

# IPSYS – A simulation tool for performance assessment and controller development of integrated power system distributed renewable energy generated and storage

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## Abstract

A key factor in hybrid systems performance assessment is the ability to model the power system accurately. This includes accurate modelling of the actual control of the system, voltages and frequency. A new simulation tool, IPSYS, has been developed for that purpose. The core of the tool is a multi bus bar load flow calculation for explicit modelling of voltage and frequency combined with explicit modelling of other services e.g. water production. This is combined with very flexible controller modelling for easy exchange of controllers. The modelling concept and verification is presented.

System performance assessment is one main activities in hybrid system projects. It is therefore essential to be able to accurately estimate the performance of a system by using a system modelling tool. In order to be able to do this a new tool has been developed, IPSYS. This includes explicit modelling of the power system using a multi-bus bar load flow. It also combines different physical domains in order to model electrical, mechanical, heat and water balances. A key element of the model is very flexible modelling of the system controllers, which together with short time steps can be used for accurate modelling of the actual controllers. The combination of the above features is novel and is very relevant in the field of hybrid system in order to facilitate development of e.g. controllers for such systems. The paper will present the modelling concept and it will present results illustrating the features of the software package as well as the results of a verification exercise involving a wind diesel system with +100 bus bars, 2 (10) diesel gensets, 2+2 wind turbines and 52 loads.

## 1 Introduction

Throughout the world many places exist where there is no power or where there are small autonomous diesel grids. It is essential for these communities that there is a supply of electrical power in order to provide services that can support their development and assist in the generation of local income. These services include telecom, clean water, health clinics and power for households and small workshops/industries. In many of the places there is a push for exploitation of local renewable energy resources such as wind and sun. The systems that will be installed in such places can be quite complex in terms of configuration and operating strategy. The performance also heavily depends on the available resources for wind - this is particularly important since

the resources can vary significantly even within small distances. For the successful completion of projects under these conditions, it is important to have a proven project procedure, which will include a technical (and derived economic) analysis of the system based on simulation results.

In order to be able to analyse such systems, a development activity was initiated at Risø with the ambition to develop a simulation model that could be linked with a GIS (Geographical Information System), wind resource analysis software (WAsP, [1]), and would be able to model controllers. The current state of development of the model is that it can accept wind input from several sources including WAsP and it features very flexible controller modelling as well as a full load flow analysis, taking both active and reactive load sharing into account.

## 2 Integrated power system simulation

Estimating the performance of isolated power systems through system simulation is a key activity of feasibility studies as well as in the development of operating strategies. Many simulation models for hybrid systems have been developed during the last 20 years, [2]. An important initiative was an EU supported project in the beginning of the 1990s, which integrated five existing models for performance simulation of hybrid systems into a common framework, [3]. They were able to simulate a limited set of configurations of hybrid systems with predefined operating strategies.

At Risø, a tool for estimating the performance of wind diesel system was developed and used in several feasibility projects, [4]. This model did not include energy storage and had only one operating strategy. Nevertheless did it prove to estimate the performance of such systems very well, but requires a lot of work and tweaking if it is to be used for other configurations.

Current state of the art simulation tools that are being applied in feasibility studies include Hybrid2, [5], and Homer, [6]. Hybrid2 can simulate a rather wide range of configurations as well as a number of predefined operating strategies, and it can also be used for a detailed simulation of system performance. Homer is a screening tool used to compare a number of specified configurations for their energy cost. The control strategy of the system cannot be set by the user.

Despite their different origins, all of the above mentioned models have several important things in common: They are only able to simulate a limited set of

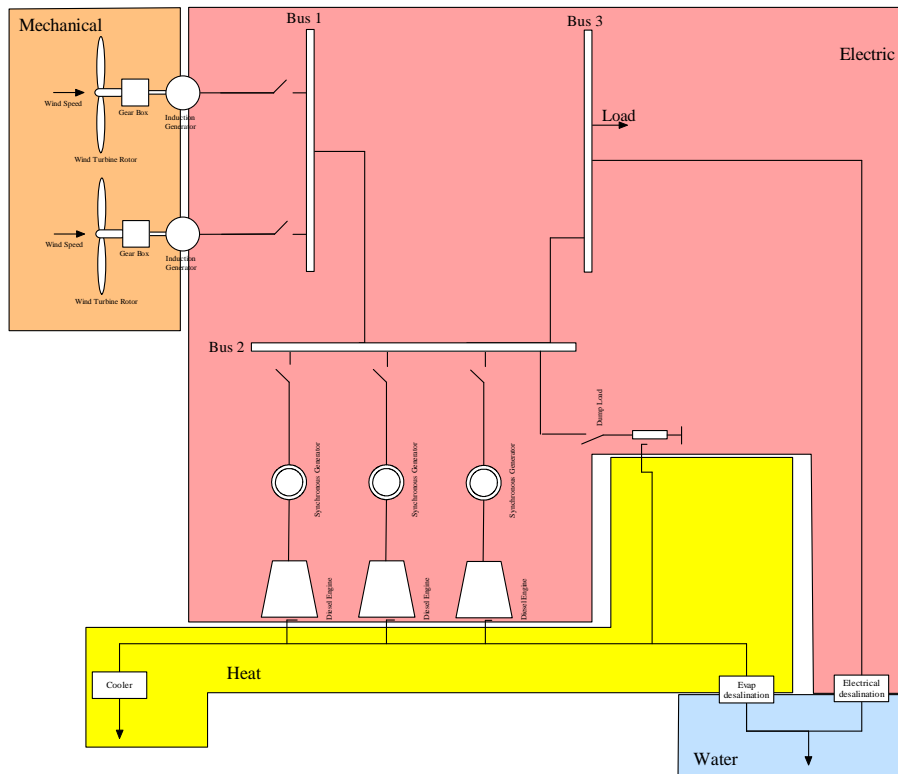


Figure 1 Scenario

configurations. The same is true for the operating strategies. All systems only model the active power balance, while reactive power is not considered. The power system is simulated as a single node i.e. the electrical grid is not explicitly modelled.

The development of a new simulation package was considered after it had been realised that assessing the performance of a real system would require modelling that system in its particular configuration, together with the particular controller. As a first step a PhD study, [7], yielded a modular system simulation package. This package was very flexible in the modelling of the system configuration as it allowed for a virtually unlimited number of system components. Another key feature were generic controllers, which could adapt to configuration changes. It was also possible to change the operating strategy by changing control parameters instead of reprogramming the system. Another novel feature was the use of short time steps to study the effects of starting and stopping individual units. This permitted a more direct representation of the real controller.

In many autonomous power systems with high penetration of renewable energy, other services such as supply of heat or water play an important role in the total economy of the system and will often be part of the project. It is therefore necessary to include them in the performance estimation. In many of these systems, derived services will have direct influence on the operation of the system, e.g. in a water production/supply system where the production of water depends on demand, especially if no storage is available. The water production may even be a combination of thermal units fed from waste heat and electricity.

Today there is an increased focus on power quality, even for small autonomous systems. In combination with creating the ability to integrate renewable resource data as well as community data (e.g. spatial information on dwelling etc.) in a GIS for use in the planning phase of a system, explicit network modelling becomes a desirable feature for the performance estimation package.

### 3 IPSYS – main features, architecture

Experience has shown that there is a need for a model which falls between the simple models used in early phases of a feasibility study, and the dynamic models used for analysis and design of dynamic controllers. The emphasis with this type of models is on the analysis and development of system wide controllers (supervisory controllers) and operating strategies. The required main features of the simulation tool are:

- Explicit modelling of the electrical network, i.e. load flow.
- Explicit modelling of load sharing between generating units, for active and reactive power.
- Flexible modelling of system configuration.
- Flexible modelling of supervisory controllers.
- Short time steps for accurate modelling of a supervisory controller.
- Ability to explicitly include other circuits/balances that interact with the electrical system  
(and system control) in order to model other products/services.
- Integration with the WAsP wind resource estimation tool.

Furthermore, the software needs to be easily extensible with new types of components, and different sources of time series needed to be accepted as input, e.g. measured time series, synthesised time series and synthesised time series based on output from WAsP.

The current version of the software includes a modified load flow algorithm that takes the active as well as reactive power load sharing explicitly into account. However, as a major constraint in the present version, all the units participating in the load sharing have to be connected to the same busbar. With this exception, the software allows for very flexible, user-configurable modelling of the system configuration, including individual representation of wind turbines and loads. It also has flexible controller modelling. The signals a controller can use are explicitly modelled and controllers can be exchanged by the user. Each controller module still has to be hardcoded, but controller parameters can be included in the input files in order to tune the behaviour of a particular controller and controllers can be exchanged by editing the input file. The current version of the package has models for mechanical, heat and water circuits/balances, making it possible to explicitly model water production from both waste heat and electrical power in order to meet a specified demand.

The scenario in Figure 1 is used to demonstrate the capabilities and potential of the IPSYS package, and, as a sample application, to compare two different control strategies. The modelled system consists of four subsystems, corresponding to four physical domains, and is centered around an electrical minigrad of three busbars. Busbar 1 connects to a mechanical subsystem through two induction generators, each of which receives mechanical power from a wind turbine. Three sets of diesel generators feed electrical power into busbar 2, where a dump load is connected as well. The diesels' speed governors are set to operate in droop mode, controlling system frequency, and each generator provides a regulated output voltage as a function of active and reactive power output. The third busbar feeds a time-variable consumer load and the pump of a reverse osmosis desalination plant. Busbars 1-2 and 2-3 are interconnected through non-ideal transmission lines.

In addition to their connection to the electrical subsystem, both diesel gensets and the dump load are attached to a thermal subsystem, in which they serve as heat sources. They exchange energy with a cooling unit and another desalination plant, which operates based on the evaporation method. Finally, the fourth domain is a freshwater subsystem, connecting the two desalination

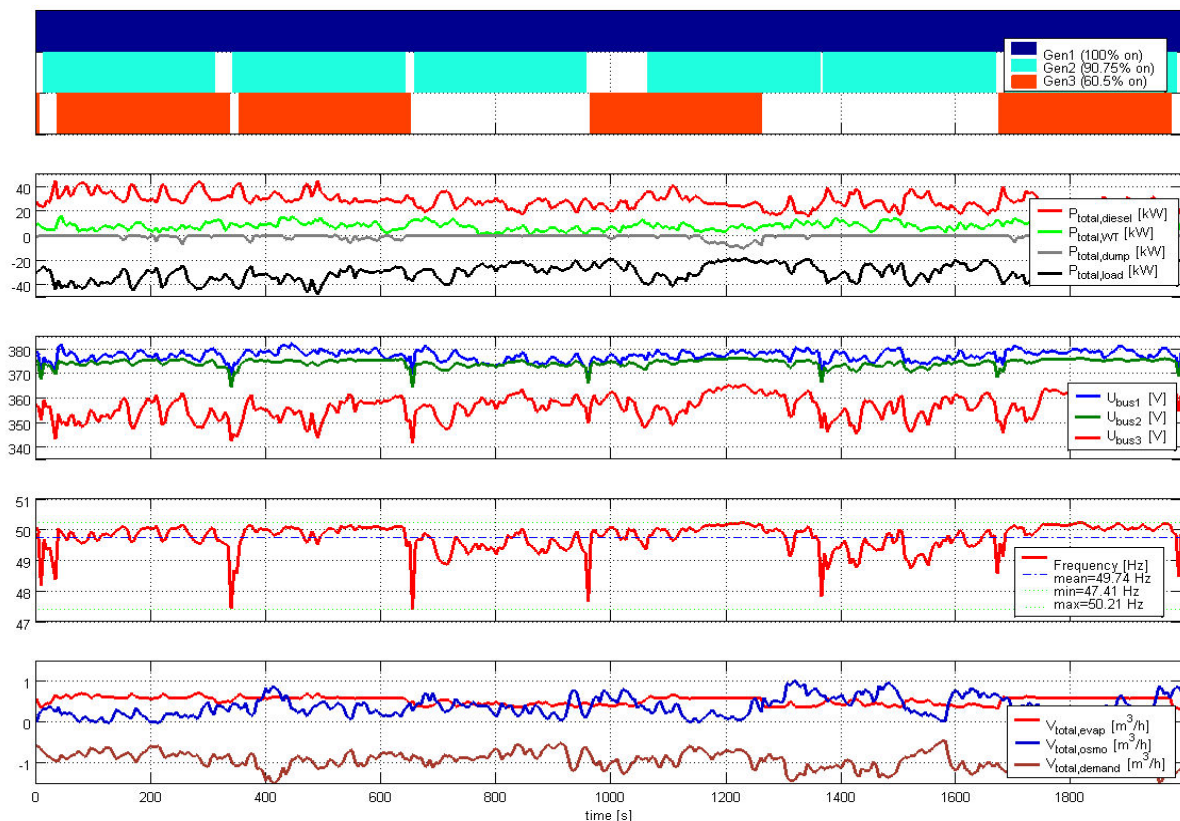
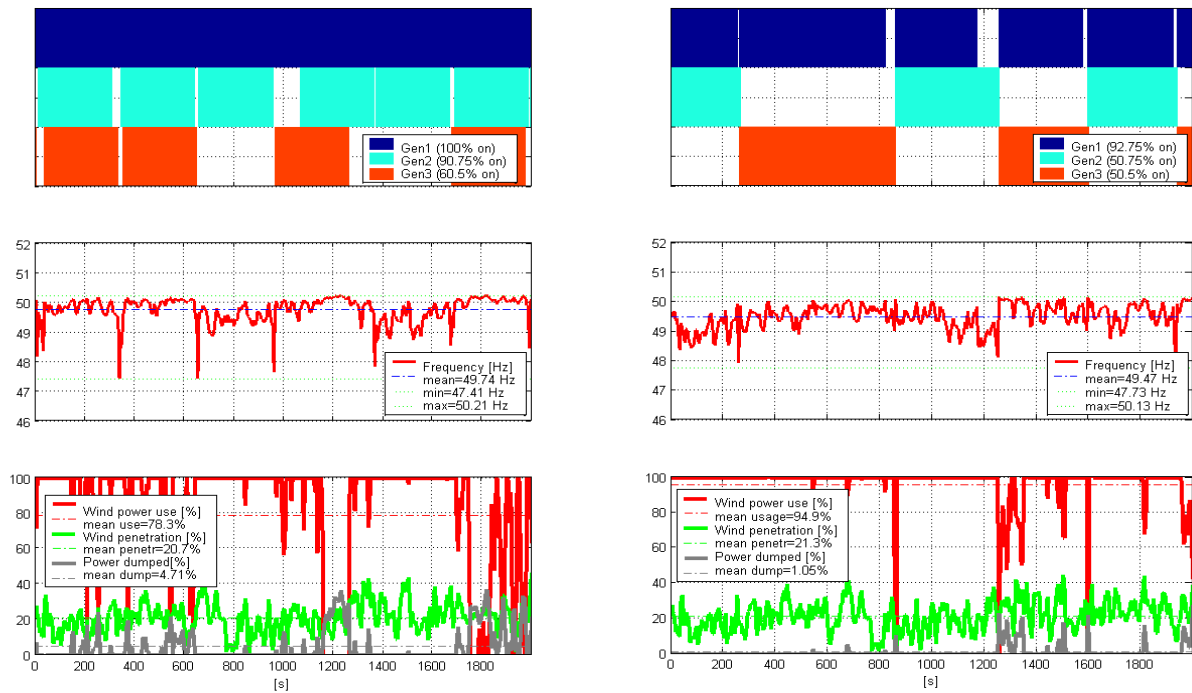


Figure 2: Selected simulation results. From top to bottom: Running state of diesel generators - active power data - busbar voltages - system frequency - freshwater demand and production

units to a time-variable water consumer.

The thermal and freshwater circuits operate on a policy that attempt to maximize the utilisation of waste heat from diesel gensets and dumpload: The cooler only dissipates excess heat which can not be used for desalination, and the heat-driven desalination unit gets priority over the electricity-driven (reverse osmosis)

## 4 Simulation examples



**Figure 3: Comparison of control strategies**

one. This establishes a weak feedback loop across the thermal, water and electrical domains, as a decrease in diesel loading will reduce the amount of heat available for desalination. To meet water demand, the throughput of the electric desalination unit will have to be raised, resulting in higher electricity demand and thus higher diesel loading.

Dispatching of the diesel generators is handled by a system controller – implemented in a controller module – which decides based on the average load factor of all gensets. If the factor falls below a preset threshold, one of the generators is being taken off-line. Similarly, an additional unit is started if the utilisation factor rises above another threshold. To prevent on/off-cycling, a minimum runtime constraint forces each genset to stay running for some time after having been started.

In order to compare results from different runs, all input state variables (wind speeds, active and reactive consumer load, water demand) receive their data from pre-generated time series instead of directly using one of the built-in time series generators. Result data from selected output variables is presented in Figure 2, gained from a run over 2000s of simulation time, at a time step size of 5s.

The control module is then being exchanged for another one with a different strategy, and the simulation is run again. Controller #2 attempts to estimate the amount of spinning reserve required to prevent generator overload during the next timestep. The instantaneous values of fluctuating input quantities – wind, consumer load, water demand – are summed up after a pre-set weighting scheme, to get an upper boundary for the expected load increase during one timestep. The generators are scheduled so that the sum of present load and expected load increase are within

the cumulative rated capacity of all units on-line. The same minimum runtime policy is used as before.

A comparison of both simulation runs is shown in Figure 3. Control strategy two (on the right) seems to have a better fuel efficiency, as can be seen from the increased use of available wind power, the smaller amount of energy consumed in the dump load, and shorter runtimes for each of the three diesel gensets. Fuel consumption data for each run is directly available from the simulation output (although not shown in the figure) and indeed reveals an efficiency advantage of about 10%.

Furthermore, control strategy one appears to result in inferior power quality, since large frequency spikes are visible in the left graph.

## 5 Verification of simulations of an island system

Verification of simulation models is important in order to establish the accuracy of the simulation results and the limits of validity of the model.

The IPSYS system simulation model is verified in two ways. The first way is the load flow part of the package. The second is the system performance in terms of fuel consumption and wind energy utilisation. The verification is based on comparison of simulation results from different software packages.

The system under study is a medium sized wind diesel system. It has one power station and existing wind farm. A further extension of the wind power capacity is included in the simulations. The system modelled includes a network with both consumer nodes and transmission nodes. The network is radial.

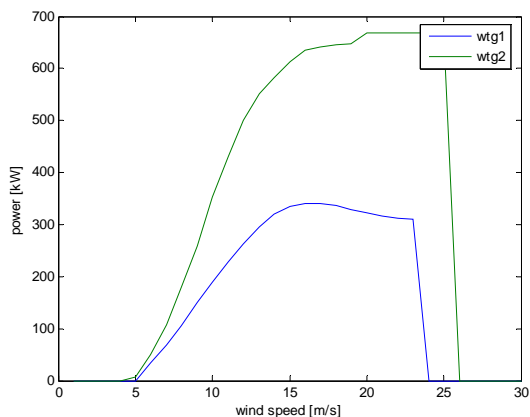
The power station has several diesel gensets installed, however, the load can be covered by two relatively newly installed gensets. These two identical

gensets are effectively the only ones being used in the verification cases. Their main data are in Table 1. The system is operated isochronously and the diesel gensets shares the load equally with respect to their rated power when operated in parallel. The gensets are operated with respect to their technical minimum load value.

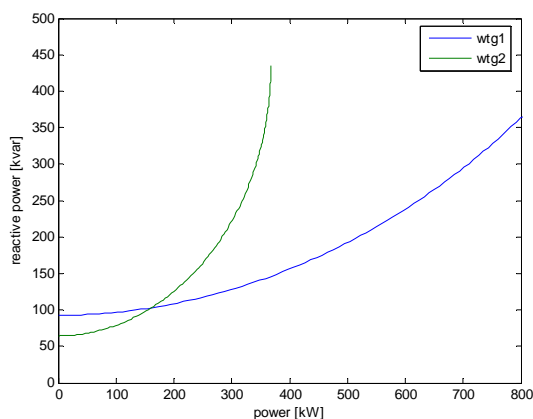
**Table 1 Diesel genset main data**

Parameter	Value	Comment
Rated capacity	4650 kVA	
Rated power	3720kW	@ cos phi=0.8
Tech. Min. load	25%	of full load
Full load efficiency	42%	of heart value
No load fuel cons.	37kg/h	

There is another 6500kVA installed in the system, but with the current load pattern they are operated except during planned and unplanned outages. All the generators are connected to the same bus bar.



**Figure 4 Wind turbine power curves**



**Figure 5 Wind turbine reactive vs. active power curves**

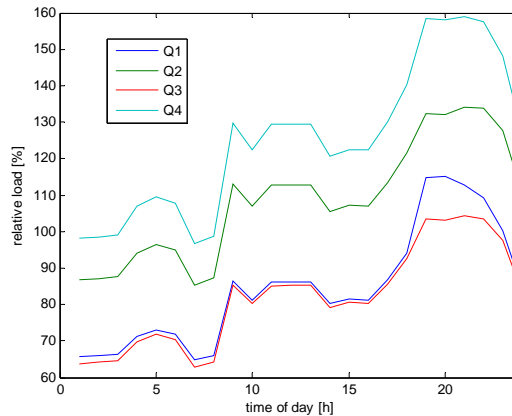
In the cases studied the installed wind turbine capacity is 1800kW (2\*600kW+2\*300kW). The wind turbines are compensated for their no-load reactive power consumption. They are characterised by their power curve and PQ-curve (reactive vs. active power).

They are connected to one bus bar, which is connected to the main generation bus bar. All the wind input is transmitted to the system. If the operational constraints of the diesel gensets are violated excess wind power is dissipated.

The network consists of 121 bus bars with 52 loads, which are connected to the network through a transformer. The network is radial, in that all loops are open. There are four voltage levels in the network. They are, however, transformed to the same voltage level in the model. The geographical extent of the network is relatively small the longest lines are approx. 15km. Several lines are in the 5km range, but the majority of the lines are below 1km. The wind turbines are situated 1.5km from the power station.

The loads of the system also covers a wide range. There is one large load a 1MW, one at 0.5MW and several in the 0.3-0.2MW range as well as a number of small loads in the range 0.1MW and below. The load profiles of the system are in Figure 6. The minimum load of the system is slightly less than 2MW and the maximum load is above 4.2MW.

The system operation is studied using two operating strategies. The first is a n-1. In this case it means that both the diesel gensets will be online all the time. Another operating strategy is more economical, but has a lower level of security of supply i.e. it allows operation of the system with only one diesel running. Technical minimum load and maximum load of the gensets are respected in the simulation.



**Figure 6 Network load profiles for each quarter – relative to the total average load**

The initial verification of the model is the load flow. The power system is modelled in the IPSYS and in DIGSILENT Powerfactory, [8]. The load flow is calculated in two cases high and low load with high wind power input. The voltages in the different nodes of the network are then compared.

For the performance verification load and wind speed time series are constructed based on the input to the model the results are compared to, WINSYS. This means that complete year time series are constructed for the 52 loads based on the quarterly load profiles and that four wind speed time series are generated based on the Weibull distributions.

The performance is then simulated for a year and the fuel consumption and wind energy production and utilisation are compared for the two models. The two different operating strategies are also simulated.

## 6 Conclusion

A new simulation tool for autonomous hybrid systems has been presented, which includes water production, bus bar voltages and exchangeable controllers in the analysis of a system.

Results of an initial verification of the simulation tool are presented.

Future work on the tool involves further validation, which is an ongoing activity, extension of the controller modelling to include a hierarchy of controllers as well as more components. A graphical user interface will also be developed to enable users outside the research community to use the tool.

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