

IPSYS – A tool for performance assessment and supervisory controller development of integrated power systems with distributed renewable energy

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Abstract

Autonomous power systems for villages and regions exploiting local renewable energy sources has a large potential with many sites throughout the world where such systems will provide energy at lower costs than conventional diesel-only systems. The system configurations of these systems will often be complex due to the mix of generation and desire to optimise the utilisation of the renewable energy potential. It involves the control of systems with large amounts intermittent power production, interaction with conventional types of generation and often also control of the consumption and energy storage.

During the feasibility, design and evaluation phases of projects that implement such systems it is essential to be able to reliably assess the technical performance of the system. The simulation package, IPSYS, has been developed as tool for analysing such systems. The emphasis has been the ability to calculate the performance in terms of e.g. fuel consumption as well as the active and reactive power flows and grid voltage levels. IPSYS also includes modelling of thermal systems that can have waste heat as input and thermal desalination units as output and a freshwater balance where the freshwater is produced by the thermal units or by electrical driven units to meet a certain demand.

Another key feature of IPSYS is the modelling of the supervisory control of the complete system. IPSYS allows for very flexible modelling of the supervisory system controller. IPSYS has been developed to allow time steps down to few seconds in order to allow accurate modelling of the control of the system. The component models can also supply many signals that the controllers can access and new components or modification of existing components are easily included in the package. This is combined with the feature that change of controller modules is done in the setup files. This means that the package does not need to be recompiled in order to include new controllers.

The paper will present a simple case illustrating the main features of IPSYS (multi bus bars, multi domains, multi controllers). It will further show results from a large simulation case that is currently being used to investigate and compare the performance of IPSYS with other simulation packages.

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 (Troen, 1988), 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.

The paper will first present the rationale of the new simulation package, IPSYS, in relation to existing packages. It will then proceed describe the main features of IPSYS by the use of a small simulation example. The final section will present a large simulation example and a comparison with an existing simulation package.

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, (Hansen, 2000). 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, (Infield et al, 1994). 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, (Delgado, 1995). 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, (Baring-Gould, et al, 1996), and Homer, (Homer, 2004). 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 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, (Pereira, 2000), 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.

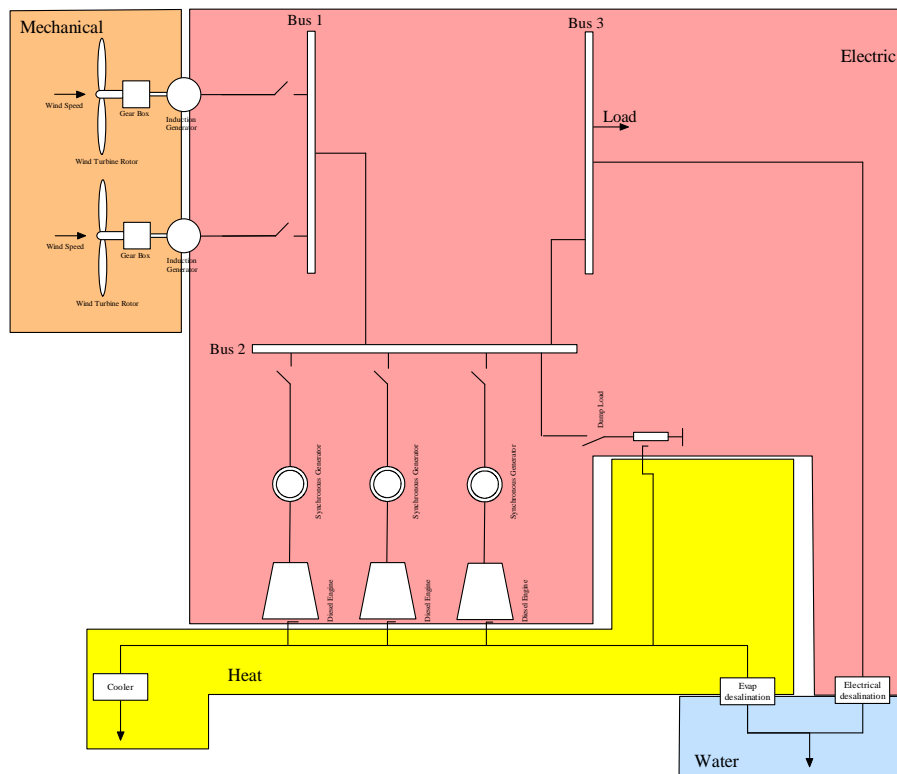


Figure 1 Scenario

3. IPSYS – MAIN FEATURES

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.

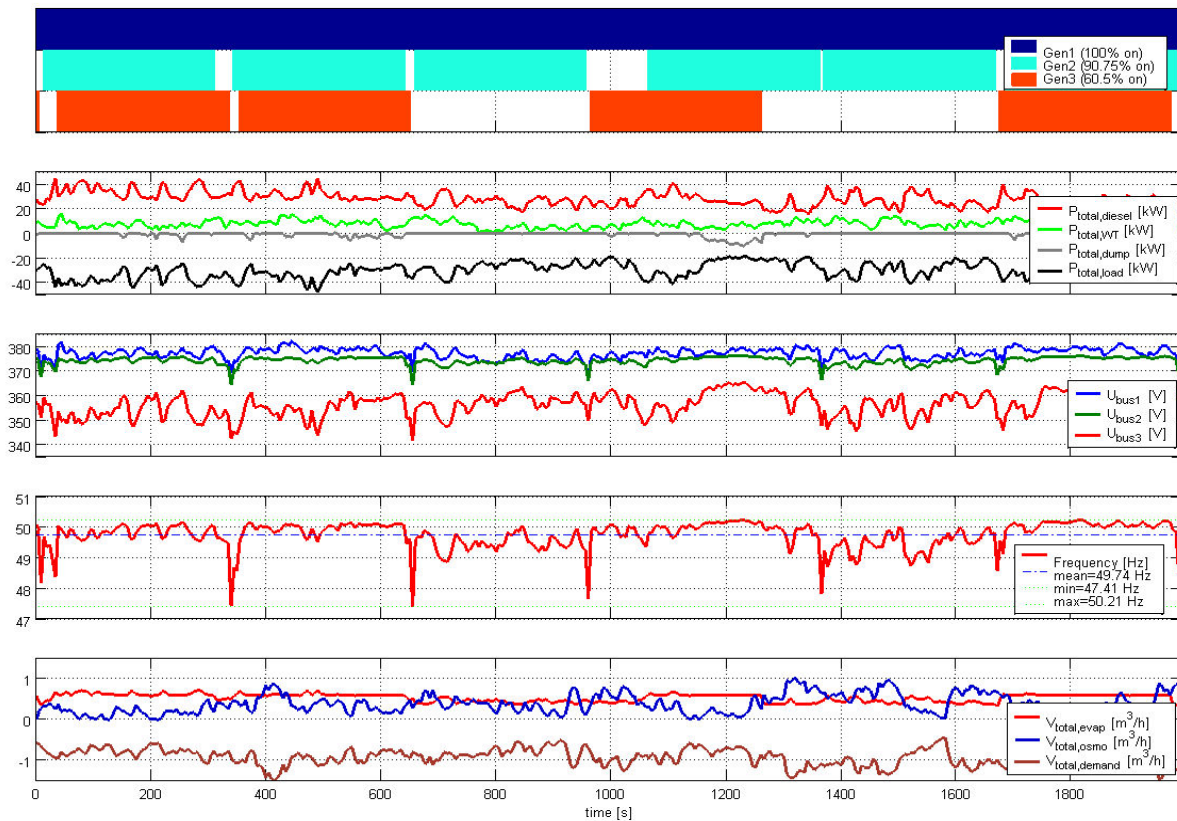


Figure 2: Selected simulation results. From top to bottom: Running state of diesel generators - active power data - busbar voltages - system frequency - freshwater demand and production

4. SMALL SIMULATION EXAMPLE

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 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) 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

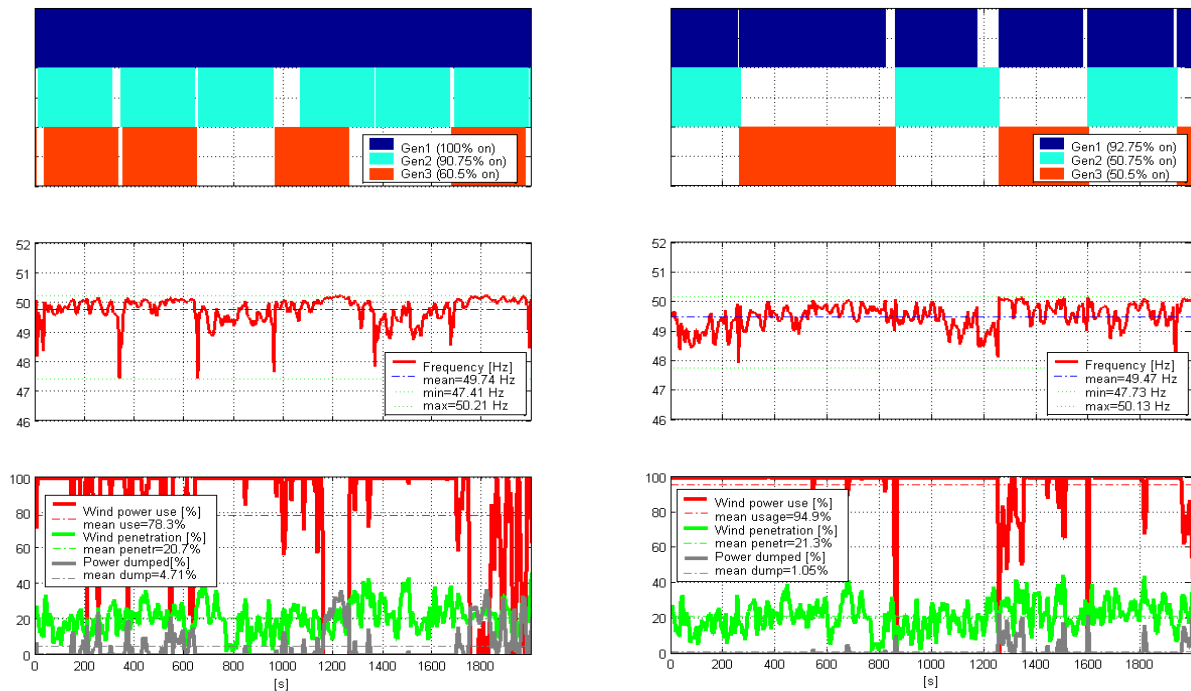


Figure 3: Comparison of control strategies

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. COMPARISON OF IPSYS TO OTHER SIMULATION PACKAGES USING A LARGE ISLAND SYSTEM AS EXAMPLE

Verification of simulation models is important in order to establish the accuracy of the simulation results and the limits of validity of the model. Initially, the IPSYS system simulation model is compared to an existing system simulation model, WINSYS, (Delgado, 1996), developed previously at Risø.

WINSYS uses a different simulation concept. It divides the year into four quarters. The load and wind input is specified for each quarter. For each hour of a weekday and a weekend day the load is specified as well as the

Weibull distribution of the wind. The load is assumed constant within the hour whereas the wind power input is calculated for each 1m/s wind speed bin and used in the simulation and the result is then weighted with the probability of that wind speed occurring based on the Weibull distribution for that hour. The dispatch strategy of the system calculates the required diesel capacity based on a minimum required diesel capacity and effectively two parameters: a load margin (percentage of rated capacity), wind margin (percentage of installed capacity). From the ranked list of diesel gensets, gensets are chosen to be online until the spinning capacity exceeds sum of the load and the wind margin multiplied with the installed wind capacity subtracted the wind power production.

The system under study is a large wind diesel system. It has one power station and wind farm. 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, only four of them are included in the simulation. Their main data are in Table 1. The system is operated isochronously (modelled as a very small droop, 0.2%) and the diesel gensets shares the load equally with respect to their rated power when operated in parallel (they all operate on the same relative droop curve). The gensets are operated with respect to their technical minimum load value. All the generators are connected to the same bus bar.

Table 1 Diesel genset main data

Parameter	Genset 1,2	Genset 3,4
Rated capacity [kVA]	3125	4650
Rated power@ cos phi=0.8 [kW]	2500	3720
Tech. Min. load [% of full load]	25	25
Full load efficiency [% of heat value]	42	42
No load fuel cons. [kg/h]	25	37

In the case presented here, 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, Figure 4, and PQ-curve (reactive vs. active power), Figure 5. They are connected to one bus bar, which is connected to the main generation bus bar via a cable connection. All the wind input is transmitted to the system. If the operational constraints of the diesel gensets are violated excess wind power is dissipated (this does not occur in the year simulated).

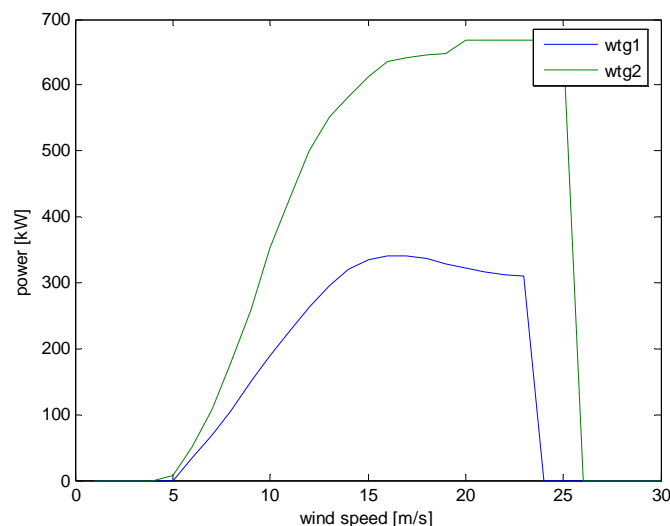


Figure 4 Wind turbine power curves

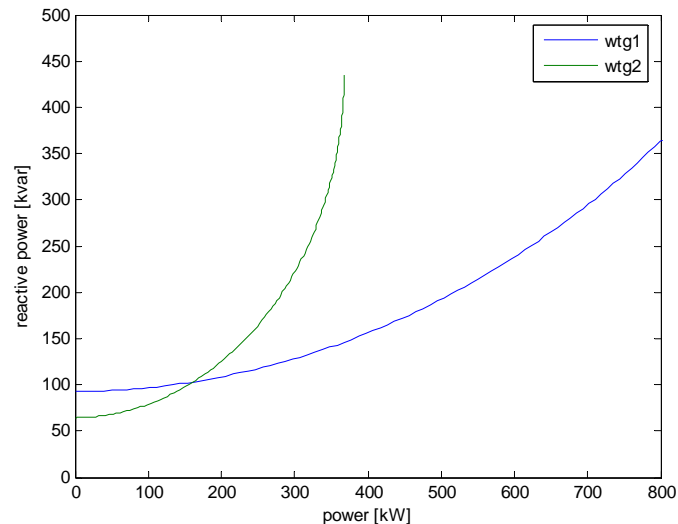


Figure 5 Wind turbine reactive vs. active power curves

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 wind input is synthesized. This is done by using the Weibull distributions specified in the WINSYS input, one for each hour of the day for each quarter of the year, as input to a function that creates a time series also taking the correlation into consideration. Two time series are synthesized with 1 hour time steps, one for each type of wind turbine. They are then applied to the wind turbines (one of the time series for each wind turbine type is time shifted). The wind time series are modified to have the same mean as in the WINSYS model. The wind input to IPSYS then gives the same production of wind energy as WINSYS.

The loads of the system cover a wide range. There is one large load of 1MW, one of 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 more than 3.2MW and the maximum load is above 7.4MW. The total load of the system is 42340MWh/y. The time series values are generated based on the quarterly load profiles, Figure 6. The reactive power load time series are constructed in a similar way. The power factor is taken from the static load flow analysis data.

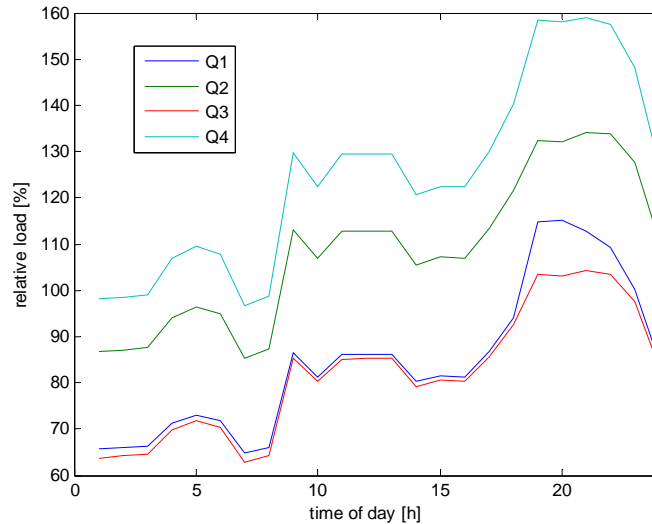


Figure 6 Network load profiles for each quarter – relative to the total average load

The performance of the system is simulated for one year. As described above the wind input has been modified in order to make the energy content equivalent for the two models. The main figure of comparison is the fuel consumption. Since the wind energy content of the two simulations is the same the main differences between the models are the modelling concept, time series vs. (semi-)statistical, and the derived differences in dispatch strategy and dependence on the actual instance of the time series used in the time series simulation of IPSYS.

Initially are shown some time series results of the IPSYS simulation. The active power production and consumption time series are in Figure 7. The figure clearly illustrates the four levels of the load depending on quarters of the year. It is also notice how the gensets 3&4 act as base load units and genset 1 as peak load unit.

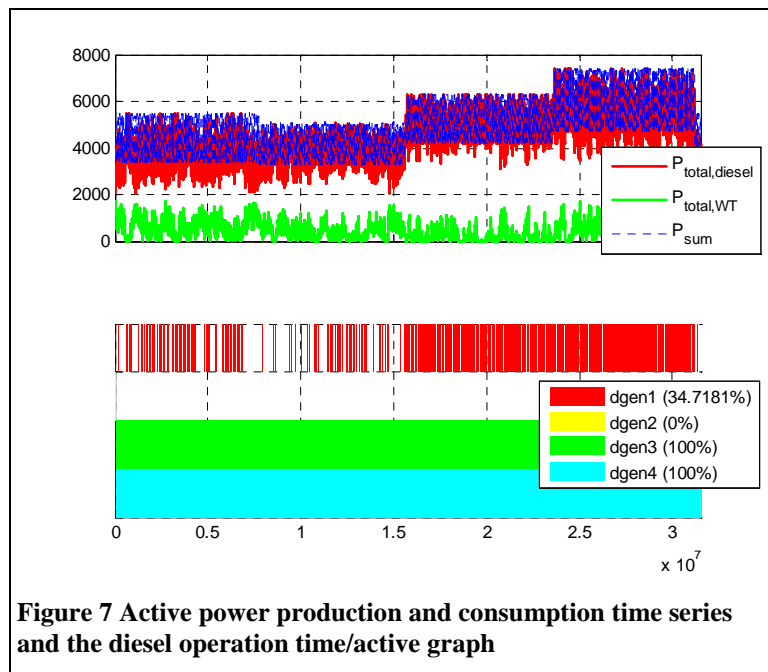


Figure 7 Active power production and consumption time series and the diesel operation time/active graph

Table 2 Comparison of aggregated results from IPSYS and WINSYS

	WINSYS	IPSYS	Deviation [%]
Wind energy production	4295	4258	-0.9
Load	41409	42340	+2.2
Diesel load	37075	38082	+2.7
Fuel consumption	7634	7786	+2.0
Diesel op. time	21511	20580	-4.3

The aggregated results of the simulations are collected in the table, Table 2. The results are generally close to each other. The most significant thing to notice is that the operation time of the diesel gensets are lower in the IPSYS simulation even though the load is slightly higher than in the WINSYS simulation. The deviation in the load can be attributed to constructing the load from 52 time series, especially since there many free parameters when time series are constructed from statistical data. The reason for the higher deviation of the load of the diesel gensets compared to the load is that the diesel genset load includes the losses in the grid. The deviation of the diesel operation time can originate from both the statistical vs. time series modelling as well as the IPSYS time steps of 5min, which can result in changes in the diesel dispatch.

In general can it be concluded that the performance of IPSYS and WINSYS is very similar. Further studies of the implications of the deviations that originate from comparing two different modelling concepts are needed. This involves especially time series synthesis and dispatch. However, the deviations are small between the models, which indicates that IPSYS is already applicable for project use.

6. CONCLUSION

A new simulation tool for autonomous hybrid systems, IPSYS, has been presented, which includes water production, explicit modelling of both active and reactive power, bus bar voltages and exchangeable controllers in the analysis of a system. The model is capable of handling the interactions between the different domains coming from the interdependencies of the domains through components as well as through the controller.

Results of an initial comparison of IPSYS to an existing the simulation tool, WINSYS, are presented. It shows good agreement between the two models even though the models differ significantly in their modelling approach, IPSYS being a time series model and WINSYS being a semi-statistical model.

Future work on the tool involves further validation, which is an ongoing activity. An important extension of the model is to include an advanced model of lead acid batteries including lifetime prediction. A major focus currently is the extension of the controller modelling to include a hierarchy of controllers to enable easier modelling of complex systems. A graphical user interface is also current under development to enable users outside the research community to use the tool.

7. REFERENCES

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