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A DECISION SUPPORT SYSTEM FOR DESIGN AND ASSESSMENT OF HYBRID SYSTEMS FOR COGENERATION OF ELECTRICITY AND WATER

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ABSTRACT

A decision support system (OPEN-GAIN DSS) for the design, assessment and implementation of a hybrid energy system is presented. The DSS integrates a number of operational actions that can be accessed to answer all the questions raised during the phases of the decision making process and to assist in making reasonable decisions. A suite of design and modeling tools have been developed and adopted into the DSS environment in order to implement the logic of the DSS actions. The design of the hybrid system is based on a simplified algorithm with minimum data requirements, while the performance assessment of the system is accomplished with the aid of a time-series simulation model. A Monte-Carlo approach has been adopted to quantify the underlying risk and the evaluation action is based on a Multi-Criteria Analysis framework. The operation of the DSS is demonstrated through a case study concerning a medium-size prototype unit in Tunisia.

Keywords: renewable energy sources, hybrid energy system, decision support system

1. INTRODUCTION

The cogeneration of electricity and water through desalination by exploitation of renewable energy sources (RES) is becoming an increasingly promising option, especially in arid and remote areas, where alternative energy supply is either unavailable or too costly to develop (Mathioulakis, Belessiotis, and Delyannis 2007). Various aspects should be taken into account when designing a stand-alone energy production system. The energy sector in Europe is expected to be influenced by two factors: the need to meet Kyoto commitments and the issue of energy supply security (Hemmes, Zaharian-Wolf, Geidl and Anderson 2007). In view of this, the sustainability of the energy supply system must be assessed on the basis of its environmental impacts as well as the need to assure that the system has the capacity to meet the requirements set by the consumers. Renewable energy resources, such as solar and wind power, are inexhaustible and environmentally friendly potential energy options. However, neither a standalone solar nor a wind energy system can provide a continuous supply of energy, due to daily and seasonal variations (Elhadidy and Shaahid 2000). In order to satisfy the load demand, hybrid energy systems are implemented that combine solar and wind energy conversion units with conventional diesel generators and energy storage systems.

The design, assessment and optimization of such a hybrid energy system would require an overall system engineering approach. System analysis emphasizes a holistic approach to problem solving and the use of mathematical models to solve important characteristics of complex systems, which can be further integrated into a Decision Support System (DSS) to address the problem of decision making in a generic way.

Several research groups have presented methods for designing renewable and hybrid energy systems (Bernal-Agustin and Dufo-Lopez 2009). These methods range from simplified algorithms (Siegel, Klein, and Beckman 1981; Celik 2006; Kartalidis, Arampatzis and Assimacopoulos 2008), based on monthly average values of renewable energy potential (solar radiation and wind speed), to more sophisticated time series simulation models (Ekren and Ekren 2009), requiring detailed meteorological and energy demand measurements. Experience has shown that simplified algorithms are best suited to the preliminary design (sizing) of the hybrid system's components while simulation methods are more useful in assessing the performance of the system under realistic operational conditions and various management rules.

Numerous papers have been published on the optimum economic design of PV and/or wind and/or diesel systems with energy storage, such as batteries. Usually, the optimum configuration is selected for minimizing the total cost of the entire system or the levelized cost of energy i.e. total cost divided by the energy supplied by the system (Elhadidy amd Shaahid 2000; Dufo-Lopez, and Bernal-Agustin 2005). However, decision making in real hybrid energy systems is complex, principally due to the inherent existence of trade-offs between economic, environmental and social factors. For the sustainability assessment of a hybrid system, appropriate indicators have been proposed (Afgan and Carvalho 2008) and the use of multi-criteria evaluation methods is essential, in order to account for the combined effects of all criteria under consideration.

Available software tools to support system designers have the form of specialized hybrid system simulation models, which can be used to evaluate the performance of a system, and generic optimization or multi-criteria assessment applications. There is thus far no integrated decision support system capable of answering all the questions raised during the phases of the decision making process (from the preliminary design to the selection of the most efficient configuration) and helping in making reasonable decisions. The DSS presented in this paper was designed to provide guidance in framing the problem in an integrated way, to assist system designers in making decisions by answering all the questions raised and to help selecting the optimal hybrid system configuration.

The different components of a hybrid energy system for cogeneration of water and electricity and their roles are introduced in section 2. Section 3 presents the conceptual design of the DSS, outlining the role of the DSS actions in the phases of the decision making process. The architectural design of the DSS is presented in section 4, while the functional capabilities of the DSS are demonstrated in section 5.

2. HYBRID ENERGY SYSTEM CONFIGURATION

A hybrid energy system produces power from more than one generating source such as wind-driven turbines, solar panels and conventional diesel engines. The system stores excess power in battery storage units. Such a system should be tailored to the specific energy resources available at the specific site and to meet the power generation needs. A configuration representative of this system is presented in Figure 1.

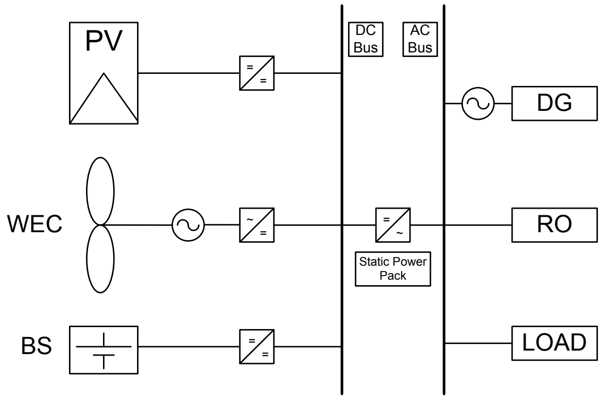


Figure 1: General configuration of the hybrid energy system

The main parts of the system are: the Wind Energy Conversion system (WEC); the Photovoltaic system (PV); the Diesel Generator (DG); the Battery Storage system (BS); the Reverse Osmosis plant (RO); and other power loads (LOAD), if the system is designed to supply energy to additional units at the installation area.

3. CONCEPTUAL DESIGN OF THE DSS

Decision making is the study of identifying and choosing alternatives based on the values of evaluation criteria and on the preferences of the decision maker(s). Making a decision implies that there are alternative choices to be considered, and in such a case it is necessary to identify as many of these alternatives as possible and to select the alternative with the highest probability of success or effectiveness and that best fits with the goals. Decision making is also the process of sufficiently reducing uncertainty and doubt about alternatives to allow a reasonable choice to be made among these. Table 1 presents the phases during a typical decision making process and summarizes the questions that is expected to be answered.

Table 1: Phases in the decision making process

Phase	**Questions**
Feasibility Analysis	- Is it possible to satisfy power and water requirements of a remote area with a RES powered desalination system?
Preliminary Design	- Which are the alternative configurations of the hybrid energy system? - What is the size of each energy component?
System Assessment	- How does each configuration perform under realistic conditions? - What is the investment cost? - What is the operational cost during the life cycle of the project? - What are the environmental costs/benefits?
Screening and Refinement	- Does the configuration satisfy the water and power requirements of the area? - Does the configuration efficiently exploit the RES Potential of the area? - How sensitive are the expected outputs to changes in the component sizes or other input parameters? - Are there dominated configurations?
Risk Assessment	- How do uncertain conditions influence the system performance? - Which are the extreme scenarios and their consequences? - What is the risk of system “failures”?
Evaluation	- Which are the preferences of stakeholders? - Which features and performance indicators are important?
Selection	- Which is the optimal configuration?

The design specification of the DSS is to support the user through the decision making phases of Table 1. This is accomplished through six operational Actions.

The role of each DSS action in the decision making process is depicted in Figure 2.

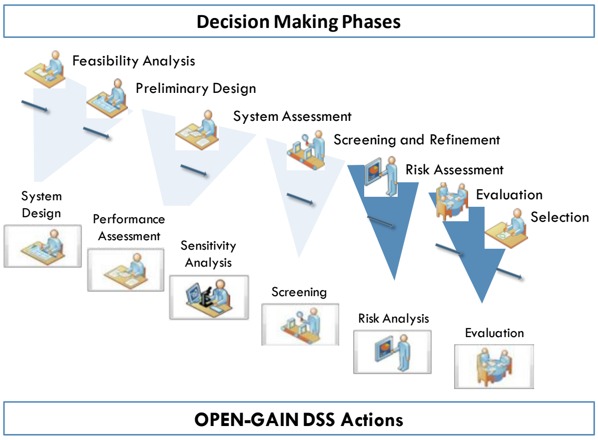


Figure 2: Relation between decision making phases and DSS actions

The six DSS actions are:

System Design Action. The aim of this action is to identify the set of alternative system configurations that satisfy the water and energy requirements of the examined region. The output of this action is a list of alternative configurations, distinguished by the sizes of the various system components and energy management rules.

Performance Assessment Action. The purpose of this action is to assess the performance of each alternative configuration, based on detailed meteorological and demand data. This is accomplished through a time series simulation of the system, producing detailed results on the energy flows, and information on the status of the components and the failures of the system. These results are used to compute the values of a set of performance indicators (presented in Table 2) which is the main output of this action.

Sensitivity Analysis Action. This action serves to examine the importance of each parameter on the performance of each alternative configuration. The information gained by performing this action may guide the user to proceed to minor or major revisions of the system.

Screening Action. This action can be used to highlight the trade-offs that must be made by the decision maker/s and to identify the configurations that do not appear to warrant further attention. The main output is the elimination of dominated configurations from the evaluation step. Dropping dominated configurations is logical because a valid evaluation methodology (like Multi-Criteria Analysis) will never choose a dominated alternative.

Risk Analysis Action. The purpose of this action is to quantify the risk that arises due to the uncertainty associated with the parameters used as input to the assessment step. This is accomplished through a Monte-Carlo simulation. The output of the action is a number of risk indicators, so that risk can be traded off against other indicators when evaluating the alternative configurations.

Evaluation Action. This is the final action on the DSS workflow and serves to evaluate the list of alternative configurations on the basis of the indicators produced in the “Performance Assessment” and “Risk Analysis” actions. The methodology used in this action is a multi criteria analysis using the preferences of the decision maker/s on the importance of the evaluation criteria (indicators). The output of this action is a ranking of the alternative configurations and their overall scores (values).

Table 2: Performance indicators

No	Indicator/Description
1	*Energy Delivered / Energy Demand* Describes the energy balance of the system. For the system to be operating without problems, the indicator should be equal to “1”.
2	*Renewable Energy Delivered / Energy Demand* Describes the contribution of the renewable energy to the energy balance of the system. Higher values are preferable, as they indicate high use of RES to meet energy demands.
3	*Renewable Energy Delivered / Energy Collected* Higher values are preferable, indicating maximum exploitation of the WEC and the PV systems to meet energy demands.
4	*Diesel Engine Operation Time (%)* Lower values are preferred as they indicate limited usage of the diesel engine to meet energy demands.
5	*Daily Average Diesel Engine Cycles* Describes the frequency of the use of the diesel engine. Lower values are preferable.
6	*Energy Delivered by the Battery / Demand* The ratio of the energy delivered by the battery to the energy demand for the simulation period.
7	*Battery Time below Critical Depth of Discharge* The percentage of the time that the battery charge level is below a critical threshold. Lower values are preferable.
8	*Capital Cost* The total purchase cost of the system, calculated as the sum of the cost of its components. Lower values are preferable.
9	*Diesel Consumption Cost* The annual cost fuel consumed by the diesel engine. Lower values are preferable.
10	*Green House Gases Emissions* The annual amount of CO_2 released due to diesel engine use. Lower values are preferable, indicating smaller environmental impact.
11	*RO Unit Stable Operation* The ratio of the total time that energy production is not adequate to meet the energy requirements of the RO unit vs. the duration of the simulation period. The indicator should be equal to “1” to ensure that the RO unit is operating without problems.

4. ARCHITECTURE OF THE OPEN-GAIN DSS

The OPEN-GAIN DSS is a software tool, designed to support the decision making process presented in previous section. The software was developed in Microsoft Visual Basic .NET and the database in Microsoft Access. Figure 3 presents the different parts of the tool, and the way they are integrated to provide the decision support functionalities.

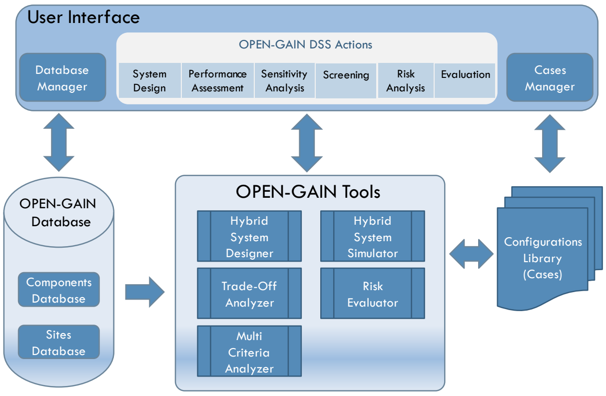


Figure 3: OPEN-GAIN DSS Architecture

4.1. User Interface

The User Interface is the part of the software that the user sees and interacts with the DSS software. The different parts of the User Interface allow the user to:

- Perform the DSS Actions presented in section 3 and to view the results of those actions.
- Manage the OPEN-GAIN Database through the Database Manager.
- Manage the library of alternative system configurations (cases), produced and assessed by the DSS actions, through the Cases Manager.

4.2. Database and Configuration Library

The OPEN-GAIN Database is the central repository for data and findings of the project. It consists of two parts:

- The Components Database contains all the available equipment in the market for the power subsystem in order to adopt the optimum equipment. This equipment consists of wind generators, photovoltaic modules, batteries, diesel engines and power electronics. The components are registered in the database with their operational, economic and environmental characteristics.
- The Sites Database mainly contains meteorological data for the Renewable Energy sources (wind and solar availability). Other data concerning the sites are the quality of the sea and brackish water and demand profiles for potable/desalinated water and electricity.

The Configurations Library is a storage area for the alternative system configurations generated, assessed and evaluated with the aid of the OPEN-GAIN DSS.

4.3. OPEN-GAIN Tools

The heart of the system is the collection of OPEN-GAIN Tools. It's a suite of independent modeling tools, integrated and adopted into the OPEN-GAIN DSS environment in order to implement the logic of the DSS actions. The five tools are:

Hybrid System Designer. Sizes a hybrid energy system based on a minimum set of meteorological data and design parameters. The procedure that is used for the sizing of the installed RES components and their auxiliaries is based on specific goals and constraints. The design goals concern the maximization of RES exploitation, the minimization of the undelivered excess energy, the minimization of costs (capital and operating) and the minimization of environmental impacts. The operational constraints are the constraints and stable operation of the desalination plant. Detailed description of the design procedure can be found in Kartalidis, Arampatzis and Assimacopoulos 2008.

Hybrid System Simulator. Simulates the performance of the hybrid energy system, according to the design, based on detailed meteorological data (time-series) and operational strategies. A one hour time step is used throughout the simulation. The electrical load and the renewable resources are treated as constants within each time step. The mode of operation of the simulator is as follows: Under normal operating conditions (i.e. adequate solar radiation and/or wind speed), the WEC and PV feed the energy demand (RO plant and additional power LOAD). The excess energy (i.e. the energy above this demand) from WEC and PV is stored in the battery system until full storage capacity is reached. If the output from WEC and PV exceeds the load demand and the battery's state of charge is maximized, then excess energy is dumped (undelivered energy) or fed back into a utility grid, in case of grid-connected systems. The diesel generator is used to support the system in meeting the energy demand, when the WEC and PV systems fail to manage it and battery is depleted.

Trade-Off Analyzer. Performs trade-off display and dominance analysis on a set of options.

Risk Evaluator. Quantifies the risk of an option due to uncertainty about long-term future using Monte-Carlo simulation.

Multi Criteria Analyzer. Analyzes complex decision problems by evaluating alternative options on the basis of conflicting criteria following a Multi-Criteria Analysis framework.

Figure 4 depicts the role of OPEN-GAIN tools as building blocks for the implementation of DSS actions

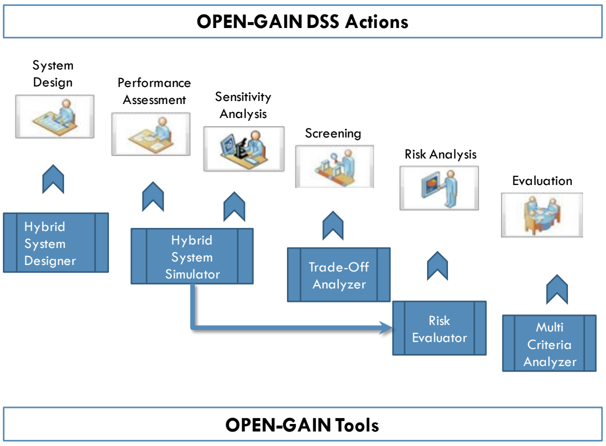
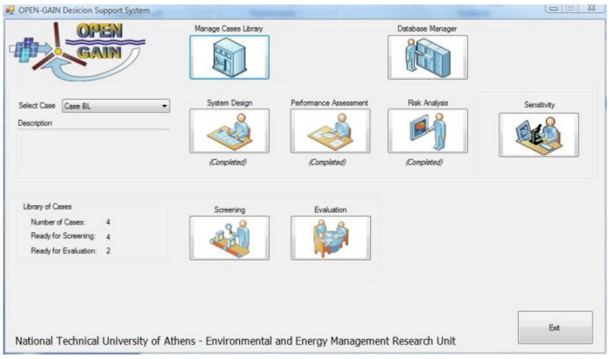


Figure 4: Relation between OPEN-GAIN Tools and DSS actions

5. OPERATIONAL ASPECTS

The operation of the OPEN-GAIN DSS is demonstrated in this section through a case study of the design and implementation of a pilot hybrid power plant. The prototype unit will be installed in the campus of the C.R.T.En research institute in a seaside location 25 km from Tunis, Tunisia. It is designed to meet the water and electricity needs of a small community situated in an arid area not connected to the electricity network. For meeting local water needs, the capacity of the desalination unit is set at 24 m^3/d. Further assumptions include the additional power needed to meet the external electricity load, estimated at 4 kW, and the quality of brackish water to be desalinated (TDS = 16,000 mg/l).

Figure 5 presents a screenshot of the DSS front-end. A friendly GUI allows the user to have access to the six DSS-Actions, either sequentially, during the decision making phases, or separately.



Select Case: Case BL

Description

(Completed)

(Completed)

(Completed)

Library of Cases

Number of Cases: 4

Ready for Screening: 4

Ready for Evaluation: 2

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Figure 5: OPEN-GAIN DSS Front-End

The system design action of the DSS has been described in Kartalidis, Arampatzis and Assimacopoulos 2008 and will not be elaborated here. The results from the performance assessment, sensitivity analysis and risk analysis actions refer to a single configuration (Tunis Pilot Plant). The installed power of the system components, as was proposed by the system design action, is presented in Table 3

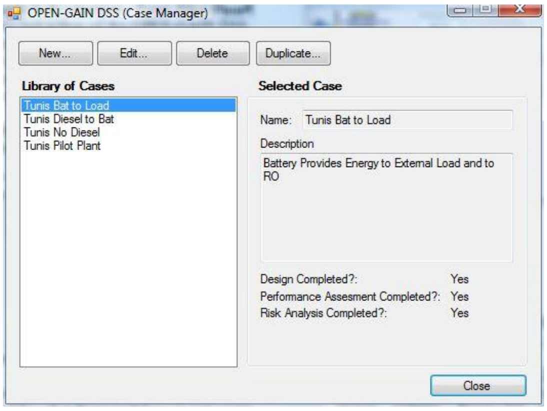
Table 3: Components sizes for case study

Component	**Model**	**Total Size**
PV Panel	Green Solar 185W	15 (kWp)
PV Inverter	Sunny Mini Central 5000	15 (kW)
WEC Turbine	Proven 15	15 (kW)
WEC Inverter	Windy Boy 6000A	18 (kW)
Diesel Engine	Perkins 404C 22-G	22 (kW)
Energy Manager	Sunny Island 5048	15 (kW)
Batteries	Sun Extender Concorde	40.32 (kWh)

The screening and evaluation actions are demonstrated by comparing the base case (Tunis Pilot Plant) to three alternative configurations:

- *Battery to Load*: Corresponds to the same component configuration as in the base case where the battery system can also be used to cover external electricity demand (by default, the battery system provides electricity only for meeting the RO unit energy requirements and not external load). This case is expected to increase the exploitation of the renewable energy through more intensive use of the battery.
- *Diesel to Battery*: Corresponds to the same component configuration as in the base case, where the diesel engine can be used to charge the battery system when the battery charge level falls below a critical point. This case is expected to decrease the period of time that the battery charge is below the critical level, thus increasing its lifetime.
- *No Diesel*: Corresponds to an alternative configuration to the power plant, where all components are of the same size, except for the diesel engine which is not included. This case is used to examine the role of the diesel engine in meeting the energy demand when the renewable components fail to manage it.

Figure 6 is a screenshot of the OPEN-GAIN DSS Cases Manager, which is used to manage the library of alternative system configurations, produced and assessed by the DSS actions.



Library of Cases

Tunis Bat to Load
Tunis Diesel to Bat
Tunis No Diesel
Tunis Pilot Plant

Selected Case

Name: Tunis Bat to Load

Description

Battery Provides Energy to External Load and to RO

Design Completed?: Yes

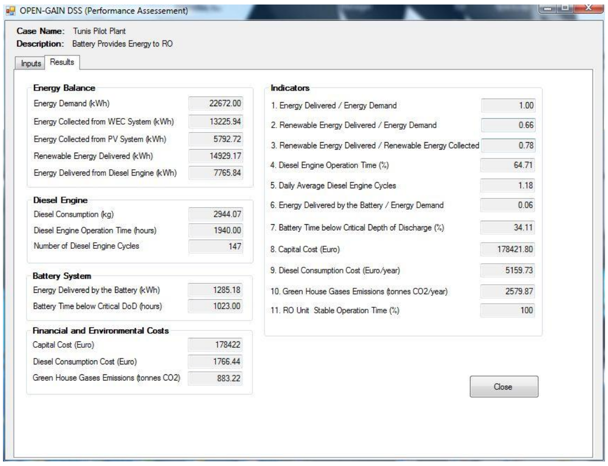
Performance Assesment Completed?: Yes

Risk Analysis Completed?: Yes

Figure 6: OPEN-GAIN DSS Cases Manager

5.1. Performance Assessment of Tunis Pilot Plant (Base Case)

The output of the performance assessment action, on the basis of 3,000 measured hourly meteorological data, is presented in Figure 7. The left column of the results page contains summary results for energy flows, diesel engine operation, battery status and financial and environmental cost. The right column presents the values of the eleven performance indicators, as described in Table 2. The main conclusions from the presented results are:



Case Name: Tunis Pilot Plant
Description: Battery Provides Energy to RO

Energy Balance	
Energy Demand (kWh)	22672.00
Energy Collected from WEC System (kWh)	13225.94
Energy Collected from PV System (kWh)	5792.72
Renewable Energy Delivered (kWh)	14929.17
Energy Delivered from Diesel Engine (kWh)	7765.84

Diesel Engine	
Diesel Consumption (kg)	2944.07
Diesel Engine Operation Time (hours)	1940.00
Number of Diesel Engine Cycles	147

Battery System	
Energy Delivered by the Battery (kWh)	1285.18
Battery Time below Critical DoD (hours)	1023.00

Financial and Environmental Costs	
Capital Cost (Euro)	178422
Diesel Consumption Cost (Euro)	1766.44
Green House Gases Emissions (tonnes CO2)	883.22

Indicators	
1. Energy Delivered / Energy Demand	1.00
2. Renewable Energy Delivered / Energy Demand	0.66
3. Renewable Energy Delivered / Renewable Energy Collected	0.78
4. Diesel Engine Operation Time (%)	64.71
5. Daily Average Diesel Engine Cycles	1.18
6. Energy Delivered by the Battery / Energy Demand	0.06
7. Battery Time below Critical Depth of Discharge (%)	34.11
8. Capital Cost (Euro)	178421.80
9. Diesel Consumption Cost (Euro/year)	5159.73
10. Green House Gases Emissions (tonnes CO2/year)	2579.87
11. RO Unit Stable Operation Time (%)	100

Figure 7: Performance assessment results

- The hybrid system is capable to provide all the power required for the operation of the RO unit as well as the additional power needed to meet the external electricity load (indicators 1 and 11).
- The share of renewable energy to the total energy supplied to the loads is 66% (indicator 2), while the remaining 34% of the energy required to match the loads is supplied by the diesel generator. This results in extensive use of the diesel generator (indicator 4) as well as frequent start/stop cycles (indicator 5) that contribute to wear-off of the diesel engine. The contribution of the renewable energy is expected to increase with increasing PV (or WEC) size. It is thus important to further investigate the influence of PV size on the performance of the system.
- The percentage of the renewable energy collected and delivered to the demand is 78% (Indicator 3). The remaining 22% is excess energy that needs to be dumped. This energy can be better exploited by installing a battery system with higher capacity (Indicator 6 values indicate that the battery system is under-used).
- The results can help the user to quantify the expected energy production, the annual fuel cost, the CO_2 emissions, the expected battery and diesel engine cycles, the installation cost etc.

5.2. Sensitivity analysis on the PV size

The influence of the installed PV size on different aspects of the system is illustrated in Figures 8 to 11. The charts presented in these figures have been produced using the sensitivity analysis action of the OPEN-GAIN DSS, where PV size ranges from 10 kWp to 20 kWp.

As illustrated in Figure 8, the contribution of the renewable energy to the energy balance increases with increasing PV size (from 61% to almost 69% when PV size changes from 10 to 20 kWp). However, as can been seen in Figure 9, the excess renewable energy that must be dumped also increases. This means that a larger battery system is required in order to better exploit the renewable energy potential of the area.

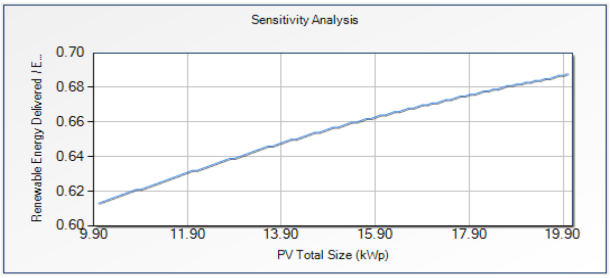


Figure 8: Influence of PV size on the ratio of renewable energy delivered to the total energy demand

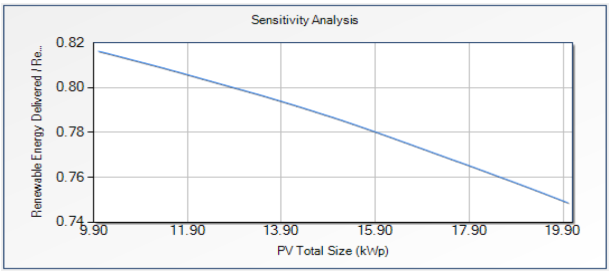


Figure 9: Influence of PV size on the ratio of renewable energy delivered to the renewable energy

The extensive use of PV system makes the diesel generator less important and the diesel consumption decreases with increasing PV size (Figure 10). However, more start/stop cycles of the diesel generator are required if PV size increases (Figure 11). This is due to the fact that the diesel generator is used to meet the shorter but more frequent peaks of the energy demand that is not met by the renewable energy components.

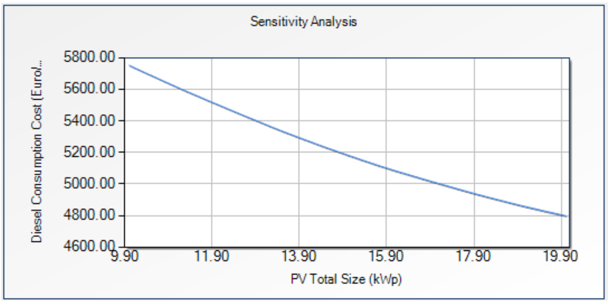


Figure 10: Influence of PV size on the diesel consumption cost

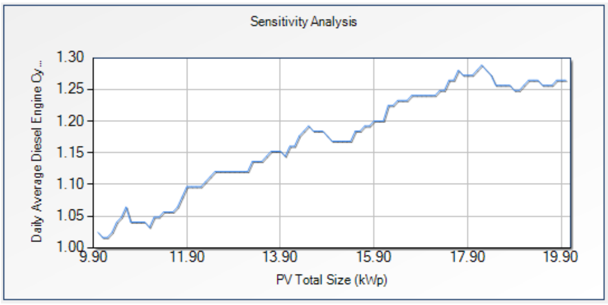


Figure 11: Influence of PV size on the daily average diesel engine cycles

5.3. Comparison of alternative cases

The use of the screening action of the OPEN-GAIN DSS is demonstrated by comparing the performance of the base case to the three alternative cases, all designed to meet the same energy requirements as the base case.

A comparison of the base case (Tunis Pilot Plant) and the battery to load case (Tunis Bat to Load), is presented in Figure 12. From the results presented in the Figure it is evident that:

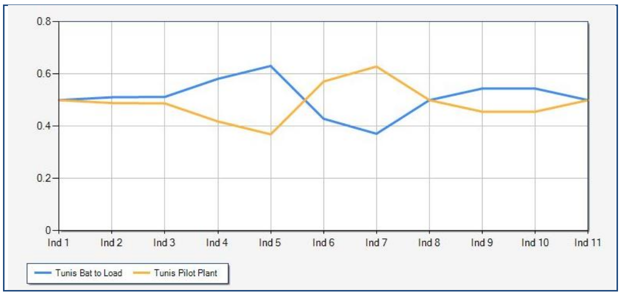


Figure 12: Comparison of base case and the battery to load case

- The "Battery to load" case performs significantly better in Indicators 4 (Diesel Engine Operation Time), 5 (Daily Average Diesel Engine Cycles), 9 (Diesel Consumption Cost) and 10 (Green House Gasses Emissions). The use of the battery system to cover the external load results in less intensive use of the diesel engine. For example, diesel consumption cost drops to 4,317 from 5,160 Euro/year in the base case while the daily diesel engine cycles drops to 0.69 from 1.18 in the base case.
- As expected, the "Battery to load" case also achieves higher exploitation of the renewable energy. The contribution of renewable energy to the energy balance (indicator 2) rises to 69% from 66% in the base case. The percentage of renewable energy collected and delivered to demand (indicator 3) also increases (from 78% to 82%).
- However, because of the intensive use of the battery, the "Battery to load" case performs lower in indicators 6 (Energy Delivered by the Battery / Energy Demand) and 7 (Battery Time Bellow Critical DoD).

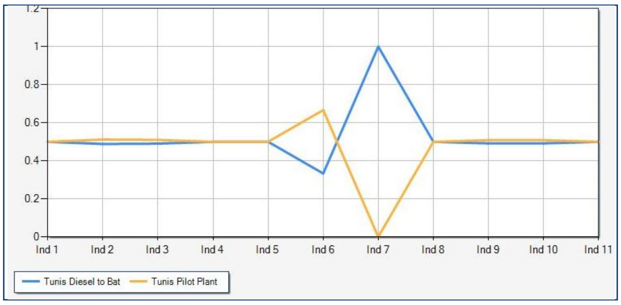


Figure 13: Comparison of base case and the engine to battery case

A comparison of the base case (Tunis Pilot Plant) and the engine to battery case (Tunis Diesel to Bat), is presented in Figure 13. The applied energy management rule significantly decreases the percentage of time that the battery is below the critical charge level (indicator 7). In fact, this percentage drops to 0%, from 34% in the base case. However, the use of the battery becomes more intensive (indicator 6), because part of the energy generated by the diesel engine must first be stored in the battery before it is delivered to the demand.

A comparison of the base case (Tunis Pilot Plant) and the case without a diesel engine (Tunis No Diesel) is presented in Figure 14. This is an extreme case that results in zero diesel consumption, also affecting the relevant indicators (indicator 4 - diesel engine operation time, indicator 5 – diesel engine cycles, indicator 9 – diesel consumption cost and indicator 10 – GHG emissions). However, the main drawback of the configuration is that it is unable to fully meet the energy demand (both the demand of RO unit and the external load). The ratio of the energy delivered to energy demand drops to 0.68 while the RO unit stable operation time is reduced to 87%. This means that 13% of the time, the produced energy is not sufficient to operate the RO unit. This percentage would decrease if the size of the renewable energy components is increased.

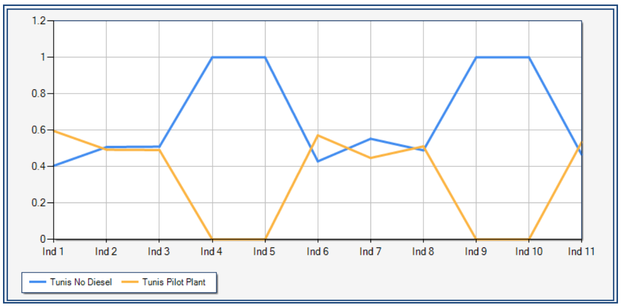


Figure 14: Comparison of base case and the case without a diesel engine

5.4. Sensitivity analysis of the No Diesel case

Figures 15 and 16 present the variation of the RO unit stable operation time with the size of the PV and battery system, respectively. It is obvious that, even when increasing the size of each component by 300%, fully stable operation of the RO unit (100%) is not achieved. The indictor reaches a maximum value of 96% when increasing the size of the PV system and rises almost linearly when increasing the battery size.

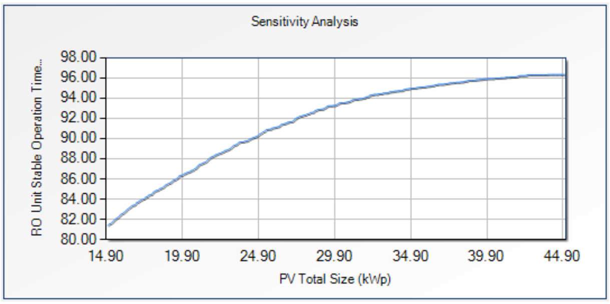


Figure 15: The RO unit stable operation time, as the PV total size rises from 15 kWp to 45 kWp

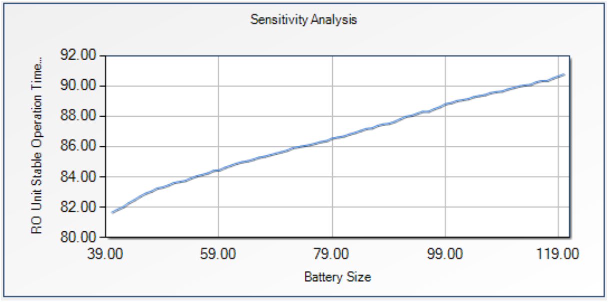


Figure 16: The RO unit stable operation time, as the battery size rises from 40 kWh to 120 kWh

5.5. Risk Analysis

The Risk analysis tool action provides information about the distribution of the performance indicators if the risk parameters of the system are taken into account. These parameters are:

- Diesel Price
- Mean Wind Speed
- Solar Radiation
- Daily Water Demand
- Daily Power Demand

The user provides the distribution and the specific values governing the parameters (e.g. mean value, deviation etc.). The results are given as histograms of the distribution of the performance indicators. Figure 17 illustrates the distribution of the diesel consumption cost indicator.

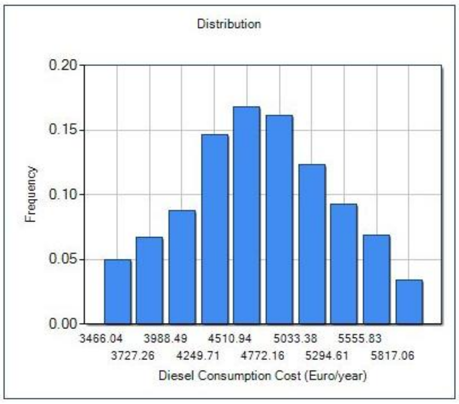
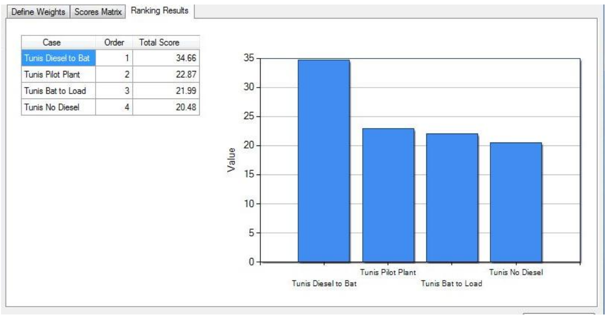


Figure 17: Diesel consumption distribution

5.6. Evaluation

Evaluation is the last action of the OPEN-GAIN DSS. The user selects cases from the cases library in order to evaluate them using a multi criteria analysis and obtain a ranking. The user defines weight factors for the multi criteria analysis according to their experience and priorities. A typical ranking for the 4 alternative cases is illustrated in Figure 18.



Case	Order	Total Score
Tunis Diesel to Bat	1	34.66
Tunis Pilot Plant	2	22.87
Tunis Bat to Load	3	21.99
Tunis No Diesel	4	20.48

Figure 18: Cases ranking histogram

The “Tunis Base Case – Diesel to Battery” has the best performance, while the other three cases all have lower scores.

6. CONCLUSIONS

The OPEN-GAIN DSS is a software tool that can help the user/designer to design and evaluate the performance of renewable energy hybrid power plants for producing water and electricity. The software's interface is user friendly with an integrated meteorological and components database. The outputs of the software provide practical results for the user/designer. The system design provides accurate design results but also expected operational results. The performance assessment is a simulation tool that can evaluate different operational strategies of the hybrid system. The sensitivity analysis tool gives the variation of the indicators as a function by defining a size range for different components, and risk analysis can provide information for probability distribution of some indicators. The screening and the evaluation indicates the best alternative according to the specific needs.

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