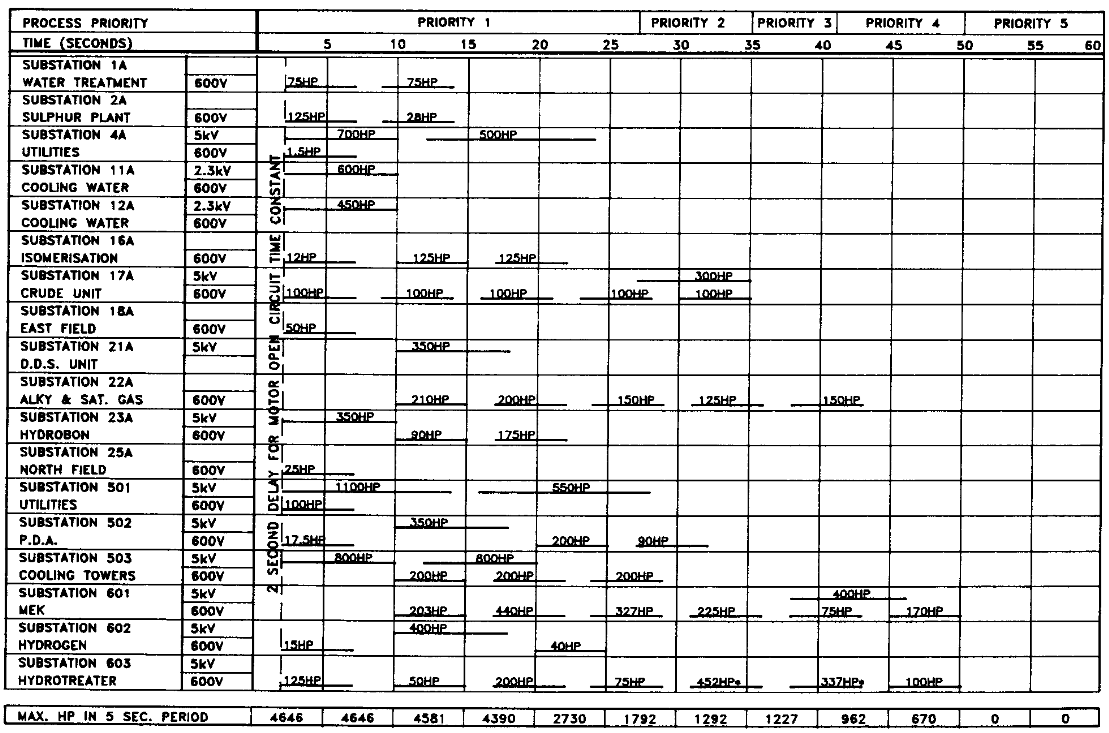
The concept of "motor group timers" was introduced to provide flexibility to the system. As previously noted 600V motors were grouped into blocks not exceeding 200 HP and each individual 4,000V motor formed a "group". Each group is controlled by a timer whose timing range is 0.01 seconds to several minutes. Priority #1 groups are set at 0.01 seconds (virtually instantaneous) and other priorities placed to suit. This system allows for addition of future loads and fine tuning as required.

The voltage drop at which the system is to be initiated was studied. NEMA standards indicate that contactors may drop out at levels below 85% nominal voltage. However, tests show that contactors might remain held-in down to 65% nominal voltage. It was decided to use 75% nominal voltage to trigger the arming sequence as this is a mid range between NEMA (85%) and test (65%). This value also provides good separation with the selected "restored" voltage level of 90%.



* DENOTES A GROUPED LOAD ASSOCIATED WITH MORE THAN ONE 600V MCC.

FIGURE 5 : BAR CHART SHOWING COMBINED CRITICAL MOTOR HORSEPOWER AGAINST PROCESS PRIORITY; USING A TIME BASE ONLY



* DENOTES A GROUPED LOAD ASSOCIATED WITH MORE THAN ONE 600V MCC.

FIGURE 6 : BAR CHART SHOWING COMBINED CRITICAL MOTOR HORSEPOWER AGAINST PROCESS PRIORITY; USING VOLTAGE RECOVERY AND TIME BASE CONCEPT

SYSTEM LOGIC REVIEW

The principal logic of the "arming" sequences is shown in Fig. 7 and is summarized below:

- Power loss is detected and measured. The running status of motors is recorded.
- The voltage dip is compared with the simultaneous stoppage of motors.
- If the number of motor starts in the last hour is less than 2, the system "arms".
- The motor open circuit time constant timer is activated.

Fig. 8 shows the principal logic of the "start" sequence:

- If the system is armed, the motor open circuit time constant time has elapsed and the system supply voltage been restored, a start sequence permissive signal is given.
- The first priority group of motors is examined for their running history status. If any one or all motors in the group were running prior to the interruption and are now stopped, the Group #1 timer is activated.
- At the completion of the group timer period, all primary drives in the group are given a permissive "Go" re-start signal.

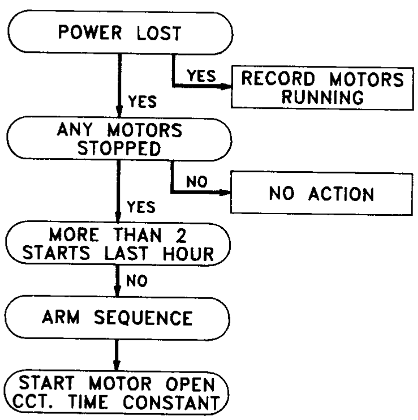


FIG. 7 - SIMPLIFIED 'ARMING' SEQUENCE LOGIC

- Each motor restart circuit performs the following checks prior to initiation:

  a) Does the motor have a running history?
  b) Has the power been restored for 2 seconds?
- If these conditions are true, a 3 second start command is given.
- When the motor status input shows a successful start a "ready" condition is signalled. If the motor fails to restart in 3 seconds a "failed" condition is

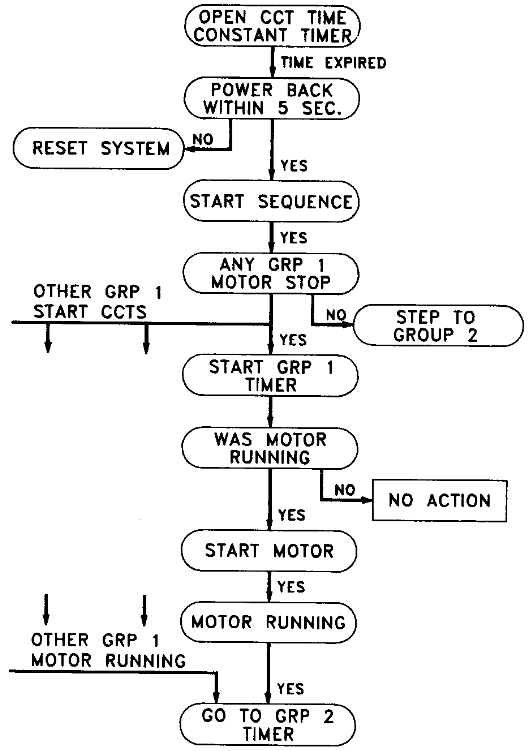


FIG. 8 - SIMPLIFIED 'START' SEQUENCE LOGIC

recorded and a ready signal given (the ready signal is required to complete the circuitry which allows subsequent groups of motors to start.)

- All motor "ready" signals are cascaded to provide a "group ready" condition which permits lower priority groups to start. The group start time is then recorded.
- In the case where both a primary drive and its standby are running, simple interlocking is used to ensure that the standby is not started while the primary drive is accelerating.

ADDITIONAL FEATURES

It was also anticipated that a second power interruption may occur while the motors were re-accelerating from the initial power dip. In such circumstances a condition could occur where motors already restarted would stop (due to the second voltage dip) and motors which had not yet been started would be restarted. Therefore a second power loss circuit was included to completely restart the program.

REPORTING FUNCTIONS

To verify the performance of the re-acceleration system under actual voltage dip conditions, it is required to record the following information:

a) Motor running/stopped status at the moment of power interruption.

b) Motor running/stopped status at the completion of the power interruption.

c) Acceleration time for each group of motors.

d) Total re-acceleration time for all groups.

The method chosen to gather this information is:

1) Interrogation of the PLC registers by means of programmed software and a lap top computer.

2) Down loading the data at home base into hard copy. The technology used for this transfer of data is a spreadsheet program coupled with a proprietary interrogation software.

The method of recording the data at the PLC's was to place the status and time information in the various bit and integer registers. It was agreed to limit data storage to the last five events. The number of stored events is limited by the PLC memory capacity.

A real time clock integral with the PLC's was not available at the time of design, but this feature is currently being incorporated in all PLC's.

To overcome the absence of real time recording, a strategy of comparing the system hard copy with the power monitoring equipment printout was employed. Fig. 9 shows a typical report generated after a power interruption.

Individual substation constants, i.e. substation no., motor groups, drive designations, are permanently written into the spreadsheet program. The volatile data is presented in the event columns. Due to the architecture of the PLC's registers, block transfers of data were not possible and individual macros had to be written to extract the pertinent information.

SYSTEM PRE-COMMISSIONING TESTS

The following tests were made prior to placing the system into operation.

1) A test rig comprising 10 switched inputs operating through a master on-off was built to verify the hard input/software interface and simulate motor running/stopped status.

2) A milli amp calibrator, 4-20mA output, scaled in 0-100% was used to model supply voltage fluctuation.

3) To test the circuit the following conditions were simulated:

   a) Stop all motors under test, but maintain the input voltage at 100%.

   b) Reduce the input voltage to 75%, but maintain motor running status.

   c) Stop all motors under test and simultaneously reduce voltage to 75% for a period not exceeding 5 seconds.

   d) As (c) above, but not re-apply the voltage.

Only the condition under (c) initiated the system. This procedure was repeated three times. On the third test the system did not operate, thus proving the starts per hour restriction. Several other simulated tests were made to verify the performance of the system and the generation of historical data. As a final check to verify the system performance permission was obtained from the Refinery Operations to manually impose loss of power at one substation considered to be less critical. The test results were satisfactory and the system performed as designed.

OPERATIONAL EXPERIENCE

Since the re-acceleration system was commissioned in late 1991, the refinery has been subjected to three power interruptions, all on feeder M-9. On each occasion power was restored within 1 second. At the first power interruption the system operated successfully at 3 out of 10 substations, however on the second and third interruptions the system performed successfully at all 10 substations.

Investigations were conducted to determine the lack of success during the first power interruption.

Recorded data was obtained from two sources, the power monitoring equipment and the PLC historical data print-out, see Figures 2 and 3. The power monitor showed that on the first interruption, a line to ground fault had occurred and that the centre phase voltage had decayed almost instantaneously, but the other two phase voltages had decay times of 150 msec. The PLC historical data records indicated that no motors were running when the voltage was interrupted, therefore, the system did not attempt a restart.

On the second and third interruption, the power monitor showed that all phases decayed almost equally within 300 msec. The PLC historical data showed that the motors that had been running were all restarted.

The voltage detection transducer (120V AC input) is connected to one phase to ground of the switchgear P.T. secondary.

From these observations, it was concluded that in the case of the unsuccessful re-acceleration, the transducer was not monitoring the same phases as the motor starter control circuits. Under these circumstances the control circuit transformer voltages (connected to the centre phase) dipped and de-energized control relays, prior to the transducer sensing voltage dip. Therefore, no history of the motor running was recorded and a restart was not initiated. To overcome this problem a second transducer is being be added to monitor the other side of the PT secondary and its signal inputted to the PLC. This arrangement will sense all 3-phase supply voltage decay variations.

SUBSTATION 603 RE-ACCELERATION PROGRAM REPORT RECORDING DATE: 09-APR-92 TIME: 02:35.46PM		STATION ID NO: 5 Hydrotreater								
HISTORY = 1 designates motor was running prior to re-acceleration STATUS = 1 designates motor successfully re-accelerated TIME values are shown in hundredth of seconds		09/04/92 12:57 RECORD EVENT #3			08/04/92 15:14 RECORD EVENT #2			07/04/92 15:14 RECORD EVENT #1		
		HIST	STAT	TIME	HIST	STAT	TIME	HIST	STAT	TIME
MOTOR GROUP NO. 1 RE-ACCELERATION	P-219 NO. 2 VACUUM FRACT. PA PUMP	0	0		0	0		0	0	
	P-261 AUX. LUBE OIL PUMP FOR C-262	0	0		0	0		0	0	
	Group Re-acceleration Time			0			0			0
MOTOR GROUP NO. 2 RE-ACCELERATION	MB-202 FORCED DRAFT FAN BLOWER EAST	1	1		1	1		0	0	
	P-220 NO. 2 VACUUM BOTTOMS PUMP	0	0		0	0		0	0	
	Group Re-acceleration Time			285			227			0
MOTOR GROUP NO. 3 RE-ACCELERATION	P-222 TEMPERED WATER PUMP	0	0		0	0		0	0	
	P-212 VACUUM FRACT. PA PUMP	0	0		0	0		0	0	
	P-229 TEMPERED WATER BOOSTER PUMP	1	1		1	1		0	0	
	P-229A TEMPERED WATER BOOSTER PUMP	1	1		0	0		0	0	
	Group Re-acceleration Time			6			7			0
MOTOR GROUP NO. 4 RE-ACCELERATION	P-262 PACKING COOLANT PUMP	1	1		1	1		0	0	
	P-224 PACKING COOLANT PUMP	1	1		1	1		0	0	
	E-236A LUNGSTROM MOTOR	1	0		1	0		0	0	
	P-208 ATMOS. BOTTOMS PUMP	1	1		1	1		0	0	
	P-209 NO. 1 VACUUM FRACT. PA PUMP	0	0		0	0		0	0	
	P-213 VACUUM OVERHEAD PUMP	1	1		1	1		0	0	
	Group Re-acceleration Time			298			298			0
MOTOR GROUP NO. 5 RE-ACCELERATION	MB-203 INDUCED DRAFT FAN	1	1		1	1		0	0	
	Group Re-acceleration Time			7			6			0
MOTOR GROUP NO. 6 RE-ACCELERATION	P-221 NO. 2 EAST VACUUM RECYCLE PUMP	0	0		0	0		0	0	
	P-221A NO. 2 VACUUM FRACT. RECYCLE PUMP	0	0		0	0		0	0	
	P-215A NO. 1 VACUUM RECYCLE PUMP	1	1		1	1		0	0	
	Group Re-acceleration Time			6			7			0
SUBSTATION 603 TOTAL RE-ACCELERATION TIMES:				1528			1529			0

FIGURE 9: TYPICAL REPORT GENERATED AFTER A POWER INTERRUPTION

CONCLUSIONS

The re-acceleration system has proven to be an invaluable aid, for operations, to enable the refinery to ride through momentary power disturbances. The presence of on line power monitoring device and PLC historical data recording are extremely useful to carry out troubleshooting and to measure re-acceleration system performance.

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