Novel design methods and control strategies for oil and gas offshore power systems - DTU

Novel design methods and control strategies for oil and gas offshore power systems
This doctoral thesis is devoted to the research of innovative design methods and control strategies for power systems supplying future and existing offshore oil and gas facilities. The author uses these methods to address five research challenges: i) the definition of the optimal waste heat recovery technology, ii) the identification of the best working fluid to design efficient, light and cost-competitive waste heat recovery units, iii) the integration of dynamic criteria in the project phase to discard infeasible designs, iv) the development of a novel control strategy to optimally operate the power system, and v) the enhancement of its dynamic flexibility using the model predictive control. The case study of this work is the power system of the Draugen oil and gas platform (Kristiansund, Norway), where the possibility of equipping one of the gas turbines with abbottoming cycle unit is investigated. The optimal technology is determined by programming a multi-objective optimization procedure, capable of optimizing the design of Rankine and Brayton engines. The objective functions are the daily carbon dioxide emissions, the weight of the components and the economic revenue. The optimization routine is interfaced with validated models sizing the heat transfer equipment. This software integration provides an initial estimate of the module compactness and of the impact of the pressure drops on the system performance. Finally, part-load and economic models quantify the spared emissions and the feasibility of the investment. The organic Rankine cycle technology has the largest potential to decrease the carbon dioxide emissions (10 - 15%). On the other hand, the steam Rankine engine is more competitive from an economic perspective. The air Bryton cycles give the lightest modules (10 - 60 t). Therefore, this technology should be employed to retrofit existing offshore facilities with extended lifetime. Steam and organic Rankine engines are competing alternatives for new installations. The findings suggest to lean toward the use of organic Rankine cycle turbogenerators, if fuel-flexibility is a main priority for the platform operator. Engineering efforts should focus on cutting the production cost of the expander and on minimizing the core volume of the primary heat exchanger. In the selection of the working fluid, benzene and iv Abstractcyclopentane are the organic compounds giving the highest performance, compactness and economic revenue. Considering the use of organic Rankine turbogenerators, dynamic analyses simulating critical scenarios (i.e. trip of one gas turbine) are shown to be valuable complements of the steady-state design procedure. The use of dynamic criteria can help identifying those candidates which do not meet the requirements of offshore electric grids. Specifically, the use of low-weight units is discouraged. It entails frequency fluctuations outside the specified tolerance (i.e. 4%), and instabilities in the process variables. Additionally, the proposed simulation tool can detect the system designs which expose the working fluid to unacceptable risk of chemical decomposition. Accounting for such phenomenon is of paramount importance as it may compromise the performance and lifetime of the components. This work pays further attention to the design of an innovative controller to optimally operate one gas turbine connected to an organic Rankine cycle unit. The regulator uses the linear model predictive control to maintain the quality of the power supply, and, at the same time, to track the maximum performance of the plant. The speed of the pump of the organic Rankine cycle unit is varied to maximize the energy conversion efficiency of the plant. The controller can also verify real-time the actual feasibility of the optimal working condition with respect to operational constraints, i.e., the acid formation at the outlet of the primary heat exchanger and the decomposition of the working fluid. The results demonstrate that the activities at the peak efficiency are practicable from 40% load to nominal power. The potential fuel savings are around 3%. The increment of the final revenue can be up to 10%. More conservative control strategies are advised at low-power activities (especially when burning combustibles with a high-sulfur content), or when the thermal stresses on the working fluid should be minimized. Additionally, the controller is demonstrated to improve the dynamic flexibility of the plant compared to the reference controller designed by the gas turbine manufacturer. The model predictive control can reduce the frequency fluctuations in the range of 20 - 40%, considering the gas turbine alone. The reduction increases up to 60%, connecting the engine to the organic Rankine cycle module. The analysis on the effect of unmeasured disturbances (i.e. fouling in the heat transfer equipment) confirms the stability of the dynamic response. On the other hand, the results pinpoint the need for real-time upgrading of the internal models. This task is achievable adopting intelligent adaptation and learning techniques.