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Integration of fuel-based energy system at offshore oil & gas installation with wind farms, main grid and other renewable energy systems

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Preface

This report present ideas of combined wind power and combustion based power system for offshore oil and gas installations. The challenges relates to two types of concepts: stand-alone system and grid-connected system are also presented.

The report can be used for further extension for a possible project proposal related to this topic.

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Contents

1 Introduction

Nowadays, energy produced at offshore installations for oil and gas production and transport represent about 30 % of total Norwegian emissions of climate gases. The offshore power production is currently mainly based on use of gas or diesel turbines with an efficiency that is quite low (~20-25 %).

There is a potential for substantial decrease of emissions of CO_2 and NO_X from the offshore sector and in some cases possibly also cost reductions, if gas/diesel turbines can be partly substituted by the power from renewable sources. Electrification of the offshore installations by use of power cables from shore can reduce emissions. However, in most cases, obviously depending on distance, this seems to be associated with too high cost. An alternative approach is to use offshore wind turbines installed close to the oil and gas installations, which combined with gas/diesel turbines, can operate in an island mode, without the need for the cable connection to shore. An interconnection between the offshore wind farms, the oil and gas platforms and onshore grid can result in reduced operation costs, increased reliability and reduced CO_2 emissions.

One of the most important aspects of reliable power system with high security of power supply is maintaining a balance between the power demand and the power generation used to meet the demand. Different time frames require different techniques of balancing the generation and load. In the unit commitment time frame, operations will turn on enough units to meet forecasted demand. On land power systems, this typically occurs between six hours start-up and synchronize to the grid. The use of wind power forecasting can significantly improve the integration of wind power by improving reliability and minimizing costs.

In the wind energy community, it has been known that a short-term energy back-up with diesel, gas and energy storage may compensate for fluctuations in the power output of the wind turbine and raise the fuel saving potential; for small isolated hybrid power system that used a parallel combination of dispatchable (can be turned-off and on) and non-dispatchable power generation sources.

This report provides the state-of-the-art of control system for connecting oil & gas platforms to mainland power grids, connecting off-shore wind platforms to mainland power grids and connecting offshore wind platforms to oil and gas platforms. The emphasis of this report is to provide suggestions and possible research areas on how to reduce the fuel consumption and consequent CO_2, NO_X, SO_X emissions by integrating dispatchble and non-dispatchable energy sources with the smart control of loads on the existing oil and gas production.

The report first presents overall relevant system geometries, then possible energy input from offshore wind and cost of integration. We finalize with the conclusions and future work in last section.

2 Overall System Geometries Relevant

2.1 Options for Structures of the Integration of Offshore Wind Farm and Oil & Gas Installations

Jimmy Baringbing, Erlend Randeberg, Øystein Lund Bø, IRIS

This section presents options for structures of the integration of offshore wind farm and oil and gas installation. This includes the process of selecting the appropriate alternatives of integration and its sizing with appropriate control strategy. The issue introduces a challenge with regard to control, reliability and stability of the power system. The development of the integrated systems aims to achieve high energy efficiency, high reliability and low cost integration.

2.1.1 Introduction

The application of renewable energy system has become an increasingly important topic in recent years. Wind energy is one of the most promising energy sources to be used for renewable electricity generation in near future. This section gives a summary of options with regards to integration of offshore wind farm and oil and gas installations. However the evaluation of the correct type of system strategy needs to be considered so that the system can be optimized. Essentially, there are two main strategies when offshore wind farm and thermal power systems at oil and gas platforms are to be integrated. Physical integration of wind farm and the thermal power system is illustrated in Figure 2.1.

1. The first strategy includes no grid connection, only interaction between local stochastic and controllable power systems. The stochastic models are a necessity to be robustly developed considering the demand and wind generation uncertainties in order to obtain optimal scheduling of generators in an offshore wind farm integrated controllable thermal power system.
2. The second strategy includes interaction with the onshore grid, allowing flow of energy to and from the offshore energy system.

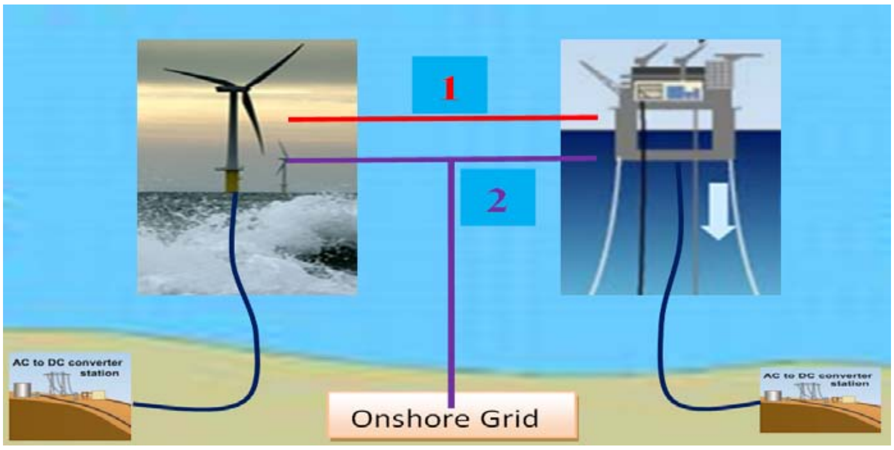

Figure 2.1 Physical integration of wind farm and thermal power system.

2.1.2 Alternative 1: offshore wind farm and platform with thermal power system

2.1.2.1 Characteristic of hybrid system connection

Hybrid energy systems are characterized by combining different power generation devices or two or more fuels for the same device, with aim to optimize global efficiency of the process. Hybrid systems can be designed to maximize the use of renewable energy, resulting in a system with lower emissions than those of conventional methods. Naturally, hybrid system connection depends upon the energy resources available and the load demand. The first alternative is a so-called “stand-alone system”, with offshore wind farm and platform with thermal power system. The combination of these types of energies needs to involve electrical energy production systems that can be run in parallel. In this hybrid connection, the two energy sources have to compensate one another in order to produce energy in continuous regime and over the load system.

Here are some different characteristics needed to obtain the conception of stand-alone system such as:

1) *Control strategy for autonomous supply*
   To further maintain a stable operation of an autonomous supply system, the total power generation systems, both offshore wind farm and platform with thermal power system could be effectively controlled. The target of this is to meet the power demand of the connected load systems.

2) *Stochastic and controllable system integrated*
   The increasing share of offshore wind energy and platform with thermal power system leads to strong and unpredictable fluctuations of electricity supply with regard to power generation and transmission system. As a consequence, this will require stochastic programming and controllable hybrid system integrated in a regional power generation system consisting of thermal power units, wind energy and possibly different energy storage systems [4].

3) *Increased need for storage buffer*
   The storage buffer could be used to generate electricity during times of peak demand. The setting capacity for energy storage could significantly mitigate the drawbacks to the fluctuating nature of the wind and thermal power and provide a cost-effective means of meeting peak demand. Recent advanced technology to store hydrogen in offshore wind turbine towers and possibly even foundation has been discussed in [5]. The criteria for selecting this system largely depend on the correlation between the type of technology used and the selected site setting of operations. Moreover, this could potentially consider identifying the paramount considerations associated with using storage buffer and analyze of cost-effective design.

4) *Installed capacity and wind forecast should be planned according to power/energy demand*

The power outputs of the wind power are dependent on the maximum and minimum capacity. This relates to the importance of high-quality wind power forecasts and capacity forecasts. For instance, the proper and better wind forecast lead to short or long-term power fluctuations from offshore wind farms should be planned according to power and energy demand for regulating power in general.

Active control of thermal power system for "matching" with both stochastic supply and demand

Active control of thermal power could be eventually ensured through: (a) daily, weekly, seasonal or even cyclic patterns in demand; (b) supply and prices in presence of options storage facilities; and (c) over certain period of observations. In practice, stochastic programming is mostly concerned with problems on supply and demand that require an accurate decision on the basis of given probabilistic information on random quantities. Therefore, the unpredictability of matching with both thermal power supply and demand is necessary to be taken into account.

5) *A stand-alone thermal power system with "auxiliary" wind power supply*

When a stand-alone thermal power and with "auxiliary" wind power supply is available, offshore wind turbine and thermal power system produce energy to feed the supply and demand needs. When the generated power exceeds the energy supply and demand needs, the excess power supplies the energies to the option storage facilities. Offshore wind turbine and thermal power system are not sufficient to fulfil supply and demand needs; the required power is produced using the energy storage facilities.

2.1.2.2 Integrated components of alternative 1

(1) Transmission from the wind farm and oil and gas platform to the onshore

There are three basic types for the transmission of wind generated electricity and controllable power systems from offshore to onshore [1]-[4]:

1. <u>High voltage three phase A.C. (HVAC) transmission</u>

   HVAC is the most straight forward technical solution for offshore wind power transmission. The connection of large offshore wind farms to the grid by a three phase A.C. transmission line can be split into three parts:

   - *The offshore substation*. An offshore substation is needed for the transformation of the medium voltage of the wind farm network to their voltage of the transmission line.
   - *The submarine cable.*
   - *The onshore connection to the mainland grid (onshore substation)*

   The main components of existing offshore wind farms connected with HVAC power transmission commonly are encountered:

   - AC based collector system within the wind farm
   - Offshore station that includes transformer and reactive compensation

- Three core XLPE (cross linked polyethylene insulation) HVAC cable
- Onshore transformer station and compensators

2. <u>High voltage D.C. transmission (HVDC)</u>
   For transmission over large distance and/or for transmission of large power capacities the HVDCT presents a more suitable technical solution than a three – phase A.C. transmission. In general there are two different technologies are used for rectifying from A.C to D.C: the traditional thyristor based technology and a new technology, based on insulated Gate Bipolar Transistor (IGBT) with pulse width modulation (PWM).

   Power systems start to face problems when integrating thousand megawatts of wind power, which is produced in a stochastic behaviour due to natural wind fluctuations. The rapid power fluctuations from the large scale wind farms introduce several challenges to reliable operation and contribute to deviation in the planned power generation which may lead to power system control problems. Therefore, adequate models of an Automatic Generation Control (AGC) system which includes large scale wind farms for long-term stability simulation is needed to investigate the capability of regulating power control and different load and production conditions.

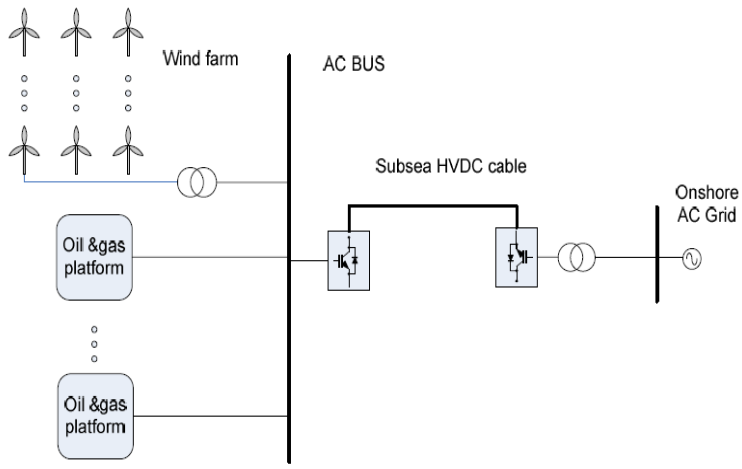

Figure 2.2 VSC HVDC offshore transmission: connecting wind platforms to oil & gas installation (Source: [3])

Multi-terminal VSC-HVDC system for integration of offshore wind farms and green electrification of platforms in the North Sea has been proposed in [3] as shown in Figure 2.2. A multi VSC-HVDC consists of three or more VSC terminals with different control objectives. A three terminal VSC-HVDC connecting an offshore wind park a platform and onshore grid was analyzed in that paper. The trends of electricity in the offshore oil/gas platforms by HVDC connection from onshore by applying multi terminal HVDC (MTDC) could be a competitive solution for interconnecting offshore wind farms and other offshore system into the onshore national grid. The keys of proposed control strategy for such a system are:

- Voltage source converter (VSC) was selected for its suitability for MTDC system and for its flexibility in control
- An equivalent circuit of the VSC in synchronous d-q reference frame has been established and decoupled control of active and reactive power

3. Parallel case with AC and HVDC light
   The parallel case could have the following inherent properties such as transmission capacity that can be built in steps. Transmission energy losses will be then reduced and ride through capability during faults.

2.1.3 Alternative 2: grid-connection system, offshore wind farm and thermal power plant connected to shore

2.1.3.1 Characteristic of hybrid system connection

The second alternative is grid-connected system composed of offshore wind farm and thermal power plant connected to shore.

The main different characteristics are needed to obtain the concept of stand-alone system such as:

1) *Integration with onshore grid (power quality requirements)*
   In principle, the integration contains the rules for connecting offshore wind farm, thermal power plant to the onshore grid. Recommendations to wind farms include the following aspects: operation at varying grid frequency, operation at varying grid voltage, active power control, reactive power control and operation in case of grid faults.
   It is desirable to have good power quality at the receiving end of onshore grid. The most important aspects of power quality that will be required are such in terms of transient voltage variations, flicker and harmonics. Harmonic distortion is mainly associated with variable/speed wind turbines because these contain power electronic converters. Flicker can result from unwanted and annoying fluctuations in electric light due to the strength of the grid connection.
   A number of factors affect the interaction between offshore and onshore grids:
   - Stability following a disturbance event
   - Controllability of power flows to avoid congestion
   - Compensating for the variability in wind power by ramping up/down the conventional power plants
   - Coordinated planning of the capacity in the two grids

2) *Onshore grid can act as energy buffer*
   Capturing the energy from offshore wind farms and thermal power at oil and gas installation is a complex issue due to their location and stochastically availability of wind power for wind prediction occur in short-term or in long-term. To

control such as energy supply and demand, onshore grid can act as an energy buffer and smooth their power output.

3) *Energy surplus and shortage can be handled through export and import*
The energy surplus and shortage can be principally handled through export and import. The main purposes are: to keep an active power balance within the desired range; to keep the power generation in balance to the power consumption and to keep the power exchange synchronous area to the planned power exchange. Related to this, the challenges will be to operate robust control power for the power fluctuations and deviations from (a) the planned power generation, (b) demand and (c) different resolution of the exchange schedules on the interconnections.

4) *Changes in production and consumption of energy offshore can be handled*
Ahmatov et al. [6] reported that nowadays, modern wind turbines are equipped with a fast acting pitch control system, which enables the machines to adjust the active power output to any value between minimum and full power within seconds. The major part of the modern wind turbines are variable-speed wind turbines. Use of variable-speed control provided by the power electronic converters, improves and speeds up the power control capability. The modern wind turbines can, with some limitations, be applied for providing the regulating power reserves and for contributing to the power balance.
The major issue from large offshore wind farms is to comply with the fluctuating nature (short-term or long-term) of wind power production [6]. The power supplied from the wind turbines is varying according to natural wind fluctuations and turbulence. Better high-quality wind power forecasts are essential to improve the power balance in terms of day-to-day forecasts, hour-by-hour forecasts and existing offshore forecast models.

2.1.3.2 Integrated components of alternative 2

In general, the basic types for the transmission of wind generated electricity and thermal power system from the offshore wind farm to the mainland grid are similar to alternative 1. Appropriate transmission capacities must be created in order for the power to reach the load centres. The main difference is slightly the interface of power control for the interconnection between offshore wind farm and thermal power plant connected to onshore grid.

The main challenge in the integrated components of alternative 2 is related to the control (or limitation) of the exchange of reactive power between the main transmission offshore wind farm, the thermal power plant and the onshore distribution grid [7],[8]. In the power system network, the balance of active power and reactive power must be maintained. This can be achieved from: 1) voltage stability with the use of active voltage control or external compensator such as Static Var Compensators (SVCs), which are required to kick out the output power from wind farms that may vary significantly within a short-term; 2) control equipment enables power and voltage control for important transient stability; and 3) coordinated automatic generation control (AGC) may be applied to limit the wind power generation during critical hours as shown in Figure 2.3 .

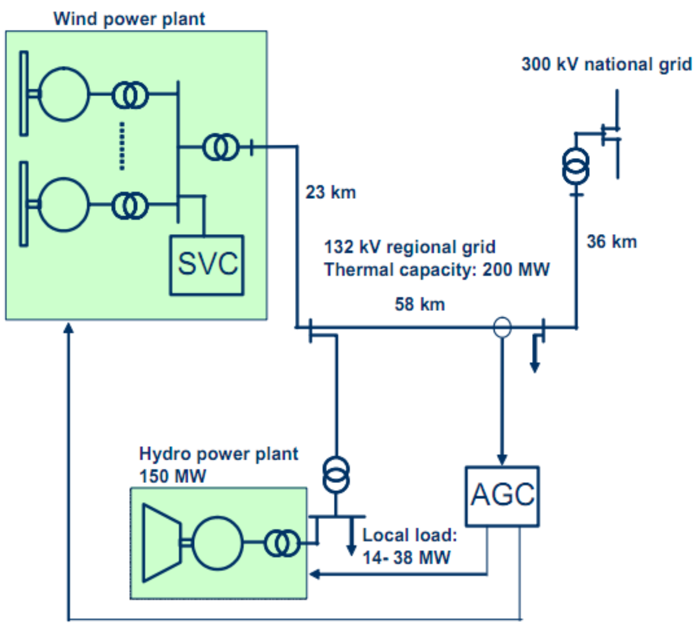

Figure 2.3 Static var compensator (SVCs) and automatic generation control (AGC) (Source: [7])

2.1.4 Conclusive remarks

There are two possible alternatives of integrating offshore wind farm and oil and gas installation. However, there are some issues that need to be considered such as:

- Choosing the correct size of each component of the energy system. The net hour-by-hour settlement model need to be developed in order to avoid any conflict with requirement for power control required for balancing power. Wind power output depends on meteorological conditions, In addition to the application of prediction tools for power schedule planning, a higher level of reserve power should be provided. Moreover, a main challenge related to voltage control is to maintain acceptable steady-state voltage levels and voltage profiles in all operating conditions, ranging from minimum load to maximum load and zero wind power.
- Optimizing the energy management within the system. For instance, the changing direction of the power through DC connection without activation of the thermal power plant may lead to fast fluctuations of grid frequency and reduced power quality on the other side of the DC connections. Power fluctuations may be introduced into the transmission system and even distributed to the neighbouring transmission systems.
- Finding the optimal configuration in planning aiming to obtain the lower cost integration.

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2.2 Control System for Autonomous Hybrid Power Systems Involving Wind Power System

Rambabu Kandepu, Teknova

2.2.1 Introduction

It is very common to use diesel generators as the power source for remote places. The technology for renewable energy is growing and becoming commercialized, it might be economical to use renewable energy sources such as wind and solar. Hybrid distributed power system[1] has many advantages, as it can increase reliability of power supply, decreases the dependence on a single energy source, and reduce the transmission and distribution losses etc. At the same time, with the increase of electric power based on renewable energy sources, the pollution into the environment decreases drastically. The main characteristics of hybrid distributed power systems providing distribution voltage are located at or near the point of use with appropriate value of location.

The use of renewable energy as part of, or as the major contribution of, the power supply system can be very attractive for many remote places. It has already been demonstrated in [3] that hybrid power systems may constitute the most economical solution in many applications, and may also provide a more reliable supply of electricity through the combination of several energy sources. The possibility of using local energy resources, i.e. renewable energy sources (sun, wind, water flow, biomass, etc.), which can be found almost everywhere including remote areas, is an appealing solution from the economic and logistic points of view. The already matured renewable energy industry can provide efficient and reliable components for integration into power supply systems and the cost of components is expected to continue declining. However further improvement of the design and operation of hybrid power systems is still needed to allow the widespread application of this technology for the electrification schemes of remote areas.

However, the widespread application of hybrid power systems to the electrification schemes of remote areas still depends on improvements in the issues of design and operation that yield a definite technical and economical solution. The main limitations of the present hybrid power systems technology are related to the control and supervision of the power system [3].

2.2.2 Control challenges of hybrid autonomous power system from Pereira [3]

The simplest way to include renewable energy into standard diesel-powered systems, without increasing the risk of loss of load, is to operate the renewable energy devices (wind turbines, photovoltaic panels, etc.) in parallel with a continuously running diesel

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1 Hybrid power systems are defined as combination two or more energy conversion devices or two or more fuels for the same device, than when integrated, overcome limitations inherent in either. Hybrid systems can address limitations in terms of (higher) fuel flexibility, (enhanced) reliability, (lower) emissions, efficiency and economics.

generator. In this mode of operation the renewable power acts as a negative load, reducing the average load of the diesel engine. If the renewable power production is always just a fraction of the total load, i.e. systems with low penetration of renewable power, then diesel engines operate at normal limits, fuel savings are modest and a minimum of supervision is needed.

On the other hand, if the renewable power is large enough to supply most of the load, then fuel savings can be significantly increased depending on the operation strategy adopted. But the problem that complicates the operation of hybrid power system (HPS) with high renewable energy penetration arises from the stochastic nature of the renewable resources, e.g. wind and sun. For example, a highly fluctuating wind flow makes the electrical output from a wind turbine vary quite vigorously in time periods of seconds and minutes. This means that a wind turbine that is meeting a load quite satisfactorily one moment may well fail to meet the load by a large amount only a few seconds or minutes later.

Another common situation is the combination of low load and high renewable energy production. If the excess power in the grid cannot be removed renewable energy generators would probably be shut down by a high frequency limit set point. In systems without storage a dump load controller is normally used to provide power balance and frequency stability.

In some applications, additional voltage control is required to maintain the voltage quality. All these devices (such as a dump load) and controllers would add an extra investment cost that may be larger than the benefits that the system may produce. Only with the use of an adequate control strategy it is possible to integrate all different components creating an optimized, cost effective system.

2.2.2.1 Control challenges

The control strategy for hybrid power systems shall determine the best mode of operation, i.e. the combination of generators and (controllable) loads used to attend the demand, considering the constraints of security of supply, power quality and economy. This is complicated by several factors:

- The variation of the demand – remote places with small electricity networks can experience rapid changes in power requirements (usually demand growth) and load shape from year to year.

- Power variation – The demand normally presents large variations on a minute basis, very low valleys and high peaks, etc.

- The renewable energy resources – renewable sources of energy (e.g. wind and sun) are stochastic by nature, site-specific, and very difficult to predict.

- The number of renewable energy generators – the uncertainty of the renewable power production is related to the characteristics of the renewable energy resource, the type of generator and other physical parameters. The larger the number of devices, the more reliable is the power contribution from the renewable sources because the variations of power are smoothed out and the probability of sudden failures/shut-down is reduced by the uncorrelated power output of several generators.

- The number and size of diesel generators – it is not feasible to have a variety of diesel generators to match different load conditions. However systems with several diesel generators and/or with different capacities are more flexible for selecting the best combination of machines to meet the load at any time of the day.

- Power quality requirements – the required quality of the supply, in terms of variations of frequency and voltage and probability of loss of load, is an important condition for the decision of which generators should be in service.

2.2.2.2 Operation strategies

The following table from [3] gives some common operation strategies in practice to improve the control of hybrid power system operation.

Table 2.1 Some common operation strategies that can be used by a supervisory controller to improve HPS operation

Operation Strategy	*How it is implemented*	*Objective(s)*
Spinning reserve	determining the minimum diesel capacity based on renewable energy and load forecasts	avoid system collapse in case of a sudden loss of renewable power generation or increase of demand
Load management	by switching on/off different optional and deferrable loads (e.g. water pumps, desalination units, etc.)	power balance of the system and minimum loading for diesels
Minimum run time	pre-set a minimum duration for each diesel operation	reduce diesel on/off cycles
Hysteresis	measuring a power surplus over the demand before switching off diesels	reduce diesel on/off cycles
Storage management (short-term storage)	flywheel, hydraulic/pneumatic reservoir, battery bank	compensate rapid power fluctuations
Storage management (long-term storage)	battery bank, pumped water	reduce diesel on/off cycles and safe fuel

2.2.2.3 Summary from survey of hybrid power system projects

Ref [3] shows a survey of different hybrid power system projects across the world. Below is the summary taken from the thesis, which focuses on the control aspects of the hybrid power system.

Some controllers, such as in Denham, Frøya, Kythnos, Rathlin, Cape Clear, Marsabit and Foula are designed with a close integration of components. They incorporate tasks that are normally performed by the components' controllers. These tasks, wind turbine pitch control, diesel load sharing, charge / discharge of battery bank, are related to the dynamic control of the system. The controllers with close integration of components are reported to have excellent performances as indicated by wind penetration, fuel savings and other parameters. However they also have poor robustness. The fragility of the close integration concept is that component failures (even minor faults) can lead to partial or total system breakdown.

The projects in Dachen, Fuerteventura, Foula, La Desirade, Marsabit and Denham are examples of the site-specific approach. In this approach, the system configuration, type of controls and control strategy are defined with a specific application in view. The site-specific solution incorporates the engineering cost (only specialised design teams can perform this work) for designing and implementing a system. Changes in system characteristics, e.g. load growth or upgrade of components, if not predicted initially, will require an entire redesign of the system. The system package solution is represented by the projects in Frøya, Kythnos, Rathlin and Cape Clear. The expert knowledge of hybrid power systems specialists is used to design a package solution where the same combination of components and controls (system configuration) is operated according to a pre-defined set of rules (control strategy). In this case, proper sizing of components is important to guarantee efficient operation in different applications. The main drawbacks of the system package solutions are:

- Limited number of possible configurations – normally only one or a few system configurations can be used for each package concept. This limitation prevents the optimal utilization of local resources and the adaptation to local needs.

- Limited expansion (upgrade) possibilities – the operation strategies (programmed in a supervisory controller) rely on a close integration of various system components. The system expansion can be difficult because new components have to be integrated into the control strategy, requiring an analysis of the new configuration and operation conditions (that changes because of the different interaction among system components).

Table 2.2 lists some of the hybrid power systems across the world.

Table 2.2 Hybrid power systems across the world

LOCATION / COUNTRY	DIESEL (kW)	WIND (kW)	DUMP LOAD	OTHER LOADS	PV (kW)	STORAGE (kWh)	SUPERVISORY CONTROLLER	WIND PENETRATION	OPERATION DATE
SAL / CAPE VERDE	2 x 500 1x 800 1 x 620 1x 400	2 x 300	-	2 x 250 (RO desalination) 1 x 60	-	-	Operators (manual)	22% (month) 14% (3 years)	(1994-)
MINDELO / CAPE VERDE	2 x 2300 2 x 3300	3 x 300	-	1 x 250 (RO) 1 x 500 (RO) 2 x 400-750	-	-	Operators (manual)	17% (month) 14% (3 years)	(1994-)
DACHEN ISLAND / CHINA	1 x 280 1 x 256 2 x 100 1 x 560	3 x 55 2 x 20	127	-	-	-	PC based Start/stop wind turbines	26.1% (month) 15.4% (year)	(1989-)
FUERTEVENTURA / CANARY ISLAND	2 x 75	225	100	16.5kW (RO) 8 kW (Ice) 70kW(Lights)	-	-	industrial PC includes load management	?	(1992-)
FOULA ISLAND / SHETLAND ISLANDS	1 x 28 1 x 18 (hydro)	1 x 60	90 25	96kW (heating)	-	1400 kWh (hydro)	Umac 6000 computer Includes control of hydro output Operators interaction (constraints)	70% (3 months)	(1990-)
LA DESIRADE / GUADELOUPE	1 x 160 3 x 240	12 x 12	-	-	-	-	Start/stop wind turbines based on frequency setpoints and diesel loading	40% (instantaneous)	(1993-)
MARSABIT / KENYA	1 x 100 1 x 200	150	-	-	-	-	Limiting wind turbine output Includes pitch control	46% (3 years)	(1988-)
CAPE CLEAR /	1 x 72	2 x 30	-	-	-	100	Dedicated microcomputer Sophisticated software	70% (instantaneous)	(1987-1990)
RATHLIN ISLAND / Northern Ireland	1 x 48 1 x 80 1 x 132	3 x 33	-	-	-	73	Dedicated microcomputer Sophisticated software includes pitch control, charge/discharge of battery, load sharing of diesels	100% (instantaneous) 70% (year)	(1992-)
KYTHNOS ISLAND / GREECE	3 x 125 2 x 250 3 x 633	5 x 33, 1 x 500	-	-	100	330	Dedicated microcomputer Sophisticated software Includes components control	?	(1995-)
FRØYA ISLAND / NORWAY	1 x 50	1 x 55	72	-	-	27	RTU – remote terminal unit Converter is a P & Q controller Includes dump load control, charge and discharge of battery, start/stop of diesels	100% (instantaneous) 94% (8 months)	(1992-1996)
DENHAM / Australia	2 x 288 2 x 580	1 x 230	-	-	-	-	Dedicated microcomputer SCADA system Power control through wind turbine inverter and pitch mechanism	70% (instantaneous) 23% (6 months)	(1998-)
LEMNOS ISLAND / Greece	2 x 1200 2 x 2700 1 x 2600	8 x 55 7 x 100	-	-	-	-	PC w/ Windows NT SCADA system Sophisticated "intelligent" software Advisory system for operators	?	(1995-)

2.2.3 Hybrid power system research facilities

Table 2.3 gives an overview of different countries with various dimension of diesel capacity, various types of generators, dump and consumer load, storage capacity, features and installation date. Several types of generators are classified as wind turbine simulator, fixed speed and asynchronous generator, VAWT fixed speed and asynchronous generator, two-speed and asynchronous generator, variable speed and synchronous generator, downwind fixed speed and asynchronous generator.

Table 2.3 Hybrid power system research facilities

Research Laboratory / Country	DIESEL (kW)	WIND (kW)	DUMP LOAD	CONSUMER LOAD(5)	PV (kW)	STORAGE (kWh)	Features	Installation Date
NREL / USA	2 x 60	1 x 20(a) 1 x 75(a) 1 x 20(c) 1 x 10(e) 1 x 50(f)	-	100kW	-	16 (24V) 180 (120V)	3 AC buses and 3 DC buses PC based control system Advanced data acquisition system	1996
CRES / Greece	1 x 45	1 x 30(a)	45kW	20kVA	-	-	PC based control system	1995
DEWI / Germany	1 x 30	1 x 50(a) 1 x 30(b)	?	75kVA 127 x 1 kW	-	?	?	1992
RAL / England	1 x 85	45(b)	72kW	48kW	-	45 (flywheel)	Dedicated microcomputer controller PC data-logging system	1991
EFI / Norway	1 x 50	1 x 55(a) 1 x 55(b)	55kW	40 kW 20kVAr	-	27	Dedicated microcomputer controller Data acquisition w/ transient recorder	1989
RERL - UMass / USA	1 x 15	1 x 15(a)	16kW (1994)	16kW (1994)	-	-	PC based control system 4 operating strategies (same as HYBRID1) Advanced data acquisition system(1994) Rotary converter for AC-DC-AC	1989
IREQ / Canada	1 x 35	1 x 50(c)	17kW	50kW	-	-	-	1986
AWTS / Canada	2 x 50	1 x 40(b) 1 x 35(c) 1 x 65(d) 1 x 80(e) 1 x 50(f)	190kW	115	-	-	-	1985
RISØ / Denmark	1 x 30	1 x 55(b)	75kW	25kVA	-	-	PC based control system Sophisticated data acquisition system	1984

[a] wind turbine simulator; [b] fixed speed, asynchronous generator; [c] VAWT, fixed speed, asynchronous generator; [d] two-speed, asynchronous generator; [e] variable speed, synchronous generator; [f] downwind, fixed speed, asynchronous generator

2.2.4 Modular supervisory controller from Pereira [3]

The current practice for designing hybrid power systems is usually based on two approaches: 1) the site-specific solution that incorporates engineering cost (only specialized design teams can perform this work) for designing and implementing a system; 2) and the system package solution, which is usually difficult to add to existing power plants, which offers a limited number of possible configurations and expansion possibilities, and is not robust due to the close integration of components.

The modular supervisory controller developed by Pereira offers an alternative approach to the system design with the aim of overcoming the technical difficulties of the current engineering practice and contributing to open the market of hybrid power systems.

The term modular refers to a set of design characteristics that allows the use of basically the same supervisory controller in different projects. The modular software of the supervisory controller uses high-level models of the components and priority numbers to self-adjust to different system configurations. The control strategy is defined by the main goal of the system and/or by the components priority numbers. Changing the priority numbers of the components automatically modifies the operation strategy.

In the highest level of abstraction all components are identical. They are simply units (or devices) that exchange electric power with each other using a common grid. The communication protocols and I/O interfaces of the supervisory controller, other important features of the modular concept, have been developed based on the common characteristics of the high-level models of the components. This allows the exchange and upgrade of components without changing the connection link and communication processes. In the second level of abstraction, the different types of components are grouped as generator – the power sources, consumer – the sinks, and storage. With these middle level models most of the operation strategies are derived and the sequence of tasks of the modular controller can be determined.

The modular supervisory controller algorithm is implemented in a computer program called SuperCon using an object-oriented design. The code has been tested through several simulations using different hybrid system configurations and different control strategies. The simulations use both real (measurements) and synthetic input data (wind and load). Grid frequency variation, diesel generator operation and actions of the supervisory controller are some of the outputs used to analyze the performance of the modular supervisory control algorithm.

The ultimate objective of Pereira's work is to develop simulation tool and SuperHPS which support the development and testing of the modular supervisory controller. SuperHPS is a time-series based program that simulates the energy flow and grid characteristics of an arbitrary hybrid power system with or without a supervisory control system. An input parameter is used to make SuperHPS call the program SuperCon to perform simulations including a supervisory controller.

SuperHPS has been developed with the new dispatch models. Dispatch models, another contribution of this thesis, use simple mechanical and electrical equations to describe the components' behavior and performance in a time scale of few seconds up to minutes. Although transients are not represented some time constants and response delay times are included in order to simulate the starting up and stopping of various components. Therefore the interaction between supervisory controller and components can be investigated in order to determine the most efficient operation strategy.

Different solutions of control systems for hybrid autonomous power systems involving wind turbines:

2.2.4.1 Rhodes autonomous power system

Rhodes autonomous power system [1] will be implemented in 2012, with the aim to replace the conventional power units in the production side with wind turbine on an autonomous base. The example studies of Rhodes island in Greece with the control of voltage and frequency of an autonomous power system, consist of two types of conventional units; gas, diesel and steam units with automatic voltage controllers.

a. Voltage and frequency are to be controlled within the constraints. The study included different types of wind turbines; fixed speed and variable speed.
b. Three different types of frequency controllers are investigated; inertia control, droop control and combined control
c. When the variable speed wind turbines are implemented, it is challenging to maintain the frequency constant, when there is any change in the load/wind characteristics/any fault etc.

Conclusions:

- Non interconnected systems face the problem of reduced inertia especially when wind turbines tend to substitute conventional units
- Auxiliary frequency control needed in variable speed wind turbines to allow expanded wind power penetration beyond the rule of thumb of 30 %

- Technology such as flywheel is available but only advanced frequency control capability of modern wind turbines can expand the penetration levels

2.2.4.2 Wind turbines with fuel cells

The fluctuation caused by the wind disturbances is solved by using in-direct electric production using wind turbines [2]. The schematic diagram is shown in Figure 2.4.

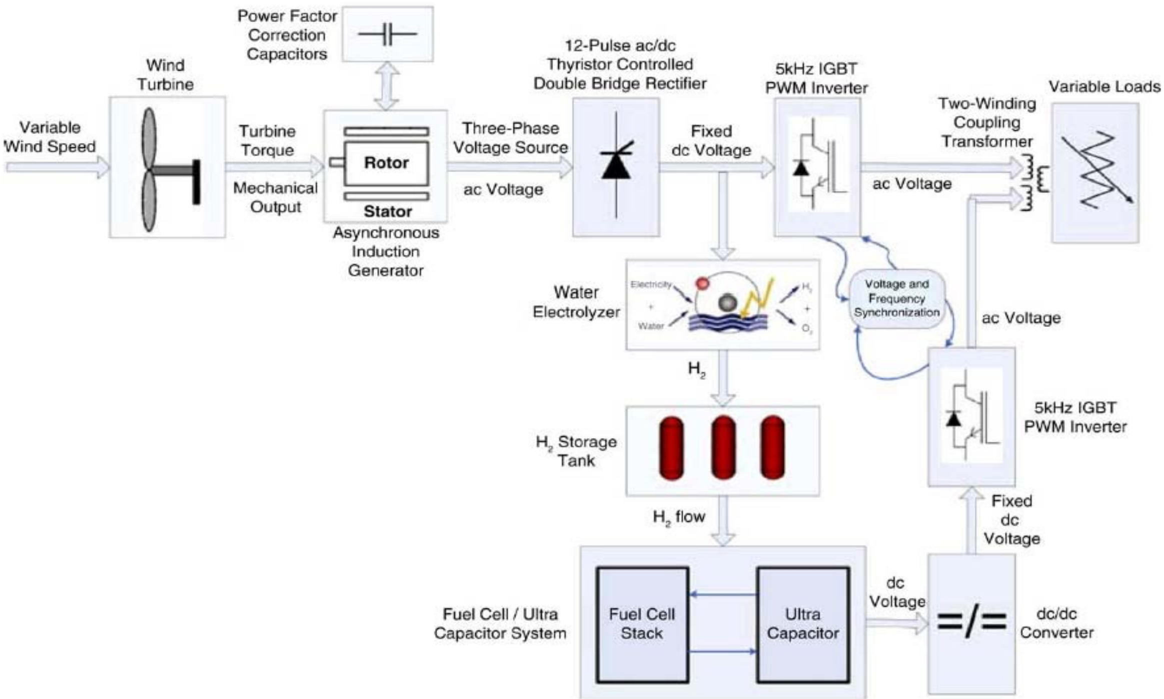

Figure 2.4 Schematic diagram showing electric production using wind turbines and fuel cells (Source: [3])

2.2.5 Conclusions

The control system for an autonomous hybrid system involving a traditional power generation such as diesel generators, and renewable energy conversion such as wind turbine has several challenges. Most of these challenges depend on the specific case and depend on many key parameters, which are listed below:

- Type of renewable energy sources
- Depth of renewable energy penetration into the total energy production
- Type of components in the renewable energy production
- Information about forecasting of renewable energy source and feed forward control
- Type of control structure; Supervisory control, Optimization layer in the control system
- Requirements on power quality
- Availability of energy storage, type and size of energy storage

- The control problem is solved by de-coupling the electric power conversion directly from the wind turbines.

Depending on the parameters listed above, most of the present controllers have the basic feedback loops which have the P&ID (Proportional, Integral and Derivative) controllers. These feedback loops constitute the basic feedback loops in any control system. The improvement can be achieved by having a supervisory control loop on the top of these feedback loops. Furthermore, if we can get information about the weather forecast in advance, feed-forward loops can be implemented in addition to the feedback loops. The supervisory control will then be able to optimize the performance of the power system by minimizing a desired cost function; cost of the fuel, minimizing the wear and tear, optimized deviation of the performance from optimal for each power system etc. The other advanced control system on top of the supervisory control system could be model predictive control, which uses the models of the power system and try to foresee the behaviour of the hybrid power system by simulating the models with different chosen operating criteria and selecting the optimal operating criteria.

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- http://etd.lib.montana.edu/etd/2005/guda/GudaS0805.pdf
- http://repositorio-aberto.up.pt/bitstream/10216/43377/2/19914.pdf
- http://vbn.aau.dk/files/16919120/Analysis_of_a_novel_autonomous_marine_hybrid_power_generation.pdf
- http://users.ntua.gr/pgeorgil/Files/J13.pdf
- http://users.auth.gr/~seferlis/Publications/2009_IJHE_Ipsakis_Voutetakis_Seferlis_et_al.pdf
- http://ipac.kacst.edu.sa/eDoc/2010/190648_1.pdf
- http://ceai.srait.ro/index.php/ceai/article/view/225/162
- http://iris.elf.stuba.sk/jeeec/data/pdf/1_110-1.pdf
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2.3 Options for Energy Optimization Strategy

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Energy optimization strategies with aim to obtain fuel savings, more stable engine control and emission reductions are essential and critical. This section provides different perspective of energy optimization strategy in terms of *backup*, *power quality* and *grid limitations*.

2.3.1 Wind park operator

A wind farm is composed of many individual wind turbines, up to over a hundred in some cases, distributed over a large geographic area. It is shown in Figure 2.5. The fundamental problems that will be faced related to network stability of wind park are: dynamic stability, short-circuit power, network upgrades, power balancing between the wind farms and other independent power producers, import, export and natural loading on high-voltage networks [3]. The ability to optimize hybrid configurations of renewable energy systems is achieved in order to maximize performance while minimizing cost. Maximizing the power harvesting from the wind park is one of the main drivers for the operators in the design of the wind turbine control system.

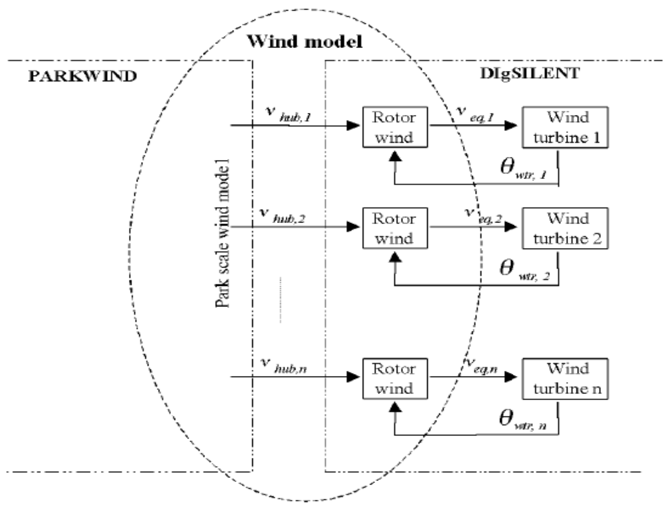

Figure 2.5 Example of a wind park (Source: [2]).

Better wind power forecasting models are essential to predict the wind power production in short-term or long-term in advance. Wind power forecast needs to be taken into account in the formulation of the optimization strategy.

Distributed energy generation is prevalent with the rapid expansion of alternative energy. This creates challenges related to power quality. Numerous metrics are used to measure the power quality of a wind turbine, the most common of which are such as power factor, reactive power and harmonic distortion [5].

Several optimization methods of wind turbine energy have been discussed in [5] (and references therein) such as:

- Boukhezzar proposed a non-linear approach to control a variable-speed turbine to maximize power in the presence of generator torque considerations.
- Datta and Ranganathan developed a search algorithm to track the peak power points for variable-speed wind turbines.
- Muntenau applied a linear-quadratic stochastic approach to solve the power optimization model and tested it using an electromechanical wind turbine simulator. A trade-off between the efficiency of energy conversion and input variability in the simulation experiments.
- Muljadi proposed a pitch control strategy to maximize power and minimize turbine loads for different wind speed scenarios.
- Andrew Kusiak developed data mining and evolutionary computation to optimize power factor and the amount of power by a wind turbine. Problem optimization problems are formulated to solve constraint problem due tu dynamic modelling of wind turbines (e.g. wind speed, blade pitch angle, generator torque, active power, power factor and rotor speed). The optimization of the active power and the power factor has been performed by supervisory control of a wind turbine.

An evolutionary computation approach for optimization of power factor and power output of wind turbines has been investigated in [5]. Data mining and evolutionary computation are integrated to optimize the power factor and the amount of power produced by a wind turbine. The plots of active power, the power factor and the wind speed of a turbine over 36-hour period are shown in Figure 2.6.

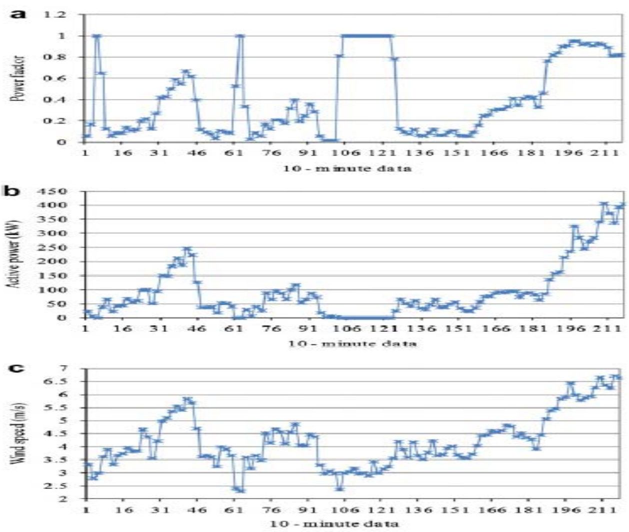

Figure 2.6 Active power, power factor and wind speed plot for a wind turbine (Source: [5]): (a) power factor, (b) active power and (c) wind speed

Maximizing the power harvesting from the wind is potentially one of the main drivers in the step of designing wind turbine control systems. In [4], the wind farms design optimization can be achieved by considering several factors such as:

- The wind resources assessment to determine the best location of wind turbine and to maximize the energy production
- Detailed analysis of various turbine types, size and height to maximize the electricity production within wind park
- The design of reliable electrical collector system
- Environmental and regulation constraints
- Operational and maintenance costs
- Constructability

In [7], C.F. Moyano observed that wind power forecast needs to be taken into account in the formulation of the optimization strategy for the wind park control. In general, this concept is based on classical unit commitment and dispatch and taking into account the characteristics of the turbines and generation limits obtained from wind power forecast. This strategy allows wind parks to follow requests from a system operator or from a wind park dispatch centre, regarding active/reactive power to be generated. Such functionality allows wind park generation to become quite flexible allowing their participation in electricity markets and their response to system operator request when a network restriction demands the reduction of generation in a geographical area.

2.3.1.1 The typical energy optimization model

Typical energy optimization models are ranging from backup power, power quality and grid limitations.

- *Backup*

  Storage (e.g. flow-battery storage options) is viewed as a means to install additional wind capacity in grid (rather than to increase the efficiency of existing installations). Storage can be feasible if applied in several applications in parallel. For instance, integrated wind farms wind turbine with hydrogen storage technology combining with trading, power balancing, power quality and other options [8]. Figure 2.7 shows wind generators, conversion with electrolyzer, firming storage and transmission pipeline of diverse renewable resources.

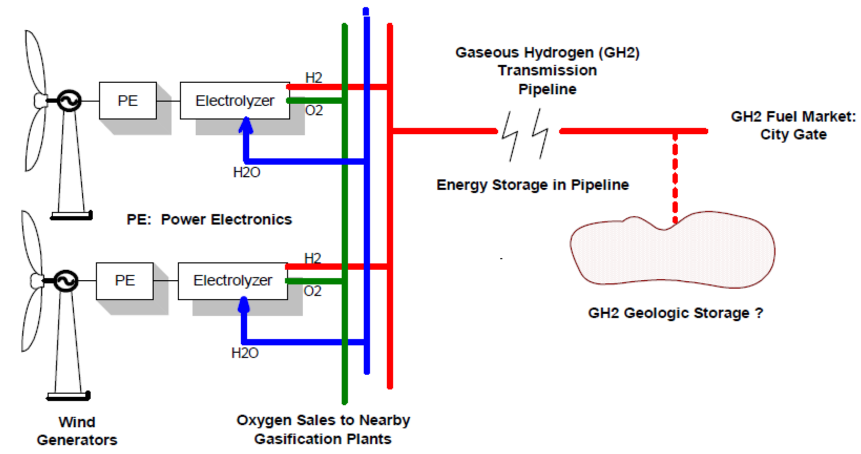

Figure 2.7 Hydrogen storage with wind turbines (Source: [8]).

- *Power quality*

  In [2], T. Thiringer investigated how much wind turbines can affect the power quality, preferably before an installation takes place. In general, there are four power quality aspects to reactive power exchange with the grid such as:

  1. *Steady state voltage impact.* A change of steady state voltage level is an inherent consequence of injecting a current into the grid. The key to the control of the voltage level is the reactive power control.
  2. *Impact by dynamic voltage fluctuations (flicker impact).* The user of power electronic converters in wind turbine systems provides a possibility to reduce the dynamic voltage fluctuations.
  3. *Injection of harmonic currents*. The voltage total harmonics should be a very high value.
  4. *Voltage transients due to switching actions.* The switching actions are usually not a problem for variable-speed systems.

- *Grid limitations*

  The offshore wind farm will be fairly large and located in areas with relatively weak grids. This relates to grid issues considering the potential use of plans for wind power. Grid codes contain the rules for connecting generators to the grid. The Transmission System Operator (TSO) provides the rules fitted to system needs. The grid codes recommended by Statnett in [6], contain several recommendation to wind farms such as:

  - Operation at varying grid frequency (normal 49.0-50.5 Hz, limited 47..0 -51 Hz)
  - Operation at varying grid voltage (normal+/-10%, cosφ=+/-0.91 ref wind farm point of grid connection)
  - Active power control (remote control maximum production, system for ramp-rate limitation and participation in frequency control)
  - Reactive power control (system to operate at two modes: a) set point cosφ and b) active voltage control with drop)
  - Operation in case of grid faults or abnormal grid voltages (fault ride-through for voltages down to 0.15 pu at the grid connection point of the wind farm)
  - Verification of characteristic properties such as analyzing impact on system using simulation model and make numerical wind farm model available for Statnett for simulation using PSS/E or similar).

  One common consequence of the wind power is the question of grid adequacy, the increased need of transmission and interconnection capacity. The limitation in how much power can be transmitted from one point to another is a critical task. The limitation can depend on thermal limits, angle stability limits or voltage stability limit.

2.3.2 Oil & gas installation efficiency

To fulfil the concepts of integration wind power with offshore oil & gas platforms, it is a necessity to have a comprehensive oil & gas installation efficiency. The possible interconnection to supply electric power from shore to offshore installations is shown in Figure 2.8.

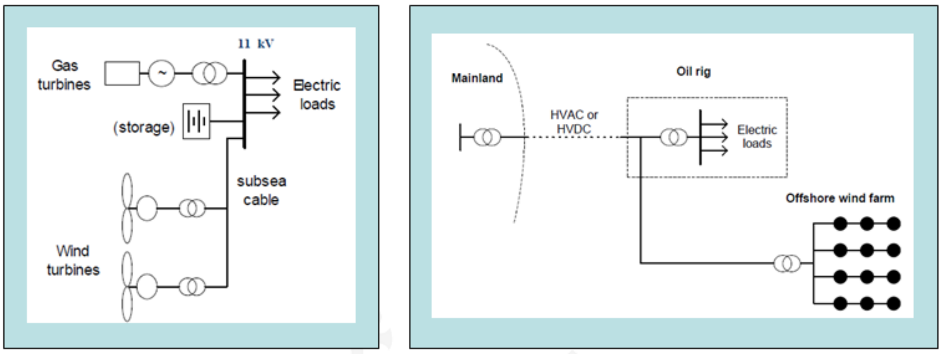

Figure 2.8 Concepts of integration wind power with offshore oil & gas platforms

There is an important principle difference between the offshore wind industry and the offshore oil and gas industry. The offshore oil and gas industry consists of uniquely designed installations. Meanwhile, the offshore wind installation will require multiple installations of identical machines. Cost effective multiple installations will require a degree of innovation which was not required in the oil and gas industry because each installation is unique.

The oil & gas installations can be defined both for mobile unit installation (e.g. drilling rig) and fixed installation (e.g. production platform). The terms "efficiency" in oil & gas installation may relate to (a) lower cost of integration and maintenance costs, (b) high operational efficiency to maximizing the plants profit, (c) truly integrated solutions with every elements working right, (d) right design for long terms purpose and (e) long life cycle management.

2.3.3 Conclusion

The energy optimization strategy is basically essential for various alternatives taking into account various constraints of backup (e.g. energy storage), power quality (e.g. balancing production and load) and grid limitations. Challenges related to integration of wind power are such as: stochastic sources; balancing production and load; and energy storage. Applying appropriate computation approach for energy optimization strategies will help: to enhance better fuel savings of operations due to the electricity power utilization; to provide more stable engine control (e.g. mitigate the power harmonic distortion and transient over voltage); and to reduce emissions so can extend the life of the wind park components.

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3 Energy Input from Offshore Wind

3.1 Wind Input Data for Studies on Integration of Off-shore Wind Farms into Combustion Based Power Supply Systems of Oil & Gas Installations

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Integration of wind farms into local power supply systems have up to now mainly been studies for on-shore or island power supply of small isolated grids. Research dates back to the mid 1980th. Focus was on wind/diesel systems for the supply of isolated electricity grids with power ranges of a few kW up to several 100 kW. Besides basic studies on optimal components, system configuration and optimal control were performed in view of system stability and the of maximum fuel saving (see e.g. [1,2,3]). Simulation studies in this context have been performed based on system and wind data measured on site.

For more generalized studies there was a need for procedures to generate synthetic wind data covering the whole range of possible meteorological situations for various locations. Bases for the respective schemes is the comprehensive statistical characterization of the time and space structure of the wind field, as analyzed by micrometeorological research (see e.g. [4,5]). Essentially, the time structure of the wind speed fluctuations is characterized here by their power spectral density. Knowledge of the spectral characterization enables setting up an appropriate scheme for data synthesis [6]. A simple application of this procedure for the generation of input time series for the analysis of turbine performance in the time scale of seconds in view of its influence on hourly energy gain is e.g. given by [7]. An application of this procedure on wind/diesel studies is e.g. given by [8]. Basically, in those studies, the wind input to the turbine is characterized as unique time series, affecting the whole rotor without taking into account its spatial extension. To account for the effect in the time scale of seconds, the wind field is inhomogeneous over the area of the rotor – resulting in a damping of high frequency fluctuations by the associated spatial averaging – the data are to be appropriately filtered.

The scheme as described up to now reaches its limits when, on one hand the wind power gradients across the rotor are in itself focus of interest in the context of calculations of mechanical stress, or when on the other hand the lumped power output of several turbines acting on the same system (wind farm) is of interest. The method as described in [6] can however be extended to derive three-dimensional wind fields. As additional information the coherency of the wind field is needed. Based on the approach described in [4] extended analysis on the wind field coherency in the spatial scale of several meters up to kilometres is have been performed for onshore locations (see e.g. [9]).

Studies using the data generated that way have been applied in a basic way for both studies on wind farm/diesel systems [10] and integration studies for large scale wind farms in the utility grid [11]. These studies point out that the relative fluctuations in the lumped power output of spatially extended systems are generally smoothed as compared to the fluctuations in the power output of single turbines, the coherency in dependence of the separation being the governing quantity.

A more comprehensive, generally applicable procedure is given by [12,13] offering schemes applicable to both, input data generation for studies on grid interconnection and analysis of mechanical loads of turbine components. In [12] the mutual shading of the turbines within a wind a farm are explicitly taken into account. This concerns both the reduction of the wind speed in the wake of the turbines and the added turbulence in the wake flow. The explicit discussion of the application to energy system studies are given by [14,15].

A study dedicated to analysis of the performance of off-shore wind parks is given by [16]. This study reveals the general applicability of the data generation schemes discussed, but also points out several shortcomings concerning the parameterization of the processes involved. Notably, the coherency governing the smoothing cannot be coped with using parameters extracted from on-shore sites.

Similar findings hold for description of the wakes behind the turbines, e.g. [17]. This study is based on data from the ALPHA-VENTUS offshore wind farm. It is concluded that the characteristics of the turbulence intensity in the wake flow and the recovery of the wake deficit with down flow distance from the turbines need further investigation.

In conclusion on the state of the art, it can be stated that general schemes for the supply of synthetic wind field data is accepted. However, for the application of the schemes for the offshore case, there is still a need to include new findings on the (cross-)spectral characteristics and the turbulence structure in the marine boundary layer in model parameterization.

In addition, having achieved a satisfactory parameterization, it has to be analyzed, whether the classical assumption of normally distributed fluctuations that forms the basis for the current synthetization schemes reflects the occurrence of extreme fluctuations in a realistic way. The deviations of the distribution of gradients in measured wind time series with both, high and medium time resolution from the characteristics for a normally distributed set have been shown (e.g. [18,19]). Depending on the sensitivity of the system response to the occurrence of extreme fluctuations, modifications of the synthetization scheme may be necessary.

Based on the current state of knowledge, simulation studies for the coupling of wind farms with oil and gas platforms have been performed by [18,19]. Whereas [18] concentrates on long term analyses with lower time resolution in combination with an stability analyses under singular disturbances, an own preliminary study [19] focuses on system stability on a minutely time scale under continuously fluctuating input using synthetic wind speed data with 3 Hz resolution, presenting the input to linear turbine arrays at perpendicular inflow. A comprehensive study combining the analysis of the stress due to short term fluctuations with integrated long term analyses is up to now missing. The sensitivity analyses with respect to the fluctuation characteristics mentioned above has to be based on this comprehensive tool.

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3.2 Options to Match Wind Generation with Thermal Power Stations in Isolated Grids

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This section gives information of the wind input to the systems. The attainable fuel savings can be achieved by integrating wind power to stand alone systems in dependence of system design and control.

Starting with the topic of fuel savings, Figure 3.1 gives the layout of a simple wind/diesel system may be used to introduce the basis problems of such a match.

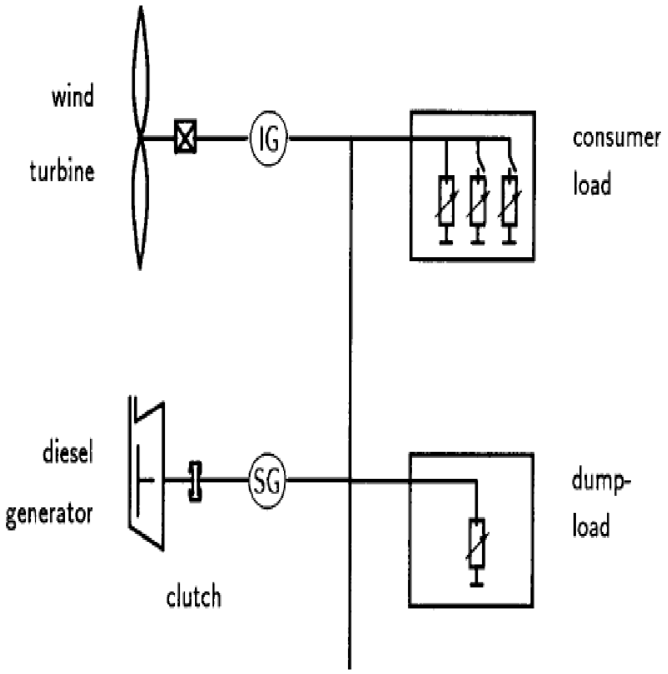

Figure 3.1 Scheme for the basic combination of a wind turbine ad a thermal power station (here: a diesel gen-set).

3.2.1 Statement of the problem

The initial system starts from a system without wind turbine. Then the presence of a small wind turbine with rated power less than the minimal load is added, this naturally contributes to the supply of the load. As a result of this contribution is to reduce the apparent load for diesel gen-set. The resulting fuel savings will typically depend on the efficiency characteristics of the gen-set (see Figure 3.2).

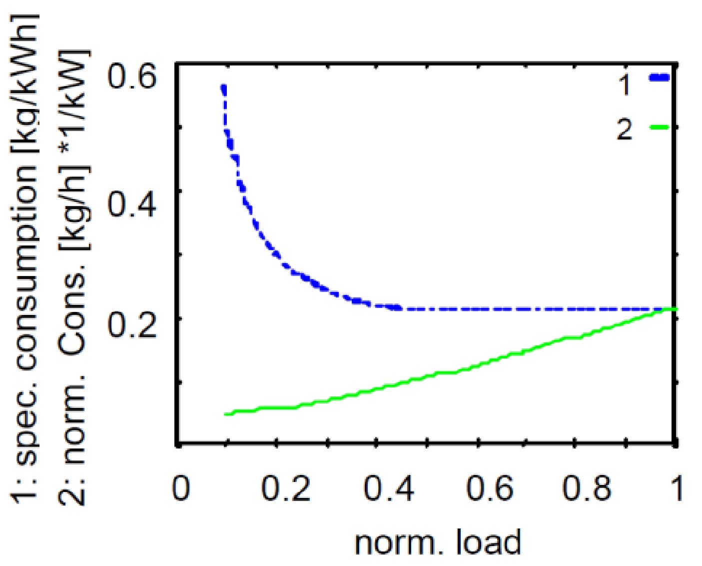

Figure 3.2 Typical characteristic fuel consumption as function of power delivered to the load of a gen-set.

With load close to the rated power of the gen-set and small wind penetration rates (less than ~30% of the rated power) the fuel savings will be proportional to the injected energy from the wind turbine. For increasing size of the wind turbine, specific fuel savings will be reduced, due to the decreasing efficiency of the gen-set at part load operation. For wind penetrations close to 1 the gen-set is pushed to the idling mode, keeping about ~10% of the rated fuel consumption at no load operation.

Thus, fuel savings for a system with a continuously operating gen-set are limited, even with the use of oversized wind turbines. To increase the fuel savings, the gen-set must be allowed to stop when pushed to the no load operation. This gives requirement to both system structure and control. Concerning system control we may subdivide into control to assure system stability and power quality at time scales down to milliseconds. This control is already necessary for systems with continuously operation gen-set to allow for the smooth parallel operation of several generators at a common bus-bar. Examples for respective works are given by [e.g. 1,2,3,4,5]. In addition, control for the energy flow management is needed, working on time scales from seconds to hours.

3.2.2 Optimal control for system dispatch

Whereas the short term control is quite developed, as it can to a large extend rely on the control methods applied in systems using a number of conventional dispatchable generation systems (diesel gen-sets, gas turbine generator systems etc.), in the field of long term control things are less well developed. For the systems incorporating wind turbines, this non-dispatchable character together with the high stochastic variability of the wind field calls for control schemes that take knowledge of the fluctuation characteristics of the wind field explicitly into account.

An example for this field of problem is given by the control for the simple system sketched in Figure 3.1, with intended operation to stop the diesel given that the wind power is sufficient to cover the load. This option requires that both generator of the diesel gen set and of the wind turbine are capable to form the grid, unless other additional components are added to the system. Due to the fact that the wind turbine power output follows the continuous wind fluctuations, the situation concerning the power balance of turbine output and load changes rapidly. Both measurements and simulation calculations [see e.g. 6] show that a number of the respective level crossings – especially when the average power output of the turbine is equal to the load may reach quite significant number. Examples are given in Figure 3.3, showing different operation strategies and different options of system design. Average diesel start numbers for systems with different control strategies as a function of the penetration of the system with wind energy, i.e., the ratio of annual average wind power to annual average load. The diesel start numbers are given as annual average diesel start numbers per hour. The results are gained with one-year wind data measured at a site near the North Sea coast, annual average wind speed is 5.4 m s J at 10 m height a.g.l, respectively 6.2 m s -~ at turbine hub height 22.4 m). The turbulence intensity is 0.17.

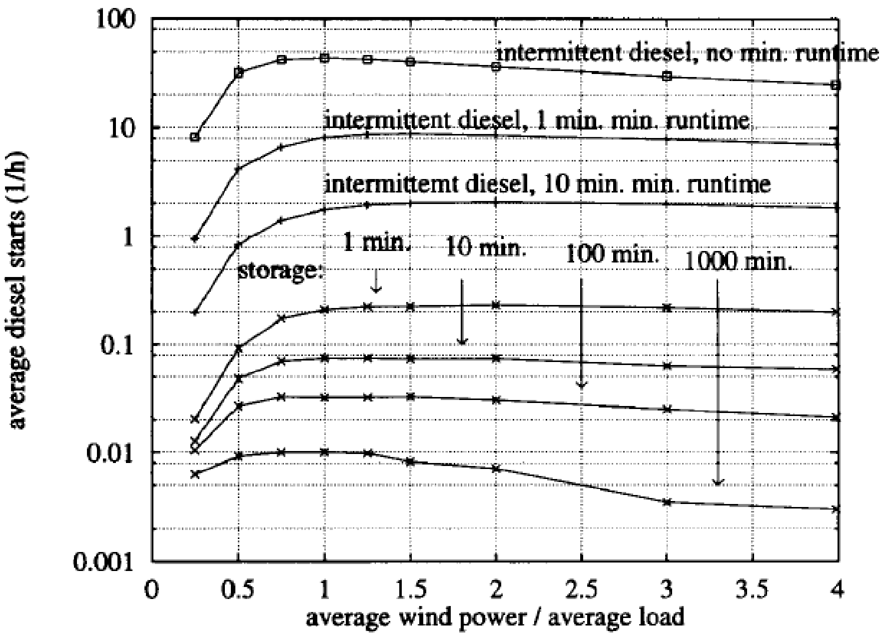

Figure 3.3 Different operation strategies and different options of system design with wind energy

From the figure, it may be extracted that, for a system with instantaneous switching option discussed above, the frequency of diesel start/stop events may reach ~1/min. Some reduction of diesel start numbers can be achieved by the introduction of minimum runtimes of the diesel engine. As discussed in [6] a reasonable dead-time of the response may also be taken from the wind signal by linking the action of diesel stop to a minimal residence time of the wind speed above the critical level.

3.2.3 Addition of storage capacity

The introduction of storage capacity is necessary for achieving a substantial reduction of numbers of starts/stops. As can be taken from the lower curves in Figure 3.3, adding a storage capable to cover the load for one minute leads due to a reduction of the diesel start event by a factor of ~100. The use of a storage capacity for 100 min leads to an annual average of less than 0.1 starts per hour. For storage capacities of several hours, the number of starts per hour reaches a saturation value, determined by the large scale meteorological situation with time constants up to several days. Those fluctuations would have to be levelled out with storage capacities of several days to weeks. These results were gained assuming the use of a lead-acid battery as storage. However, it is not a realistic option to realize storage capacities of less than an hour, as to deliver the required discharge currents, the batteries would have to be remarkably oversized with respect to the required energy.

3.2.3.1 Effect of different operation strategies/storage capacity on potential fuel savings

Having stated the advantages of the delayed response of diesel stop for the cycling of the diesel engine in systems without storage, a drawback has to be stated. Due to the increased runtime of the engine for systems with delay response as compared to systems with instantaneous, intermittent reaction, the diesel savings are reduced (see [6]). For systems with storages, the fuel consumption is well reduced as compared to the storage-less systems with intermittent operation. Storage losses had been taken into account in these analyses.

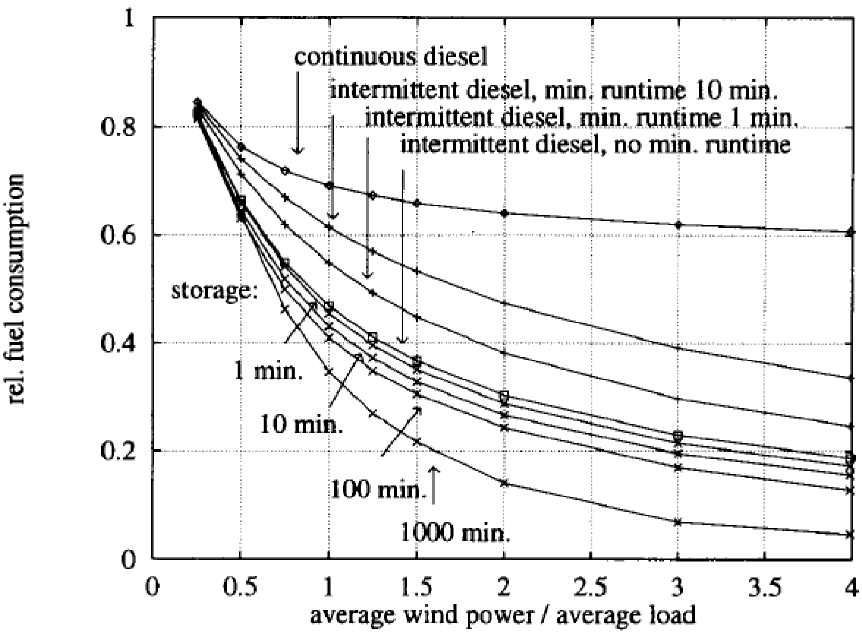

Figure 3.4 Diesel fuel consumption for the systems presented in Figure 3.3

3.2.4 Option for storage capacities

Concerning the options for storage systems currently mainly 3 types of technologies are discussed since long, each being best suited for one range of desired storage time. These are the flywheel storage for storage times in the order of minutes, (lead acid) batteries for storage times of ~10 min up to hours and days and hydrogen storage i.e. electrolyser, gas storage, fuel cell chain, for storage times up to seasons.

A comprehensive discussion on design options typically limited to systems of several 10 of kW has been performed in the EU-hyress Project (see e.g. [8] and www.hyress.org). The storage design for systems up to a power range of MW is discussed by [9].

From [8] and [9] it may be concluded that both options, hydrogen subsystem and battery storage with long-term energy storage in the form of H_2 are proven technology today.

3.2.4.1 Flywheel storages

For storage capacities equivalent to a few minutes of load flywheel storages are considered as best option for the power range of 10 of KW to MW (see e.g. [10,11,12, 13].). Two flywheel integration schemes are discussed. The more simple concept used the fixed mechanical coupling of the flywheel to the generator axis (see e.g. [8] has the drawback that it requires a flexibility in the frequency of the supplied grid. The second option uses an AC/DC/AC link for the electrical coupling of the system. This allows on one hand for a fixed frequency grid, on the other hand the flywheel may be operated with a broad range of rotational speed, enhancing the storage capacity of the system. Systems using Flywheel storage are commercially available and in operation since about 2005.

3.2.4.2 Battery storage

For the time range of several minutes to hours batteries are used. The respective systems have to use inverters for coupling the DC bus-bar of the batteries to the main AC bus.

Experience with battery storage dates back to the early 1980th, where typically village power supply systems in the power range of several 10's of kW to about one MW had been designed (see e.g. [14], [15], [16]).

For systems in the power range of several MW a system based on hydropower and diesel is backed up with a battery bank using lead acid batteries. It is shown that that large battery capacities as large as 500 kWh can be realized and successfully operated [16]. Batteries for mains grid support in the MWh range are also in operation. These systems use advanced battery technologies, e.g. sodium sulphur batteries [see e.g. [17]. The use of technologies under development as redox-flow batteries is envisaged (see e.g. [18]).

3.2.4.3 Hydrogen storage

The hydrogen (electrolyser, gas storage, fuel cell) option basically offers the opportunity to realize large storages with high energy content. Drawback is the low efficiency (typically <50%, see e.g. [19]) for the conversion path electricity to gas to electricity). Nevertheless, experimental wind energy systems using the hydrogen storage chain have been setup up e.g. in Norway [20] and Canada [21]. System sizes are in the range of 100 kW.

Due to its low efficiency, the hydrogen storage system has to be combined with a high efficiency storage system to level out short term imbalances in the energy flow and confining its function to the seasonal energy storage [22].

Due to its characteristics, it may be concluded here that that a hydrogen storage system is not well suited for the inclusion in a larger wind/diesel system, unless an extremely high degree of energetic autonomy is requested.

3.2.4.4 General conclusion on storage technologies for larger scale wind/thermal systems

Summing up the abovementioned characteristics of the different storage options, it seems reasonable to take both flywheel storage and storage with advanced battery technologies (e.g. sodium sulphur) into consideration. Each of these technologies can fill out a distinct role in the supply scheme, flywheel storage for the levelling out of short term imbalances of demand and supply, the battery technologies for levelling out fluctuations on the scale of hours. Whether there is a need for these services has to be determined in dependence of the overall system sizing, especially the expected overall contribution of the of the wind energy to the load coverage.

3.2.5 Concluding remarks to the requirements on extended information on the wind input to the systems

For both the optimal (advanced) dispatch of the thermal (diesel) generation units and the operation of the storage units (see e.g. [23], [24], [25]), extended information - especially forecast information – on the wind speed evolution on the different time scales appears valuable (see e.g. [26]). Whereas the forecast of the wind speed on an hourly time scale is in a quite elaborated state [27] – fostered by the necessity of wind information to manage the large scale integration of wind power into the utility grid – the shortest term (time scale minutes) forecast is less developed (see e.g. [28] as one of the few examples).

With new developments on the instrumentation side, however, options for forecasts in the 1 s time scale can be envisaged [29].

3.2.6 References

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4 Cost of Integration

4.1 Brief Assessment of Different Cost Figures

This section gives description concerning the integration cost of offshore wind power, thermal power plant and onshore grid. Two alternatives for possible connections have been discussed in Section 2.1.When two alternative strategies are chosen and connected, an impact analysis level and probable outage costs of integration before and after the connection is paramount necessary. The integration cost can be defined as the extra costs for the system when appropriate alternative will be properly selected.

4.1.1 Cost figures for alternative 1

Alternative 1 is so-called "Stand-alone system", with an offshore wind farm and a platform with thermal power system. When the specific power system is operated, all involved factors consider the costs of their own resources operations and the prices on the market. Cost of integration including stability of power systems and uncertainties figures and attractiveness relate to alternative 1: no grid connection, mean lower infrastructure cost shall be considered.

The primary cost may include the installation of wind turbines and thermal power, connections from wind turbines and thermal power, storage volume, power cable routed down the tower, energy conversion, and control strategy system. The cost model associated with internal pressure, control strategy, fixed based cost and uncertainty events are necessary to be developed. Figure 4.1 shows cost figures for transmission lines infrastructure. Increasing distance of location installation will increase the amount of power used, but as a consequence the distance will affect the cost figures.

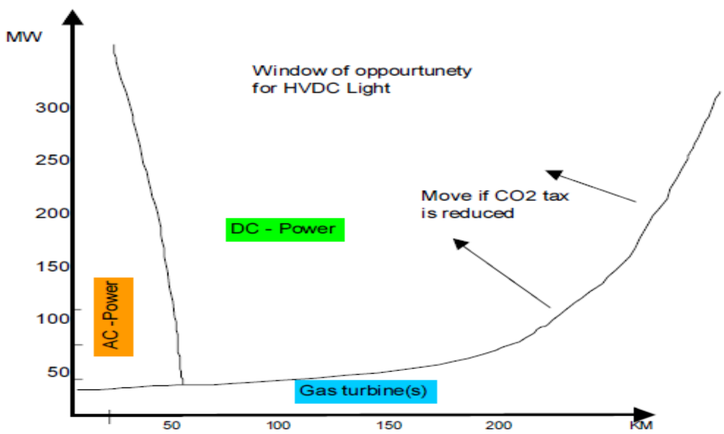

Figure 4.1 Transmission lines infrastructure.

The stronger need for back-up power supply for oil and gas installation is essential aiming to guarantee power and energy demand, energy offer, load power and output power constraints. Energy storage is costly in case of absence of onshore grid which can act as energy storage buffer. For example, generating and storing hydrogen in the win turbine towers has been proposed in [6]. The most cost-effective storage volume would be created using as much wall surface and as little cap surface as possible. Figure 4.2 shows how cost/mass ratio varies with storage volume.

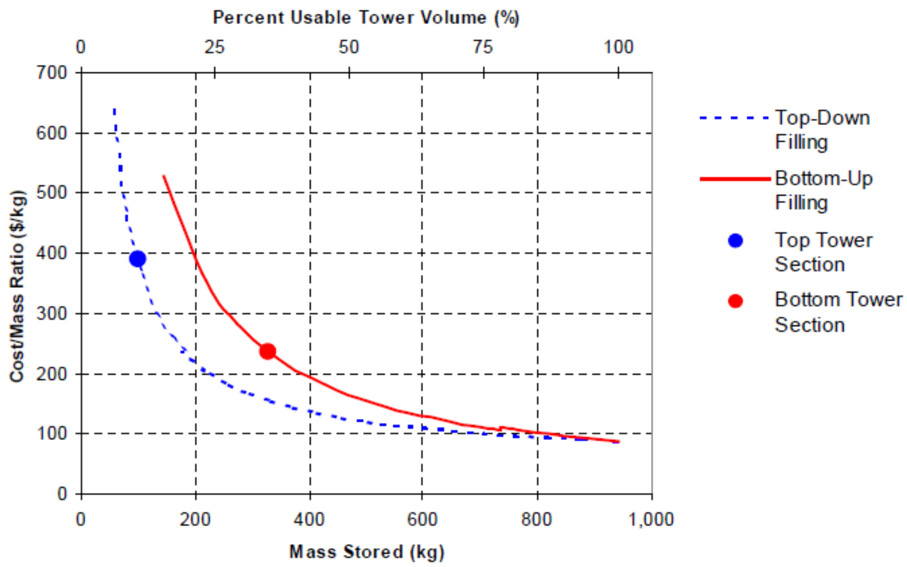

Figure 4.2 Effect of storage on cost/mass ratio [6]

One of available tool (PROMAPS) has been developed by Goodtech for conducting techno-economical risk management in large and complex power systems [5]. PROMAPS is the primary tool for analyzing substation design taking into account regularity and outage cost when selecting the redundancy level of the substation. PROMAPS calculates the cost of the current risk level and compares this with the cost of purchasing spinning reserves, activating system protection or other power system actions.

4.1.2 Cost figures for alternative 2

The alternative 2 depends of the grid-connected system, the offshore wind farm and thermal power plant connected to shore. Cost and attractiveness relate to alternative 2:

1) Onshore grid connection is costly, especially at large distance to shore. The output power of wind turbine generation depends on wind velocity. The costs of grid connection can be split up in two main parts. The costs for the local electrical installation and the costs for connecting the wind farm to the electrical grid.
2) Flexible situation (changes in production and load) needs robust power control for balancing power and scheduling. In the power system network, the balance of active power and reactive power must be maintained.
3) The grid connection may be a bottleneck

When this alternative is chosen, the cost and financial conditions are known and the uncertainty associated with depreciation time and interest disappears, leaving production and O&M costs as the main uncertainties. The other approach to calculate of cost of integration is to use a gradual and linear increase of the costs throughout the depreciation period. Unless otherwise stated above, the costs are included wherever applicable cost analysis such as grid connection, storage volume, storage pressure, control strategy, thermal power connection, power connections and uncertainties.

4.1.3 Structure of the system

When selecting the energy supply for a platform the operators have to evaluate a number of different criteria [3]:

- Greenfield or brownfield upgrade or extension
- Application of the energy on the platform
- Local regulations
- Installation cost

An example of the OPEX parameter values, associated with the solution of Gas turbine and power from shore are illustrated in Table 4.1.

Table 4.1 Life-cycle OPEX parameters [3]

OPEX parameters	NCS	Average	
Electricity wholesale price	46.7	66.7	$/MWh
Fuel sales value	0.24	0.24	$/Sm³
HVDC Light converter losses	4 %	4 %	
HVDC Light cable losses	4–6 %	4–6 %	
Fuel to electricity conversion at 100% efficiency	10.8	10.8	KWh/Sm³
GT turbine efficiency	40 %	30 %	
Released CO_2 at 100 % efficiency	0.21	0.21	
CO_2 tax or trade value	56.3	16.7	$/ton
Released rate of NO_x	0.4	0.4	kg/kWh
NO_x tax (over 20 year horizon)	7.5	2.5	$/kg
GT O&M costs/yr per 25 MW unit (+ WHR + ST in NCS)	2.5	1.7	M $/year
HVDC light system O&M (all sizes)	0.7	0.7	M $/year
Analysis period	20	20	years
Interest rates – net present value	7 %	7 %	

4.1.4 Connecting oil and gas platforms to mainland power grids

DC cable transmission systems are generally immune from the drawbacks associated with long-distance AC cables. In fact, voltage source converter (VSC)-based high-voltage direct current (HVDC) systems are designed to transmit large amount of power over long cable distance. A major cable distance limitation was thus lifted upon the arrival of VSC transmission to offshore applications.

Key components of a VSC-based HVDC system are shown in Figure 4.3. The main difference between DC and AC transmission is the presence of an AC-to-DC converter that rectifies onshore grid AC power to DC power for the purpose of transmission and the presence of a DC-to-AC converter at the consumer end that synthesizes DC power back into AC power. While the converters increase the cost of the DC system, the number of required cables is reduced from three for the AC system to two for the DC system. This reduction, combined with the reduced DC cable size due to inherently higher utilization efficiency, results in cable cost savings that could more than compensate for the converter cost as the cable distance increase.

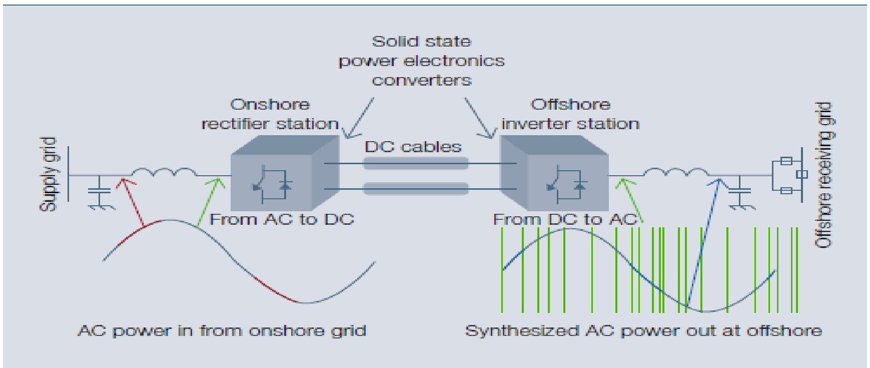

Figure 4.3 Principal and key components of a VSC-based HVDC system (source: [3])

4.1.5 Conclusions

From a review of the literature, there is reliable information regarding the cost of integration of stand-alone system and grid-connected system. In addition, the potential for integrating alternative 1 or alternative 2 in a larger economic context is essential to be studied.

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5 Conclusion

This report presents concepts for combined wind power and combustion based power systems for offshore oil and gas installation. Options for how to structure the integration of offshore wind farms and oil and gas installation have been discussed. Stand-alone and grid-connected systems are the two main possible concepts.

Control systems for autonomous hybrid power systems with traditional power generation such as diesel generators and renewable energy conversion such as wind turbines have several challenges. These depend on many key parameters. The use of appropriate supervisory control systems will help to foresee the behaviour of the hybrid power system by simulating the models.

The optimization problem of obtaining high energy efficiency is substantial for various alternatives, taking into account numerous constraints or factors to enhance the efficiency of the power production.

Various types of wind input data for studies on integration of off-shore wind farms into combustion based power supply systems for oil and gas installations have been described. The attainable fuel saving can be achieved by integrating wind power to stand alone system in dependence of system design and control. A brief assessment of different cost figures related to stand-alone systems and grid-connected systems has also been performed.

Based on the topics discussed in this report, a starting point for further possible research areas and project proposals in the near future is offered.