STRATEGIES FOR INCREASING ENERGY EFFICIENCY OF ELECTRICAL AUX LOADS IN LNG AND PETROCHEMICAL FACILITIES

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Abstract – Liquified Natural Gas and Petrochemical facilities utilize onsite generation or utility power to supply the plant auxiliary loads including lighting, process heaters, pumps, compressors, fans, building Heating Ventilation and Air Conditioning, Uninterruptible Power Supply etc. Power consumed by these plant auxiliary loads is a direct cost to the operating facility and minimizing the consumption can yield savings. A variety of strategies are available today including right-sizing and reducing losses in transformers, high efficiency motors, energy efficient prefabricated plant buildings, LED lights with smart controls, and solar street lighting. Implementation of such strategies can also help the user achieve their carbon reduction goals. This paper will explore such strategies from standpoint of ease of implementation, cost-benefit, and value to the end user. The goal is to provide a menu of options that may enable the user to choose the right combination of strategies to achieve their individual energy efficiency targets.

Index Terms —Gas Insulated Switchgear (GIS), Inlet Guide Vane (IGV), Light Emitting Diode (LED), High Efficiency Motor, Substation, Transformer, Uninterruptible Power Supply (UPS), Variable Speed Drive (VSD).

I. INTRODUCTION

In recent years, there are growing concerns about the impact of human activity on the environment that is leading to global warming and drastic changes in the climate. There is increasing pressure from both the public and regulations to make industrial facilities more energy efficient, reduce their environmental impact and achieve a lower carbon footprint.

This paper will focus on typical electrical consumers within Liquified Natural Gas (LNG) and petrochemical facilities (generically referred to in this paper as process facilities). Various measures and technologies to increase energy efficiency will be reviewed. In recent times, there is a lot of interest in electrification of process loads (example- electric motor driven compressors replacing gas-turbine compressors) that has the effect of increasing electrical power demand while reducing the facility's carbon footprint. This topic is outside the scope of this paper. However, some of the measures described in this paper can also be used for increasing energy efficiency in electrification projects.

Equation (1) will be used for return-on-investment or payback period in months of service (excluding any downtime for maintenance or other reasons):

$$Payback = \frac{\Delta Cost}{\Delta kW \times \frac{\$}{kWh} \times 24\frac{Hours}{Day} \times 30.41\frac{Days}{Month}} \tag{1}$$

where, $\Delta Cost$ represents the higher Capital Expenditure (CAPEX) cost that needs to be paid for the improvement measure and ΔkW is the reduction in net electrical load (or losses). The average $\frac{\$}{kWh}$ is assumed as 0.06 for the purpose of evaluation in this paper.

Section II will focus on reducing the transformer losses, Section III deals with utilizing high efficiency motors, Section IV describes various strategies for increasing energy efficiency of permanent plant buildings, Section V describes energy improvement measures for plant lighting and Section VI relates to a specific application in which using Variable Frequency Drive (VFD) in lieu of inlet guide vanes yield energy savings.

II. MINIMIZING TRANSFORMER LOSSES

A. Specifying Practical Operating Point for Evaluating Losses and Efficiency

Process facilities have several transformers operating continuously throughout the year. The majority of the transformers may be of distribution class (2.5 MVA and below). The US Department of Energy (DOE) has prescribed minimum efficiency requirements for Dry type and Liquid-Immersed distribution transformers under the Code of Federal Regulations 10 CFR 431 [3]. Transformer manufacturers will comply with these minimum efficiency levels by default unless the application is specifically exempted. In recent times, with the growing interest in electrification projects, the need for medium sized power transformers and larger utility transformers (above 69 kV and 50 MVA), has increased. However, for medium and large power transformers, the manufacturers will focus on providing the most cost competitive design that may not be necessarily optimized for losses unless required by user's specification.

The losses in a transformer are broadly classified into two categories- No-Load losses and Load losses. The No-Load losses or core losses do not vary according to the loading of the transformer. They are constant and occur 24 hours of the day so long as the transformer remains energized. Load losses or I^2R losses vary proportional to the loading of the transformer (square of the load current). At lower loading, the Load losses will be significantly lower than at the 100% rating and the No-Load losses may have bigger impact on the efficiency. Specifying the loading where the transformer is most likely to operate will allow the manufacturers to optimize their design and maximize the efficiency close to the operating point. The below example illustrates the difference between two designs that are optimized at different operating points.

Table I shows the efficiencies and losses at 100% loading for three different transformer ratings. Bidder 1's design has lesser No-Load losses and higher Load losses than Bidder 2's design. Therefore, at 100% loading, the total losses for Bidder 2 are lower than Bidder 1. Bidder 2's design would yield a savings of 37 kW or daily saving of 888 kWH.

TABLE I
LOSS EVALUATION @ 100% LOADING

	Bidder 1		**Bidder 2**	
Transformer Rating (x Quantity)	**No-Load Losses (kW)**	**Load Losses (kW)**	**No-Load Losses (kW)**	**Load Losses (kW)**
20 MVA (x2)	10.0	128.0	17.7	110.6
16 MVA (x2)	9.0	105.0	13.9	87.6
12.5 MVA (x1)	9.6	66.5	14.0	69.1
Total Losses for all units (kW)	580.0		543.0	

However, if the transformer is expected to operate most of the time at 50% loading, Bidder 1's total losses come out to be lower than Bidder 2's total losses as shown in the load-corrected Table II. Bidder 1's design would yield a savings of 13 kW or daily saving of 312 kWH.

TABLE II
LOSS EVALUATION @ 50% LOADING

	Bidder 1		**Bidder 2**	
Transformer Rating (x Quantity)	**No-Load Losses (kW)**	**Load Losses (kW)**	**No-Load Losses (kW)**	**Load Losses (kW)**
20 MVA (x2)	10.0	32.0	17.7	27.7
16 MVA (x2)	9.0	26.3	13.9	21.9
12.5 MVA (x1)	9.6	16.6	14.0	17.3
Total Losses for all units (kW)	180.7		193.6	

The most cost-effective way to achieve optimized design is to specify the practical operating point and to provide a loss evaluation factor ($/kW) at the time of competitive bidding. This is also a useful step for the end user to plan capital and operational expenditures.

B. Optimizing Transformer Ratings

Forced-cooled transformers can be 8% to 10% less expensive than equivalent self-cooled transformers. However, they may operate with higher copper losses when the loading is below the natural cooled rating and fans are not running. Consider the Main-Tie-Main configuration shown in Fig. 1.

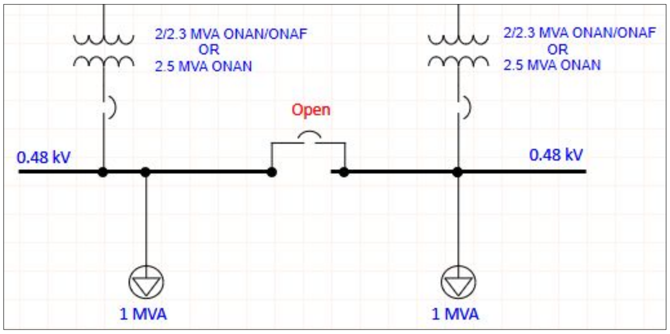

Fig. 1 Main-Tie-Main LV System Supplied by Redundant Transformers

Normal operation will be with tie breaker open and each transformer supplying its respective half bus. Since each transformer must be sized to carry the total bus load (tie breaker closed scenario when one transformer is taken out of service), the required rating would be 2/2.3 MVA ONAN/ONAF including a 10% margin.

During normal operation with tie breaker open, the fans will not be operational since the loading (1 MVA) is well below the ONAN rating. The transformer will be operating at close to 50% of ONAN rating. If the next higher rating of 2.5 MVA ONAN is selected, each transformer will normally operate at 40% of its ONAN rating and will have lower losses as shown in the Table III below-

TABLE III
LOSS COMPARISON BETWEEN FORCED COOLED AND NATURAL COOLED RATINGS

Rating (MVA)	**Cooling**	**No-Load Loss (kW)**	**Load Loss (kW)**	**Total Loss (kW)**
2/2.3	ONAN/ ONAF	2.5	$21.5*(0.5)^2 = 5.4$	7.9
2.5	ONAN	2.7	$23.1*(0.4)^2 = 3.7$	6.4

The net delta in losses for the pair of transformers would be 1.5*2 =3 kW or a daily saving of 72 kWH.

Using the equation in Section I, the payback period considering the savings in Operating Expenditure (OPEX) can be calculated-

$$Months = \frac{\Delta Cost}{3 \times 0.06 \times 24 \times 30.41} \tag{2}$$

Above equation yields payback in 76 months or 6 to 7 years of operation (excluding downtime). Further, any maintenance cost for the cooling fans will also be avoided.

For larger power transformers, the delta in CAPEX cost between forced-cooled rating and next higher self-cooled rating may be significantly higher and there may not be enough OPEX savings to provide similar payback.

C. Optimizing the Number of Transformers

Consider the two Main-Tie-Main Motor Control Center (MCC) lineups supplied from 2/2.3 MVA transformers as shown in Fig.

2a. Each transformer will be normally operating at 50% of ONAN rating as explained previously.

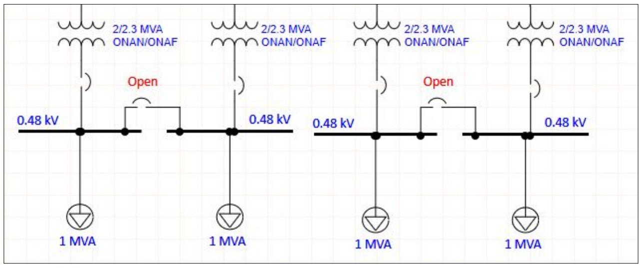

Fig. 2a Two Main-Tie-Main LV MCCs

An alternative arrangement is to combine the two Main-Tie-Main LV MCCs into a single Main-Tie-Main-Tie-Main MCC as shown in Fig. 2b.

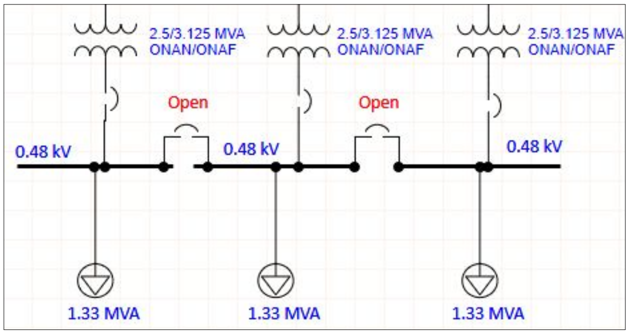

Fig. 2b Alternate Arrangement with a Single Main-Tie-Main-Tie-Main LV MCC

In this arrangement, all the loads from the two LV MCCs shown in Fig. 2a are distributed equally between Bus A, B and C. Each of the three transformers are increased in size from 2/2.3 MVA to 2.5/ 3.125 MVA and will be normally operating at 53% of their ONAN rating with the LV tie breakers open. If one transformer must be taken out of service, the associated tie breaker can be closed and the load from that bus can be supplied from the adjacent transformer.

In this example, even though the cost of each 2.5/3.125 MVA transformer would be 10 to 15% higher than the 2/2.3 MVA transformer, there is net CAPEX saving due to elimination of one transformer, its associated foundation and cable connections. Additionally, there will be OPEX savings due to reduction in transformer losses as summarized in Table IV below:

TABLE IV
LOSS COMPARISON BETWEEN MAIN-TIE-MAIN VERSUS MAIN-TIE-MAIN-TIE-MAIN CONFIGURATIONS

Scheme	**% Loading of each transformer**	**No-Load Loss (kW)**	**Load Loss (kW)**	**Total Loss (kW)**
Main-Tie-Main (4x 2 MVA)	40%	4*2.5 = 10.0	4*21.5*(0.5)^2 = 21.5	31.5
Main-Tie-Main-Tie-Main (3x 2.5 MVA)	43%	3*2.7 = 8.1	3*23.1*(0.53)^2 = 19.5	27.6

The total delta in losses would be 3.9 kW or a daily saving of 93.6 kWH. Maintenance costs will also be lower due to elimination of one transformer. One downside of the arrangement shown in Fig. 2b is that the short circuit levels on the LV bus will be higher. In the example arrangement with one tie closed and loads modeled with 80% constant kVA (motoring loads), the short circuit levels are 43 kA on the Fig. 2a (MTM) MCC and 58 kA on the Fig. 2b (MTMTM) MCC. Another downside of the arrangement shown in Fig. 2b is that often facilities have many A and B motors that may make it challenging to distribute the loads uniformly between the three buses.

D. Three-winding Transformer in Lieu of Two-winding Transformers

Consider the example shown in Fig. 3a where there are two-winding 30 MVA transformers supplying 13.8 kV switchgear buses. An alternate arrangement is to replace the two-winding transformers with three-winding transformers rated 60/30/30 MVA each as shown in Fig. 3b.

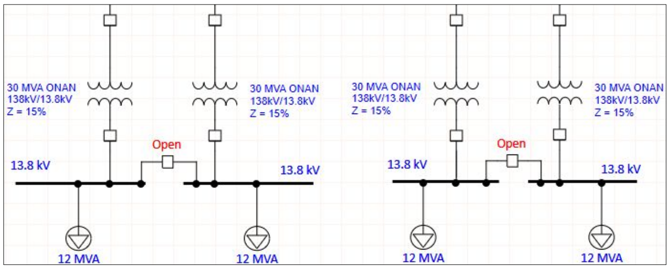

Fig. 3a- Arrangement with 4x Two-winding Transformers

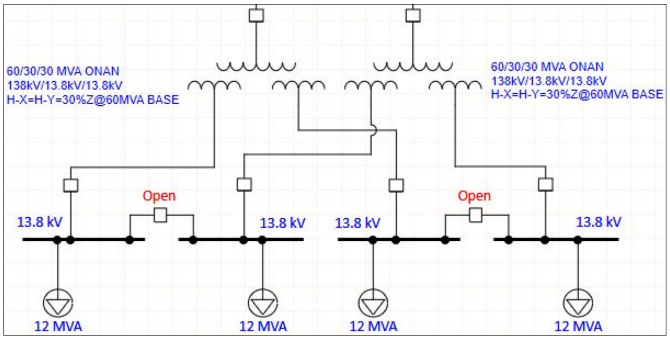

Fig. 3b- Arrangement with 2x Three-winding Transformers

Table V summarizes the calculated losses for the two arrangements-

TABLE V
LOSS COMPARISON BETWEEN THREE-WINDING VERSUS TWO-WINDING TRANSFORMERS

Rating (MVA)	**No-Load Loss (kW)**	**Load Loss (kW)**	**Total Loss (kW)**
2x 60 (Three-winding)	2* 25 = 50	2*295*(0.4)^2 =94.4	144.4
4x 30 (Two-winding)	4*14 = 56	4*185*(0.4)^2 =118.4	174.4

The total delta in losses would be 30 kW or a daily saving of 720 kWH. There will also be CAPEX savings when replacing four two-winding transformers with two three-winding transformers due to reduced foundation requirements, HV circuit breakers and connections. However, there could be some additional complexity with three-winding transformers if the secondary windings are unequal (different MVA or voltages) or OLTC is required. Refer to the paper presented in 2019 PCIC conference [1] for more information regarding three-winding transformer application.

III. HIGH EFFICIENCY MOTORS

Specifying and purchasing motors with superior efficiency ratings can both reduce the electrical load requirements and provide an economic return on investment, depending on the motor utilization and energy costs. NEMA motor efficiency levels include Energy Efficient and Premium Efficient. Some manufacturers have included their own efficiency levels above NEMA Premium Efficient that they call by various trade names. The rate of return-on-investment increases with larger motors and higher utilization.

An evaluation was performed for an LNG facility with 210, continuously operating, 460 V, 40 HP condenser fans using a manufacturer's Energy Efficient motors, Premium Efficient Motors, and Above Premium Efficient motors. Table VI compares the total facility losses for the three different designs.

TABLE VI
LOSS COMPARISON FOR DIFFERENT MOTOR DESIGNS

Load Description	**Total Power Consumption Measured at Upstream Bus Including Transformer and Cable Losses**		
	Energy Efficient (kW)	Premium Efficiency (KW)	Above Premium Efficiency (kW)
210 Condenser fans (each 40HP)	6200	6129	6099

Considering the reduction in losses, upgrading from Energy Efficient motors to Premium Efficient motors would provide a return in 44 months while upgrading from Energy Efficient to Above Premium would require 39 months. Returns will vary depending on application but considering a motor's lifetime is roughly around 20 years, purchasing high-efficiency motors is a good strategy in many applications. A difference to be noted with the Above Premium motors is that they are typically NEMA design A, that have very high Locked Rotor Current (LRC) values and have lower power factors which result in higher kVA consumption. Table VII compares the LRC values for three motor designs-

TABLE VII
TYPICAL LRC VALUES

	Energy Efficient	**Premium Efficiency**	**Above Premium Efficiency**
LRC (% of Full Load Amps)	600%-650%	610%- 700%	Above 800%

The Above Premium motors also consumed 105.4% of the kVA that the Premium motors consumed. The higher LRC and kVA consumption may affect equipment sizing, cable sizing, require modification to power factor correction, or may not be an issue at all depending on the system configuration, but should be considered before selection.

IV. OPTIMIZING FOOTPRINT AND ENERGY EFFICIENCY FOR PERMANENT PLANT BUILDINGS

A. Modular Prefabricated Construction

Substation buildings and other plant buildings can be stick-built at site or built as a modular prefabricated construction offsite. The benefit of prefabricated buildings is that they can be built in a controlled environment at the building manufacturer's facility with more focus on energy efficient materials. They are typically compact and optimized for heating and cooling compared to stick-built construction.

B. Gas Insulated Switchgear

GIS is more common at 34.5 kV and above and has limited application at 13.8 kV and 4.16 kV. GIS tend to be very compact when compared to Air Insulated Switchgear (AIS). For instance, a 34.5 kV GIS will only be 24" wide compared to 48" width for AIS switchgear. Cost of GIS may be 20% to 30% more than AIS. The delta in cost will be offset when considering the reduction in substation footprint. Additional savings can be obtained based on reduced Heating, Ventilation and Air Conditioning (HVAC) requirements due to the smaller substation footprint. However, one downside of traditional GIS is that it uses SF6 which is a greenhouse gas and has global warming potential that is 23,500 times more than CO_2. Therefore, there is an increasing interest in the industry to transition away from SF6. A new alternative that is emerging is to utilize clean air in lieu of SF6 in GIS. Clean air is environmentally friendly and free from any regulatory concerns. Such 'green' switchgear support sustainability goals of the electricity industry and are expected to be increasingly popular in the future.

C. Outdoor Transformers in Lieu of Indoor Transformers

Indoor dry type transformers up to 100 kVA are commonly utilized for lighting and UPS applications. Sometimes larger units (1.5 MVA to 5 MVA) may be installed inside substation buildings (example- large VFD drives, load centers etc.). Such large dry type transformers are large contributors to the heat load and will cause the HVAC units in the substation building to be significantly larger. Therefore, to the extent practical, it is desirable that users avoid large indoor transformers and go with outdoor units instead. These outdoor units can be dry type or liquid-filled and interconnected to the downstream bus using bus duct or cables.

D. Roof-Mounted Solar Panels

Solar panels are increasingly becoming popular to offset a portion of the utility power requirements in homes, residential buildings, and offices. Their energy conversion efficiency depends upon the location and availability of abundant sunlight.

When combined with battery storage, they can serve to provide backup power in the event of loss of normal utility supply.

In process facilities, there may be several buildings including substations, administrative buildings, storage, and warehouse buildings. Fitting these buildings with roof top solar panels increases energy efficiency and can help the facility owner achieve carbon reduction goals. However, adding solar panels involves capital costs and will also require additional maintenance over the life of the plant. Facility owners will need to evaluate the cost benefit of this option. In substation buildings that already have UPS, the solar panels can be connected to the same battery system. This provides an alternate source to recharge the UPS batteries and eliminates the need to have a separate set of batteries for the solar panels.

E. Occupancy Sensors and Smart Controls to reduce lighting and cooling levels

LED lighting is now commonly used for internal lighting in buildings. Besides requiring significantly lower power, LED lighting can be easily fitted with smart controls and are dimmable. Substations are not continuously occupied buildings and are only occasionally accessed by authorized personnel. If occupancy sensors are provided, the lighting levels can be lowered, as an example, to 30% either by dimming or by turning off some of the lights. When personnel enter the substation, the occupancy sensor can automatically increase the illumination to 100%.

Like lighting, the cooling inside the substation building can also be regulated with smart controls and occupancy sensors. Most electrical equipment will be typically rated for operation in 40°C ambient. Therefore, running the cooling to maintain a 21°C environment inside an unoccupied substation building all-round the year can result in additional power consumption that is not necessary. Only the temperature of battery room within the substation needs to be tightly controlled to avoid loss of life to the batteries. Further, if flooded lead acid batteries are used, the battery room will need to be adequately ventilated and have certain number of air exchanges to ensure that the concentration of H_2 gas generated remains at safe level. Such requirements will add to the HVAC load in the substation. On the other hand, sealed type batteries are available that have very low hydrogen emissions and may not even require a dedicated battery room which can provide energy savings. There are also alternatives such as sodium nickel chloride batteries that can be stored outdoors and may further reduce the substation cooling/ ventilation requirements. The cost benefit of these alternative battery technologies is not evaluated in this paper.

In case of plant administrative buildings, workshops and warehouses, programmable smart controls can be incorporated that lower the lighting and cooling levels during known periods of unoccupancy (example- at night, during weekends etc.).

V. PLANT LIGHTING

A. LED Lighting with Smart Sensors

Plant lighting is typically a small portion of energy consumption within a process facility. For instance, according to the 2015 Energy Star Guide [2], lighting only represents 3% of energy usage in refineries. Still there are potential energy improvement measurements and innovations that can be part of the overall energy conservation strategy for the user.

LED lighting is becoming more and more popular today in process facilities for general plant lighting. Using LED light fixtures instead of High-Pressure Sodium (HPS) light fixtures can yield approximately 40% in energy savings. For example, a 40 W LED can give the same lumens output as 70 W HPS and a 125 W LED can give same lumens output as 250 W HPS. Some other advantages of LED lighting are that they can be turned on almost instantaneously and can easily incorporate dimming controls. Most new process facilities in the US are opting for LED lighting as default.

Lighting controls can greatly aid reducing the energy consumption from lighting systems by turning off the lights during the day in areas where there is adequate daylight. Some LED lighting systems today also offer smart lighting controls using wireless technology. The lights can work in standalone mode where each light fixture can sense movement in the area and can turn on to full brightness. After a set time delay, if no movement is detected, the fixture can go down to a lower illumination level (say 30%) and further cut down consumption. In group control mode, the fixtures will communicate with a hub wirelessly. The benefit is that the illumination level of a zone or area in the plant can be controlled in concert based on occupancy level like the occupancy controls inside buildings as explained in the previous Section. However, LED light fixtures with smart controls may be 20% to 25% more expensive than standard LED fixtures. Hence it is important to perform a cost-benefit study to determine if it makes sense.

B. Solar Lighting

Solar lighting is mostly popular for outdoor decorative lighting, garden, deck, and pathway lighting. Recently, solar lighting is starting to be used for streetlights, parking lot lighting and traffic lights. In process facilities, where lighting is critical and required to be highly reliable, there may be limited application of solar lighting. However, it can be considered for non-process areas within the facility such as secondary roads, parking lots and Outside Battery Limit (OSBL) pipe racks. Solar light fixtures will be 40 to 50% more expensive than conventional light fixtures due to solar panels and batteries. However, there can be Total Installed Cost (TIC) savings due to the elimination of lighting cables/ wiring/ raceways and no electricity consumption. Users need to be aware that there may be additional maintenance requirements for the solar panels and batteries, and certified fixtures for use in hazardous areas may not be readily available.

VI. VSD DRIVEN COMPRESSORS VERSUS INLET GUIDE VANES FOR FLOW CONTROL

For large compressors in process facilities, drivers are typically electric motors. In most compressor operating schemes, the process conditions require turndown which allows for a reduction in flow to the compressor while still ensuring that the compressor is operating within its design limits. To achieve the turndown requirement, compressors can utilize Inlet Guide Vanes (IGV) in the suction to reduce the flow. IGVs inherently utilize the electric motor at or near the nominal full load of the machine. An electrical means of achieving the required turndown is to introduce a Variable Speed Drive (VSD) to vary the speed of the electric motor thus reducing the flow of the compressor. The proven technology behind both low voltage and medium voltage VSDs, available from multiple suppliers, offer operators the opportunity to meet the system turndown requirements along with the added benefit of reducing the power consumption of the electric motor. Although the capital cost of adding the VSD, particularly at the medium voltage level, is higher than utilizing an IGV, the energy savings over the long term could outweigh the initial cost of the VSD. As an example, for a given compressor with a 5000 kW motor driver, in which the process conditions dictate that at certain times during the year, the compressor operates at 80% flow, using a VSD to achieve the turndown would result in a payback over time as indicated in the table below. For the purposes of the calculation, it is assumed that that the reduction in flow is directly proportional to the reduction in motor power i.e., a 5000 kW motor operating with the compressor at 80% flow would result in a power reduction of 1000 kW.

Table VIII
5000 kW COMPRESSOR DRIVER WITH VSD VERSUS IGV

	Initial Cost Multiplier	**kWh savings per month**	**Payback (Months operating at 80% flow)**
VFD	10x	730,000	21
IGV	1x	-	-

The addition of VSDs within the electrical system requires consideration for the potential harmonics generated by the VSD, especially at the medium voltage level. There are means available within the VSD design such as utilizing input filters or selecting a VSD technology such as voltage source inverter (VSI) both of which minimize the harmonic content from the drive into the electrical system. The additional cost of the harmonic mitigating measures needs consideration when evaluating the benefits of VSDs versus IGVs.

VII. CONCLUSION

In this paper, several strategies were discussed that can aid LNG and Petrochemical facilities to reduce their auxiliary load consumption and increase energy efficiency. Tables IX – XIII below summarize these strategies from the standpoint of initial cost, ease of implementation and payback.

TABLE IX
TRANSFORMERs

	Initial Cost	**Ease of Implementing**	**Payback**
Transformer Losses	Varies (may be minimal if considered upfront during competitive bidding)	Easy	Varies (can be immediate if initial cost is minimal)
Optimizing Transformer Rating	8% to 10% adder	Easy	6 to 7 years
Optimizing Number of Transformers	10% to 15% less expensive	Higher Difficulty	Immediate
Three-winding Transformers	20% to 30% less expensive	Higher Difficulty	Immediate

TABLE X
MOTORS

	Initial Cost Adder	**Ease of Implementing**	**Payback**
Premium Efficiency Motors	15% adder over energy efficient	Easy	3 to 4 years
Above Premium Efficiency	20% adder over energy efficient	Higher Difficulty	3 to 4 years

TABLE XI
PERMANENT PLANT BUILDINGS

	Initial Cost Adder	**Ease of Implementing**	**Payback**
GIS Switchgear	20 to 30%	Higher Difficulty	Varies*
Outdoor Transformers	30 to 40% (due to fluid containment and foundation)	Higher Difficulty	Varies*
Roof-mounted Solar Panels	Varies based on size of system (can be substantial cost)	Higher difficulty	Varies*
Occupancy Sensors & Smart Controls	Insignificant as % of total building cost	Easy	Immediate

*- To be evaluated by user based on optimization of building and energy savings

TABLE XII
PLANT LIGHTING

	Initial Cost	**Ease of Implementing**	**Payback**
LED lighting with smart controls	20% to 25% adder	Medium	Varies (to be evaluated by user)
Solar Lighting	40% to 50% adder	Higher Difficulty	1 to 2 years

TABLE XIII
FLOW CONTROL OF COMPRESSORS

	Initial Cost	**Ease of Implementing**	**Payback**
VSD	High	Higher Difficulty (Requires multiple pieces of equipment and can require significant space)	2 to 3 years
IGV	Low	Low Complexity	-

As summarized in the tables above, a variety of solutions are available to improve energy efficiency in process plants. Some measures have more complexity and front-end costs that may not be practical for every application. Ultimately, the user needs to do a cost-benefit analysis and careful consideration of operating expenditures while selecting the strategies to meet their energy conservation goals.

VIII. REFERENCES

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IX. VITAE

Shankar Nambi received his B.S. in Electrical Engineering from the University of Mumbai and M.S. in Electrical Engineering from Clarkson University. He has over 23 years of engineering experience and has worked on several projects in Oil & Gas, Mining & Metals and Power Generation. He is a registered Professional Engineer in the States of Texas and Maryland. He is also a member of the IEEE PES Transformer Code Committee. He is currently working with Bechtel Energy, Inc. as an engineering supervisor and specializes in transformer applications.

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