Introduction

Based on many decades with experience on utilizing compressed air produced with piston and screw compressors, ship owners, ship designers and shipyards have established historically- and traditions-based compressed air circuit designs. The standard approach in such designs are dedicated application- and capacity-based compressor selections, intrinsically lacking the potential that can be utilized in a holistic design approach.

In the recent years, significant attention has been directed towards reducing investment costs and operational costs of most systems on board ships. Simultaneously, there are environmental drivers of change through stricter legislations, IMO regulations and *i.a*. expectations concerning the UN sustainable development goals. TMC has therefore developed the TMC System Solution® where the design approach is defined by the consumers and consumption patterns for a complete utilization of relevant pressures and capacities for different applications and consumers on board. This is enabled with detailed calculations from experienced engineers, the employment of compressors from the TMC Marine Compressors® range and the right set-up for the right need. A full-scale TMC System Solution® approach allows for reduced energy consumption, improved air quality, lower maintenance costs and reduced load on the ship crew, reduced life cycle costs and lower CO_2 footprint. When additionally applying the TMC Smart Controller with condition monitoring capabilities, a flawless utilization of compressed air can be implemented on board.

The traditional installation design

Many technical inventions have been developed since the need for compressed air on board ships to start the engines arised early in the 20th century (~1935). Initially, the need for compressed air with lower pressure for instruments and service were low. The starting air to start the engines was therefore utilized by reducing the initial pressure of 30 bar to less than 10 bar for other applications than starting air. At the time, piston compressors dominated the shipping industry. In 1995 TMC launched screw compressors for marine applications, TMC Marine Compressors®, nearly 65 years after the twin screw supercharge invention (~1930).

With the introduction of TMC Marine Compressors® there was no longer a need for reducing the starting air pressure down to lower pressure levels for other consumers and applications. Whilst screw compressors in lower pressure ranges are available for numerous applications on board the ship, the classical design of utilizing starting air with significant excess pressure is still now and again applied.

Typical compressed air solutions on board a medium sized LNG Carrier is per date 2-3 piston type compressors for starting air and 7 - 8 screw compressors for different applications. The screw compressors are individually specified according to technical specifications often dictated by empirical data that *i.a*. covers capacities (m^3/h) and pressure requirements (bar), operating and ambient temperatures and air quality.

A classic design approach starts with the specified technical requirements and inversely calculates the right compressors for the right applications, applications isolated. The present solutions are class approved and functional, design is based on existing design approaches and specifications generally do not require and/or allow changes to be undertaken.

Compressed air solutions are simple systems with no logic, *per se*, and are in principal simple and functional. Figure 1 shows an illustration of typical standalone application areas on board an LNG Carrier. The application areas can range from working and control air to N_2 feed air system applications, compressed air for scrubber applications (SCR) and air lubrication systems (ALS).

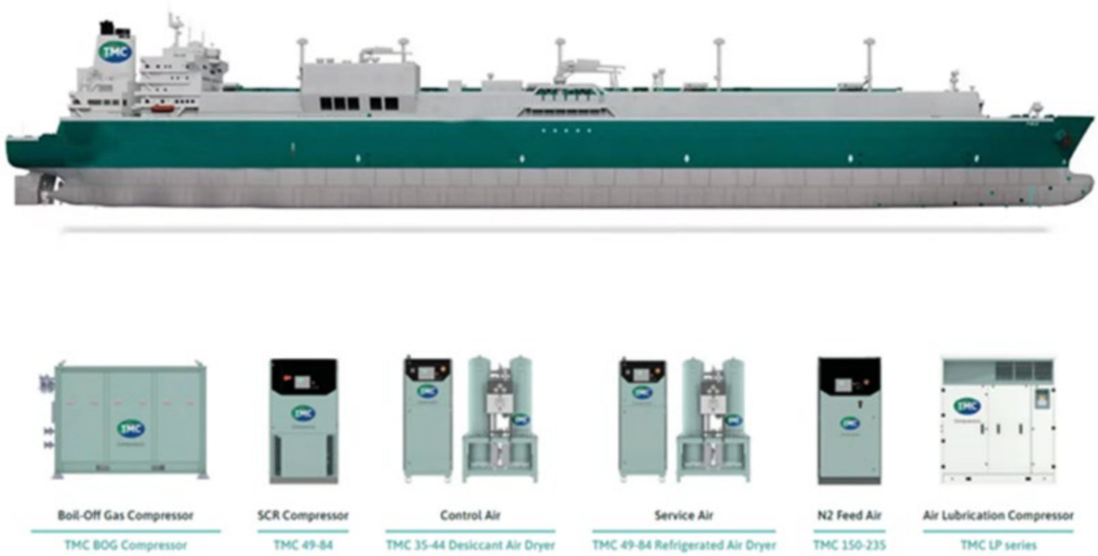


Figure 1. Typical application areas for compressed air on board LNG Carriers.

When the compressed air solution on board is designed separately based on individual specifications and no overall system philosophy is applied, the compressor solutions will inherently contain individual redundancy and safety margins. The Class and owner requirements are sometimes misinterpreted which can cause increased capacities and more equipment added. The compressed air consumptions and simultaneity factors may not be aligned, causing imbalance in high versus low running hours. In principle, a classic design approach will therefore generate higher investment and operating costs due to excess redundancy, spare capacities and larger maintenance schedules. More compressors and separate receivers will be required to fulfil the individual system margins.

TMC System Solution®

Air should not be pressurized more than required. If there are pressure reductions in the system, the energy will be wasted, as is the case when control air is taken from starting air receivers. An engineering rule of thumb dictates that 1 bar increase in pressure requires 7 % more energy. The TMC System Solution® design contains an optimized production and utilization of pressurized air on board ships based on a unified, scalable system. The pressurized air can be used for multi purposes at different pressure levels including, and not limited to, control air applications, working air applications, instrument air applications, Nitrogen gas feed air applications and SCR applications. The TMC System Solution® design is *approved in principle* by DNV® in accordance with the DNV Rules for Classification of Ships Pt.4, Ch.6 July 2020, maintaining requirements to redundancy and safety.

Main design elements of the TMC System Solution®, cf. Figure 2

A. A scalable **common compressor bank** containing several compressors, engineered with the right pressure levels and capacities. Utilisation will depend on the consumption rate.

B. **Common receivers** will act as a common energy source and optimize pressure alignment and balance the air demand.

C. **Pressure alignment** that ensures that the lowest possible pressure is positive, *i.e*. energy will be saved.

D. The distribution of the compressed air is undertaken based on the different **air quality requirements** and implementing correct air quality steps based on drying and filtering the air.

E. The TMC Smart Control **common control system**, that enables optimized utilisation of the compressed air, and provides possibilites for condition monitoring in real time and predictive maintenance.

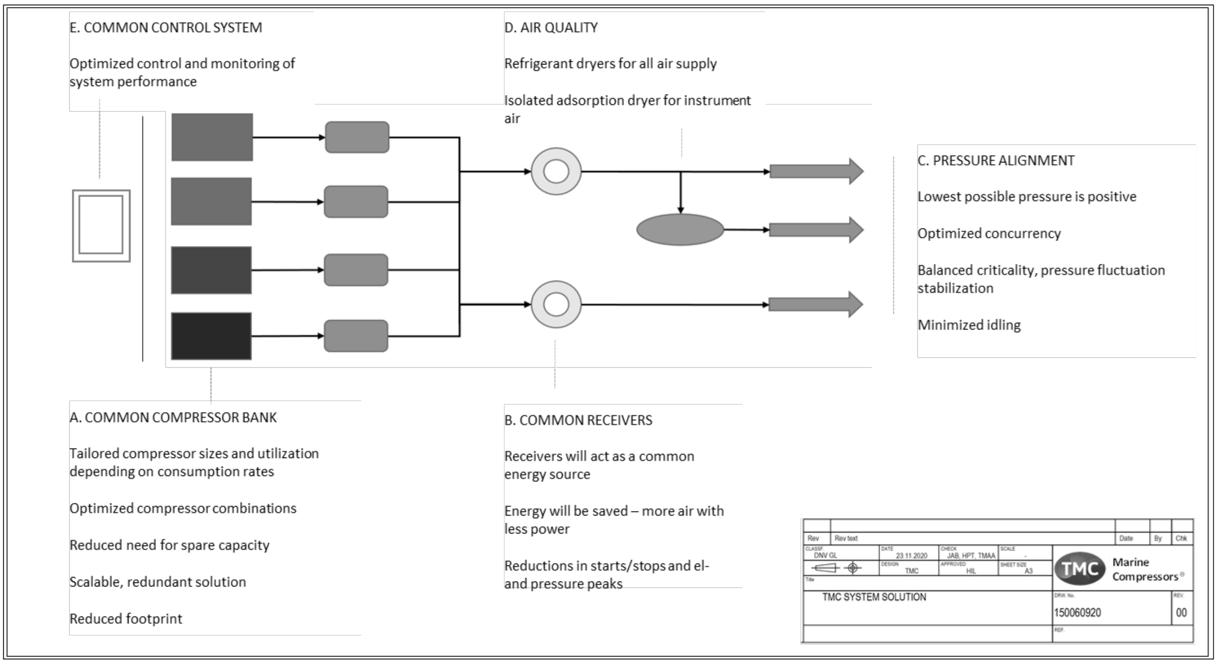


Figure 2. TMC System Solution® design principles.

The system controller allows for sequencing and optimizing load distribution, as well as condition monitoring of the system, cf. Figure 3. A balanced design gives better utilization of the equipment by *i.a*. controlling the criticalities and priorities of the consumers and alignment of pressure.

Figure 3. Proprietary TMC Smart Control data insight user interface for real time condition monitoring.

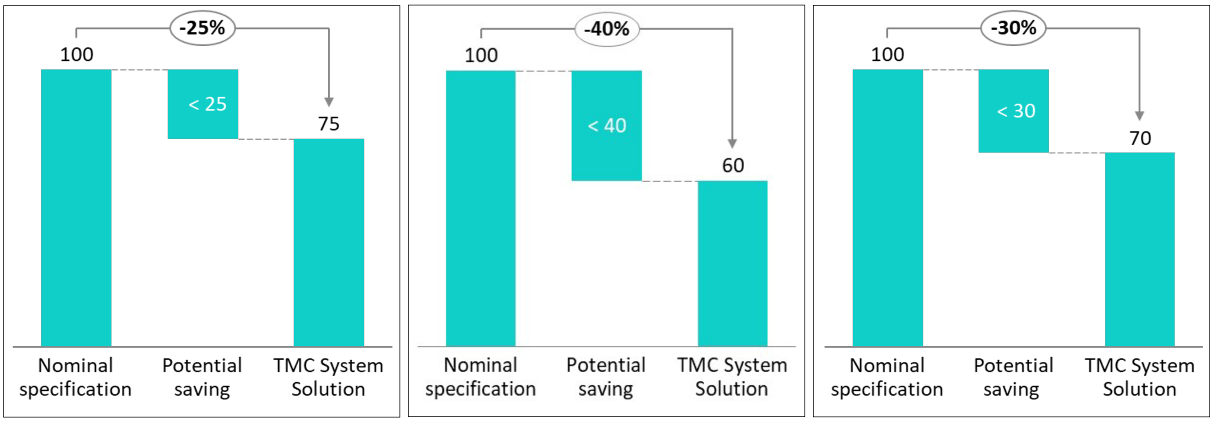
With the system design approach, an optimal compressor combination can be implemented and even downsizing of compressors and air dryers can be done when compared with a classical design approach. Fewer compressors can provide the required capacities and pressures, giving a lower physical footprint where space is often a scarcity on board the ship. Dryers and filters are normally more dependent on specifications than actual requirements, and with the system design approach the actual requirements are met. Pipes and receivers are dimensioned to the required capacities, and thus not over-engineered.

The operational advantages of the system design are *i.a*. fewer and smaller load peaks, *i.e*. *peak shaving*, reduced buffer time and less idling. With the system design concept, fewer starts and stops are generated with a smoother load on the compressors. Additionally, a reduction in purge air can be achieved on the dryers.

Running idle between the regulating settings will cause a waste of energy. Similarly, a classical design will cause higher number of starts and stops, heat peaks and current peaks, increased noise and increased wear and tear. When implementing the TMC System Solution® equipped with TMC Smart Air® compressors this is avoided.

When applying the TMC System Solution® design, significant savings can be obtained from the investment phase (CAPEX) throughout the lifetime of the compressor (OPEX). Depending on *i.a*. the vessel type, number of applications included in the design, consumer patterns, capacities and pressures it is possible to achieve up to 25 % reductions in CAPEX per date (Figure 4a). As energy consumption is a critical parameter for efficient and sustainable operations, the TMC can obtain up to 40 % reductions in the energy used when compared with a traditional compressor system design (Figure 4b), and simultaneously up to 40 % reductions in GHG emissions. With the TMC System

Solution®, the full potential of TMC Marine Compressors performance is utilized inducing reduced maintenance costs of up to 30 % (Figure 4c).



a) b) c)

Figure 4. Potential savings [%] with implementing the TMC System Solution® compared with a nominal specification traditional design; a) CAPEX*; b) Energy (reduction in kWh)*; c) Maintenance costs*.

* Requires *i.a.* a minimum number of consumers and a minimum requirement in capacity, pressure and air quality.

Summary

With the TMC proprietary TMC System Solution® design, it now becomes possible to achieve significantly better utilization of the air compressor systems on board the ship. To enable the complete set of advantages of the system design capabilities, it is required to start with an early-phase system evaluation with main emphasis on the consumers:

- Consumer list and consumption
- Concurrency
- Air quality
- Continuancy
- Decide the pressure
- Criticality
- Arrangement of receivers and piping layout

The next steps in the design phase contains system alignment, dimensioning, calculating and engineering the system. TMC has extensive experience with compressed air system design from offshore applications, and have together with customers verified TMC system designs and experienced that a holistic system design approach has a significant impact on compressor performance and operational costs, as well as energy savings and reductions in emissions.