STRATEGIES FOR DEVELOPING AND IMPLEMENTATION OF AUTOMATIC MOTOR RESTARTING SCHEMES IN OIL/GAS FACILITIES

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Abstract – Automatic motor restarting is one of the strategies used in Oil and Gas facilities to minimize production losses after the occurrence of certain power supply disturbances with the purpose of maintaining the industrial process running.
Aim of this paper will be to review the strategies for the developing of an Automatic Motor Restarting Scheme, electrical studies required and the different trends for their physical implementation.
Case studies with real case applications and lesson learned will be shown.

Index Terms - Automatic Bus Transfer, Electric motors, Industrial plants, Motor restarting, Motor reacceleration, Substations, Voltage drop/dip,

I. INTRODUCTION

A primary goal of a correct designed industrial electric power system is to minimize production losses in industrial facilities, after the occurrence of certain supply disturbances in order to maintain the industrial process running or with a minimum impact to the operations.

Oil and Gas facilities industrial facilities use numerous electrical motors for critical functions that require continuous operation.

Power supply disturbances caused by cleared short-circuits upstream, generation and public supply voltage outages or a simple Automatic Transfer System (ATS) of a selective secondary substation may lead to unit shutdown due to tripping of critical electrical motors.

Reconnection or re-energization of electrical driven motors after one of above outages is an important design feature in process facilities for minimizing production losses and avoid unsafe conditions [2].

Automatic Restarting of critical electric motors is a common strategy at most oil and gas facilities to minimize the impacts to the industrial process after the occurrence of a supply disturbance.

Purpose of an Automatic Motor Restarting Scheme is to restart sequentially a group of Medium Voltage (MV) and/or Low Voltage (LV) motors when voltage is restored after an abnormal voltage condition: e.g. upstream short-circuits, generation loss. ATS operation that causes that a group of running motors become stopped [6].

Since all motors in the industrial facility will be involved, the developing of this Automatic Motor Restarting Scheme is a multidisciplinary activity, leading by Electrical designer discipline and with the participation of Process, Operation and Instrument disciplines; both from the Engineering/Designing Company and from the final user.

II. MOTOR RESTARTING vs. MOTOR REACCELERATION

A. Motor reacceleration:

This is related with short-duration voltage sags or dips, caused typically by relay clearing of short-circuits in the HV utility grid or in the upstream HV/MV industrial distribution networks and where the magnitude of the dip and their duration do not cause the opening of the LV/MV contactors or interrupters. Typical sag duration is no longer than 200 msec.

During these disturbances, running induction motors experiments a lightly decrease in the operating speed, increasing the motor slip and therefore a reduction in torque output, but that is be sufficient to meet the instantaneous load torque requirements.

When voltage is restored to the motor terminals, the corresponding motor torque curve will provide accelerating torque until the motors reach normal operating speed.

Since motors just decrease their operating speed lightly, the further acceleration should not impose high current requirement to the system.

B. Motor restarting:

The term motor restarting considers that during a long duration voltage dip, for example the one that occurs during the automatic transfer of a selective secondary substation, the circuit breakers and contactors for medium voltage and low voltage motors will open automatically. Under this disturbance, the involved motors become fully stopped.

After voltage is restored the motors must be restarted to maintain process continuity. To avoid large voltage dips during such motors restarting, this process is done sequentially.

Automatic motor 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.

It shall be highlighted that practices from several Oil and Gas Companies and other technical papers [1], [2], [6], [8] the term motor reacceleration is used instead of motor restarting. When dealing with this activity, engineers shall be use the proper terminology as used in their companies.

The aim of this paper is to discuss about the term motor restarting defined above.

III. PHYSICAL IMPLEMENTATION OF MOTOR RESTARTING SCHEME

A. Control logic

Motor reacceleration as defined above in section II does not require any physical devices to be implemented, since it depends of the natural response of the power system and induction motors torque-curve-load curves [3], [9].

However, the implementation of a motor restarting scheme requires that additional devices and control logic shall be included in the motor control circuit.

The logic to be implemented consists basically in to identify if the motor was running or not previous to be voltage loss. If the voltage busbar where is connected the motor is loss, then the motor becomes stopped due the opening of contactors and circuit breakers.

The control logic shall check if the voltage successfully returns within a preset value (e.g. in less than 8 seconds) to continue with the motor restarting sequence, otherwise the motor restarting will be disabled.

After the voltage returns, a motor restarting command is given according the step/time delay assigned to each motor. [1], [4], [11].

B. Implementation

1) Electromechanical time relays.

Historically, the first motor restarting schemes (or reacceleration as called in several companies), they were implemented by the using two dedicated electromechanical time relays in the motor control circuit.

An off-delay (drop-out) time relay is used to detect if the motor was running and the loss and subsequent return of the busbar voltage within the preset value.

After the voltage return, an additional on-delay (pick-up) time relay will close their contacts to restart the motor. This on-delay time relay is set to the step (delay) assigned to the motor.

In Figure 1 is shown a very simplified motor restarting scheme using electromechanical time relays and motor contactor. This scheme, which with customized variations and improvements; it was plenty used in Oil and Gas installations between the 1960´s and 1990´s.

It is clear that the control circuit of all motors that require motor restarting shall contain both timer relays: off-delay and on-delay relays, and each one shall be individually set.

Tailoring of this scheme were done to cover the different particularities of the facility, like motor controlled through automatic circuit breaker, remote control from field, control from DCS or automatic starting facilities (due process conditions).

2) Dedicated PLC, SCADA or DCS.

Other further designs have considered the application of a programmable logic controller (PLC) for motor restarting in each motor control center or well a common PLC for motor restarting of a complete substation or group of substations. In the latest category can be included the usage of the electric SCADA system or the process Distributed Control System (DCS) for motor restarting (reacceleration) purposes.

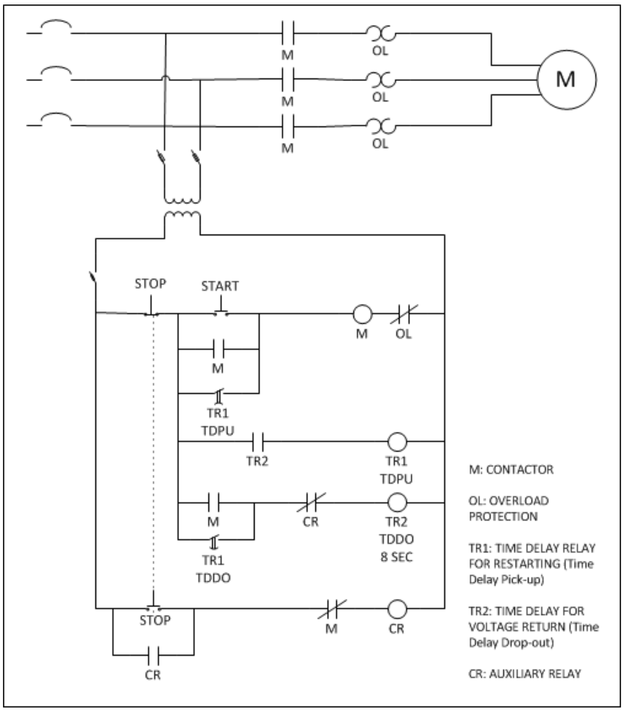

Fig. 1 Simplified motor restarting using electromechanical time relays

Concerns with this design deals with the fact that all motors involved with the restarting scheme shall be connected to the PLC; taking to the PLC at least the running status and the restarting command, plus the signal of healthy voltage of each busbar.

In some facilities, the use of a PLC or SCADA to perform the motor restarting function has raised in some maintainability problems and difficulties for further modifications of extension of the system.

3) Microprocessor motor protection relay.

The use of microprocessor based motor protective relays has provided another media for the physical implementation of the motor restarting.

In most of the relays used for protection of MV motor and high level devices for LV motors, the motor restarting (reacceleration) is already built-in function or can be easily programmed with the logic aforementioned.

4) Dedicated electronic restarting relay.

When in the LV motor control centers are used very simple electronic motor protective relays (e.g. just overload protection) or still are used some kind of electromechanical motor protections, current trend is to use in each motor control a small dedicated electronic restarting relay. This small device has built-in the control logic for motor restarting.

Both in the microprocessor motor protective relays and dedicated electronic restarting relay, it is necessary to set the maximum voltage return time (off-delay relay) and restarting time delay (on-delay relay). Some devices also may require additionally setting of the level when the busbar voltage has returned and can be considered as correct to allow the motor restarting (e.g. 90%).

In Figure 2 is shown a simplified scheme using a dedicated electronic restarting relay.

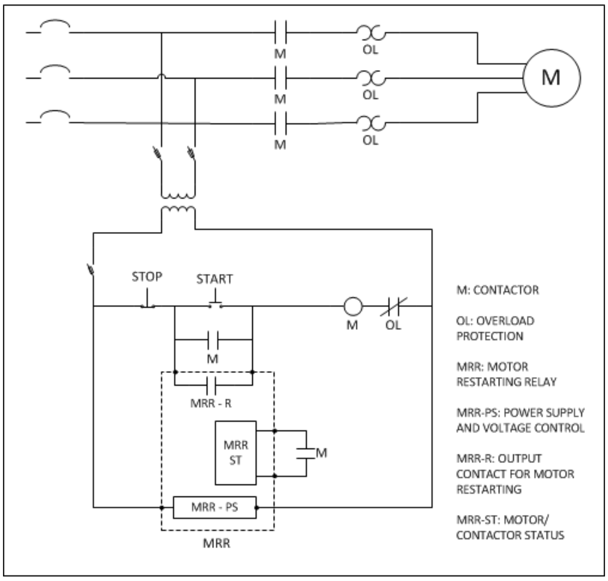

Fig. 2 Simplified scheme using a dedicated electronic restarting relay.

The final means to implement the motor restarting scheme will depend of the final user practices and the specific constraints that need to be applied in a project. Other issues like maintainability, field testing and future expansions should be also considered.

IV. DEVELOPING OF AUTOMATIC MOTOR RESTARTING SCHEME

A. General

As per definition for motor restarting, during a long duration voltage dip, the circuit breakers and contactors for medium voltage and low voltage motors will open automatically and therefore the involved motors become fully stopped.

When voltage is restored and motors are restarted, they will draw their locked rotor currents.

During the process of restarting of a group of motors or even a single motor, the voltage dip must not be dropped extremely to upset running motors and the voltage profiles in the busbars and motor terminals shall be maintained above the minimum pre-specified voltage limits as defined in facility or project practices to avoid an undervoltage tripping. Typical minimum values are 85% - 90% rated voltage at busbars and 80% - 85% at motor terminals.

In order to prevent total system collapse due overload and an excessive voltage drop when multiple motors restart simultaneously, critical motors shall be grouped in an order based in process categories and restarted in step intervals.

The number of steps, time intervals and nominal connected motor load on each step are determined by a specific power system study called Automatic Motor Restarting study or Motor Reacceleration study.

This study shall be performed in order to predict voltage and current profiles of each restarting step. Additionally, the study 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.

B. Motor restarting Philosophy

The need for motor restarting (reacceleration) 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.

If restarting is specified for a motor, this shall restart automatically only if it was running prior to the supply voltage dip, and if supply voltage returns within a specified time (for example, 8 seconds). Motors which were previously stopped will not be subjected to reacceleration.

For Emergency Switchgears longer voltage restoring time shall be considered, to take into account the time for starting Emergency Diesel Generators.

Motor involved in the Automatic Motor Restarting scheme will start in a specific fix step, where other motors are also starting simultaneously.

Motors to be included in each step will be categorized according to the motor priority defined in Table I and the Automatic Motor Restarting study (Motor Reacceleration study). Motor priority must be defined by Process discipline.

Restarting of each motor group will be in fixed time steps. Schemes using 5 or 6 seconds steps are typically used. Motors that take more time to start, e.g. blowers, shall be previously identified, and considered in the Automatic Motor Restarting study.

Figure 3 shows graphically the total time involved in a motor automatic restarting.

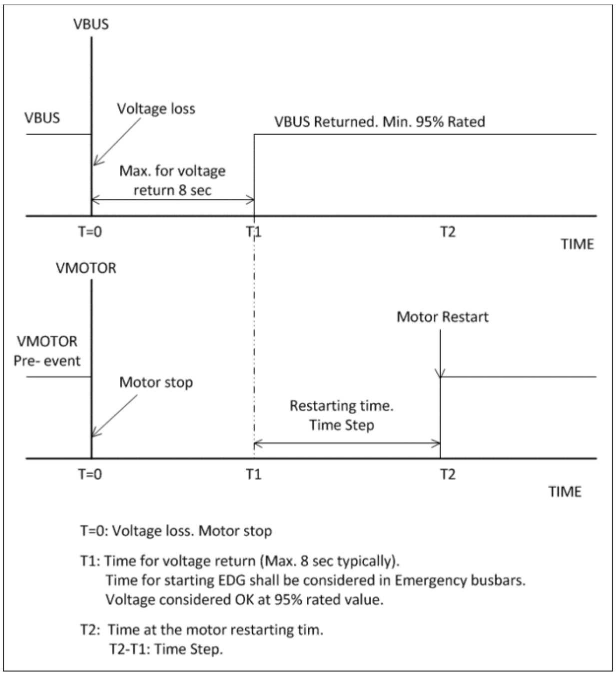

Fig. 3 Total time involved in a motor automatic restarting

Non-motor loads, e.g. lighting, HVAC, are not included in the restarting scheme due the fact as per design conditions; they remain connected to their busbars after the disturbance, unless they had been undervoltage tripped.

C. Procedure for developing a Motor Restarting Study

Automatic Motor Restarting study (or Motor Reacceleration study as called in several Companies) is a study lead by Electrical discipline, but that requires close cooperation with process and operation groups during the engineering phase and later during future plant upgrading.

In an early stage, Process/Operational groups shall define the process priority of all motors in the plant, as shown in Table I (A, B, C, NA).

After motor priorities assigned, electrical group assigns a time step to each motor through an extensive electric system study. The number of steps, time intervals and nominal connected motor load on each step of the refinery substations are selected depending on plant complexity, motor priority and connected load size, with the main purpose to maintain the operations in a safe and orderly manner for several power generation/power supply scenarios.

TABLE I
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 or lubrication pumps.
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.

[1], [2], [9], [10]

For each step, a simultaneous static motor starting study is done, in order to select the motors to be included in each step, in order to avoid overload and an excessive voltage drop in the power system.

The study will evaluate that in each step the voltage drop in all busbars is above the limit established (85%).

Initial results obtained with the Motor Restarting study, are revised later on together with 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 of Motor Restarting study are repeated in order to guarantee that there is not any excessive voltage drop in load buses and get the final motors assigned to each restarting (reacceleration) step.

This time step assignment shall be set at site according the scheme used in the facility to implement the motor restarting scheme.

In Table II is summarized the procedure for developing a Motor Restarting Study in Oil and Gas industrial facilities.

TABLE II
PROCEDURE FOR DEVELOPING A MOTOR RESTARTING STUDY

Activity	Description
Priority definition	Process group defines the process priority of all motors in the facility.
Initial step assignment	Electrical group assigns a time step to each motor based in the motor priority through electric system studies.
Multidisciplinary Workshop	Motors allocated in each time step are revised with involved Process and Operational groups.
Final step assignment	Electrical Group runs again the electric system studies to considerer the changes in the multidisciplinary workshop.
Setting at site	Time step assignment for each motor are set at site: time relays, restarting relay, PLC, SCADA, etc.

V. ELECTRICAL ASPECTS OF A MOTOR RESTARTING STUDY

A. General

Motor Restarting study consists in the developing of simultaneous static motor starting studies, one per each time step, in order to select the motors to be included in each step. Motor restarting scheme, as explained above, is based in the fact that in case on an event, the motors become totally stopped.

Aim of the study is to allocate the largest number as possible of motors in early steps, but verifying that the voltage in all busbars, evaluating them in each step, it is above the limit established (e.g. 85% at busbars, 80% at motor terminals).

Motor allocation is an iterative process shall consider the motor priority defined by Process group and the total connected load size. Motors in higher priorities should be restarted, if possible, before motors in lower priorities. However, this is not a must, since the final time step assigned will depend of the compliance of the voltage drop criteria in all busbars. [1], [2].

Therefore, if a high priority motor cannot not be restarted in one specific step, due a violation of the voltage drop criteria, in such step may be started motors with lower priorities. This situation typically occurs with large size motors.

In case of future expansion or upgrading of the facility, the motor restating study shall be repeated before the inclusion of this new equipment in the motor restarting schema. This will depend however on the number and size of new motor additions.

B. Premises to consider in the simulations

The number of steps, time intervals and nominal connected motor load on each step of the refinery substations shall take into account the worst operational scenarios of the power system.

Typically, simulations shall be performed for two types of operational cases, depending on the supply source involved: supply for the normal source or supply from an emergency diesel generator (EDG).

Main subjects to be considered in the simulations for each kind supply are the following:

1) Supply from the normal source.

- Maximum normal loading
- Minimum short-circuit current contribution from external power supply and in-site power generation shall be considered.
- All medium and low voltage switchboards, with a selective secondary scheme, shall be considered with tie circuit breaker closed and therefore one incoming line or transformer feeding the overall substation.
- Emergency switchboards, with both normal and emergency supplies, shall be considered with the normal feeder supplying the total load connected to these switchboards.
- Due typically all steps for a complete motor restarting scheme will take a time between 60 sec to 120 sec, the response of the transformers on-load tap changers (OLTC) should be considered.

2) Supply from emergency diesel generator.

- Maximum emergency loading
- In case of an external supply blackout, the emergency switchboards are supplied only by the corresponding diesel-generators feeder.
- Generators, governors and excitation systems shall be modelled in detail.

It is understood from above considerations that for Emergency switchboards it shall be performed simulations both for normal and emergency supplies from EDG. The worst time steps results for these two shall be used as the study results for motors feed from emergency switchboards.

Normally, the worst case corresponds to the supply from the EDG.

A commercial electrical software program shall be used for motor restarting analyses using the above considerations. This program shall have the capacity to simulate a several motor starting in a single run, one after one: monitoring of large number of parameters, and thus facilitate assessing the full impact of successive large scale motor restarts.

The number of successive runs will be the number of total steps required by the motor restarting scheme.

From the experience achieved from several studies, it has been obtained that the timing between each successive start step should be among 5 or 6 seconds. This time is sufficient according the power system studies and the protective relaying coordination, for starting each load.

Motors that take more time to start, e.g. blowers, special pumps, compressors, transportation belts, etc.; shall be previously identified and considered in the Motor Restarting study as taking several steps for restarting.

Dynamic parameters, like speed or torque, are not evaluated, since in other studies, like Motor Starting study, and in the vendor motor datasheets, it is revised that the motors are suitable to start with a minimum voltage in their terminals and in the busbar; for example, 85% at busbars, 80% at motor terminals. Therefore, if the voltage profile is above of that values it is assured that there is not any problem with the motors.

It is important to take into account that non-motor loads, e.g. lighting, UPS, HVAC, heaters, etc., and that are feed from circuit breakers; remain connected to their busbars after the disturbance, unless they had been tripped by undervoltage. They will become in service immediately the voltage returns. Their loading and inrush effects shall be included in the motor restarting study.

C. Example of Motor Restarting study.

An oil and gas facility with external supply and in-site generation is used as example of the developing of a motor restarting study.

This facility has one Main Substation for Interconnection with National Grid and with in-site Generation plant using 154 KV, 34.5 and 11 kV installations.

Also there are six large process Unit substations with utilization voltage of 11, 6.3, 0.69 and 0.4 kV.

MV and LV switchgears are equipped with Automatic Transfer System (ATS).

In all aforementioned substations, there are emergency switchboards to supply critical loads from EDG´s. These are also equipped with ATS.

Maximum loading of this facility is 90 MW with a peak load of 110 MW.

There are a total 804 MV and LV motors, moving in the range from fractional kW up to MW. This number includes all motor with continuous, intermittent and spare duties. 603 of these motors are subjected to restart after voltage dips, outages, or bus transfers.

Of these 603 motors, 460 are with continuous and intermittent duty and therefore, included in the simulations required by the Motor Restarting study.

These 460 motors represent 42,290 kW subjected to motor restarting.

In this facility, motors are restarted in 5 second steps. Supply voltage shall return in 8 second. For Emergency Switchgears voltage restoring time was assumed in 12 seconds, to take into account the time for starting Emergency Diesel Generators.

In Figure 4 and Figure 5 are shown respectively a summary of kW and number of motors restarted in each time step per substation. This facility requires 22 steps to allow the complete restarting of the plant.

Motors connected to the emergency switchboards shall be submitted to the evaluations, one when feed from the normal supply and another when feed from the EDG.

Due that, in those cases the steps are fixed for the worst result obtained in the motor restarting study and that in this case is due the limitation caused when the Emergency Diesel Generators.

During motor restarting point of view, a MV busbar have to consider not only the MV motors restarting in one step, but also the LV that may be restarting in the same step, since in this facility, MV busbars, 11 and 6.3 kV, feed the MV/LV transformers.

Step	Time Delay (sec)	kW of Rated Power restarted in each step						Sub-total (kW)
		SS-1	SS-2	SS-3	SS-4	SS-5	SS-6	
0	0	2458	313	288	389	103	985	**4535**
1	5	0	0	0	79	514	0	**592**
2	10	1067	1693	660	1225	234	30	**4909**
3	15	0	90	30	625	0	0	**745**
4	20	250	135	160	180	208	1400	**2333**
5	25	0	90	0	2140	0	510	**2740**
6	30	491	500	1400	250	0	2030	**4671**
7	35	0	90	0	1320	0	0	**1410**
8	40	431	773	1000	555	1660	880	**5299**
9	45		1297	0	355	0		**1652**
10	50		744	0	338	1680		**2762**
11	55		590	0	654	0		**1244**
12	60		250	669	552	560		**2031**
13	65			53	0	0		**53**
14	70			530	2765	148		**3443**
15	75				0	0		**0**
16	80				183	783		**966**
17	85				0	400		**400**
18	90				2195	0		**2195**
19	95				90	0		**90**
20	100					0		**0**
21	105					0		**0**
22	110					221		**221**
	Sub-total (kW)	**4697**	**6564**	**4789**	**13895**	**6510**	**5835**	**42290**

Fig. 4 Summary of kW restarted in each time step (continuous and intermittent duty).

Step	Time Delay (sec)	Number of motors restarted in each step						Sub-total (kW)
		SS-1	SS-2	SS-3	SS-4	SS-5	SS-6	
0	0	19	9	2	20	6	4	**60**
1	5	0	0	0	3	28	0	**31**
2	10	8	14	13	31	3	1	**70**
3	15	0	2	1	5	0	0	**8**
4	20	1	3	1	4	6	1	**16**
5	25	0	2	0	4	0	2	**8**
6	30	13	3	1	1	0	3	**21**
7	35	0	2	0	11	0	0	**13**
8	40	17	18	1	2	2	1	**41**
9	45		23	0	1	0		**24**
10	50		8	0	9	2		**19**
11	55		13	0	18	0		**31**
12	60		1	10	9	1		**21**
13	65			9	0	0		**9**
14	70			2	36	4		**42**
15	75				0	0		**0**
16	80				5	6		**11**
17	85				0	2		**2**
18	90				4	0		**4**
19	95				2	0		**2**
20	100					0		**0**
21	105					0		**0**
22	110					27		**27**
	Sub-total (kW)	**58**	**98**	**40**	**165**	**87**	**12**	**460**

Fig. 5 Summary of number motor restarted in each time step (continuous and intermittent duty).

In Figure 6 is shown a typical voltage profile behavior in the MV and LV busbars of one of the substations of this facility, during the automatic motor restarting sequence. Similar profiles shall be obtained for all other MV and LV busbars in the facility and in the Emergency panels when these are feed exclusively from the emergency diesel generators (EDG).

As can be observed in Figure 6, the minimum voltage at MV and LV busbars is always larger than 85%.

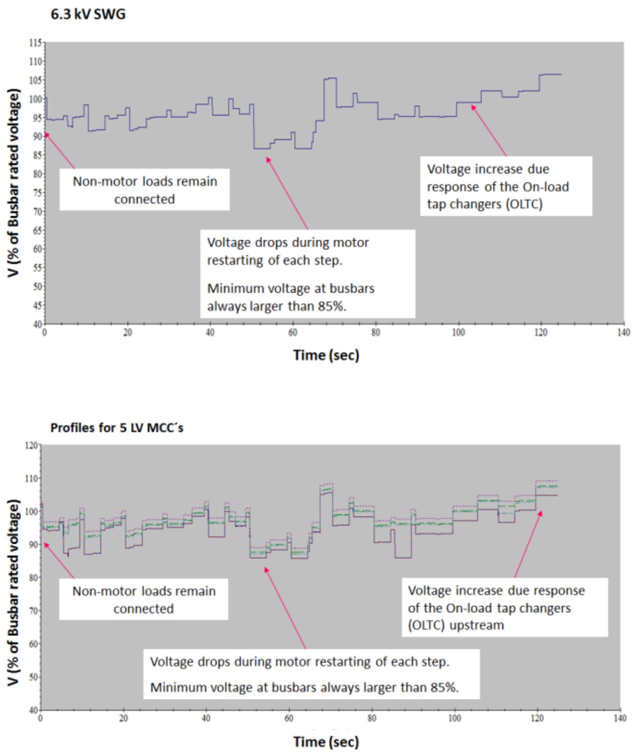

Fig. 6 Typical voltage profile in MV and LV switchgears during restarting of MV and LV motors

When voltage returns, the voltage drop at step 0 considers the motors restarting in such step plus the loading and inrush effects of the no-motor loads and that remain connected. The loading of these loads shall be considered in the all the remaining steps.

Due the total duration of the motor restarting scheme, near of 2 minutes, it can be observed a voltage increase due response of the transformers On-load tap changers (OLTC) located in the facility power system.

In references [1], [2] and [10] are presented other methodologies for performing motor restarting studies (motor reacceleration studies) considering the practices used in different facilities.

VI. CONCLUSIONS

In this paper was presented the motor restarting/motor reacceleration scheme, as one of the well proven strategies used large Oil and Gas industrial facilities to minimize production losses due electrical interruptions.

Application criteria for motor restarting, physical implementation of this scheme, multidisciplinary relationships for the developing of the study and premises for power system simulations have been revised.

Additionally, they were discussed the electrical aspects to consider in a motor restarting study. Premises to consider in the simulations and an example of Motor Restarting study have been presented.

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VIII. VITA

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