

STARTING LARGE SYNCHRONOUS MOTORS IN WEAK POWER SYSTEMS

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Paper No. PCIC-2013-14

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Abstract –Utility company standards for power quality are making it difficult for industrial users to start large induction and synchronous motors due to high inrush current. This paper will present a large oil company’s challenges starting large motors driven by the utility company in a relatively weak power system in East Texas while not violating the Utility company’s standards. A workable solution is an air cooled pulse width modulated (PWM) voltage source variable frequency drive (VFD) system designed to start multiple large horsepower, medium voltage synchronous motors without any measurable voltage flicker. Various combinations of motor design (induction vs. synchronous) & starting methods are reviewed and final design schematic diagrams are documented. Challenges encountered during the design & start-up are described and solutions with final performance details are provided.

Index Terms — motor starting, weak power systems, adjustable speed drive, variable frequency drive, variable speed drive, VFD, synchronous motor

I. INTRODUCTION

A large Oil and Gas Company undertook a major upgrade of a 1940’s vintage gas plant in East Texas installing four 15 kV electric driven centrifugal compressors ranging from 8,100 to 17,500 HP. The objective of the project was to both increase the capacity of the plant and replace obsolete & high maintenance large (over 5,000 HP) existing gas engine driven compressors. Additionally, eight new 5kV compressors were installed including all requisite 480V ancillary and lighting system loads. Electrical demand increased over fifteen fold from less than 4 MW to about 60 MW with over 65% of that total attributable to the four new 15 kV centrifugal compressors. Lower anticipated life cycle operating costs (investment vs. maintenance and up time) pointed to electric in lieu of gas drivers for the new compressors. It was desired to start the four compressors loaded or in recycle to eliminate emissions associated with blowing down (unloading) the compressors. Compressor speed turn down was not required for this installation. The existing plant electrical distribution system was upgraded and expanded with a new 138 kV substation and all of the associated 15 kV, 5 kV, & 480V electrical infrastructure (switchgear, MCC, cables, and tray).

Upon project completion, there was essentially a new electrical distribution system retaining only a fraction of the

original circuits for the remaining in-service equipment and lighting.

A. Utility Constraints

During Front End Engineering Design (FEED), it was discovered that the Utility had the following constraints for the proposed 138kV substation:

- 1) *Limited available short circuit current:* Calculated to be 7,459A three phase @138kV which would affect the large motor (8.1 kHP to 17.5 kHP) starting ability;
- 2) *Strict voltage flicker requirements:* Requested to limit voltage flicker (dimming of lights resulting from voltage drops) to 1-1/2%. This rule limited the ability to start the large compressor motors without special starting methods;
- 3) *Limited available transmission line capacity to the facility:* 63MW at 90% power factor (per the utility contract) without a major rebuild of the existing 138 kV transmission lines. Note that the total plant demand load is currently over 60 MW and rising @ 99% power factor.

In summary, the Utility did not have a “stiff” system but did have very stringent flicker requirements. A “stiff” system is more immune to flicker during high current inrush when starting large motors. The project had a significant challenge to start the loaded compressor motors and maintain power quality standards imposed by the Utility.

II. ALTERNATIVES & FINAL DESIGN

A. Motor Starting Alternatives Considered

Multiple motor starting alternatives were considered to address the voltage flicker limits. Some options were considered only in passing and others were investigated more thoroughly as follows:

- 1) *Auxiliary Starting Motors (Diesel or electric):* One option considered was to install “pony” motors to bring large motors up to partial speed before transferring to the normal bus. This option was quickly discounted by inspection due to the excessive field equipment requirements,

complexities with the required clutch arrangement, and overall reliability.

- 2) *Switched Starting Capacitors*: Installation of large banks of switched starting capacitors common to all motors on the main 15 kV switchgear bus was considered only in passing as a viable option. Capacitors would be switched in and out with vacuum breakers to correct the very low power factor of a motor during starting acceleration. This option was discounted due to the potential for electrical system resonance issues, arcing during switching operations, risk of self-excitation of other motors on the bus, and overall system protection issues.
- 3) *Reduced Voltage Solid State (RVSS) Soft Start Dedicated to each Motor*: Significant time was invested in evaluating the alternative of using solid state reduced voltage starters as this was the initial Concept Select recommendation. A Soft Start manufacturer performed unloaded motor starting analyses for both large induction and synchronous motors. If the compressors had been loaded (i.e. not vented), the starting calculations would have indicated higher inrush current and/or increased acceleration time. The analysis results for the 14,000 HP synchronous motor were as follows:
 - a) RVSS Soft Start: 375% FLA for 23.0 sec. acceleration time and equivalent locked rotor time of 6.5 sec;
 - b) Across the Line Start: 460% FLA for 4.3 sec. acceleration time and equivalent locked rotor time of 3.6 sec.

To summarize, installation of a soft start system would only reduce the starting current by approximately 20% while increasing the acceleration time by over 400% for synchronous motors. Similar results would be anticipated for induction motors. The marginal reduction in starting current would not have reduced the voltage flicker to the required 1-1/2% and the extended acceleration time at the higher starting current would result in unacceptable rotor heating. Accordingly, this alternative was finally discarded.

- 4) *Load Commutated Inverter (LCI)*: LCI systems have been available for many years and have been used for large synchronous motor control. This option was not considered due to a number of complexities. Primarily, position sensor feedback was needed for starting that would have required additional hardware on the motor. The rectifier section of the LCI system has a high harmonic content and low starting power factor that would have required additional studies for power line quality to ensure compliance with the flicker limitations.
- 5) *Reduced Voltage Auto Transformer (RVAT)*: Auto transformer starting methods can be more

effective for reducing voltage flicker than the RVSS soft start method described above. Said another way, the RVAT produces more torque per unit line amps than the RVSS. This is because a transformer is used to reduce voltage to the motor. A transformer transforms the voltage while conserving kVAs; whereas, other **series** type starters (reactor, RVSS) drop voltage and therefore absorb kVAs. The impact to the motor is similar between the RVAT and RVSS. Consequently the RVAT was not considered after the RVSS starting study showed that excessive motor heating would be encountered during starting.

- 6) *Reactor Starting*: Reactor starting was not considered even though it is simpler than RVAT or capacitor starting and without the system resonance issues associated with capacitor starting. As described above, reactor (in series) starting provides poor starting torque and there were concerns with overall power system stability during the transition to full voltage (i.e. bypass reactor). For large motors of the Project's size, large reactors would have been required that may result in power system disturbances. This starting method has the additional issue of excessive motor heating common to low voltage starting methods.
- 7) *Voltage Source PWM Starting Variable Frequency Drive (VFD)*: Inherently, the VFD starting method results in the highest (100%) torque per unit line current. Several design options were considered using large VFD(s), either dedicated and sized for each motor or one common and switched between motors. The final design recommendation was a shared/ common single large starting VFD coupled with a 15 kV switching scheme that proved to be the lowest cost and technically acceptable option. This solution builds upon a similar paper submitted to the IEEE PCIC 2010 which documents the capability of a Voltage Source VFD to start motors without exceeding motor full load amps (1).

The other alternatives investigated only partially corrected for current inrush and the associated resulting voltage flicker or potentially had significant system concerns. Table 1 below provides a qualitative summary of the various starting methods described above.

TABLE I
COMPARISONS OF STARTING METHODS

Method	Torque	Flicker	System Resonance	Motor Restarts	Cost/Simplicity
Across the Line Start	Good	Poor	None	One	N/A
Pony Motors	Good	Good	None	Multiple	High
Starting Capacitor	Good	Good	Poor	One	Low
Reactor	Poor	Fair	Poor	One	Low
RVSS	Poor	Fair	None	One	Fair
RVAT	Fair	Good	None	One	Fair
PWM VFD	Best	None	None*	Multiple	High
LCI VFD	Best	None	Fair	Multiple	High

*With Sine Filter

B. Synchronous versus Induction Motors

Prior to starting system design, the type of motor to be utilized had to be determined, induction or synchronous. Induction motors are simpler, lower in cost, and easier to control; synchronous motors are marginally more efficient and provide reactive power (VARs) to improve system wide power factor.

The use of synchronous motors was selected in lieu of induction motors even though they are appreciably higher in initial cost and require a more complicated starting system design. However the selection of the synchronous motors was justified by the 1% improvement of efficiency compared to induction motors. Additionally, once transferred to the power line, synchronous motors allowed for improvement of the overall plant power factor (PF) thus increasing the available real power on the current limited Utility transmission lines. The Utility limited the load to 63MW based upon a 90% PF; by improving the PF (the plant is currently operating at 99% PF), the project would be able to add an additional 7.0 MW load and stay within the capacity of the existing transmission lines.

C. Final Design Selected

After evaluating all of the considered alternatives, the project recommended a single/common starting VFD coupled to four (4) 12.47 kV synchronous motor compressor drivers. This combination addressed voltage flicker concerns, reliability requirements, lowest operating (kWh energy) costs, and extended motor life/maintenance reductions. This was not necessarily the lowest cost initial investment (CapEx) solution and a premium was paid for this scheme versus some of the other alternatives investigated. However, it was determined that the benefits far outweighed the additional costs and potential risks. This system would result in the lowest long term operating and maintenance costs (OpEx).

Only air cooled VFDs were considered as air cooled units have lower complexity (i.e. no hoses, pump seals, water to water heat exchangers, outdoor heat exchangers, or a deionization tank) and subsequent higher reliability than liquid cooled VFDs. After a long period (up to three months) of inactivity, most water cooled drives require significant wait time to pump water through the deionization

tank to ensure non-conductivity. This is not an issue for air cooled technology.

Previous experience with starting VFD's had shown that a motor can be started unloaded with a VFD rated at only 25% of the motor HP rating. Available air cooled VFD's are well within that range as the largest motor for this application was 17.5 KHP. In order to minimize unloading requirements (venting of compressors), a 60% or 10 KHP air cooled VFD was specified.

Also, a "start duty only" VFD allows savings associated with climate control. The control house was specified with an HVAC system sized only for the ambient temperature & humidity plus the no load heat losses from the VFD input transformer. The full load VFD thermal losses were not considered for the HVAC design even though they can be substantial (4% or 300 kW at full load). However, the VFD is only fully loaded for less than one minute during the start cycle; accordingly, at least ten (10) consecutive large motor starts can be made without an unacceptable temperature rise in the building. This fact was borne out during commissioning and startup. At the User request, a redundant outside air exhaust fan was provided in the VFD building should the air conditioning system fail to keep up with the VFD heat load. To date, this feature has never been utilized.

III. APPLICATION CHALLENGES

The End User did impose a number of special technical, testing, and project execution requirements upon the Drive Vendor which did complicate the design, testing, and execution of this project

A. Technical Specifications

A combination of User Operations philosophy, cost considerations, and machinery design requirements dictated that the Drive Vendor provide the following deliverables:

- 1) **Redundancy/Backup:** The User recognized that the selection of one VFD for starting four motors meant that that one VFD was a single failure point that could result in total plant shutdown. Redundancy in the design was requested of the VFD vendor. The vendor supplied a drive that allowed for 60% output capacity even if a rectifier, transformer, or output phase failed which could still start the compressors by additional unloading. This required dual transformers in parallel and parallel output phases. Once the motors are running, the drive can be isolated for repair.
- 2) **Test Mode:** The User required a one button self test of the VFD system to ensure that the VFD would be available and operational when called upon. Since the VFD is for starting duty only, it would be idle/ offline and unpowered for more than 99.99% of the year. Activation of the self test performs the following offline functions while the 15 kV motors are running normally:

- a) Close the preselected 12.47 kV switchgear feeder breaker to the VFD;
 - b) Close the integral VFD feeder breaker to energize the input transformer and power cells;
 - c) Power up the VFD cooling fans;
 - d) Energize the power cells;
 - e) Perform self test of the VFD controller;
 - f) Issue failure alarm to operator should any portion of this test fail.
 - g) This test does not check the operation of any parts of the system that would conflict with operating equipment; accordingly, the motor breakers and synchronization scheme is not tested. Neither is the output transformer bypass scheme tested as that requires feed back from a motor.
- 3) *Drive Inrush:* To reduce the 1200% power up inrush current of the drive internal input transformer, a current limiting reactor with shorting contactor was utilized to limit the inrush to 75% of drive full load current rating.
 - 4) *Drive Output Transformer:* Motor size is large, and most commercially available VFD designs are limited to 4.16kV, 6.0kV, or 7.2 kV applications. In this instance, the project team and compressor vendor had already determined that 12.47kV was the most suitable voltage for the motors due to the existing power system infrastructure and the motor size. Accordingly, a step up transformer was required for the drive design to obtain the proper motor voltage.
 - 5) *Sine Filter:* A sine filter consisting of an inductor and capacitor was required on the drive output for the following reasons:
 - a) *To reduce detrimental effects of output transformer:* Since a transformer can exacerbate ringing and resonance surges from a drive artificial voltage (DC pulses to simulate a sine wave current), that may damage motor insulation (2).
 - b) *To limit liability:* Since the motor supplier was a different vendor from the VFD supplier.
 - 6) *Excitation System:* The motor starts synchronized with drive output frequency and at unity power factor. The motor rotor needs excitation before the drive starts. The VFD outputs a control signal to the exciter controller as part of the control scheme and upon transfer to across the line, it hands off control to the exciter to maintain VAR or power factor control.
 - 7) *Output Transformer Response at Low Frequency:* A drive output transformer does not have linear response from 0 to 60 Hz (simply put, a transformer cannot step up DC voltage). At low

frequency, voltage output from the transformer and motor break-away torque performance is very poor. To obtain proper performance, vacuum circuit breakers were installed in the output to bypass the transformer during motor acceleration from 0 to 20 Hz and then insert the transformer from 20 to 60Hz. This stepped approach requires the drive to switch between two different drive V/Hz settings to maintain the motor's fixed 12.47kV to 60 Hz ratio.

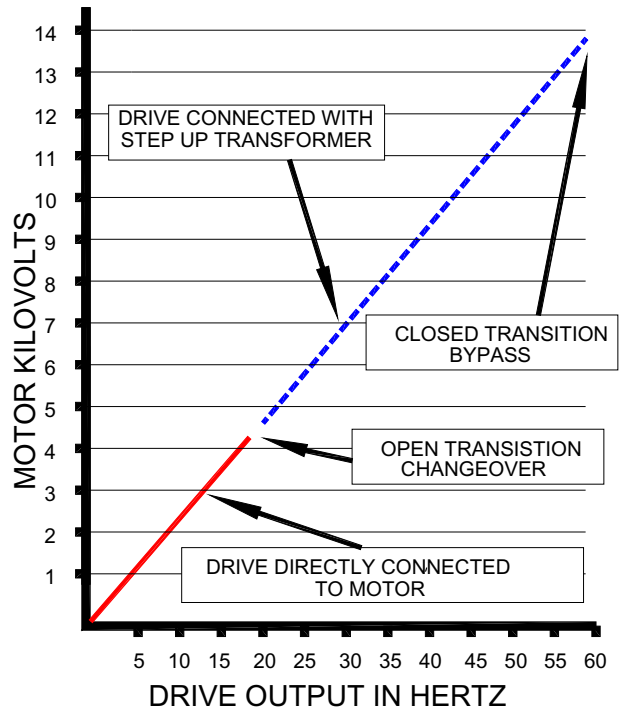


Fig. 1 Two Stage Acceleration

- 8) *Application Concerns:* The compressor selected was a high speed centrifugal unit that required a speed increaser gear box. On a four pole synchronous motor, the rotor could rotate up to 90° either forward or backward to get in synchronous position. However, reverse operation would damage the compressor. A ratchet could be installed, but this requires mechanical servicing and adds complexity. Without the use of encoders, the VFD determines the exact rotor position by measuring the stator transient voltage during rotor magnetization and adjusting the drive voltage at startup to ensure only forward rotation.

B. Interface Coordination and System Responsibility

The User assigned system responsibility to the VFD manufacturer. However, the 15kV switchgear was purchased directly by the User and the 12.47 kV motors were purchased by the compressor packager which is typical (mechanical/machinery issues drive that decision).

The VFD manufacturer proved to be the optimum choice for system responsibility for the following reasons:

- 1) Provided the most critical and complex components of the system (VFD with synchronizing logic to the Utility, breaker switching logic PLC, and synchronous motor exciter controller in addition to the VFD building);
- 2) Provided design guidance and one-line requirements to the User to obtain bids from switchgear vendors;
- 3) The only entity willing and technically able to provide a complete string test utilizing both his provided equipment and representative switchgear & synchronous motor to prove the total system during the Factory Acceptance Test (FAT);
- 4) Participated in the switchgear vendor's FAT after installation of the VFD Vendor's switching logic PLC in the switchgear building to prove PLC control of the 15 kV breakers.

Accordingly, the end User issued three separate purchase orders from different vendors for (1) switchgear/power building, (2) VFD, VFD Building, exciter controllers, & Switching Logic PLC, and (3) compressors/motors. Meetings were held with all parties and drawings when released were shared to ensure equipment and controls compatibility. The VFD vendor developed and manufactured the drive, purchased and programmed the User specified Breaker Switching Logic (BSL) PLC, and purchased a commercially available dedicated synchronous motor AC exciter controller from a third party.

C. Factory Acceptance Test (FAT) Events

In keeping with the User's "system responsibility" approach, the VFD vendor was required to functionally "string test" the full system. This included not only his equipment but also representative switchgear and synchronous motor to be utilized in the field. During the User specified Factory Acceptance (FAT) string testing all of the major components (VFD, switching logic, switchgear, and exciter controller) worked together to start the synchronous motor to the User's satisfaction. However, the exciter controller failed multiple times with circuit board damage. The failure occurred during transition/switching from the VFD/motor period (i.e. 0- 20 Hz) to the VFD/output transformer/motor period (i.e. 20- 60 Hz). This result was completely repeatable (all four exciter controllers were damaged) and it was assumed that a surge was occurring in the motor exciter winding. When the exciter controller manufacturer was unable to determine the failure cause or offer a solution, that exciter controller was abandoned and a different exciter controller manufacturer was selected.

The new exciter controller design (one required for each motor) used a commercially available low voltage VFD (by main VFD vendor) with modified software. Normally this product provides variable voltage and frequency with a fixed V/Hz ratio. The software was modified to maintain the frequency fixed at 60Hz with an output infinitely adjustable up to 460V. This simulates the same performance of a

thyristor controller starter output. Additional equipment added to the low voltage VFD included a sine wave output filter, VAR and power factor controller, and a PLC for control of the synchronous motor power factor after the drive has transferred the motor to the normal power line.

Testing of the electrical system components individually and together in a string test proved to be very important in identifying and resolving what could have been a very serious problem in the factory before field installation.

D. Site Acceptance Test (SAT) Events

Once all equipment was installed in the field with compressors and testing had begun, four minor unanticipated issues occurred.

- 1) *Exciter Controller:* During the check out of the VFD and motor, the motor was stopped while running on power line. During coast down of the motor, the capacitors on the DC bus of the new design low voltage exciter failed dramatically. This would happen even if the exciter controller had no power. Exciter winding voltage would not decay as normally expected and would actually increase.

Referring to Fig. 2 below, the exciter circuit was designed without isolation contactors as originally configured. During non-powered coast down of the motor, the capacitors (B) in the sine wave filter on the low voltage VFD exciter controller were in resonance with the motor exciter windings (A). The resulting AC voltage (C) would go to high levels exceeding the VFD capacitor rating (D). Voltages on the exciter are normally 420VAC or less, but were documented over 700VAC exceeding the limits of the motor exciter winding insulation.

The sine wave filter capacitors (B) were removed from the VFD exciter and the resonance problem disappeared. However, harmonics from the VFD based exciter controller (2KHz PWM) output became unacceptably high and the motor exciter manufacturer required that the sine filter capacitors be retained. Surge arrestors were tried without success (continued to experience unacceptable voltage spikes). The final solution was both simple and inexpensive; an output contactor was added to instantaneously isolate the exciter controller from the motor whenever the motor was tripped.

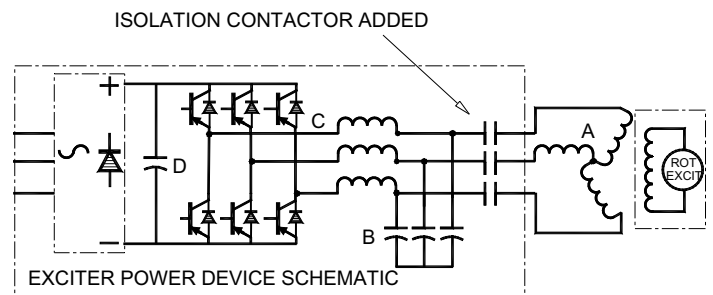


Fig. 2 Exciter Controller to Motor Interface

- 2) *Power Factor Control Handoff:* During the start sequence, the VFD maintains the Power Factor (pf) at 1.0 via the Exciter Controller. However, upon completion of the motor start sequence, the VFD was to hand off pf set point control to the DCS to permit the plant DCS operator to maintain overall plant pf. That was a mistake; it was one interface not assigned under the VFD Vendor's "system responsibility" mandate. The DCS output was missing subsequently driving the pf to extremely lagging (close to -0-) and tripping the motor on a pf fault. The DCS was removed from the control circuit. Upon completion of the starting sequence, pf set point control was handed over to the exciter controller PLC which was reprogrammed to only accept manually entered pf values between 1.0 and 0.8 leading.
- 3) *Potential Transformer Location:* The manufacturer of the VFD had installed a 5kV PT (potential transformer) for feedback on the drive output as part of the original design. When the drive was directly connected without the step up transformer accelerating the 12.47kV motor to 20 Hz @ 4kV, the drive v/Hz relationship was not compatible with the PT and it overheated. PT's are designed for full voltage at 60 Hz, not extended periods of 20 Hz at full voltage required for testing and commissioning. The PT wiring was relocated to the primary of the output transformer circuit so that it only operated above 20 Hz and then only for 2 minutes before reaching 60 Hz..
- 4) *Relay Settings:* An independent 25 relay (synchronism check) used for permissive to transfer to line was set at too tight of a tolerance and created nuisance transfer failures on some of the motors. The problem appeared to be on the motor with larger torque variances. It was difficult to troubleshoot because it is not a latching device and is independent of the VFD diagnostics.

E. Final Observations and Performance of the Package

The VFD method of starting limits motor starting current inrush to much less than 100%; in fact during the four (4) minute starting sequence, the motor starting current typically never exceeded 40% over the full speed range since the compressors were started either fully unloaded (for the largest 17.5 kHP nitrogen compressor) or only partially loaded for the rest. Hydrocarbon compressors were in recycle and not blown down for starting. This compares with about 300-375% inrush using a reduced voltage soft start.

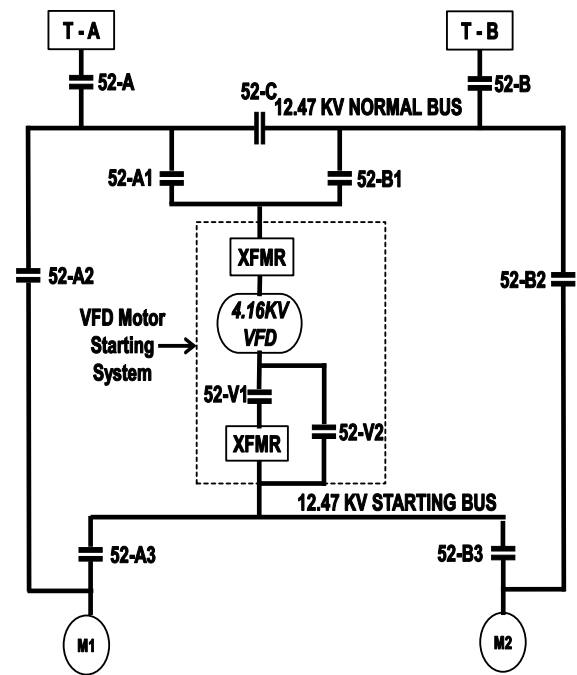


Fig. 3 Starting VFD System: Example for two Motors

Please reference Fig. 1 Two Stage Acceleration and Fig. 3 Starting VFD System Schematic above for an explanation of the Motor Startup sequence described below. This sequence can be monitored on the Breaker Switching Logic (BSL) PLC HMI.

- 1) Assuming Motor M1 must be started, Operator in field pushes the start button on selected compressor control panel which only operates if multiple permissives including "VFD Ready" is received from BSL PLC;
- 2) BSL PLC closes VFD feeder breaker 52-A1 and integral VFD input transformer soft start breaker to energize VFD cells and start VFD cooling fans;
- 3) BSL PLC closes motor starting breaker 52-A3, output transformer Bypass Breaker 52-V2, and ensures that Normal Bus Breaker 52-A2 and Output Transformer Breaker 52-V1 are open;
- 4) VFD controller takes control and ramps motor from 0 to 20 Hz (33% of full speed); approximately 2 minutes are required up to this point;
- 5) At 20 Hz, the BSL PLC performs open transition switching of the output transformer bypass scheme by opening 52-V2 and then closing 52-V1;
- 6) Motor speed coasts down to about 15 Hz and VFD Controller "catches" motor and ramps motor from 15 Hz to 60 Hz;
- 7) Upon reaching 60 Hz (full speed) at rated voltage, the drive microprocessor located compares the voltage, frequency, and phase angle of the Utility/Normal Bus with that of the VFD output and

makes corrections to the VFD output as necessary;

- 8) When the Normal and VFD starting buses are synchronized and receives independent confirmation from the "25 Sync Check Relay", the VFD controller directs the BSL PLC to initiate a closed transition transfer by closing Normal Bus Breaker 52-A2 and then opening Starting Breaker Bus Breaker 52-A3. A total of 4 minutes time is typical from initial start command to transfer.
- 9) VFD remains energized for 30 minutes during which time Step#s 1 & 2 are bypassed and the VFD is immediately available to start another motor by going to the Step# 3 breakers for the following motor (i.e. 52-B2 & 52-B3).
- 10) There is only a marginal temperature rise in the VFD building during this 4 minute starting sequence.

This VFD starting method completely eliminated any potential for voltage flicker. Additional benefits of this starting system were complete elimination of all motor and coupling stresses as well as motor heating concerns during starts; in fact, the Max Starts/Hour feature in the motor protection relays for the four VFD started motors was turned off. Compressors were started multiple times per hour during the commissioning and startup period with no rotor heating concerns.

These advantages provided by VFD starting over other starting methods reduced the commissioning time on the compressors; no starting delays were required for cooling time for the motors during the multiple shutdowns and restarts that occurred during testing of the compressor controls and surge protection. There was never any wait time between starts required for the motor to cool down.

A single/common starting VFD was the most cost effective solution versus dedicated starting VFD's. The cost for four dedicated VFD's, one per compressor, far outweighed the additional investment required in switchgear and controls. The VFD was sized to about 60% (10,000 HP) of the largest motor knowing that if it could start the largest 17.5 kHP motor, all of the other compressors would definitely start. In fact, selection of sizing was over conservative on the VFD as the compressor models showed that only 25% (4,400 HP) of the largest motor horsepower was needed to start any compressor fully unloaded. The larger 10 kHP VFD was selected in order to start some of the smaller methane gas compressors partially loaded to minimize any venting. The largest compressor was for nitrogen for which venting is not a concern (air is 78% nitrogen).

IV. CONCLUSIONS

Starting large motors has always been a challenge for multiple reasons. There are more constraints for the design engineer than ever before: emissions requiring loaded starts, limited utility capacity, and voltage flicker requirements. VFD technology is improving and is a viable alternative for the industrial user to mitigate the constraints without reduction of motor life while allowing multiple

restarts. This design of one single VFD with limited redundancy for starting multiple motors balances capital investment with system performance. It allows a motor to start with the most available torque with the least impact to the electrical system.

This innovative design installed in deep East Texas combines the use of the following:

- 1) Starting duty drive with a rating below the motor voltage and current rating.
- 2) Multiple differently sized motors with different protection settings and multiplexed breaker controls.
- 3) Synchronous motor with associated individual excitation controllers.
- 4) On line uncoupled test mode for confirming VFD availability.

As a result, this starting system has been performing as designed consistently starting up each motor without any failed starts or need for electrician assistance.

V. ACKNOWLEDGEMENTS

Matt Colosino owner of Crescent Power Systems with locations based in New Orleans and Houston was instrumental in bringing parties together for a successful implementation.

Takashi Morishita, Toshiaki Oka, Mike Daskalos and Mark Rayner with Toshiba International Corporation were key design engineers for the VFD system and exciter package.

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VII. VITA

Kurt LeDoux graduated from DeVry Institute of Technology with a BSEET degree in 1978 and started his career with Reliance Electric as a Service Engineer on Drive Systems. He moved to Toshiba in 1982 and has held various drive related positions in manufacturing, service and repair, engineering, and quality control. He has authored many technical papers, most regarding voltage stress issues using drives with long motor cables and step up transformers for the Society of Petroleum Engineers Electric Submersible Pump Workshop. He is presently still at Toshiba working as Product Manager for Medium Voltage Drives.

Paul W. Visser graduated from Texas A&M University in 1969 with separate BS degrees in both Electrical Engineering and Nuclear Engineering. Upon graduation, he went to work with Humble Oil & Refining Company (now ExxonMobil) performing various electrical, controls, and even drilling & workover engineering assignments onshore & offshore both in the US and on loan to Saudi Aramco. He retired from ExxonMobil and is now an independent Consulting Engineer. He originally became a student member of IEEE in 1968 and has been a Member of IEEE since 1986. Mr. Visser is a registered professional engineer in the state of Texas.

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Hien Nguyen graduated in 1982 with a BSEE degree from Kansas State University and has held positions at Western Electric and General Electric (GE) before starting at Toshiba in 1988 where he now works as a Design Engineer and PLC programmer. Mr. Nguyen received a Masters in Electrical Engineering from Prairie View A&M and is registered as a professional engineer in Texas.