RESTARTING SCHEME OF ELECTRICAL MOTORS AFTER SUPPLY VOLTAGE OUTAGES IN HEAVILY LOADED INDUSTRIAL FACILITIES

Selahattin Küçük
TÜPRAŞ – İzmit Refinery
selahattin.kucuk@tupras.com.tr

Luis Fernandez Fernandez
Tecnicas Reunidas S.A.
luisff@trsa.es

Mehmet Bayrak
Sakarya University
bayrak@sakarya.edu.tr

Ahmet Serdar Yılmaz
K.Maraş Sütçü İmam University
a.serdar.yilmaz@ksu.edu.tr

Abstract

A primary goal of an industrial electric power system is to minimize production losses in industrial facilities maintaining the industrial process running after the occurrence of certain supply disturbances.

The automatic motor restarting is one of the strategies used in the industrial facilities, especially in Oil and Gas facilities, in order to achieve this goal.

Aim of this strategy is to allow that after a voltage dip or disturbance, the medium voltage and low voltage motors will be automatically reenergized within predetermined time and in a certain order when voltage is restored. These abnormal voltage conditions may be caused by cleared short-circuits upstream, generation and public supply voltage outages or a simple automatic transfer system of a selective secondary substation operation.

This paper presents the automatic motor restarting scheme applied at a large oil refinery where more than 600 motors are assigned to automatic restarting. Application criteria for motor restarting, power system simulations and physical implementation of this scheme are discussed in this paper.

Key words – Motor reacceleration, motor restarting, and voltage drop/dip, automatic bus transfer, under voltage,

1. Introduction

Reconnection of electrical driven motors after a short out range is an important design feature in process facilities for minimizing production losses and unsafe conditions. Restarting/Reacceleration of critical motors feature is common at most oil and gas facilities [1] to carry on operation by transferring after a disturbance, those buses feeding critical motors onto healthy sources and restarting the motors, automatically. This transferring is done through the automatic bus transfer system (ATS).

In this paper the meaning of motor restarting and motor reacceleration will be same. The reacceleration/restarting scheme is based in the fact that in case on an event, the motor becomes stopped and they will be restarted (reaccelerated) according fixed steps [2], [3], [4].

When it is decided to apply a restarting design feature, a reacceleration study shall be performed in order to predict voltage and current profiles, and acceleration times of the motors. Additionally, a detailed analysis verifies the viability of the restarting sequence and provides a guide for setting under voltage and overcurrent relays on the relevant circuit breakers.

During the process for reacceleration or restarting of a group of motors, the voltage dip must not be dropped extremely to upset running motors and the voltage profiles shall be maintained above the minimum pre-specified voltage limits as defined in below paragraphs. In case of excessive voltage drops due to numerous motors' restarting, the healthy bus onto which the critical motors have already been transferred, it could be affected and also in extreme cases, the healthy bus may lead to under voltage tripping [1]. The purpose of the aforementioned studies is to avoid that this situation can occur.

Motor reacceleration considers that during the system voltage dip or disturbance, circuit breakers for medium voltage motors and contactors for low voltage motors will open automatically; if the voltage goes below the preset lower limit [5]

The need for reacceleration/restarting is determined by the criticalness of the process. One particular motor may be subjected to restarting depending on the importance of such motor to the process.

Automatic motor reacceleration or restarting does not be confused with the automatic starting (if any) due to process conditions, e.g. automatic starting of a spare motor "B" if operative motor "A" stops [3].

Dynamic parameters, like speed or torque, are not evaluated, since in other studies, like Motor Starting, and in the vendor motor datasheets is revised that the motors are suitable to start with 80% rated voltage in their terminals. So, if the voltage is above of that value, it is assured that there is not any problem with the motors [3]. Additionally, the reacceleration/restarting scheme is based in the fact that in case on an event, the motors become totally stopped.

2. Electrical System Description

A simplified one line diagram of the refinery at which motor restarting simulation is applied, it is shown in Figure 1.

On-site refinery installed electrical generation capacity is 120 MW and normal operation consumption is 67 MW, with a peak loads up to 90 MW. In addition to three on-site generators, refinery electrical energy security is ensured through two 154 kV underground transmission lines connected to the Turkish national grid. The generators are continuously operated in parallel with the national grid. A brief description of each section of the refinery electrical system under consideration is as follows.

a. 154 kV main switchgear section

It corresponds to the 154 kV main indoor gas insulated switchgear (GIS). This system includes two 154 kV incomers from Turkish utility company and two feeders 154/34.5 kV power transformers.

b. Generation section

It corresponds to the generation section at 11 and 34.5 kV level. This subsystem includes;
Two gas turbine driven generators which are 39.54 MW, 11 kV each. One steam turbine driven generator which is 41.31 MW, 11 kV. Three independent 11 kV switchgears with the generators circuits breakers. One 34.5 kV, 2500 A switchgear, double bus bar type, with main and reserve busses.

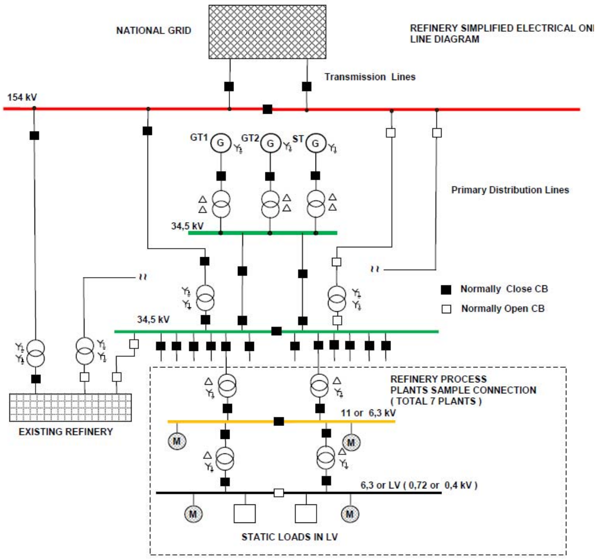

Fig. 1. Simplified one line diagram of the refinery.

c. Main distribution section.

It corresponds to the Distribution section at 34.5 kV level. This subsystem includes one 34.5 kV Switchgear, and double main and reserve bus bar.

This switchgear includes four incomers (two from 34.5 kV generation bus-bar and two from 154 kV switchgear through 154/36 kV transformers, plus a number of outgoing feeders to the Refinery process substations.

In order to limit the short circuit current level to earth and give the ground reference under island conditions, this switchgear is connected to ground through Zig-Zag earthing transformers and earthing resistors.

d. Substations section

Process plant substations include the step-down transformers which are supplied by dual 34.5 kV feeders coming from main 34.5 the kV distribution switchgear. Depending on the process plant load size and profile, there are two types of medium voltage levels (11 and 6.3 kV) for drives and for motors, and also one low voltage (LV) level for motors (0.69 or 0.4 kV). There is also a low voltage level for services (0.4 kV).

A secondary selective scheme is used to feed the loads, via step down transformers. If a service bus is de-energized by other than a busbar or incomer protection lockout, the tie-breaker closes automatically in accordance with the automatic transfer system (ATS) philosophy [6].

Basically, the bus transfer is initiated by an under voltage condition on either of left and right hand side buses. Based on the dual secondary distribution system configuration, the outage in one of two incoming feeders, say due to a fault on the cable or transformer and subsequent isolation of the feeder, will trigger an undervoltage transfer. As a result, after the transfer the two busbars are supplied by the remaining healthy feeder and all pre-selected motors will get subjected to an automatic restarting sequence.

Tie-breaker on medium voltage (MV) switchgears under normal conditions, it is normally selected as "close" position in order to get supply continuity during failure of one of incoming feeders. The operation with tie-breaker “open” is also allowed and under this condition an automatic transfer system (ATS) becomes active in case the loss on one of the incomers. All feeders and transformers are sized to continuously carry the full loads of both left and right hand busses when one feeder becomes out of operation. According to this design, MV voltage motors can only be re-started in accordance with pre-selected order after voltage recovery one of two feeders.

Provided that voltage on the de-energized bus is restored with power from the alternate bus within a pre-established time (e.g. eight seconds); all critical motors on the bus are automatically restarted according to priority order and time intervals.

On the other hand, low voltage motor control centers (MCCs), the tie-breaker in normal operation is chosen as "open" position. Low voltage (LV) electrical system feeders, transformers etc., are also designed considering to carry the full loads of both left and right hand busses when one feeder become out of operation.. Similar that in MV, all critical motors on the bus are automatically restarted according to priority order and time intervals, always that voltage on the de-energized bus is restored within the pre-established time.

In low voltage, there are also emergency switchboards (not indicated in Fig. 1), whose purpose is to supply essential loads through emergency diesel-generators (EDG) when the industrial facility electrical system is in a blackout. These LV Emergency switchboards are composed of a single busbar with two normal power supply incomers and one incomer from the emergency diesel-generator. Only one of three incomers is in service at once.

3. Essentials of Designing Process

3.1. General

The necessity for restarting is determined by the criticalness of the overall process conditions. One particular motor may be subjected to reacceleration depending on the importance of such motor to the process conditions. Motors restarting priority is classified as shown in Table 1 [1], [3].

If restarting is specified for a motor, this shall restart automatically only if it was running prior to the supply voltage dip [7], and if supply voltage returns within a specified time (for example, eight seconds).

Motor involved in the reacceleration scheme will start in a specific fix step, where other motors also are starting simultaneously. Motors to be included in each step will be selected according to motor priority defined in Table 1 and the reacceleration/restarting studies.

Non-motor loads are not included in the reaccelerating /restarting scheme due the fact as per design conditions, they remain connected to their busbars after the disturbance.

Table 1. Motor restarting priority classification

Priority class	Need for automatic restarting	Basis
A	High Priority	Safety and/or safe plant. Drives that, if lost, could cause damage to the process equipment, such as furnace charge pumps whose loss could cause overheating or coking of the furnace tubes
B	Middle Priority	Risk of production loss. Drives that, if lost, lead to relieving conditions e.g., tower feed pumps, reflux pumps, etc.
C	No priority	Unnecessary but desirable. Drives which, if lost for any length of time would cause operation upset or shutdown, such as powerhouse boiler feed water drives.
NA	Not applicable/ Not required	Manual re-start is enough or automatic restart is not possible to operational constraints.

3.2. Calculation basis

The simulation applied to the restarting of the critical drives/motors is made under the following operation network configurations [3] that represent the worst operational case:

a. Minimum short-circuit current system configuration.
- All three generators at co-Generation plant out of service.
- Only one main power transformer (154/34.5 kV) supplying the load of refinery facilities.
- At process unit substations, medium and low voltage switchboards tie circuit breaker closed, with one incoming line supplying total connected load.
- LV emergency switchboards were considered with only one normal feeder supplying the total load connected to the switchboard.
- Minimum short circuit power of 1193 MVA at 154 kV utility system bus is used to simulate the external power system.

b. Emergency switchboards are supplied only by the corresponding diesel-generators when industrial facility electrical system is blackout.

A commercial electrical software program was used for motor restarting analyses with the above assumptions. This program have the capacity to simulate a several simultaneous motor starting in one run, with monitoring of large number of parameters, and thus facilitate assessing the full impact of successive large scale motor restarts. Generators, governors and excitation systems were modelled in detail. The electrical distribution system database was used for system modeling. One line diagrams, datasheets, test reports, nameplate data etc. are also as used the part of the database. The national grid, which minimum short circuit power is given above, is represented by an equivalent symbol at the ends of the 154 kV transmission lines. The model for induction motors was selected from the vendor information data sheets.

3.3. Motor restarting sequence

The allowable voltage restore time for motor drive restarting to carry on operation in refinery in safe conditions is eight seconds for switchgears feed from normal supplies. In emergency switchboards, the restoring time is a bit longer in order to consider the starting time of the emergency diesel generator. If voltage is not restored to the buses within the pre-established time, the reacceleration scheme will be disable for such motors. If on the other hand, voltage is detected within of such pre-established time, individual timers on LV motor control centers and relays on MV circuit breakers, one for each motor, begin timing and eventually restart the motors in the pre-setting sequence. Any motor that was not operating initially (before the disturbance) is not restarted [7].

Table 2. Nominal connected motor load restarted on each reacceleration step of refinery substations, after a general system voltage outage and recovery within eight seconds

Step	Time Delay (seconds)	Nominal connected motor load restarted on each step (kW)					
		SS-1	SS-2	SS-3	SS-4	SS-5	SS-6
0	0	2458	313	288	390	103	985
1	5	75	-	-	79	514	-
2	10	1092	1693	660	1225	234	30
3	15	-	90	30	625	-	-
4	20	500	135	160	180	208	1400
5	25	-	90	-	1780	-	510
6	30	491	500	1400	250	-	2030
7	35	-	90	-	1320	-	-
8	40	431	773	100	555	1660	880
9	45		1297	-	555	-	
10	50		744	-	338	1680	
11	55		590	-	654	-	
12	60		250	669	552	560	
13	65			53	-	-	
14	70			530	2766	148	
15	75				3	-	
16	80				180	783	
17	85				-	400	
18	90				295	-	
19	95				90	-	
20	100					-	
21	105					-	
22	110					221	

Since the motors stop before being transferred to healthy bus and restarted, they draw their locked rotor currents [1] when restarted. Without setting time interval, any attempt to restart all motor simultaneously either in individual buses or in whole plant could cause partial or a plant wide power failure [1], [3].

In order to prevent total system collapse due to multiple motors restarting simultaneously [8], critical motors are grouped in an order based on the process categories as discussed previously in paragraph 3.1. In order to maintain the operations in a safe and orderly manner, restarting steps are selected depending on plant complexity and connected load size, in accordance with simulation results performed in the motor reacceleration study. The number of steps, time intervals and nominal connected motor load on each step of the refinery substations are shown in Table 2. Timing for the various steps has been set to provide a minimum interval of five seconds between each successive start; this time is sufficient according the power system studies and the protective relaying coordination.

The total time to reenergize a motor is the sum of three factors [1]:

First one is the intentional time delay for the operating time of the under voltage relay, which trips the incoming breaker.

Secondly, there is non-intentional time delay imposed on the closure of the bus tie-breaker or starting of the Emergency Generator.

Finally, after the bus tie is closed or the emergency diesel generator started and voltage returns to the busbar, the starting sequence mentioned above, adds the step delay time for re-energize and restart the motor.

As explained above, in order to avoid the overload and excessive voltage drop effect of each restarting, five seconds between step intervals has been selected.

The loads given in Table 2 shows only motor loads subjected to reacceleration/restarting. Non-motor loads like lighting, electrical heat tracing, heating, ventilating and air conditioning etc. are not included in the above list.

4. Development of Motor Restarting Simulation

There are 823 motors from kW to MW range in the refinery complex, where 622 of them may be subjected to restart after voltage dips, outages, or bus transfers. Although the restarting simulation is applied to the overall system and to all six substations at the same time, for simplicity of this paper, only will be submitted the simulation results and restarting operation sequence for substation SS-1, nevertheless, the same criteria is applied for all remaining substations.

In case of overall voltage failure in substation SS-1 which is supplied over 34.5/6.6 kV transformers, and voltage is restored within eight seconds, medium and low voltage motors are restarted in the order given in Tables 2 and 3. The similar restarting sequences are used in case of partial outages in the different busbar sections that form the substation SS-1.

Motor restarting priority and step order is defined in close cooperation with the process and operation engineers during the engineering phase to gather more reliable operation and safe motor restarting.

Initial result simulations obtained with the motor reacceleration study, are revised together the process and operation engineers in order to evaluate their suitability from operational point of view. Changes in the motors step order are normally recommended in such multidisciplinary meetings and therefore new simulations are repeated in order to guarantee that there is not any excessive voltage drop in load buses. The final results are the one summarized in Tables 2 and 3.

The number of motors restarted and nominal power in each step of substation SS-1 is shown in Table 3.

Table 3. Number of motors restarted in SS-1 and total motor load connected in each step

Step	Time Delay (seconds)	Number of motors restarted (Including three MW motors)	Nominal connected motor load on each step (kW)
0	0	26	2458
1	5	1	75
2	10	14	1092
3	15	-	-
4	20	2	500
5	25	-	-
6	30	18	491
7	35	-	-
8	40	32	431

Voltage profiles of buses during a complete motors restarting sequence in substation SS-1 in accordance with paragraph 3.2.b, it is shown in Figure 2 for medium voltage busbars and Figure 3 for low voltage busbars.

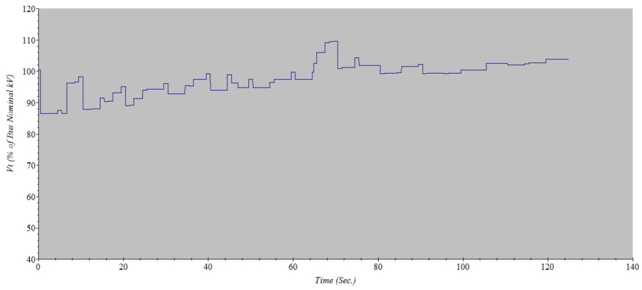

Fig. 2. MV switchgear voltage profile of substation SS-1 during MV and LV motors' restarting.

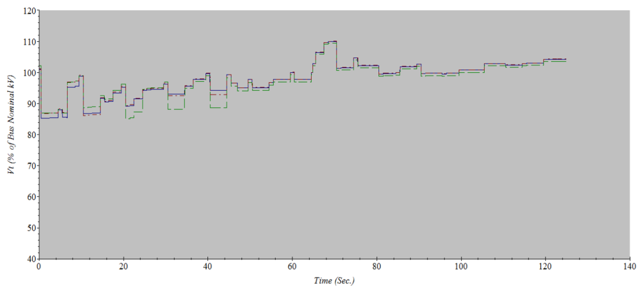

Fig. 3. LV motor control center voltage profile of substation SS-1 during low voltage motors' restarting.

As seen from figures 2 and 3, a sharp voltage drop magnitude and duration in both MV switchgear and LV switchgear is occurred in the first step due to highest motor load group restarting plus the fixed non-motor loads that remain connected. The total motor starting load in the first step, as seen from Table 2 is 4537 kW (2458 kW in SS-1 and 2079 kW in remaining SSs). The voltage at the busbar and motors is over the permissible value given paragraph 3.2 (85% busbars, 80% motors). The voltage drop and voltage profile in the remaining steps are also over the permissible values. Since the total time of the complete restarting sequence for the overall refinery is long (near 2 minutes), Figure 2 and as a consequence Figure 3 shows also the response of the on-load tap changers (OLTC) of the 34.5/6.6 kV transformers in substation SS-1 and main transformers 154/36 kV.

The similar simulations are applied to all remaining five substations. Voltage dips in each step of individual process unit substations meet the requirement of design basis.

Similar to the evaluation done for the motor restarting with normal supplies from transformers, additional simulations shall be done in the Emergency panels when these are feed exclusively from the emergency diesel generators (EDG). Voltage profile of emergency panel at substation SS-1 during motors restarting is shown in Figure 4. Since the loads feed from this panel are critical loads, there are only two restarting steps (steps 0 and 1). LV emergency panel total motor load to be restarting in these steps is 260.5 kW. As seen from figure, maximum voltage drop is below 15% and occurs in the first step. This value is acceptable since is in accordance with the limits given in paragraph 3.2a.

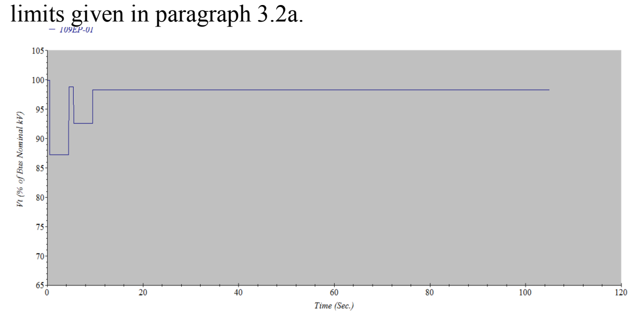

Fig. 4. Voltage profile of substation SS-1 emergency panel low voltage motors restarting

5. Implementation of Motor Restarting Scheme

Although in past projects one common programmable logic controller (PLC) was used for motor restarting of each motor control centers, due insecurity and maintainability reasons, this scheme was no used anymore in recently projects.

For the project evaluated in this paper, in MV switchgears the restarting function in is achieved by individual microprocessor based motor protective relays. In LV motor control centers, one dedicated restarting relay is implemented in each LV motor feeder [2], [4].

In both cases, the logic of those devices consist in to identify if the motor was running or not previous to be voltage loss; if the busbar voltage is loss the motor becomes stopped and the device checks if the voltage returns within the preset value (e.g. 8 seconds) to continue with the motor restarting sequence, otherwise the motor restarting is disabled. After a proper voltage returns, an on-delay timer for motor restarting is given according the step/time delay assigned for the motor.

6. Conclusions

The study presented in this paper is a practical approach used in the design engineering stage of a heavy loaded refinery complex and analyses the main results. As it is summarized in introduction paragraph, the need for motor restarting/reacceleration is to keep the process running and to minimize production losses. Therefore motor restarting analysis is performed during the plant system design stage together with early dialogue with process and operation engineers.

Motor Restarting analysis is a useful controlling tool, enabling to examine the response of the distribution system under the restarting of a successive group of motors, at different buses of plant substations; considering all possible operation modes, including minimum system configuration.

The experience gained from this study shows that motor restarting is not a single issue to be analyzed. There many factors that shall be taken into consideration to apply successfully the subject scheme. These are recommended as follows;

- Power supply sources, either national grid or on-site generation shall be available.
- Care shall be taken in setting of restarting relays and timers in accordance with predefined steps obtained from the reacceleration study. Restarting order shall be followed to avoid grouping too many loads in a single restarting step.
- Coordination shall be checked between the manufacturer's contactors and the relevant, timers' dropout voltages.
- The theoretical analysis in itself does not guarantee the behavior of electrical system during motor restarting at real conditions in the field. Correctness of analyze shall only be guaranteed by individual relay/timer settings, circuit breaker and contactors response time tests, maintenance practices etc.
- Depending on the number and size of new motor additions, the reacceleration study shall be repeated before the inclusion of these new equipment in the motor restarting schema.

For each step, a simultaneous static motor starting study is done, in order to select the motors to be included in each step. The study will evaluate that in each step the voltage drop in all busbars is above the limit established (85%).

Typical simulation results were shown for one of the refinery substations, in this case the substation SS-1. Results show that voltage profiles at MV and LV are above the permissible values ($U_{bus} > 85\%U_n$).

7. References

[1] Grewal, G., S., Pocsai, S., Hakim, M., “Transient Motor Reacceleration Study in an Integrated Petrochemical Facility”, IEEE, 1997, pp-102-106

[2] Fernandez, Fernandez L. “Upgrading a Large Oil Refinery Electric Power System”, IEEE-IAS Annual Conference. September 2001. Chicago, IL, USA.

[3] TÜPRAŞ İzmit Refinery, Resid Upgrading Project (RUP) electrical system studies. 2012 – 2015.

[4] Fernandez, Fernandez L. “Renovation for More Reliability”, IEEE Industry Applications magazine. JAN/FEB-2003.

[5] Propescu, V., Oprea, L., “Optimized Reacceleration of the Motor Load in a Large Industrial Power System”, IEEE MELECON 2004, May 12 - 15, 2004, Dubrovnik, Croatia, pp.947-950

[6] Cosse, R.,E., Bowen., J., E., Kerr., S., H., “Secondary Selective System Residual Bus Transfer – A Modern Application Approach" IEEE Transaction on Industrial Applications, Vol.41, No.1, January/February 2005, pp. 112- 119.

[7] Lubomir, S., Allcock, D., Luna, R., Bowen, J. “Motor Reacceleration to Improve Process Uptime”, IEEE Paper No. PCIC – 2011-14, pp.1 – 8.

[8] Jagaduri, R., T., Bradley, D., Kingrey, L., Nguyen, T.P., “Field Evolution of Automatic Restart of Essential Motors Using Microprocessor Based Protective Relays" 58th Annual Petroleum and Chemical Industry Conference, Toronto/ Canada. September 19-21, 2011