REDEO
RURAL ELECTRIFICATION
DECENTRALIZED ENERGY OPTIONS

EC-ASEAN Energy Facility
Project Number 24

# FINAL REPORT ON ACTIVITY 2

# ASSESSMENT OF EXISTING SOFTWARE PROGRAMMES FOR RURAL ELECTRIFICATION AND AREAS OF APPLICATION FOR CAMBODIA, LAOS AND VIETNAM

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# EXECUTIVE SUMMARY

This report under the project "**R**ural **E**lectrification **D**ecentralized **E**nergy **O**ptions - **REDEO**" presents identified computerized tools which have been developed in recent years to carry out cost and benefit analysis, comparison and decision making among the various technological energy options in rural electrification planning.

This report discusses the areas of application of identified models and computerized tools for planning in rural electrification in developing countries, such as: **RETScreen** is funded in part by Natural Resources Canada's Renewable and Electrical Energy Division (REED), **Homer** by The National Renewable Energy Laboratory's (NREL's), **Vipor** by The National Renewable Energy Laboratory's (NREL's), **Powerworld simulator** by Powerworld Corporation, USA, and **LEAP** by The Stockholm Environment Institute-Boston.

The analysis is focused on the models' required data as input, and output, as well as how to apply and use these models and tools to the target countries, namely, Cambodia, Laos, and Vietnam. The benefits and limitations have also been presented along with detailed analyses regarding each of software considered in the study.

# ASSESSMENT OF SOFTWARE PROGRAMS AND AREAS OF APPLICATION FOR CAMBODIA, LAOS AND VIETNAM

## 1. Objective

The main objective of this report is to provide a set of identified computerized decision aid tools for rural electrification planning in developing countries, especially, Cambodia, Laos and Vietnam. Application of various existing software tools to Cambodia, Laos and Vietnam has to be added by identifying to benefits and limitations from the point of view of individual country.

## 2. Scope and limitation

This report reviews the identified software which can be used to assess the costs, benefits, and the various technological options in planning for rural electrification in developing countries (e.g. Cambodia, Laos and Vietnam). Restcreen, Vipor, Homer, Powerwold simulator and LEAP were the softwares considered. These were mainly analyzed considering the following issues:

- Purpose
- Required data as input template
- Given data as output template
- Logical flow chart
- Possibility of use of the software programs (e.g. license fare etc.)

These software programs were chosen for the analysis based on the following minimum qualifications:

- The tool should be useful for the analysis of energy systems planning for rural electrification in developing countries taking into the context of sustainable development (e.g. integrating renewable energy options based electricity generation).
- The tool should have documentation that should be easily available.
- The tool should be flexible, of reasonable cost, and be able to be applied over a wide range of rural electrification situations, particularly in developing countries.
- The tool should not be country or locale specific.

## 3. Review of existing software programs

### 3.1. RETScreen

RETScreen is known as standardized and integrated renewable energy project analysis software consisting of easy to use Microsoft Excel spreadsheets. RETScreen is useful for both decision-support and capacity-building purposes. RETScreen is funded in part by NRCan's Renewable and Electrical Energy Division (REED) through the Renewable Energy Deployment Initiative (REDI). Currently, wind energy, small hydro, solar photovoltaics (PVs), combined heating and power, biomass heating, solar air heating, solar water heating, passive solar heating, ground-source heat pumps, and refrigeration are the modules that have been developed in RETScreen.

The software can be used to evaluate:

- The annual energy production,
- The costs and financial viability of the renewable energy technologies (RETs).
- The greenhouse gas emission reductions for various types of energy efficient and RETs (optional).

The product (1,000 clean energy technology manufacturers around the globe), cost, weather database, and a detailed online user guide are included in the RETscreen software. The product database provides product performance and specifications data for a number of energy technology manufacturers. One can directly "copy and paste" the useful integrated databases to the relevant cells within the software for analyzing.

The software is available free at http://www.retscreen.net/ang/t.php.

### 3.2 Homer

The National Renewable Energy Laboratory (NREL) has developed Homer as an optimization model that considers hourly and seasonal variations in loads and resources, simple performance characterizations for each of components, equipment costs, reliability requirements, and other site specific information.

HOMER can be used for evaluating the design options for both off-grid and grid-connected power systems for remote, isolated, and distributed generation (DG) applications. HOMER's optimization and sensitivity analysis algorithms can be used to evaluate the economic and technical feasibility of a wide range of conventional and renewable technology options (e.g. solar photovoltaics (PV), wind turbines, run-of-river hydro power, diesel, gasoline, biogas, alternative, co-fired and custom-fueled generators, electric utility grids, micro turbines, and fuel cells. Storage options include: battery banks and hydrogen) and to account for variation in technology costs and energy resource availability.

The software is available free at http://analysis.nrel.gov/homer/.

### 3.3. Vipor

Vipor could be used to study a village or point load which should be powered by isolated power system and which should be included in a centralized distribution network.. This software has been developed by the National Renewable Energy Laboratory (NREL). ViPOR model provides the optimal combination of rural electrification systems by using the lowest cost combination of centralized and isolated power generation.

ViPOR presents a map of a village and some information about load sizes and equipment costs are required to calculate the costs of the distribution grid and the isolated systems. Centralized generation costs are calculated using the Hybrid Optimization Model for Electric Renewables (HOMER), which has been integarated into ViPOR. The planned location (or several potential locations) of the centralized electrical power plant can also be specified on the map. Taking into account the required data, ViPOR software conceptualizes the lowest cost system and then the software decides which load points (consist of x and y coordinates and average daily electrical usage) should be powered by isolated power systems (e.g. solar home systems) and which should be included in a centralized distribution grid.

The distribution grid is optimally designed with consideration of local terrain, e.g. selection of the optimum locations for the centralized power plant, the placement of multiple transformers, and the creation of a radial network of medium and low voltage lines. The voltage drop constraint is implemented using a maximum low voltage line length, which limits the length of wire separating a demand point from its supplying transformer.

The software is available free at http://analysis.nrel.gov/vipor/.

### 3.4. Powerworld simulator

Load flow problems can be solved by Powerworld Simulator which is one of the commercially available power flow software. Various graphical options in the software make it more appealing compare to other programs used for power flow studies. It was developed by Powerworld Corporation, USA.

The free demonstration Powerworld Simulator software with some limitation on number of nodes is available free at "http://www.powerworld.com/downloads.html".

### 3.5. LEAP

The ***Stockholm Environment Institute-Boston*** has developed the ***Long-range Energy Alternatives Planning (LEAP) System*** which is an advanced software tool for energy and environmental scenario analysis. Its scenarios are based on comprehensive accounting of how energy is consumed, converted and produced in a given region or economy under a range of alternative assumptions on population, economic development, technology, price and so on. With its flexible data structures, LEAP allows the analysis of technological specification and end-use detail as the user chooses. The software tool is suitable for performing energy assessments in developing or industrialized countries, for multi-country regions, or for local energy planning purposes

LEAP includes a wide array of features designed to make creating scenarios, managing and documenting data and assumptions and viewing results reports as easy and flexible as possible. It is designed to work closely with Microsoft Office products (Word, Excel, PowerPoint) making it easy to import, export and link to data and models created elsewhere.

A summary of the specifications of the above mentioned software programs are presented in table 1.

**Table 1:** Specifications of LEAP, RETSCREEN, HOMER, VIPOR and POWERWORLD SIMULATOR software

| Name | Developer | Scope | Platform | Methodology | Cost/ Licensing | Web Site/ Contact |
|---|---|---|---|---|---|---|
| **LEAP** | SEI-Boston, USA | Integrated Energy/Environment Analysis | Windows | Physical Accounting, Simulation | Free to qualified users from developing countries. Information on licensing for other institutions is | forums.seib.org/leap leap@tellus.org |

| Name | Developer | Scope | Platform | Methodology | Cost/ Licensing | Web Site/ Contact |
|---|---|---|---|---|---|---|
| | | | | | presented in the Appendix A. | |
| **RETSCREEN** | Natural Resource Canada | Energy production, life-cycle costs and GHG emission reductions for various energy efficient and renewable energy technologies | Windows | Physical Accounting | Free | www.retscreen.net rets@nrcan.gc.ca |
| **HOMER** | National Renewable Energy Laboratory, USA | Design of off- and on-grid electrification options | Windows | Optimization | Free | www.nrel.gov/homer peter_lilienthal@nrel.gov |
| **VIPOR** | National Renewable Energy Laboratory, USA | Design of isolated electrification options (and includes in a centralized distribution network) | Windows | Optimization | Free | http://analysis.nrel.gov/vipor tom_lambert@nrel.gov |
| **POWERWORLD SIMULATOR** | Powerworld Corporation, USA | The software can be used to give an analyst a comprehensive look at issues surrounding electrical power flows in a transmission grid | Windows | Simulation, Optimization | Free demonstration Powerworld Simulator software with some limitation on number of nodes | http://www.powerworld.com info@powerworld.com |

The advantages and disadvantages of each those software programs are summarized in the table 2.

**Table 2:** The advantages and disadvantages of LEAP, RETSCREEN, HOMER, VIPOR and POWERWORLD SIMULATOR software

| Name | Advantages | Disadvantages |
|---|---|---|
| **LEAP** | • User friendly<br>• Transparent & flexible data requirements<br>• Documentations are available<br>• Available to total energy system, and detailed electric system analysis<br>• Analyzing all environmental burdens.<br>• Generates comparisons of alternative scenario results in physical, environment, and cost/benefits based decision support analysis.<br>• Medium to long-term, annual time steps.<br>• Local, regional, national and global levels for analysis | • Does not automatically identify least-cost system<br>• Does not automatically yield price-consistent solutions (e.g. demand forecast may be inconsistent with projected supply configuration).<br>• Without fuel competitiveness between renewable energy and fossil fuels[1]. (I am not clear – please clarify/check)<br>• All power plants are assumed to be available at peak load time[2]. |

[1] Although energy prices/costs can be one of up to three driving variables in specifying activity levels (for example, transportation demand) or energy intensities, prices/costs can not be factors in making choices among alternative energy technologies or fuels. Due to the nature of the model (accounting model framework, structured as a series of integrated programs that can be used, for example, to develop current energy balances, projections of supply and demand trends, and calculate the consequent environmental emissions), the model cannot analyze fuel competitiveness between renewable energy and fossil fuels.

| Name | Advantages | Disadvantages |
|---|---|---|
| **RETSCREEN** | • Reduces costs, time, risks and errors associated with preparing project pre-feasibility studies.<br>• Provides a low cost preliminary design method for project developers and industry And thus increases the initiation of project studies which help identify the best opportunities for successful RETs project implementation.<br>• Provides GHG analysis to help the user estimate the greenhouse gas emission reduction (mitigation) potential of the proposed project.<br>• Annual energy production in MWh, MW.<br>• RETScreen economic analysis can consider a variety of discount rate, taxes benefit, etc. and financial analysis indicators (e.g. Simple payback, NPV, IRR etc.) are provided for decision makers. A cash flow graph is also included. | • RETScreen looks at one technology at a time.<br>• Only annual energy production is considered, rather than a more detailed time series analysis, which would consider energy production and load variations on a much shorter time scale (e.g. 1 hour).<br>• Only in Wind Energy model, the Sensitivity and Risk Analysis tool has developed. |
| **HOMER** | • Homer searches for the optimal system considering all RETs at a time.<br>• Analyze grid or off grid rural electrification system. Homer reports both of optimal and near optimal solutions.<br>• Hourly analysis.<br>• Sensitivity analyses to determine the effect of the inputs.<br>• Results are based life cycle economics.<br>• More detailed than RETScreen software.<br>• Can model AC or DC loads. | • Can not model both of AC and DC loads. (Load modeling AC or DC at a time) (Please check)<br>• Calculates Net present cost only.<br>• GHG analysis is not available, but Carbon emission (tone/year) can be obtained |
| **VIPOR** | • Vipor is able to optimize the mix of centralized and isolated generation.<br>• It selects between grid extension and hybrid system for centralized power.<br>• It selects the optimal placement of the centralized power systems.<br>• Vipor determines the optimal placement of transformers.<br>• Vipor determines the optimal Medium voltage and Low voltage distribution network.<br>• Vipor uses Graphical user interface (GUI) | • Vipor does not consider limits of RETs option, and the optimal network might not be the best.<br>• Vipor supports only 10 RETs candidates in a network at a time of analysis.<br>• Vipor does not consider power losses in distribution system. |
| **POWERWORLD SIMULATOR** | • A full featured power system simulation package includes AC/DC Optimal power flow analysis, pricing, etc.<br>• It is user-friendly and highly interactive,<br>• The simulator has extensive graphics and animation capabilities.<br>• A detailed online help file has been integrated. | • Free demonstration Powerworld Simulator software with some limitation on number of nodes |

[2] In fact, only a proportion of plants will be available at any given time (planning, faults, forced plant maintenance). If all power plats are assumed to be available at peak load time, and then the reserve margin of power system might be overestimated in the peak load and underestimated it during the lowest load.

A detailed discussion of these software programs is given in Appendix A.

### 3.6. Solargis

The Solargis project is European project (JOULE 2 Program) for integration of renewable energy technologies and for decentralized electricity production in Euro and developing coutries. The Solargis project is coordinated by the Centre d'Énergétique (CENERG) – ARMINES (France). This Solargis tool has been developed through a partnership between CENERG and various institutions as follows:

- Conphoebus (Italy)
- IER-CIEMAT (Spain)
- CRES (Greece)
- INESC Porto (Portugal)
- RAL (United Kingdom)
- NMRC (Ireland).

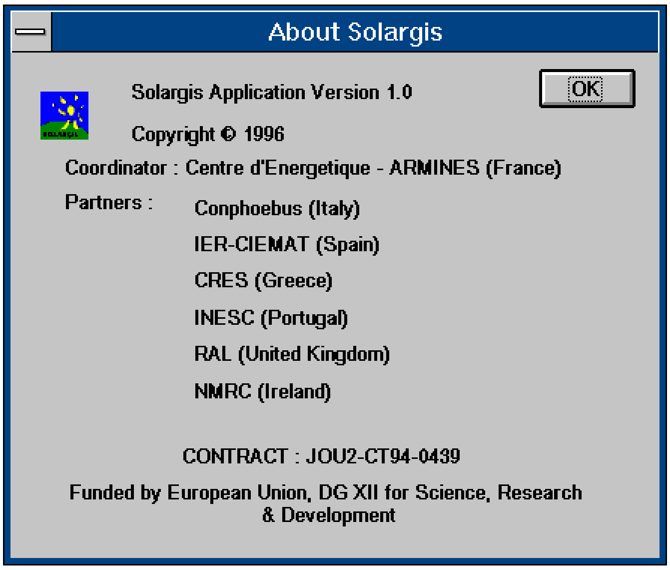


Figure 1: Information about the Solargis tool

The Solargis project is intended:

- To provide a methodology for such integration studies, that will include the use of a Geographical Information System
- To lead integration studies in six selected regions:
  - Sicily (studied by Conphoebus, IT),
  - Andalucia (studied by CIEMAT, SP),
  - Crete (studied by CRES, GR),
  - Region of Cabo Verde (studied by INESC, PO),
  - Region of Tunisia (studied by ARMINES, FR),
  - Region of India (studied by RAL, UK, and NMRC, IRL).

These studies will be completed in close collaboration with electric utilities or regional authorities responsible for energy planning.

The Solargis methodology covers three essential systems usable in decentralized RE:

- Isolated systems for households (wind and solar energy sources);
- Hybrid systems for the electrification of villages;
- Connection to the existing electric network.

This tool's objective is to orientate studies of integration of RE electricity production at a regional scale by using a GIS. It determines which technology of production is the most appropriate for a given place. A comparison of technologies is performed having as a base a LEC (Leveled Electricity Costs) study.

The approach implemented in the Solargis methodology is presented in figure 2.

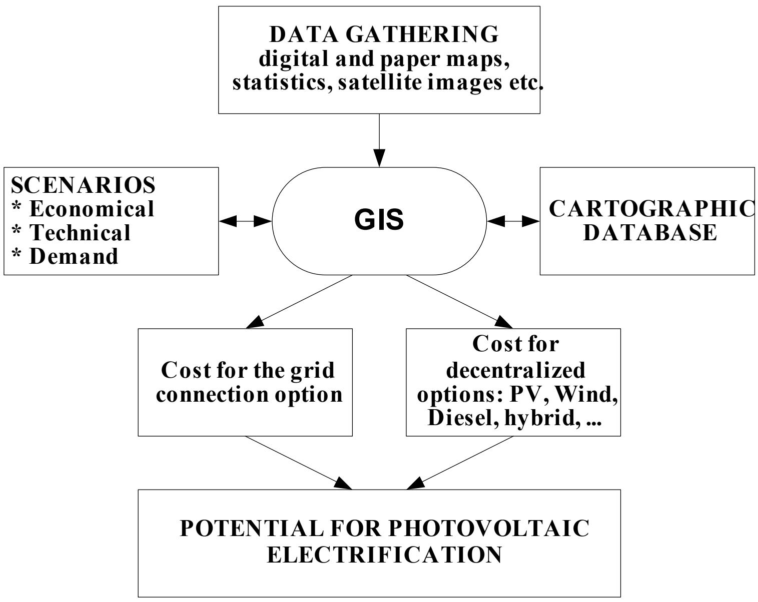


**Figure 2**: Methodology applied in the Solargis tool

The data inputs needed in order for the Solargis tool to work are:

- Wind resource maps;
- Solar resource maps;
- Population density maps;
- Maps of interconnection distances to the existing network;
- Load scenarios;
- Existing electric network;
- Technologies catalog.

This methodology devolves, as results, the users to whom a given decentralized production technology option is cheaper than the direct connection to the existing network. It permits the evaluation of the potential of electrification by means of renewable energy sources in a certain region. This factor is of great interest for the decision-makers in charge of the energetic planning at a regional scale.

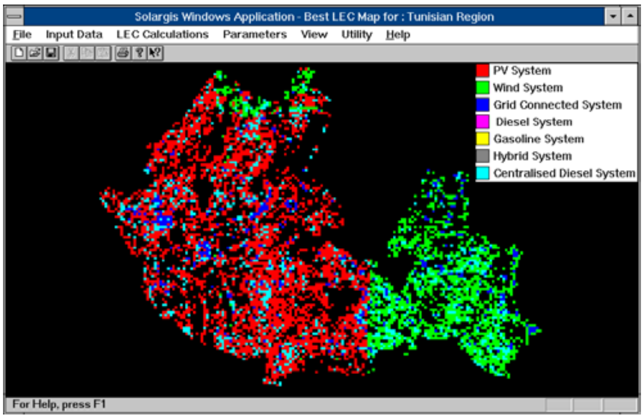


Figure 3: Example Solargis tool's output (analysis of the best production option for a given place)

## 4. Areas of application for Cambodia, Laos and Vietnam

The areas of application of these software tools for for rural electrification planning in Cambodia, Laos and Vietnam has been discussed by taking into account the decentralized energy technology options and other considerations. The considerations are in terms of input data required by each software, the ease of availability and use of these softwares in the countries, and the output of the software. For these, some qualitative guidelines have been provided.

### 4.1. RETScreen

The area of application of the RETScreen tool is presented in the table 3.

**Table 3:** The potential of RETScreen's application for Cambodia, Laos and Vietnam

| Items | Cambodia | Laos | Vietnam |
|---|---|---|---|
| 1. Input data (1) | | | |
| *Biomass* | NA | NA | NA |
| *Small hydro* | NA | NA | NA |
| *Solar* | NA | NA | NA |
| *Thermal* | NA | NA | NA |
| *Wind* | NA | NA | NA |
| *The product data (RETs)* | NA | NA | NA |
| 2. Availability | Free | Free | Free |
| 3. Usability (training, help etc.) (2) | Available | Available | Available |
| 4. Output | | | |
| *The annual energy production (Mwh/year)* | Useful | Useful | Useful |
| *The life-cycle costs of the RETs (USD/Mwh).* | Useful | Useful | Useful |
| *The greenhouse gas emission* | Useful | Useful | Useful |

Notes: (1) – *In case where data is not available then one can use the product, cost, and weather database that are included in the RETscreen software tool.*

*(2) – Currently, training material is not available to access the Combined Heat & Power model.*

### 4.2. HOMER

The statement for area of application of the HOMER tool is presented in the table 4.

**Table 4:** The potential of HOMER's application for Cambodia, Laos and Vietnam

| Items | Cambodia | Laos | Vietnam |
|---|---|---|---|
| 1. Input data (1) | | | |
| *Load* | NA | NA | NA |
| *Solar (hourly or monthly)* | NA | NA | NA |
| *Wind (hourly or monthly)* | NA | NA | NA |
| *The cost and performance data (Energy options)* | NA | NA | NA |
| 2. Availability | Free | Free | Free |
| 3. Usability (training, help, case studies etc.) | Available | Available | Available |
| 4. Output (2): Optimization for designing power systems | | | |
| *Hourly simulation of power systems* | Useful | Useful | Useful |
| *The life-cycle costs of power systems* | Useful | Useful | Useful |
| *Sensitive analysis* | Useful | Useful | Useful |

Notes: (1) – *One can use the product, cost, weather database that are included in the RETscreen software tool or other database should be developed.*

*– HOMER defines three kinds of load data: Primary Load, Deferrable Load and Thermal Load.*

*– HOMER does not contain a library of component cost and performance data. But it can be obtained at the Lawrence Berkeley National Laboratory's Distributed Energy Resources Group at http://der.lbl.gov/tech_data.html*

*(2) – Output data could be obtained including PV, wind, batteries, inverters and fuel –fired gen-sets and various combinations of these technologies.*

### 4.3. VIPOR

The statement for area of application of the VIPOR tool is presented in the table 5.

**Table 5:** The potential of VIPOR's application for Cambodia, Laos and Vietnam

| Items | Cambodia | Laos | Vietnam |
|---|---|---|---|
| 1. Input data (1) | | | |
| *Loads* | NA | NA | NA |
| *Sources* | NA | NA | NA |
| *Terrain* | GIS map | GIS map | GIS map |
| *Distribution costs* | NA | NA | NA |

| Items | Cambodia | Laos | Vietnam |
|---|---|---|---|
| 2. Availability | Free | Free | Free |
| 3. Usability (training, help, case studies etc.) | Available | Available | Available |
| 4. Output (2): Optimization for designing village electrification systems | | | |
| *Centralized vs. isolated power systems (like solar home systems)* | Useful | Useful | Useful |
| *Breakdown of costs* | Useful | Useful | Useful |
| *Revenues* | Useful | Useful | Useful |

Notes: *(1) – VIPOR defines the various kinds of load data: houses, stores, a church, temple, pagoda and a community center.*

*– One can use the generation cost curve of the wind turbines, PV panel, a single backup generator, and battery storage those could be obtained by HOMER tools. For other technologies' generation cost curves, one has to develop the analysis by other means (e.g. in the cases of biomass, micro hydro, multiple diesels).*

*– One has to convert the existing GIS data into VIPOR for analysis*

*(2) – Output data could be obtained including a map of the optimal configuration of village electrification systems.*

### 4.4. POWERWORL SIMULATOR

The statement for area of application of the Powerworld Simulator tool is presented in the table 6.

**Table 6:** The potential of Powerworld Simulator's application for Cambodia, Laos and Vietnam

| Items | Cambodia | Laos | Vietnam |
|---|---|---|---|
| 1. Input data (1) | | | |
| *Nodes* | NA | NA | NA |
| *Sources* | NA | NA | NA |
| *Line parameters* | NA | NA | Available (4) |
| *Transformers parameters* | NA | NA | NA |
| 2. Availability (2) | Free | Free | Free |
| 3. Usability (training, help, case studies etc.) | Available | Available | Available |
| 4. Output (3): | | | |
| *Generation from all the sources* | Useful | Useful | Useful |
| *Line flows, voltages drops and losses* | Useful | Useful | Useful |
| *Voltage and angles at all the nodes* | Useful | Useful | Useful |

Notes: *(1) – The rural electrification network of a project "province" could be an output of the ViPOR or similar software for network optimization*

*(2) – The demonstration version of the software can be obtained free, but it is limited only 12 buses for analysis. For a full version with up to 60,000 buses and almost unlimited number of lines, details are available at http://www.powerworld.com/.*

*(3) – In additional, the software tool can be used to obtain a comprehensive look at issues surrounding electrical power flows in a transmission network (buses, generators, transmission lines, dc lines, switched shunts, areas and zones, scale the load or generation, electrical equivalents, economic dispatch for any area, load schedules, pricing, etc. ).*

*(4) - Line parameters can be obtained from various available data (especially, in the existing distributed network that has been developed in GIS from Power company 1)*

## 4.5. LEAP

The statement for area of application of the LEAP tool is presented in the table 7.

**Table 7:** The potential of LEAP's application for Cambodia, Laos and Vietnam

| Items | Cambodia | Laos | Vietnam |
|---|---|---|---|
| 1. Input data (1) | | | |
| *Social and economics* | Available | Available | Available |
| *Energy demand* | NA | NA | NA |
| *Energy transformation* | NA | NA | NA |
| *Emission factor by fuels* | NA | NA | NA |
| 2. Availability (2) | Free | Free | Free |
| 3. Usability (training, help, case studies etc.) | Available | Available | Available |
| 4. Output (3): | | | |
| *Energy demand p* | Useful | Useful | Useful |
| *Energy conversion* | Useful | Useful | Useful |
| *Energy resources* | Useful | Useful | Useful |
| *Cost of the energy systems* | Useful | Useful | Useful |
| *Emissions* | Useful | Useful | Useful |

Notes: *(1) – The key input data includes: GDP, household size (people), households, incomes, population, income growth rate, , base year energy balance, energy technology performance, energy technology costs, energy price projections, local environmental coefficients, etc.*

*(2) – The software tool can be obtained free with a 2 years license, but this is supported only for the Non-profit/government/ academic organization based in a developing countries. For other users, one can contact directly Stockholm Environment Institute – Boston Center, leap@tellus.org.*

*(3) – In addition, the software tool can be used as a computer-based approach for fostering integrated, reliable, and ongoing energy planning. It is suitable for performing energy assessments in developing or industrialized countries, for multi-country regions, or for local planning purposes.*

## 4.6. SOLARGIS

The statement for area of application of the SOLARGIS tool is presented in the table 8.

**Table 8:** The potential of SOLARGIS's application for Cambodia, Laos and Vietnam

| Items | Cambodia | Laos | Vietnam |
|---|---|---|---|
| 1. Input data (1) | | | |
| *Wind resources map* | NA | NA | NA |
| *Solar resource map* | NA | NA | NA |
| *Population density* | Avaialble | Avaialble | Avaialble |
| *Existing network map* | NA | NA | Available |
| *Load scenarios* | NA | NA | NA |
| *Technologies catalog* | NA | NA | NA |
| *Social and economics* | Available | Available | Available |
| *Energy demand* | NA | NA | NA |
| 2. Availability (2) | NA | NA | NA |
| 3. Usability (training, help, case studies etc.) | NA | NA | NA |
| 4. Output (3): | | | |
| *Cost for decentralized options: PV, wind, diesel, hybrid… based electricity production* | Useful | Useful | Useful |
| *Cost for the grid connection option* | Useful | Useful | Useful |

*Notes: (1) – The key input data includes: digital and paper maps, statistics, satellite images, etc. The data can be categorized of Geographical data (Digital maps, Paper maps (to be digitized or scanned and analyzed), Aerial photography, Satelite images (remote sensing) and General data (Meteorological data from stations, Electric grid data, Statistical data).*

*(2) – The software tool has being applied in 6 pilot regions: Tunisia, Sicily, Andalusia, Crete, Cape-Verde, and India. For detailed information, one can contact http://www-cenerg.cma.fr/~st/solargis/.*

*(3) – In addition, the software tool can be used as a computer-based approach for comparison of grid connection option and decentralized energy options. The comparison is based on the cost of the electricity generation options for a given regional demand. As this point, the computerized tool will be allowing the planer to estimate the potential of rural electrification systems inside the studied region.*

## 5. Conclusions and recommendations

RETScreen International Clean Energy Project Analysis Software can be used to evaluate the energy production, life-cycle costs and greenhouse gas emission reductions for various types of energy efficient and renewable energy technologies (RETs). The software also includes product, cost and weather databases, and a detailed online user manual. The product, cost and weather databases and detailed online user manual have been integrated in the RETScreen software tool. This is aimed to reduce the time and costs related to preparing pre-feasibility studies on clean energy planning.

HOMER software tool is a simplified optimization model for designing power system for remote load points. Full hourly energy production cost can be also obtained by this software tool, and so it is more detailed than RETScreen. The software tool can be used to simulate the performance of the user-selected power systems that can include PV, wind, batteries, inverter, and fuel-fired gen-sets and various combinations of these technologies (on an hourly basis). In addition, one can do the sensitivity analysis to evaluate the sensitivity of the system design by taking in account the keys parameters, such as, the resource quality or component costs.

The VIPOR software tool can be used to obtain an optimal design of a village electrification system. Given a map of a project area (e.g. a village, commune, provinces) and information about load sizes and equipment costs, one can use ViPOR to decide which houses should be powered by isolated power systems (like solar home systems) and which should be included in a centralized distribution grid. The distribution grid is optimally designed with consideration of local terrain. The energy production cost curves generated by HOMERcan be used as VIPOR's input (the wind turbines, PV panel, a single backup generator, battery storage, etc). VIPOR can be used for evaluation the optimal network of only 10 RETs candidates.

Powerworld simulation software tool is used for load flow calculations. The transmission/distribution network plan with all generations and loads can be checked for technical adequacy, such as, losses, voltage, etc. The output of the ViPOR or similar software for network optimization (e.g. the rural electrification network of a project area) could be imported into the Powerworld simulator for analyzes. The free demonstration Powerworld Simulator software is limited in 12 buses only.

LEAP software tool is an integrated scenario-based energy-environment modeling tool. With its flexible data structures, LEAP allows for analysis as rich in technological specification and end-use detail. LEAP is an energy accounting framework. LEAP also supports both final and useful energy demand analyses as well as detailed stock-turnover modeling for transportation and other analyses. On the supply side, LEAP supports a range of simulation methods for modeling both capacity expansion and plant dispatch. The LEAP software also includes a built-in Technology and Environmental Database (TED) containing data on the costs, performance and emission factors for over 1000 energy technologies.

All these above mentioned software tools are designed to work closely/familiarly with Microsoft Office products (Word, Excel, PowerPoint) making it easy to import, export and link to data and models created elsewhere. The results of these software tools can be integrated into GIS software for management and analyzing further studies in energy planning, especially rural electrification planning. Particularly, in Cambodia, Laos and Vietnam, the planners can use these software tools (most of the software tools are free) in energy planning, especially in rural electrification decentralized energy options (clean energy production options as well).

An analyes of these softwares for direct application in the study countries of Cambodia, Laos and Vietnam indicates that there are certain inherent difficulties that a rural electrification planner in these countries would encounter, namely:

- Lack of renewable energy resource data. This is also exacerbated by the requirements of each software regarding the data type and its characteristics (physical, chemical and thermodynamic properties for example).
- Each of the studied software have their own "strong points" and are designed for a specific purpose. A planner, therefore, needs to be aware of all limitations and capabilities.

- Applicability of GIS for such analyses is gaining importance, due to the fact that data (economic, development, geographic, etc) are now being digitized in many countries, as well as that it provides an excellent tool to visualize for the planner at the province or at the central level to better understand the local conditions and related features. This would assist in the better allocation of resources for rural electrification.

Hence, it is important to develop a model that will take into account the useful/main features of the mentioned software tools. Incorporation of GIS as a tool would also be interesting in energy planning, especially rural electrification decentralized energy options in Cambodia, Laos and Vietnam. The restrictions in modeling rural electrification decentralized energy options are influenced by the necessary information available, such as, resource data, technology (e.g. characterization, performance etc.), costs and institutional issues (government's energy policy, import technologies tax etc.). These are limited in most of the target countries. However, not considering these issues would significantly effect the scope of the model and the validity of the analyzed results to capture a rural electrification system. Some recommendations to be considered in rural electrification decentralized energy options planning are suggested (and planned to be incorporated in the REDEO model) below:

- For the province's rural electrification planning purposes, a provincial level rural electrification model needs a reasonable prediction of the total availability of energy resources (e.g. both renewable energy resources and conventional resources) to respond to the project area's resource consumption, technology choices, environmental impacts, and policy decisions. However, to develop a reasonable projection of the total availability or energy output of energy resources in the project area involves detailed information. Those features can be specified in the REDEO's module, resource assessment.
- There are various renewable energy technologies that could be cost-effective than competitive conventional fuels in some situations. Their potentials for future application thus should be realized and incorporated in the rural electrification decentralized energy options model. It, therefore, needs to break the end use demand into detailed applications (residential, agriculture, commercial, industry, others). This model will enable to be used easily and to define and capture the potential renewable energy technology options over the study period. These specifications, therefore, are needed to incorporate in technology analysis module of REDEO whose main task is the design the power system for rural electrification.
- The resource availability, end use demand and the design of power system can be obtained from the resource module and technology module, and these results will then be input to the economic module for evaluating the most economic rural electrification power system. On the other hand, institutional information is also needed in the economic analysis module, such as, government energy policy, imported tax policy, institutional support for promotion of renewable energy technology etc. An economic analysis module is thus used to evaluate the competitiveness between renewable and conventional energy options of REDEO.
- With these specifications, the rural electrification decentralized energy options of REDEO can allow the planners to simulate complicated systems. The modelers need to apply the government's energy policy to limit the scope of the model that will take into account the availability of renewable energy technology options.
- In general, renewable energy resources could not be imported from neighboring project areas. Even though biomass might be imported from other places, but in most cases it is probably not an economic option. Thus, the renewable energy resources to

be chosen depend on the availability. Besides this constraint, location is also very important factor. The renewable energy resources have to be converted in to electricity before transmitting to the end use demand. A graphical user interface tool has to be integrated in order to help the planner a better visualization, management, update the database in rural electrification decentralized energy options planning. The GIS tool would have the ability to respond to these specifications.

Under Solargis project, the Solargis tool was developed which was a regional level study for evaluating rural electrification systems. The software tool was aimed to help the planner to manage the geographical information layers and a set of technical and economical evaluation tools, all linked to the GIS database. Case studies have been implemented in six selected regions in European and developing countries. However, this software tool can not be used in the present study and, thus a rural electrification decentralized energy options model is necessary to be developed for Cambodia, Laos and Vietnam.

The above mentioned specifications will be taking into consideration by the REDEO model under support of Geographical Information Systems (GIS). The REDEO model can be used as a flexible and computerized decision aid tool to help the planners to address the limitations from reviewed software in rural electrification decentralized energy options planning for developing countries, Cambodia, Laos and Vietnam.

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# Appendix A: REPORT ON DIFFERENT SOFTWARES

## I. OVERVIEW OF DIFFERENT SOFTWARES

### 1 RETSCREEN

**PURPOSE:** The main aim of this software (for rural electrification purpose) is to provide information regarding energy output and cost, and GHG (Green House Gas) emission, if needed, at any location.

**INPUT:** All the necessary data for evaluating and comparing the feasibility of different power generation options (e.g. cost of various components).

**OUTPUT:** Financial summary in terms of IRR or NPV, energy outputs (MWh), Capacities (MW) and Location (coordinates).

### 2 LOAD FORECASTING

**PURPOSE:** The main aim of this software is to have load forecast by incorporating various inputs in GIS database.

**INPUT:** Load categories for each of locations

**OUTPUT:** Demand and Energy forecast and their location

Outputs of RETSCREEN and Load Forecasting software are the input to VIPOR Software

### 3 VIPOR

**PURPOSE:** The main aim of the software to find an optimal network configuration for a given set of loads and source points.

**INPUT:** Candidate power plants' and loads' locations with coordinates, data of various lines and transformers (e.g. Location and power requirement of each expected load, expected revenue from each load, potential location of centralized power plant, terrain description, wire and transformer cost, maximum low voltage line length).

**OUTPUT:** Output of the VIPOR software is the optimal configuration map (network) with different sources connected with various load points.

### 4 HOMER

**PURPOSE:** The main aim of the software is to find out an optimal network configuration for a given of load and sources with consideration hourly and seasonal variations in loads and resources.

**INPUT:** Hourly Load, Solar and Wind speed data, Basic cost and performance data for each component and Fuel price and interest rate.

**OUTPUT:** HOMER reports both optimal and near-optimal solutions. It has been integrated with a grid optimization model. Solutions are ranked by net present cost and displayed in the list control. Detailed outputs can be viewed by double clicking on any solution in the list control.

## 5 LOAD FLOW

**PURPOSE:** The main aim of the software is to run load flow and calculate voltage drops and losses to see whether there is any serious violation.

**INPUT:** Network configuration, including loads, sources and line parameters information.

**OUTPUT:** Voltage and Angle at various loads, voltage drops and losses along various lines.

## 6 LEAP

**PURPOSE:** The main aim of the software is an integrated scenario-based energy-environment modeling tool (the scenarios have been taken into account the comprehensive accounting of how energy is consumed, converted and produced in a given energy system under a range of alternative assumptions on population, economic development, technology, price etc.). The software is to support one obtain the energy outlooks (forecasting), energy balances and environmental inventories, integrated resource planning, greenhouse gas mitigation analysis, and strategic analyses of sustainable energy futures.

**INPUT:** Marco economic variables (e.g. GDP/value added, population, household size, production of energy intensive materials (tones or $ steel), transport demand (passenger/km, tone/km), income distribution etc), energy demand data (Fuel by sector/sub-sector, price and income elasticity), energy supply data (capital and O&M costs, performance (efficiencies, capacity, factors, etc.), new capacity online dates, costs, characteristics, reserves of fossil fuel, potential for renewable resources), technology options (technology costs and performance, penetration rates, administrative and program costs emission factors).

**OUTPUT:** Energy outlooks (forecasting), energy balances and environmental inventories, integrated resource planning, greenhouse gas mitigation analysis, and strategic analyses of sustainable energy futures.

## 7 SOLARGIS

**PURPOSE:** The purpose of the SOLARGIS model is to provide a computer aided tool in rural electrification planning at regional scale via application of Geographical Information System (GIS) (e.g. GIS ArcView 3.0 from Environmental Systems Research Institute, ESRI), which allows a flexible integration of the different geographical information layers and a set of technical and economical evaluation tools. The SOLARGIS model is to allow the planner to select the most appropriate rural electrification system through the base of the cost of the electricity production options for a given demand. As this point, the model allows estimating the potential of rural electrification systems inside a project region. The final analyzed results will be storage in term of GIS database.

**INPUT:** For a given region, numerous data are to be required: wind and solar resources electric grid data, statistics of population in digital maps, paper maps, aerial photos, satellite images, meteorological data from stations.

**OUTPUT:** The levelized electricity cost (LEC) maps for different rural electrification systems, such as, Photovoltaic stand alone generator, Wind turbine stand alone generator, Stand alone gasoline generator, Stand alone diesel generator, Mini-grid + hybrid Wind/Diesel for a village, Mini-grid + Diesel for a village, Connection to the existing centralized electric grid. Finally, the high potential of photovoltaic areas map can be obtained (taking accounts the estimation of the total number of units, of their production, of their costs).

## II. INPUT/OUTPUT TEMPLATE FOR RETSCREEN

RETScreen is known as standardized and integrated renewable energy project analysis software consisting of easy to use Microsoft Excel spreadsheets. The software can be used to evaluate the annual energy production, costs and financial viability of the following renewable energy technologies (RETs). RETScreen is useful for both decision-support and capacity-building purposes. RETScreen is funded in part by NRCan's Renewable and Electrical Energy Division (REED) through the Renewable Energy Deployment Initiative (REDI).

### 1 General flowchart of the software

The RETScreen software's general flowchart is shown in figure 1.

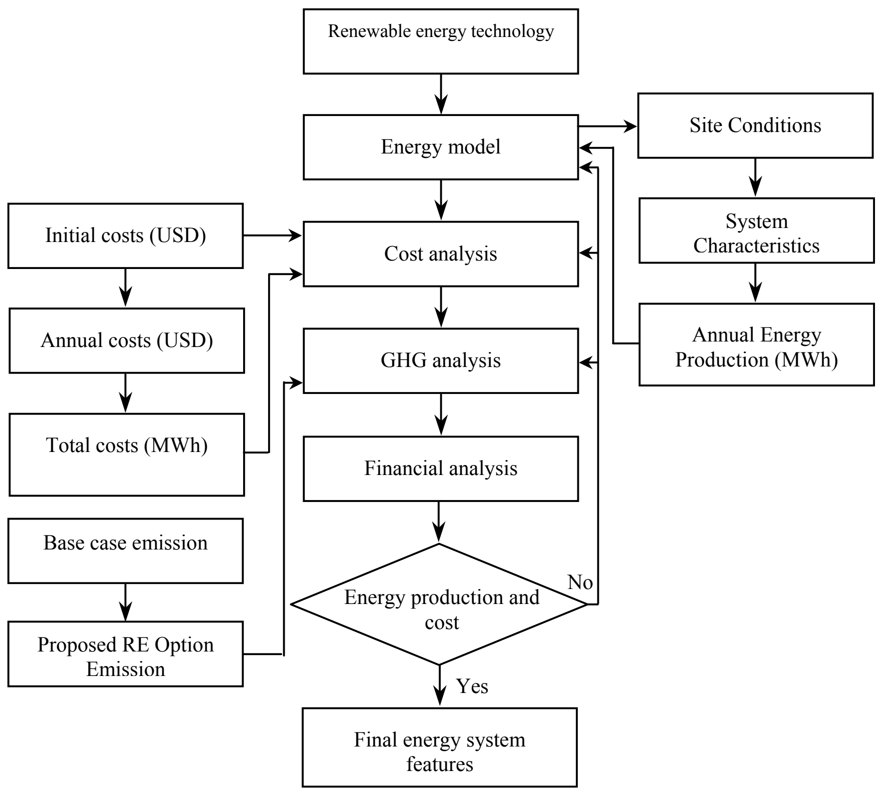


**Figure 1**: **General RETscreen software flowchart**.

- Each worksheet in the models must be completed by row from the top to bottom by entering values of the required data. First, the Energy Model worksheet is completed, and then the Cost Analysis worksheet and finally the Financial Summary worksheet should be completed. This step can be repeated several times in order to optimize the design of the renewable energy project from an energy production and cost standpoint.
- Greenhouse gas (GHG) emission analysis is optional.

## 2 General required data

### a. Common data

- Project name
- Project location
- Nearest location for weather data
- Energy demand (electrical) (MWh) (project area).
- Peak load (electrical) (kW) (project area).

### b. Individual data

1. Biomass

- Moisture content on wet basis of biomass, %
- As-fired calorific value of biomass, MJ/t
- Number of buildings (1 to 7)
- Length of trench for distribution pipe, m

2. Small hydro

- Drainage area above site, $km^2$
- Flow-duration curve type
- Mean flow/$km^2$, $m^3/s/km^2$
- Mean flow, $m^3/s$
- Firm-flow ratio
- Gross head, m

3. Wind

- Annual average wind speed, m/s
- Height of wind measurement, m
- Wind shear exponent
- Wind speed at 10 m, m/s
- Average atmospheric pressure, kPa
- Annual average temperature, °C

## 3 Outputs

The outputs from the software are:

- The annual energy production (MW, MWh) of potential renewable energy technologies.
- Costs (USD, USD/MWh) and financial viability of the potential renewable energy technologies.
- Sorting of potential renewable technologies in order of their NPV, IRR, and simple payback.
- Greenhouse gas emission reduction (optional).

## III. INPUT/OUTPUT TEMPLATE FOR VIPOR SOFTWARE

### 1 General Flowchart

The Vipor software's general flowchart is shown in figure 2.

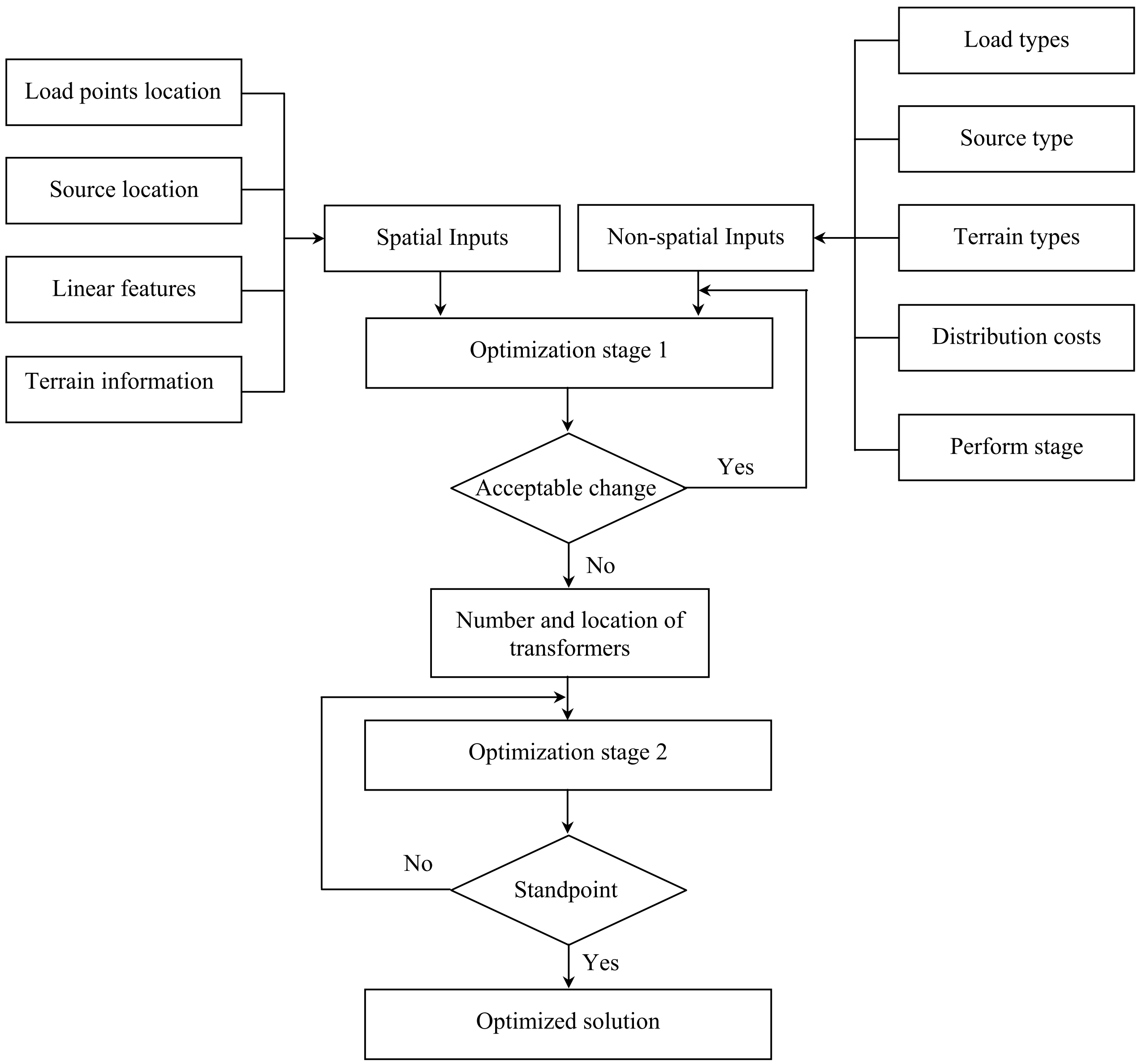


**Figure 2**: **General flowchart of Vipor software**

## 2 Input

### a. Non-spatial Inputs

### 1. Load types

Load types are shown as houses, stores, a church, temple, pagoda and a community center. The load types must be known to obtain the average daily electrical demand and separated into on grid and off grid. Generally, off grid load is smaller as compared with on grid load.

### 2. Source types

Defining source types is the most difficult part of using the software. Generation and distribution cost should be included in the total electrification cost. With different power systems (isolated or centralized hybrid power systems), the generation costs often vary dramatically. The "source type" concept is a way of dealing with the complexities of generation costs. Different source type for each different generation option can be defined and each source type can have a different generation cost curve.

### 3. Terrain Types

Grass, forest, water, and road… could be defined in the Terrain Types dialog box. Based on the terrain cost multiplier and the cost of low voltage and medium voltage wire, the actual cost of a low voltage and medium voltage wire passing through a project area would be calculated by the model.

### 4. Distribution Costs:

The Distribution Cost dialog box contains the economic inputs that ViPOR uses to calculate the cost of the centralized distribution grid. The distribution cost includes Low and medium voltage wire costs. Actual cost of lines will be calculated based on the terrain cost multipliers.

### 5. Optimization

ViPOR uses an optimization algorithm called simulated annealing to maximize profit (actually, the net present value of the profit). The quality of the solution provided by this algorithm is dependent on the amount of time it is given to solve the optimization problem. The Optimization window allows adjust meant of this time.

### b. Spatial Inputs

For determinations the cost and the proper layout of the distribution network, the software requires a *spatial* or geographic description of a project area, say the village. This spatial description must include the location and type of each load point (such as houses, schools, stores, and health posts) and at least one potential centralized power system location (such as an area of public land, a hill exposed to the wind, or a tie-in point to an existing transmission line). The spatial description may also include linear features (such as roads, rivers, and shorelines) and terrain information.

## 3 Outputs

A map of the optimal configuration will be displayed at the end of the optimization process. Cost vs. grid load, breakdown of costs and revenues are also displaced.

# IV. INPUT/OUTPUT TEMPLATE FOR HOMER SOFTWARE

## 1 General Flowchart

The Homer software's general flowchart is shown in figure 3.

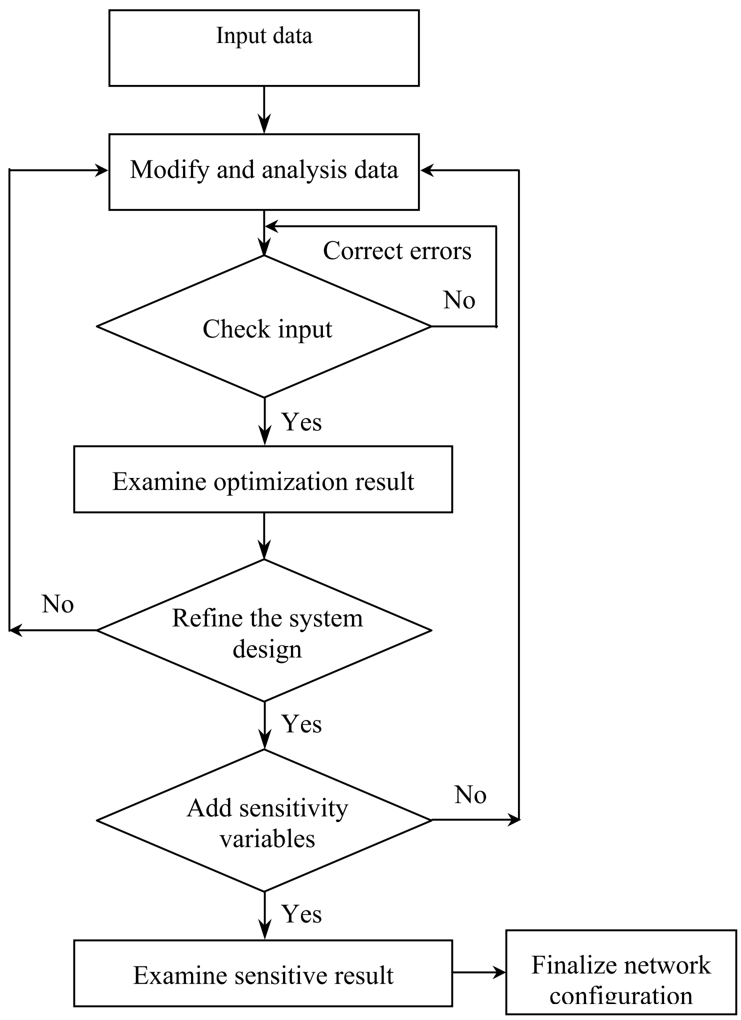


**Figure 3**: **The Homer software's general flowchart**.

## 2 Data required

### a. Load Data

HOMER defines three kinds of load data: Primary Load, Deferrable Load and Thermal Load.

1. **Primary Load**

Primary load is electrical load that must be met immediately in order to avoid unmet load. The user can add two separate primary loads to the system from the Add/Remove window. For each hour of the year, HOMER dispatches the power-producing components of the system to serve the total primary load.

The baseline data is the set of 8,760 values representing the average electric demand, expressed in kW, for each hour of the year. There are two ways to create baseline data: using HOMER to synthesize data, or importing hourly data from a file.

2. **Deferrable Load**

Deferrable load is electrical load that must be met within some time period, but the exact timing is not important. Loads are normally classified as deferrable because they have some storage associated with them. Water pumping is a common example - there is some flexibility as to when the pump actually operates, provided the water tank does not run dry. Other examples include ice making and battery charging.

3. **Thermal Load**

Thermal load is demand for heat energy. The heat may be needed for space heating, hot water heating, or some industrial process. The thermal load can be served by the boiler of a generator from which waste heat can be recovered, or by surplus electricity. If users want a generator to serve the thermal load with waste heat, they must specify a non-zero value for that generator's heat recovery ratio. If users want surplus electricity to serve the thermal load, they must indicate so on the Boiler Inputs window.

b. **Solar and wind speed data (hourly or monthly)**

Among the resource inputs, the availability of solar radiation and wind for each hour of the year require detailed data. The data can either imported from a properly formatted file, or use HOMER to synthesize hourly data from average monthly values.

1. **Solar Data**

The latitude and the amount of solar radiation available to the photovoltaic (PV) array throughout the year are defined in Solar Data. HOMER uses this data to calculate the output of the PV array each hour of the year. The latitude is an important variable in solar calculations. It is used when calculating radiation values from clearness indices, and vice versa. It is also used to calculate the radiation incident on a tilted surface. If the users do not have measured hourly solar radiation data, they can specify monthly averages and HOMER will synthesize hourly data from them. There are several sources of monthly average solar data for locations around the world. This help file contains a table of solar data for selected worldwide locations, as well as some solar data map.

2. **Wind Data**

Wind data describes the available wind resource. HOMER uses this data to calculate the output of the wind turbine each hour of the year. HOMER's synthetic wind data generator is a little more difficult to use than the solar data generator because it requires four parameters: Weibull k value, autocorrelation factor, diurnal pattern strength, and hours of peak wind-speed.

### c. Basic cost and performance data for each component

HOMER does not contain a library of component cost and performance data. But such data can be obtained from various sources, such as, the Lawrence Berkeley National Laboratory's Distributed Energy Resources Group at http://der.lbl.gov/tech_data.html.

### d. Fuel price and interest rate

The price unit of fuel is dollars per liter. It is very common to do a sensitivity analysis on this variable for two reasons. First, it is difficult to accurately predict the future fuel price. Second, the optimal architecture of the power system can vary widely depending on the fuel price.

The interest rate that one enters for HOMER's input is the annual real interest rate (also called the *real interest rate* or just *interest rate*). It is the discount rate used to convert between one-time costs and annualized costs.

By defining the interest rate, **inflation** is factored out of the economic analysis. All costs therefore become *real costs*, meaning that they are in defined in terms of constant dollars. The assumption is that the rate of inflation is the same for all costs.

### e. Search space and constraints

Search space is the set of all allowable sizes and quantities of each component. In its optimization procedure, HOMER evaluates each system in the search space and ranks each according to the total net present cost. The specification of the search space almost always involves a tradeoff between accuracy and run time. The more values users specify for a particular decision variable, the longer HOMER will run. So on some occasions, users may choose to consider larger step sizes in order to find a solution faster. Or users may choose to perform a multi-stage optimization, where first users find a rough optimum using large steps and a broad range on all decision variables, and then re-specify the search space with a reduced range and smaller steps in order to find a more precise optimum. However, when choosing to optimize, the search space should be broad enough to encompass the optimum.

Constraints are conditions which system must satisfy. HOMER discards systems that do not satisfy the specified constraints, so they do not appear in the optimization results or sensitivity results. The variables of constraints include maximum annual capacity shortage and minimum renewable fraction.

## 3 Outputs

HOMER reports both optimal and near-optimal solutions. It has been integrated with a grid optimization model. Solutions are ranked by net present cost and displayed in the list control. Detailed outputs can be viewed by double clicking on any solution in the list control. Sensitivity results are often best analyzed graphically.

# V. INPUT/OUTPUT TEMPLATE FOR LOAD FLOW SOFTWARE

## 1 General Flowchart

The Load Flow software's general flowchart is shown in figure 4.

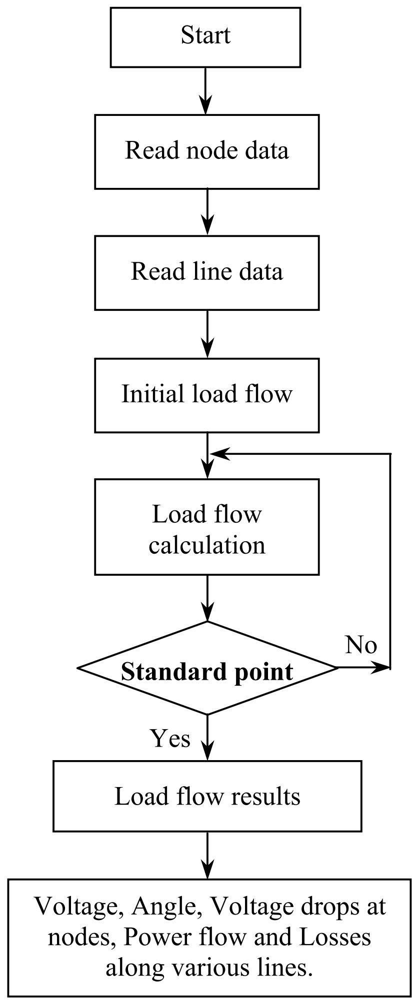


**Figure 4**: **General flowchart of load flow programming**

## 2 Data required

The output data of the network optimization software ViPOR will be used as the input to the load flow calculation.

Figure 5 shows a sample network for Load flow studies.

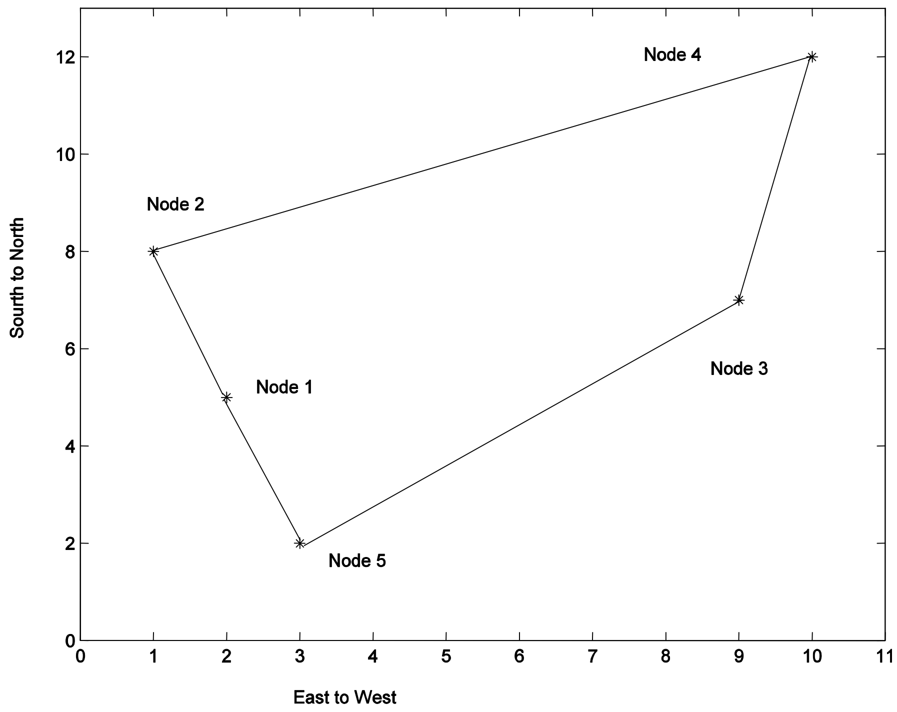


**Figure 5**: **A sample network for Load flow studies**.

## 3 Node Data

Load and source information with coordinates with respect to some reference point, this may be in the following form:

%Column 1 Node Number
%Column 2 Node Type (either load -1 or source-2 and for swing bus-3)
%Column 3 Voltage Magnitude (this can be set at 1.00 p.u. for the initial calculation at all load nodes)
%Column 4 Phase Angle (This can be set at zero)
%Column 5 Real Power Generation (p.u.)
%Column 6 Reactive Power Generation (p.u.)
%Column 7 Real Power Load (p.u.)
%Column 8 Reactive Power Load (p.u.)
%Column 9 Location information (coordinates, in miles: east to west and North to South)

## 4 Sample Node Data

**Table 1: Node Data of the Power Distribution Network**

| Node Number | Node Type | Voltage | Phase Angle | Real Power generation | Reactive Power generation | Real Power Load | Reactive Power Load | Location of the node |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 1.05 | 0 | 0.18 | 0.10 | 0 | 0 | (2,5) |
| 2 | 1 | 1.00 | 0 | 0 | 0 | 0.25 | 0.15 | (1,8) |
| 3 | 3 | 1.05 | 0 | 0.20 | 0.12 | 0 | 0 | (9,7) |
| 4 | 2 | 1.00 | 0 | 0.10 | 0.03 | 0 | 0 | (10,12) |
| 5 | 1 | 1.00 | 0 | 0 | 0 | 0.20 | 0.10 | (3,2) |

## 5 Branch Data

%Column 1 From Node
%Column 2 To Node
%Column 3 Resistance of the Branch or transformer (p.u.),
%Column 4 Reactance of the Branch or transformer (p.u.),
%Column 5 Line charging of the Branch (p.u.)

## 6 Sample Branch Data

**Table 2: Brach or Line Data of the Power Distribution Network**

| From Node | To Node | Resistance (p.u.) | Reactance (p.u.) | Line Charging (p.u.) |
|---|---|---|---|---|
| 1 | 2 | 0.001 | 0.01 | 0.0175 |
| 1 | 5 | 0.001 | 0.01 | 0.0175 |
| 2 | 4 | 0.005 | 0.05 | 0.0514 |
| 4 | 3 | 0.004 | 0.04 | 0.0415 |
| 3 | 5 | 0.002 | 0.02 | 0.0275 |

## 7 Outputs of Loadflow Module

1. Generation from all the sources
2. Line flows, Voltage Drops and Losses on the Lines.
3. Voltage and Angles at all the Nodes

# VI. INPUT/OUTPUT TEMPLATE FOR LEAP SOFTWARE

## 1 General Flowchart

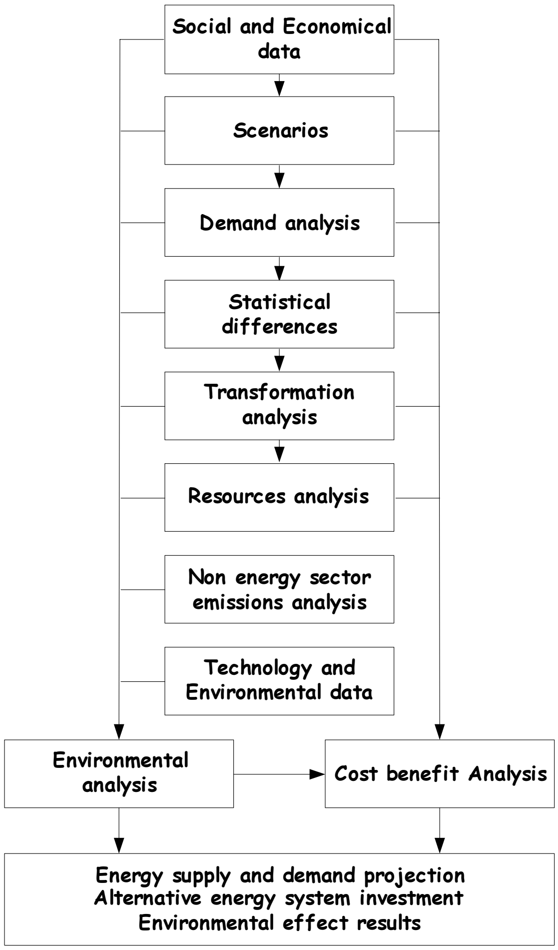


**Figure 6: Flowchart of the Long-range Energy Alternatives Planning System software**

## 2 Data required

### 1.1. Keys variables

- GDP (USD)
- Household size (people)
- Households (households)
- Income (USD)
- Population (household size*households) (people)
- Income growth rate (%).
- Population growth rate (%).
- End use urbanization (%).

### 1.2. Demand

- **Household**
    - **Urban:**
        - Refrigeration (saturation of households)
            - Existing (% share of households)
            - Efficiency (% share of households)

- Lighting (saturation of households)
    - Existing (% share of households)
    - Efficiency (% share of households)
- Other uses (saturation of households)
    - All (% share of households)
- Cooking (saturation of households)
    - Electric stoves (% share of households)
    - Natural gas stoves (% share of households)
        - Carbon dioxide non biogenic (kg/Terajoule)
        - Carbon monoxide (kg/Terajoule)
        - Methane (kg/Terajoule)
        - Non Methane Volatile Organic Compounds (kg/Terajoule)
        - Nitrogen oxides NOx (kg/Terajoule)
        - Nitrous oxide (kg/Terajoule)
        - Sulfur dioxide (kg/Terajoule)

- **Rural:**
    - Electrified households
        - Lighting
            - Electric (saturation of households)
            - Kerosene (saturation of households)
                - Carbon dioxide non biogenic (kg/Terajoule)
                - Carbon monoxide (kg/Terajoule)
                - Methane (kg/Terajoule)
                - Non Methane Volatile Organic Compounds (kg/Terajoule)
                - Nitrogen oxides NOx (kg/Terajoule)
                - Nitrous oxide (kg/Terajoule)
                - Sulfur dioxide (kg/Terajoule)
        - Other uses
        - Cooking (saturation of households)
            - Charcoal stoves (% share of households)
                - Carbon dioxide non biogenic (kg/Terajoule)
                - Carbon monoxide (kg/Terajoule)
                - Methane (kg/Terajoule)
                - Non Methane Volatile Organic Compounds (kg/Terajoule)
                - Nitrogen oxides NOx (kg/Terajoule)
                - Nitrous oxide (kg/Terajoule)
                - Sulfur dioxide (kg/Terajoule)
            - LPG stoves (% share of households)
                - Carbon dioxide non biogenic (kg/Terajoule)
                - Carbon monoxide (kg/Terajoule)
                - Methane (kg/Terajoule)
                - Non Methane Volatile Organic Compounds (kg/Terajoule)
                - Nitrogen oxides NOx (kg/Terajoule)
                - Nitrous oxide (kg/Terajoule)
                - Sulfur dioxide (kg/Terajoule)

        - Wood stoves (% share of households)
            - Carbon dioxide non biogenic (kg/Terajoule)
            - Carbon monoxide (kg/Terajoule)
            - Methane (kg/Terajoule)
            - Non Methane Volatile Organic Compounds (kg/Terajoule)
            - Nitrogen oxides NOx (kg/Terajoule)
            - Nitrous oxide (kg/Terajoule)
            - Sulfur dioxide (kg/Terajoule)
    - Refrigeration (saturation of households)
        - Existing (% share of households)
        - Efficiency (% share of households)
- Non Electrified households
    - Lighting
        - Kerosene (saturation of households)
            - Carbon dioxide non biogenic (kg/Terajoule)
            - Carbon monoxide (kg/Terajoule)
            - Methane (kg/Terajoule)
            - Non Methane Volatile Organic Compounds (kg/Terajoule)
            - Nitrogen oxides NOx (kg/Terajoule)
            - Nitrous oxide (kg/Terajoule)
            - Sulfur dioxide (kg/Terajoule)
    - Cooking (saturation of households)
        - Charcoal stoves (% share of households)
            - Carbon dioxide non biogenic (kg/Terajoule)
            - Carbon monoxide (kg/Terajoule)
            - Methane (kg/Terajoule)
            - Non Methane Volatile Organic Compounds (kg/Terajoule)
            - Nitrogen oxides NOx (kg/Terajoule)
            - Nitrous oxide (kg/Terajoule)
            - Sulfur dioxide (kg/Terajoule)
        - LPG stoves (% share of households)
            - Carbon dioxide non biogenic (kg/Terajoule)
            - Carbon monoxide (kg/Terajoule)
            - Methane (kg/Terajoule)
            - Non Methane Volatile Organic Compounds (kg/Terajoule)
            - Nitrogen oxides NOx (kg/Terajoule)
            - Nitrous oxide (kg/Terajoule)
            - Sulfur dioxide (kg/Terajoule)
        - Wood stoves (% share of households)
            - Carbon dioxide non biogenic (kg/Terajoule)
            - Carbon monoxide (kg/Terajoule)
            - Methane (kg/Terajoule)
            - Non Methane Volatile Organic Compounds (kg/Terajoule)
            - Nitrogen oxides NOx (kg/Terajoule)
            - Nitrous oxide (kg/Terajoule)

- Sulfur dioxide (kg/Terajoule)

- Industry
    - Iron and steel
        - Heat
            - Coal
                - Carbon dioxide non biogenic (kg/Terajoule)
                - Carbon monoxide (kg/Terajoule)
                - Methane (kg/Terajoule)
                - Non Methane Volatile Organic Compounds (kg/Terajoule)
                - Nitrogen oxides NOx (kg/Terajoule)
                - Nitrous oxide (kg/Terajoule)
                - Sulfur dioxide (kg/Terajoule)
            - Natural gas
                - Carbon dioxide non biogenic (kg/Terajoule)
                - Carbon monoxide (kg/Terajoule)
                - Methane (kg/Terajoule)
                - Non Methane Volatile Organic Compounds (kg/Terajoule)
                - Nitrogen oxides NOx (kg/Terajoule)
                - Nitrous oxide (kg/Terajoule)
                - Sulfur dioxide (kg/Terajoule)
        - Electricity (share)
    - Pulp and paper
        - Heat
            - Wood
                - Carbon dioxide non biogenic (kg/Terajoule)
                - Carbon monoxide (kg/Terajoule)
                - Methane (kg/Terajoule)
                - Non Methane Volatile Organic Compounds (kg/Terajoule)
                - Nitrogen oxides NOx (kg/Terajoule)
                - Nitrous oxide (kg/Terajoule)
                - Sulfur dioxide (kg/Terajoule)
        - Electricity
    - Other industry
        - Electricity
        - Fuel oil
            - Carbon dioxide non biogenic (kg/Terajoule)
            - Carbon monoxide (kg/Terajoule)
            - Methane (kg/Terajoule)
            - Non Methane Volatile Organic Compounds (kg/Terajoule)
            - Nitrogen oxides NOx (kg/Terajoule)
            - Nitrous oxide (kg/Terajoule)
            - Sulfur dioxide (kg/Terajoule)

- Transport (person)
    - Passenger (passenger/km)
        - Road (share)
            - Cars (share)
                - Conventional
                    - Carbon dioxide non biogenic (kg/Terajoule)
                    - Carbon monoxide (kg/Terajoule)
                    - Methane (kg/Terajoule)
                    - Non Methane Volatile Organic Compounds (kg/Terajoule)
                    - Nitrogen oxides NOx (kg/Terajoule)
                    - Nitrous oxide (kg/Terajoule)
                    - Sulfur dioxide (kg/Terajoule)
                - Hybrid
                    - Carbon dioxide non biogenic (kg/Terajoule)
                    - Carbon monoxide (kg/Terajoule)
                    - Methane (kg/Terajoule)
                    - Non Methane Volatile Organic Compounds (kg/Terajoule)
                    - Nitrogen oxides NOx (kg/Terajoule)
                    - Nitrous oxide (kg/Terajoule)
                    - Sulfur dioxide (kg/Terajoule)
            - Buses (share)
                - Conventional
                    - Carbon dioxide non biogenic (kg/Terajoule)
                    - Carbon monoxide (kg/Terajoule)
                    - Methane (kg/Terajoule)
                    - Non Methane Volatile Organic Compounds (kg/Terajoule)
                    - Nitrogen oxides NOx (kg/Terajoule)
                    - Nitrous oxide (kg/Terajoule)
                    - Sulfur dioxide (kg/Terajoule)
                - GNG
                    - Carbon dioxide non biogenic (kg/Terajoule)
                    - Carbon monoxide (kg/Terajoule)
                    - Methane (kg/Terajoule)
                    - Non Methane Volatile Organic Compounds (kg/Terajoule)
                    - Nitrogen oxides NOx (kg/Terajoule)
                    - Nitrous oxide (kg/Terajoule)
                    - Sulfur dioxide (kg/Terajoule)
        - Rail (share)
            - Diesel (share)
                - Carbon dioxide non biogenic (kg/Terajoule)
                - Carbon monoxide (kg/Terajoule)
                - Methane (kg/Terajoule)
                - Non Methane Volatile Organic Compounds (kg/Terajoule)

- Nitrogen oxides NOx (kg/Terajoule)
- Nitrous oxide (kg/Terajoule)
- Sulfur dioxide (kg/Terajoule)

- Electric (share)

- Freight (ton-km)
  - Road (share)
    - Diesel (share)
      - Carbon dioxide non biogenic (kg/Terajoule)
      - Carbon monoxide (kg/Terajoule)
      - Methane (kg/Terajoule)
      - Non Methane Volatile Organic Compounds (kg/Terajoule)
      - Nitrogen oxides NOx (kg/Terajoule)
      - Nitrous oxide (kg/Terajoule)
      - Sulfur dioxide (kg/Terajoule)
  - Rail (share)
    - Diesel (share)
      - Carbon dioxide non biogenic (kg/Terajoule)
      - Carbon monoxide (kg/Terajoule)
      - Methane (kg/Terajoule)
      - Non Methane Volatile Organic Compounds (kg/Terajoule)
      - Nitrogen oxides NOx (kg/Terajoule)
      - Nitrous oxide (kg/Terajoule)
      - Sulfur dioxide (kg/Terajoule)

- Commercial ($m^2$)
  - Heating
    - Fuel oil
      - Carbon Dioxide Non Biogenic (kg/Terajoule)
      - Carbon Monoxide (kg/Terajoule)
      - Methane (kg/Terajoule)
      - Nitrogen oxides Nox (kg/Terajoule)
      - Nitrous Oxide (kg/Terajoule)
    - Electricity
    - Natural gas
      - Carbon Dioxide Non Biogenic (kg/Terajoule)
      - Carbon Monoxide (kg/Terajoule)
      - Methane (kg/Terajoule)
      - Nitrogen oxides Nox (kg/Terajoule)
      - Nitrous Oxide (kg/Terajoule)

### 1.3. Statistical differences

- Primary
  - Coal (bituminous) (joule)
  - Natural gas (joule)
  - Wood (joule)

    - Woodx (joule)
- Secondary
    - Charcoal (joule)
    - Diesel (joule)
    - Electricity (joule)
    - Fuel oil (joule)
    - Gasoline (joule)
    - Kerosene (joule)
    - LPG (joule)

### 1.4. Transformation

- Transmission and Distribution
    - Processes
        - Electricity
            - Feedstock fuels: Electricity (% processes losses)
        - Natural gas
            - Feedstock fuels: Natural gas (% processes losses)
- Electricity generation
    - Process: new coal steam, new oil combustion turbine, hydro, existing coal steam, oil combustion turbine, biomass, wind, natural gas CC. The data required for each of technologies as followings:
        - Variable OM cost
        - Fuel cost
        - Capacity value
        - Max build capacity
        - Efficiency
        - Base year output
        - Exogenous capacity
        - Max capacity factor
        - Capital cost
        - Fixed OM cost
    - Output
        - Electricity
- Charcoal making
    - Processes:
        - Efficiency
    - Output fuels
        - Charcoal
- Oil refining
    - Processes:
        - Efficiency
        - Base year output
        - Exogenous capacity
        - Max capacity factor
        - Capacity value
        - Max build capacity
    - Output fuels: gasoline, kerosene, diesel, residual fuel oil, LPG
- Coal mining

- Processes:
    - Efficiency
    - Base year output
    - Exogenous capacity
    - Max capacity factor
    - Capacity value
    - Max build capacity
- Output fuels: coal (bituminous)

**1.5. Stock changes**

- Primary
    - Coal (Gigajounle)
    - Natural gas (Gigajounle)
    - Wood (Gigajounle)
    - Woodx (Gigajounle)
- Secondary
    - Charcoal (tone of oil equivalent)
    - Diesel (tone of oil equivalent)
    - Electricity (tone of oil equivalent)
    - Fuel oil (tone of oil equivalent)
    - Gasoline (tone of oil equivalent)
    - Kerosene (tone of oil equivalent)
    - LPG (tone of oil equivalent)

**1.6. Resources**

- Primary
    - Coal (bituminous) (Gigajoule)
    - Crude oil (Gigajoule)
    - Natural gas (Gigajoule)
    - Hydro (Gigajoule)
    - Wood (Gigajoule)
- Secondary
    - Charcoal (Gigajoule)
    - Diesel (Gigajoule)
    - Electricity (Gigajoule)
    - Fuel oil (Gigajoule)
    - Gasoline (Gigajoule)
    - Kerosene (Gigajoule)
    - LPG (Gigajoule)

**1.7. Non energy sector effects**

- Cement process emissions
    - Carbon dioxide Non biogenic (Tone)
- Landfill emissions
    - Methane (Tone)
- $CO_2$ sequestration
    - Carbon dioxide Non biogenic (Tone)

# 3 Output templates

## 2.1 Energy Demand

- Hierarchical accounting of energy demand
- Choice of methodologies
- Optional modeling of stock turnover

## 2.2 Energy Conversion

- Energy conversion sector (electric generation, transmission and distribution, CHP, oil refining, charcoal making, coal mining, oil extraction, ethanol production, etc.)
- Electric system dispatch based on electric load-duration curves.
- Exogenous and endogenous modeling of capacity expansion.

## 2.3 Energy Resources:

- Tracks requirements, production, sufficiency, imports and exports.
- Optional land-area based accounting for biomass and renewable resources.

## 2.4 Costs:

- Energy system costs: capital, fixed and variable O&M, fuel, costs of saving energy, environmental externalities.

## 2.5 Environment

- Emissions and direct impacts of energy system (e.g. Carbon dioxide, Carbon monoxide, Methane, Non Methane Volatile Organic Compounds, Nitrogen oxides, Nitrous oxide, Sulfur dioxide)
- Emissions from non-energy sector sources and sinks (e.g. Cement process emissions: Carbon dioxide, Landfill emissions: Methane, CO2 sequestration: Carbon dioxide).

# 4 License

License Types

| **Type of User** | **Fee for 2 year License** | **How to obtain a License:** |
|---|---|---|
| Non-profit/government/academic organization based in a developing country | No Charge | A user name and password are required to fully enable LEAP (allowing you to save changes to data). User names and passwords are provided only to licensed users of LEAP. To apply for a license, first carefully [illegible] |

| Type of User | Fee for 2 year License | How to obtain a License: |
|---|---|---|
| | | you agree to the terms, conditions, and disclaimers click **Apply for a LEAP License** at the foot of the screen. If any of the information is incorrect you must first edit your User Profile.<br>If your license application is approved, a user name and password will be sent to the email address listed on the form. License applications are normally reviewed on the day they are received, but the process may take a few days.<br>http://forums.seib.org/leap/default.asp?action=65 |
| Accredited academic institution (college, university or school) based in an industrialized country | $500 | Note: online ordering is now conducted through the Tellus institute online ordering system, http://store.yahoo.com/telluspublications/leaptwoyeara.html |
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*Note: Eligibility for each type of license will be verified. Contact SEI-B (leap@tellus.org) for information on multi-site and other licensing arrangements.*

Source: Community for Energy, Environment and Development, LEAP, Tools for Sustainable Energy Analysis, http://forums.seib.org/leap/default.asp?action=47.

## VII. INPUT/OUTPUT TEMPLATE FOR SOLARGIS SOFTWARE

### 1 General Flowchart

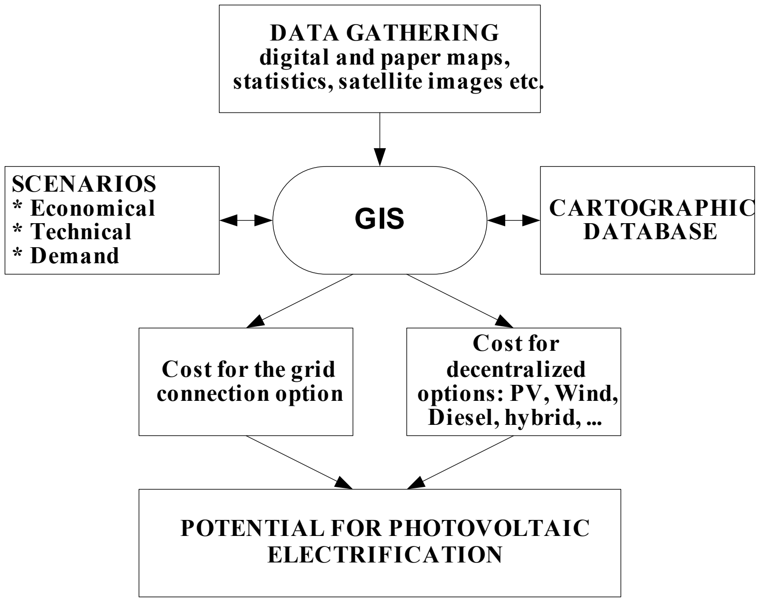



**Figure 7: Flowchart of the Solargis software**

# 2 Data required

## 2.1 Geographical data base

- Wind resource map (m/s): the data can be obtained from suggested sources below:

- NOABL (mass consistent model developed by Traci and Phillips in 1977)
- AIOLOS (mass consistent model developed by D. P. Lalas in 1988)
- WASP (dynamic model developed by Risoe National Laboratory, 1987)

This CD-ROM is mainly dedicated to the study of photovoltaic systems and does not contain more information on wind energy.

(Source: CENERG, http://www-cenerg.cma.fr/~st/solargis/)

- Solar resource map (kWh/m2.year): the solar data can be obtained from different available sources. The solar map can be developed by different methods (depending on available data, terrain complexity and the requested resolution). The methods are suggested below:

- Closest meteorological station data: The same values can be used on the whole region if there is no micro climate. This is the easiest method.
- Interpolation of meteorological stations data: This is recommended if the density of meteorological stations is high in the region.
- Solar radiation data received from satellite images: Estimation of solar radiation on the ground is a growing application of remote sensing (e.g. HELIOSAT model, analysing METEOSAT images). The basic idea of the models is that the amount of cloud cover over a given area statistically determines the global radiation for that zone.
- Considering hill shading: This method is recommended in complex terrain. The method simulates, with GIS, the sun trajectory and analyses the evolution of shadows.

This method allows a separation, for each hour of the day, of areas with only diffuse radiation from areas with diffuse and direct radiation and, as the next step, integrating the global radiation throughout the day. The model was implemented in a Shell-program using ArcInfo and other C programs. The accuracy of the results depends on the accuracy of the Digital Elevation Model (DEM).

- Population density map (people per $km^2$)

The localization of the potential electrical demand proceeds in two steps:

- Localize the potential consumers
- Quantify their need for electricity

- Medium Voltage Grid Connection Distance Map (km)

The investment cost of grid connection is depended on the length of the additional MV and LV lines and on the future demand. Depending on the accuracy needed, three methods can be used to calculate the connection length to the existing MV grid:

1. The connection length is equal to the shortest distance between the MV/LV substation and the existing MV lines. This is the simplest method but the connection length is overestimated as the possible share of the new equipment between neighbors is not considered.
2. A topology for the new MV lines is generated automatically using some robust algorithm. We have designed a code based on the Prim algorithm and implemented on Arcview and ArcInfo software. The generated topology is not economically optimal but has the advantage of being entirely automatic.
3. A planning expert from the electric utility draws the new MV lines. This is the best solution but also the more expensive.
   No map is required for the total length of low voltage lines in each pixel. This number will be estimated by correlation formulas in the Solargis Economical Analysis software.

**2.1 Technical and Economical data**

The below data categories are needed to be used to calculate the levelized electricity cost (LEC) values, to investigate different scenarios for the region project, they are below:

- Potential demand for electricity in isolated areas
- Global economical parameters (discount rate, fuel price, $CO_2$ tax...)
- The economical and technical parameters of the different electrification technologies (investment, lifetime, operating and maintenance, nominal efficiency, derated efficiencies ...).

## 3 Output templates

3.1 Levelized Electricity Cost Maps:

The current version can be used to help the planners to perform calculation in order to compare seven different rural electrification systems below:

- Photovoltaic stand alone generator
- Wind turbine stand alone generator
- Stand alone gasoline generator
- Stand alone diesel generator
- Mini-grid + hybrid Wind/Diesel for a village
- Mini-grid + Diesel for a village
- Connection to the existing centralized electric grid

3.2 High Potential Map for RE Systems

The lowest levelized electricity cost technology can be obtained for electrification system of each isolated area under different scenarios.

3.3 Statistics on the high potential areas

Finally, statistics are calculated on the high potential areas map to quantify the detected photovoltaic potential (estimating the total number of units, of their production, of their costs).

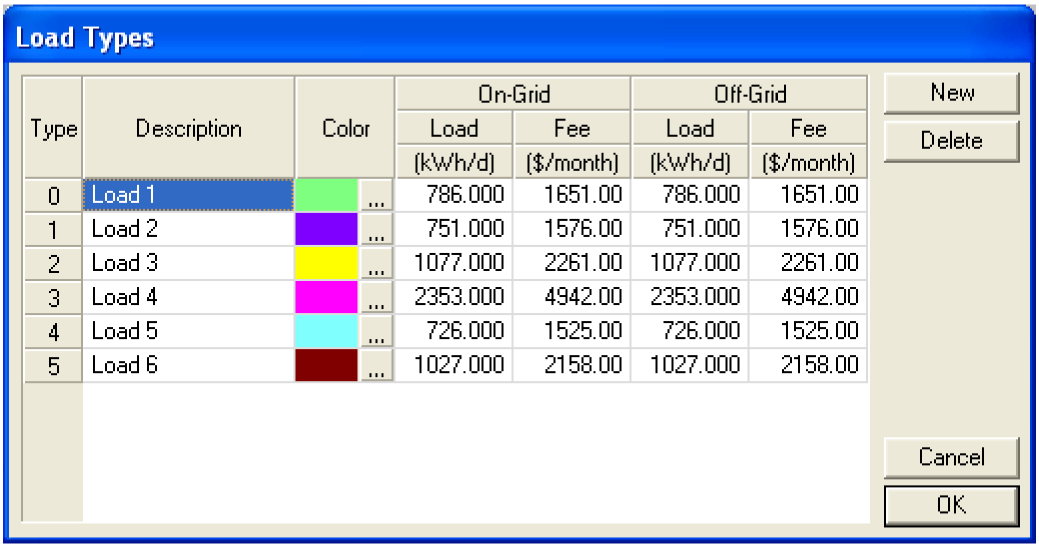
## Appendix B: VIPOR AND POWERFLOW SIMULATOR TESTING BY CASE STUDIES

### I. A CASE STUDY BY USING VIPOR SOFTWARE

A sample case study for a rural area has been developed for the demonstration of Vipor software. The main purpose of the case study is to be clear regarding the required input data and the applications of the Vipor software for the REDEO project.

### 1. Load type

Seven load types are defined. The required input data for different load types are presented in figure 1.




| Type | Description | Color | On-Grid Load (kWh/d) | On-Grid Fee ($/month) | Off-Grid Load (kWh/d) | Off-Grid Fee ($/month) |
|---|---|---|---|---|---|---|
| 0 | Load 1 | ... | 786.000 | 1651.00 | 786.000 | 1651.00 |
| 1 | Load 2 | ... | 751.000 | 1576.00 | 751.000 | 1576.00 |
| 2 | Load 3 | ... | 1077.000 | 2261.00 | 1077.000 | 2261.00 |
| 3 | Load 4 | ... | 2353.000 | 4942.00 | 2353.000 | 4942.00 |
| 4 | Load 5 | ... | 726.000 | 1525.00 | 726.000 | 1525.00 |
| 5 | Load 6 | ... | 1027.000 | 2158.00 | 1027.000 | 2158.00 |

**Figure 1**: The required input data for different load types

An area includes 6 load points. Electricity tariff is assumed to be 7 cent/kWh for both on grid, off grid options for all kind of load types (e.g. residential, agricultural, industrial, commercial etc), even though in real case it should be different at each load type and consumption time and for on gird and off grid.

### 2. Source types

Source type is the most complicated and difficult part in using the Vipor. From the recommendation of the software, the generation cost may be developed by the Homer software but only limited to wind turbines, PV panels, a single backup generator, and battery storage. Costs for other types of power systems (biomass, micro hydro, multiple diesels) must be estimated by some other means. For the case study, six source types are defined and presented as follows:

The detailed input data required for the source types are also presented in the following sections in terms of net present capital, annualized capital, O&M and Fuel cost.

## 2.1 Isolated

The generation cost for isolated source type has been developed by referring to some case studies from National Renewable Energy Laboratory (NREL) and they are presented in figure 2.

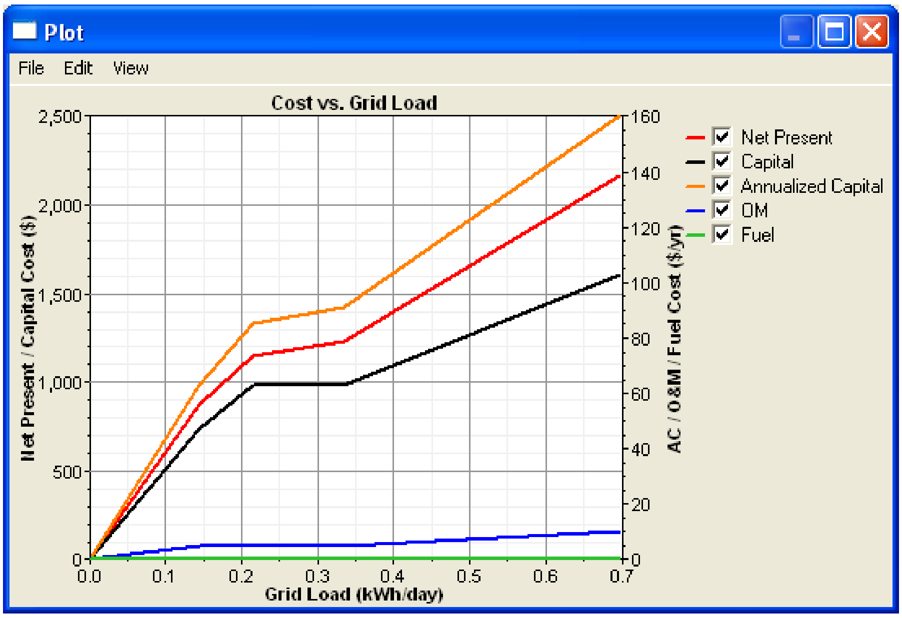



**Figure 2**: Generation cost curve for isolated source type

## 2.2 Hybrid source type

The generation cost for a hybrid source type has been developed by referring to some case studies from NREL and is presented in figure 3. The source type has been defined for a wind/diesel system.

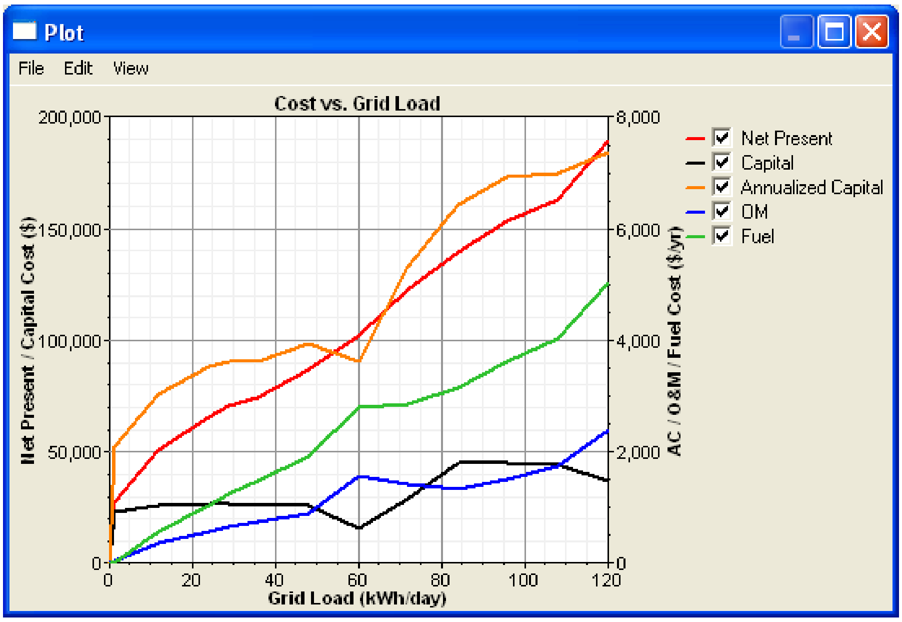



**Figure 3**: Generation cost curve for Hybrid source type

### 2.3 Grid extension source type

The generation cost for grid extension source type has been developed by referring to some case studies from NREL and is presented in figure 4.

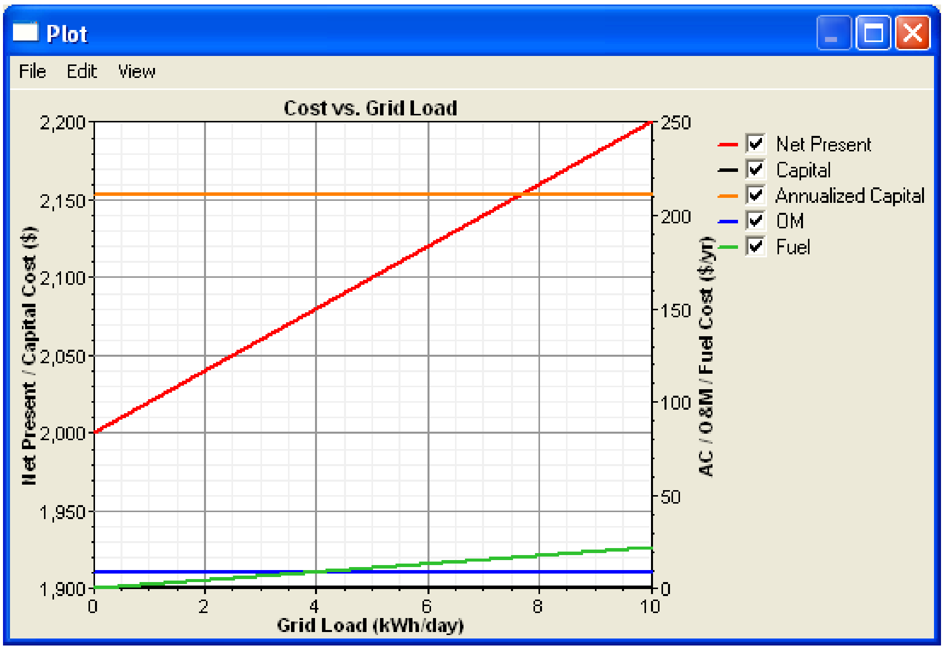



**Figure 4**: Generation cost curve for grid extension source type

### 2.4 Biomass source type

A generation cost for Biomass source type has been developed by referring to some case study from NREL and is presented in figure 5.

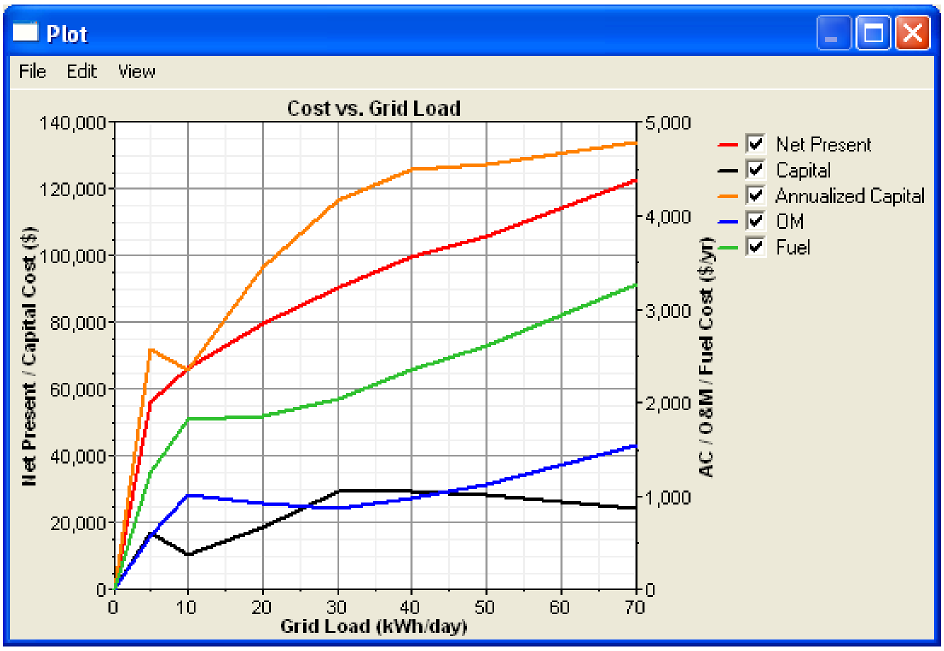



**Figure 5**: Generation cost curve for grid extension source type

## 2.5 Small hydro source type

A generation cost for Small hydro source type has developed by referring to some case studies from NREL and is presented in figure 6.

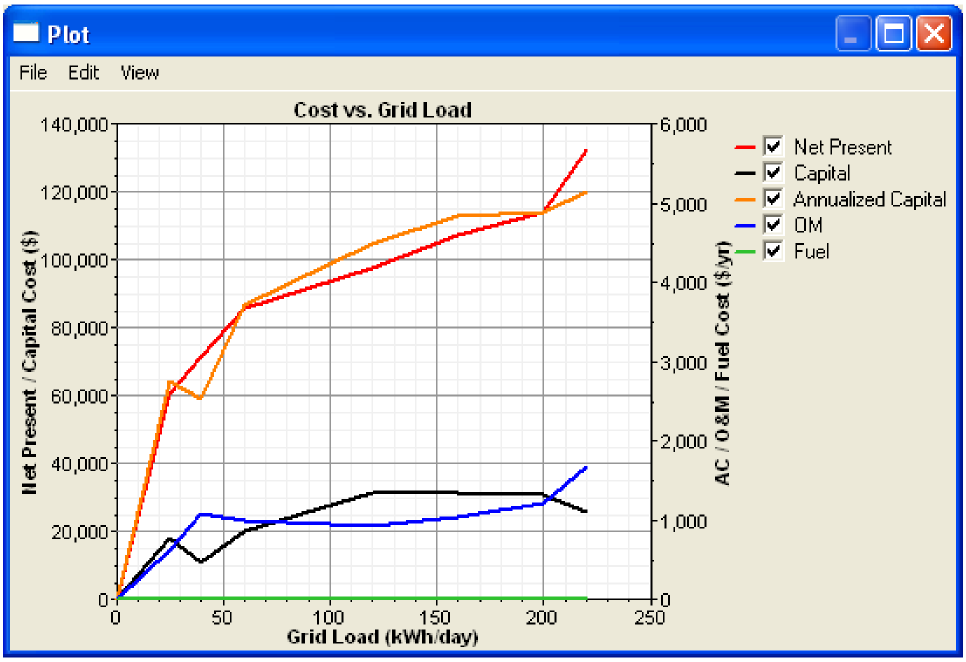



**Figure 6**: Generation cost curve for small hydro source type

## 2.6 Wind source type

A generation cost for Wind source type has been developed by referring to some case studies from NREL and is presented in figure 7.

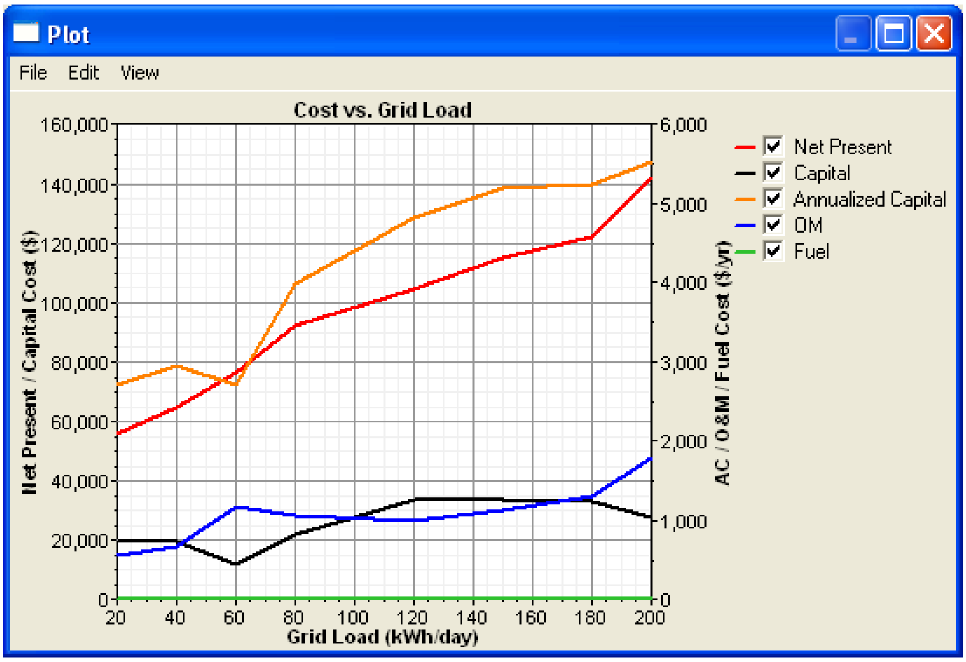



**Figure 7**: Generation cost curve for wind source type

## 3. Distribution

Distribution parameters in terms of capital cost, O&M cost is presented in figure 8. For low voltage line, the radius electricity supply is supposed to be around 600m from the transformer. The project lifetime is assumed to be 25 years. O&M cost is estimated as 2% of capital cost per year.

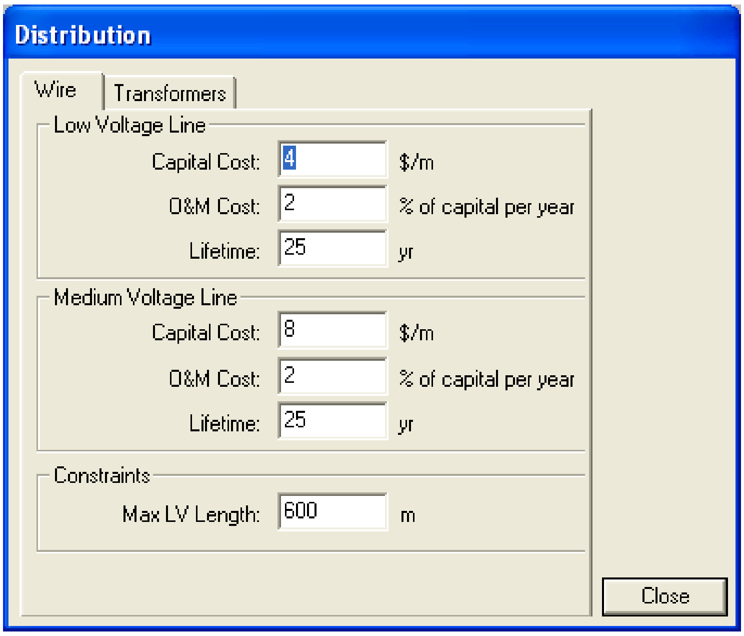



**Figure 8**: Distribution line cost parameters

The cost for connecting from low voltage network till meter at the load point is defined as connection charge. It includes the cost of connected line and meter for measurement of the electricity consumed by the load point.

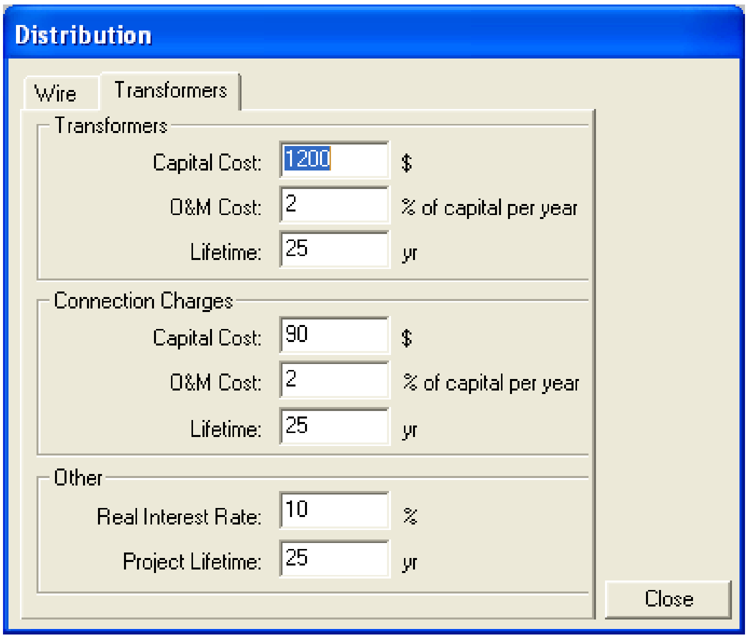



**Figure 9**: Transformer and connection cost parameters

## 4. Coordinator system

Universal Transverse Mercator, Lat/Long (decimal degrees), Lat/Long (deg/min/sec) system can be chosen by using Vipor. The coordinator system depends on the project area map source.

## 5. Results

### 5.1 Mixed option

The configuration of the distribution network is presented in figure 10, and Biomass source and small hydro power are chosen for electricity generation.

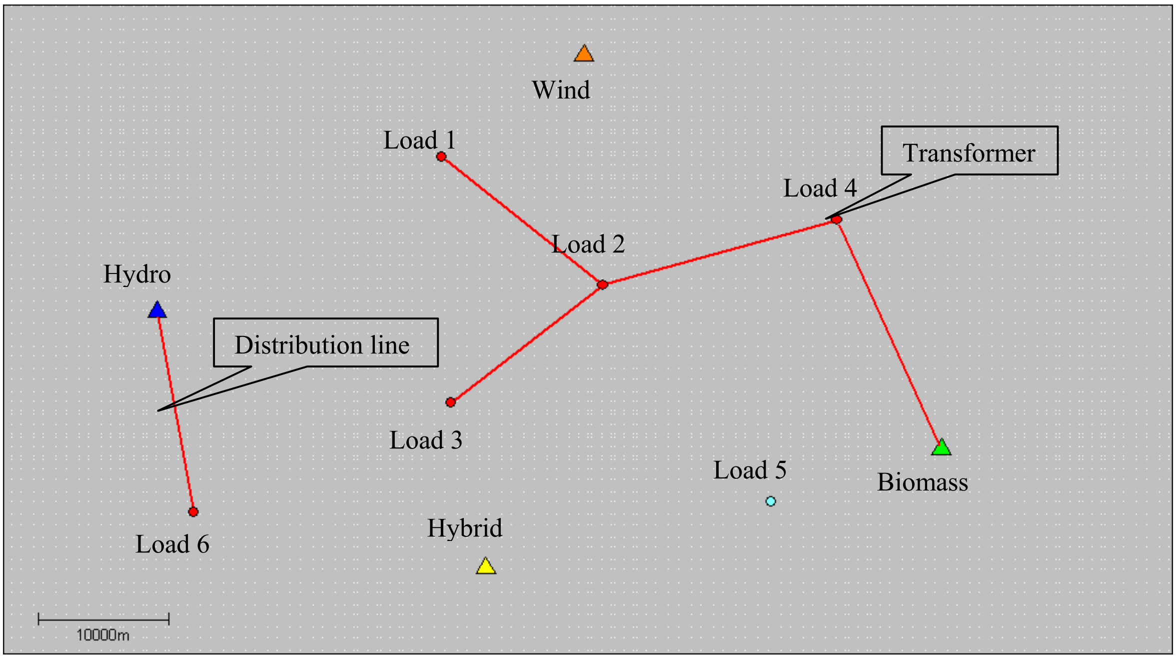



**Figure 10**: Configuration of the distribution network in mixed option

The cost vs. grid load is presented below:

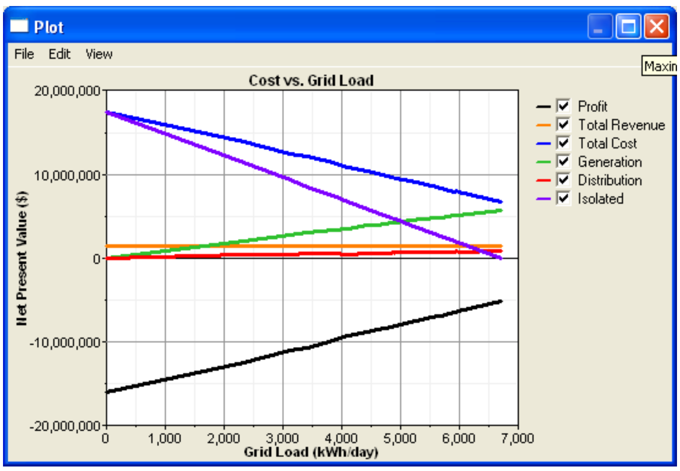



**Figure 11**: Cost vs. grid load in mixed option

An optimization algorithm called simulated annealing has been used in the Vipor software to design the least-cost distribution system. Randomly, ViPOR may add a node to the distribution grid, move a transformer, or select a different centralized system location. Any change that results in a lower total cost (called a downhill move) is accepted and the system is allowed to continue to evolve from that point. Otherwise, changes that result in a higher total cost (uphill moves) are treated probabilistically: some are accepted and some are rejected. If a change is rejected, the system returns to its previous state and another change is attempted. The tolerance of a simulated annealing algorithm to uphill moves is controlled by a parameter called *temperature*. The evolution of total cost is presented in figure 12.

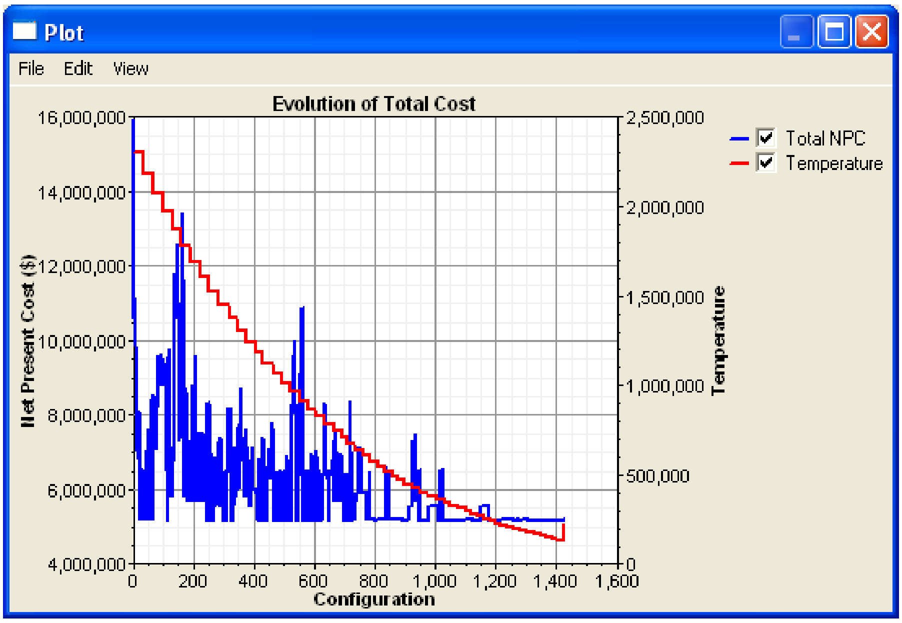
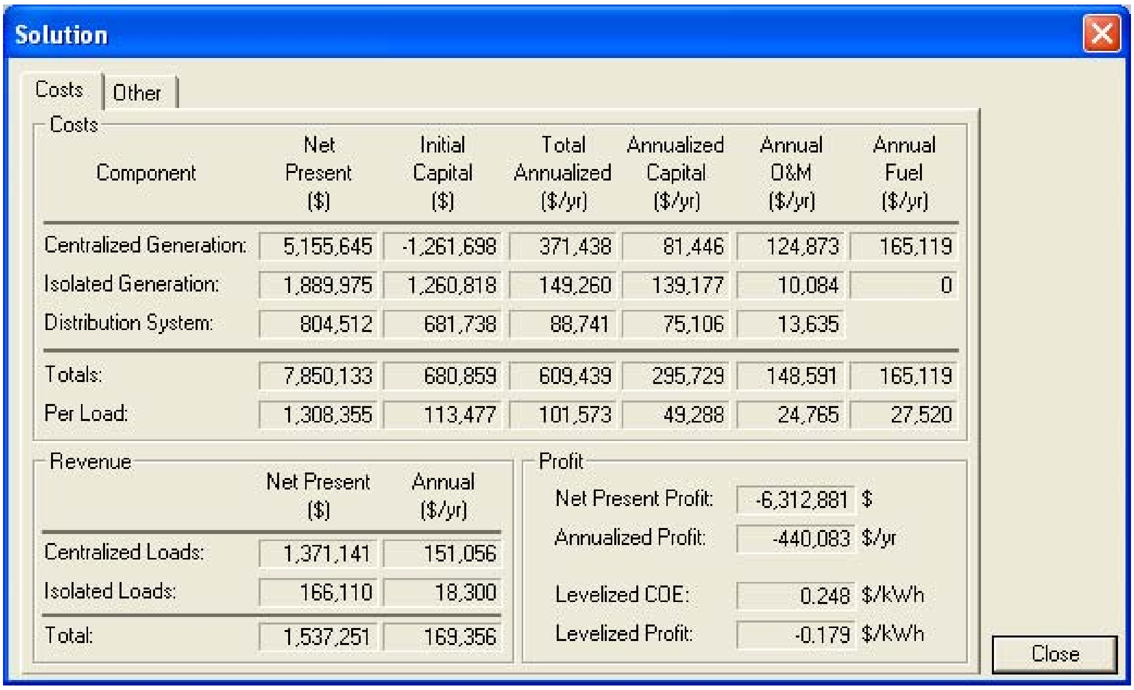



**Figure 12**: The evolution of total cost in mixed option

The cost breakdown is presented in figure 3.




Costs

| Component | Net Present ($) | Initial Capital ($) | Total Annualized ($/yr) | Annualized Capital ($/yr) | Annual O&M ($/yr) | Annual Fuel ($/yr) |
|---|---|---|---|---|---|---|
| Centralized Generation: | 5,155,645 | -1,261,698 | 371,438 | 81,446 | 124,873 | 165,119 |
| Isolated Generation: | 1,889,975 | 1,260,818 | 149,260 | 139,177 | 10,084 | 0 |
| Distribution System: | 804,512 | 681,738 | 88,741 | 75,106 | 13,635 | |
| Totals: | 7,850,133 | 680,859 | 609,439 | 295,729 | 148,591 | 165,119 |
| Per Load: | 1,308,355 | 113,477 | 101,573 | 49,288 | 24,765 | 27,520 |

Revenue

| | Net Present ($) | Annual ($/yr) |
|---|---|---|
| Centralized Loads: | 1,371,141 | 151,056 |
| Isolated Loads: | 166,110 | 18,300 |
| Total: | 1,537,251 | 169,356 |

Profit

| | | |
|---|---|---|
| Net Present Profit: | -6,312,881 | $ |
| Annualized Profit: | -440,083 | $/yr |
| Levelized COE: | 0.248 | $/kWh |
| Levelized Profit: | -0.179 | $/kWh |

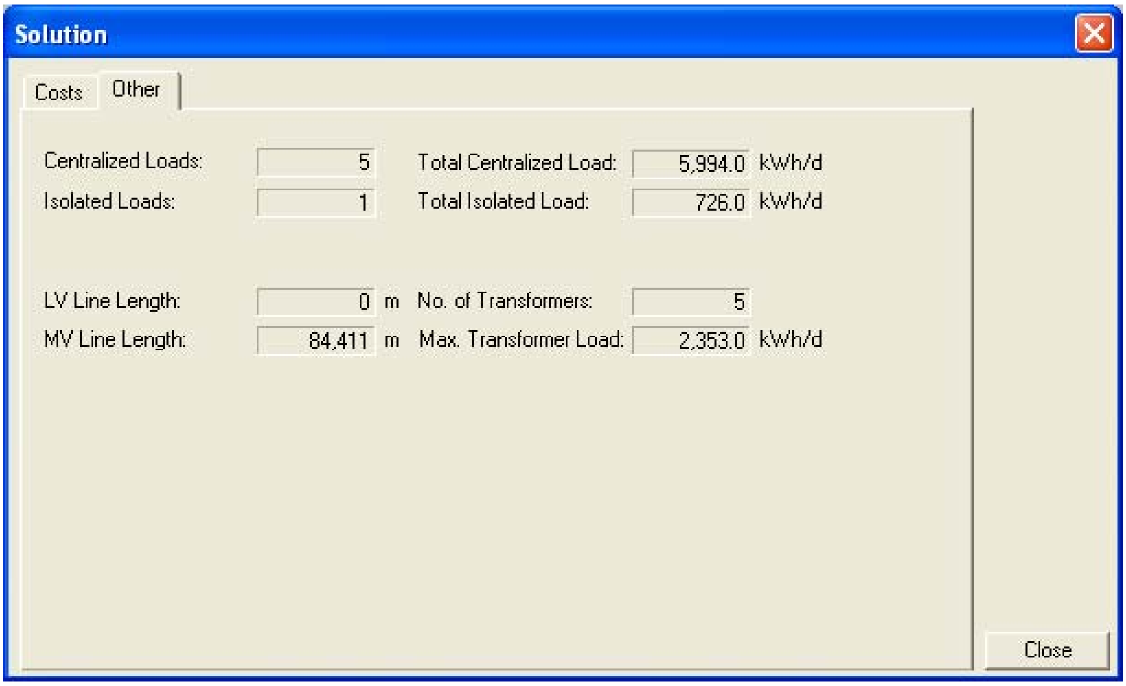



**Figure 13**: The cost breakdown for the network in mixed option

### 5.2 All centralized option

The configuration of the distribution network is presented in figure 14, and Biomass and hydro power sources are chosen for electricity generation.

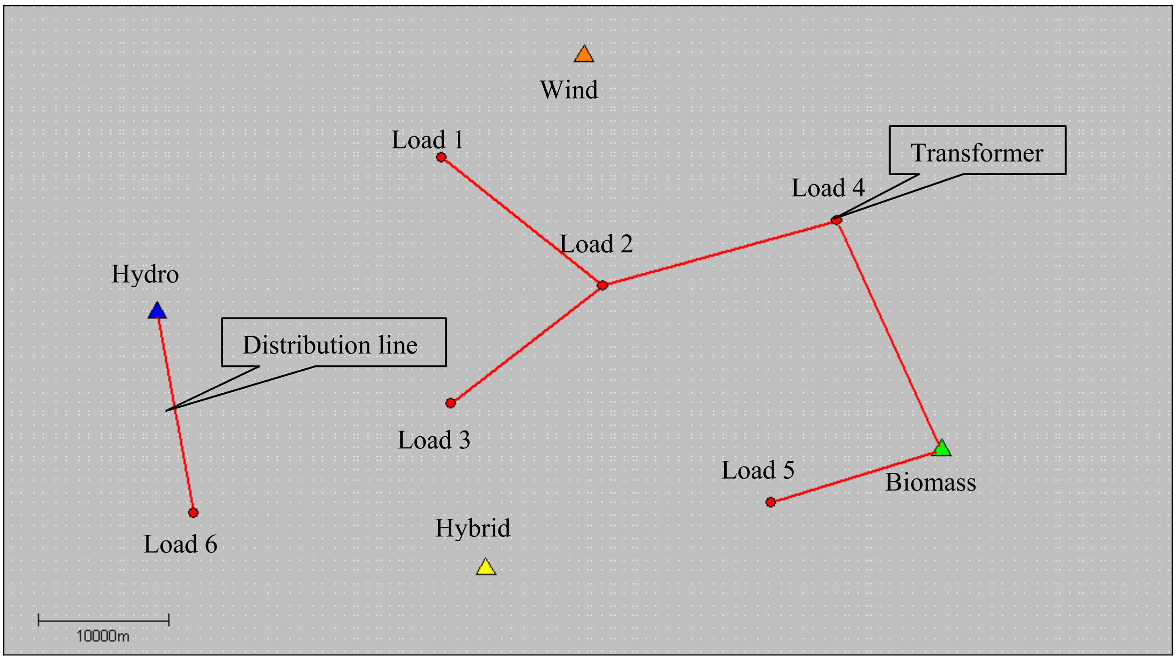
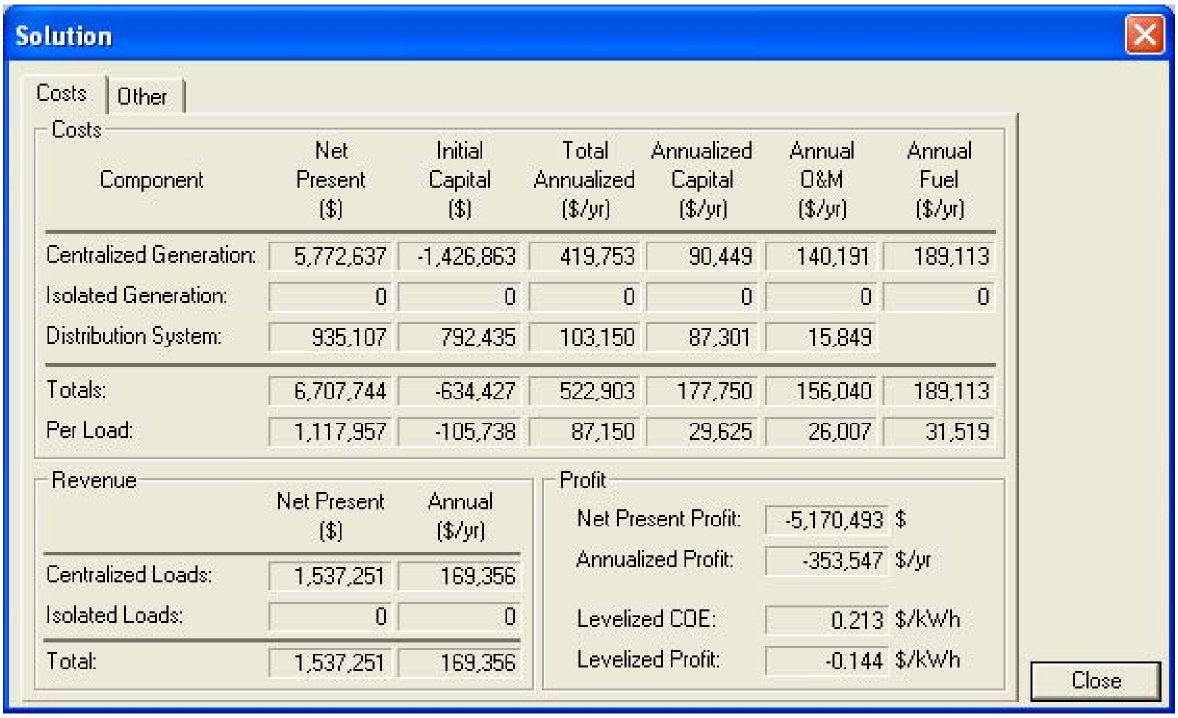



**Figure 14**: Configuration of the distribution network in all centralized option

The cost breakdown is presented in figure 15.



Solution

Costs | Other

Costs

| Component | Net Present ($) | Initial Capital ($) | Total Annualized ($/yr) | Annualized Capital ($/yr) | Annual O&M ($/yr) | Annual Fuel ($/yr) |
|---|---|---|---|---|---|---|
| Centralized Generation: | 5,772,637 | -1,426,863 | 419,753 | 90,449 | 140,191 | 189,113 |
| Isolated Generation: | 0 | 0 | 0 | 0 | 0 | 0 |
| Distribution System: | 935,107 | 792,435 | 103,150 | 87,301 | 15,849 | |
| Totals: | 6,707,744 | -634,427 | 522,903 | 177,750 | 156,040 | 189,113 |
| Per Load: | 1,117,957 | -105,738 | 87,150 | 29,625 | 26,007 | 31,519 |

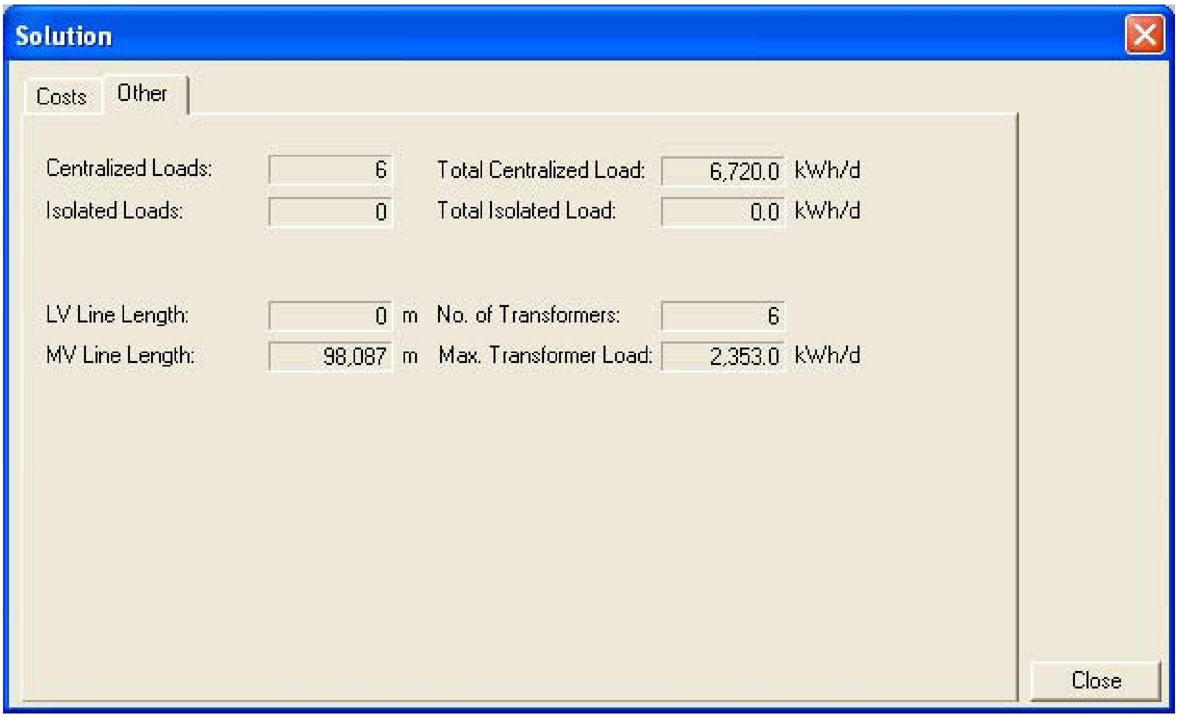
Revenue

| | Net Present ($) | Annual ($/yr) |
|---|---|---|
| Centralized Loads: | 1,537,251 | 169,356 |
| Isolated Loads: | 0 | 0 |
| Total: | 1,537,251 | 169,356 |

Profit

| | | |
|---|---|---|
| Net Present Profit: | -5,170,493 | $ |
| Annualized Profit: | -353,547 | $/yr |
| Levelized COE: | 0.213 | $/kWh |
| Levelized Profit: | -0.144 | $/kWh |

Close



Solution

Costs | Other

| | | | | | |
|---|---|---|---|---|---|
| Centralized Loads: | 6 | | Total Centralized Load: | 6,720.0 | kWh/d |
| Isolated Loads: | 0 | | Total Isolated Load: | 0.0 | kWh/d |
| LV Line Length: | 0 | m | No. of Transformers: | 6 | |
| MV Line Length: | 98,087 | m | Max. Transformer Load: | 2,353.0 | kWh/d |

Close

**Figure 15**: The cost breakdown for the network in all centralized option

## 5.3 All isolated option

The configuration of the distribution network is presented in figure 16.

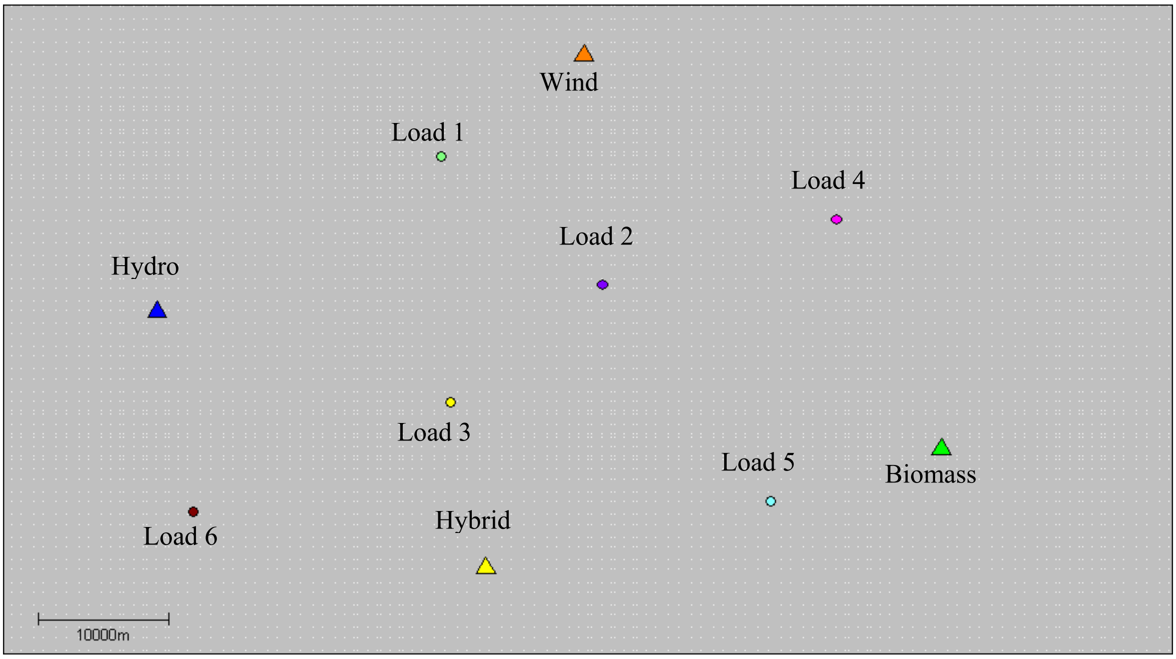
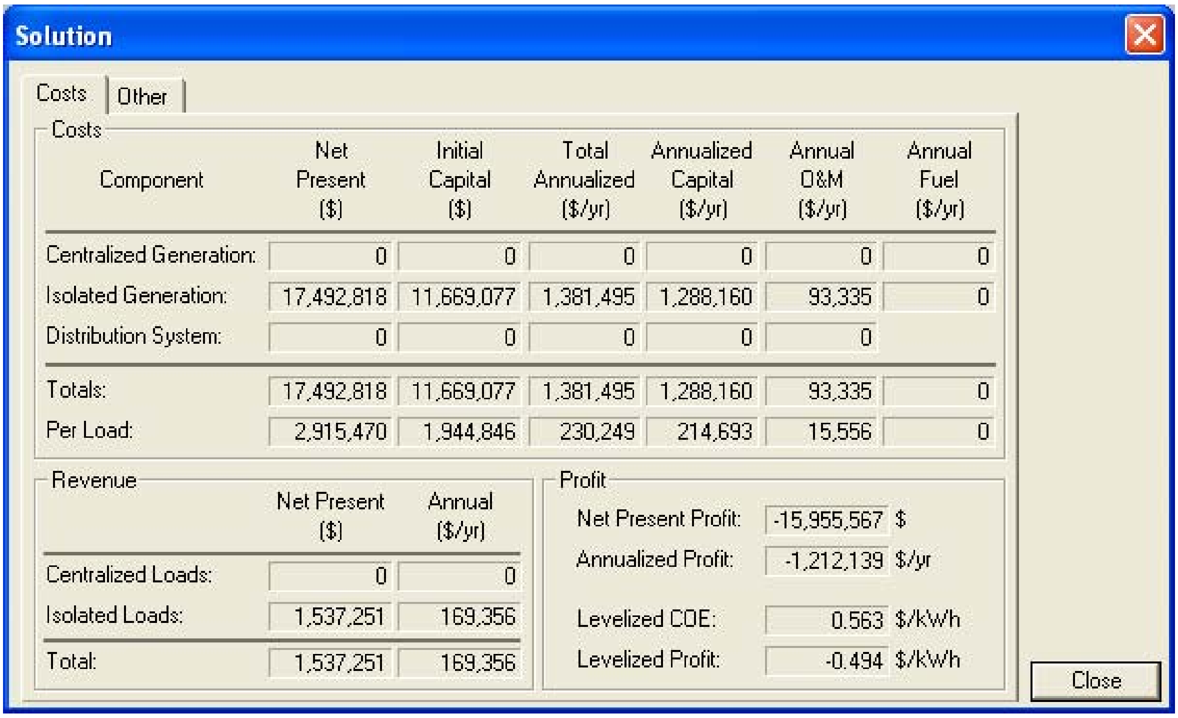



**Figure 16**: Configuration of the distribution network in isolated option

The cost breakdown is presented in figure 17.



Solution

Costs | Other

Costs

| Component | Net Present ($) | Initial Capital ($) | Total Annualized ($/yr) | Annualized Capital ($/yr) | Annual O&M ($/yr) | Annual Fuel ($/yr) |
|---|---|---|---|---|---|---|
| Centralized Generation: | 0 | 0 | 0 | 0 | 0 | 0 |
| Isolated Generation: | 17,492,818 | 11,669,077 | 1,381,495 | 1,288,160 | 93,335 | 0 |
| Distribution System: | 0 | 0 | 0 | 0 | 0 | |
| Totals: | 17,492,818 | 11,669,077 | 1,381,495 | 1,288,160 | 93,335 | 0 |
| Per Load: | 2,915,470 | 1,944,846 | 230,249 | 214,693 | 15,556 | 0 |

Revenue

| | Net Present ($) | Annual ($/yr) |
|---|---|---|
| Centralized Loads: | 0 | 0 |
| Isolated Loads: | 1,537,251 | 169,356 |
| Total: | 1,537,251 | 169,356 |

Profit

| | | |
|---|---|---|
| Net Present Profit: | -15,955,567 | $ |
| Annualized Profit: | -1,212,139 | $/yr |
| Levelized COE: | 0.563 | $/kWh |
| Levelized Profit: | -0.494 | $/kWh |

Close

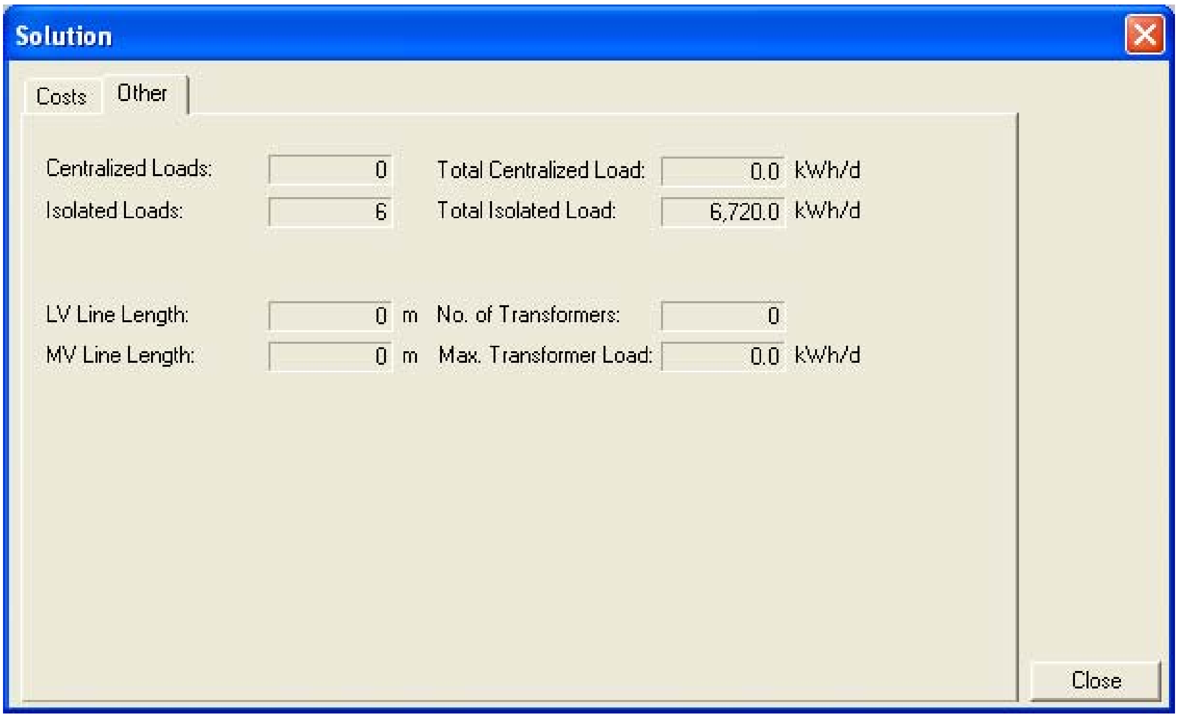



**Figure 17**: The cost breakdown for the network in isolated option

## 6. Results analysis

### 6.1 Load types

Load types depend on the user. For each load type, one specifies the average *daily electrical demand*, both on grid and off grid, in *kWh/day*. The *monthly electricity fee*, in *$/month*, also is required for each load type and it can be different for the on grid and off grid cases. The monthly electricity fee is used to calculate the revenue and the configuration which maximizes profit will be searched by the software. In case without monthly electricity fee, the revenue will be not considered and the software will simply minimize costs.

### 6.2 Source types

The source types are the most complicated part in using Vipor. The definition of the source types normally combines using Homer software or others. A generation cost curve is required before using Vipor. The generation cost curve presents how the generation costs increase with system size. Thus, *net present cost ($)*, *capital cost ($)*, *annualized capital ($/year)*, *O&M ($/year)* and *Fuel cost ($/year)* are required as the input data for using Vipor.

### 6.3 Results

The Vipor software is concerned with the overall cost of electrification, thus generation and distribution costs are included. Furthermore, under different scenarios, electricity could be supplied/generated from different source types, say individual solar home systems or centralized system of varying size or it could be come from a larger distribution grid if the project area is not so far from the current grid and the connection is seen more economic, or electricity can be generated by mixing all options.

The results obtained after running the Vipor is an optimal configuration of planning network with an economic generation and distribution. The configuration presents what kind of source type must be chosen and the number and the location of transformers that must be installed in order to meet the demand at the project area.

A cost break down of the configuration will be presented as the final result in terms of *net present cost ($)*, *capital cost ($)*, *annualized capital ($/year)*, *O&M ($/year)* and *Fuel cost ($/year)*.

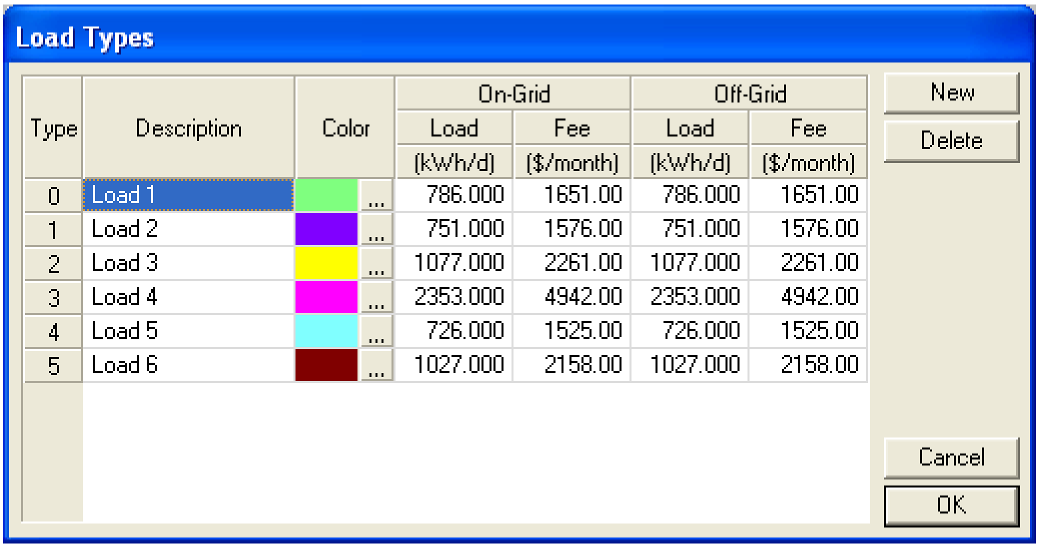
The cost components will be separated in centralized or isolated generation, distribution. Cost per load is also calculated by the Vipor software. The revenue is calculated from the monthly electricity fees.

## 7. Conclusions

### 7.1 Input data for load types

Generally, the number of load point is unlimited in Vipor. For each load type, input data requires the average *daily electrical demand*, both on grid and off grid, in *kWh/day*.

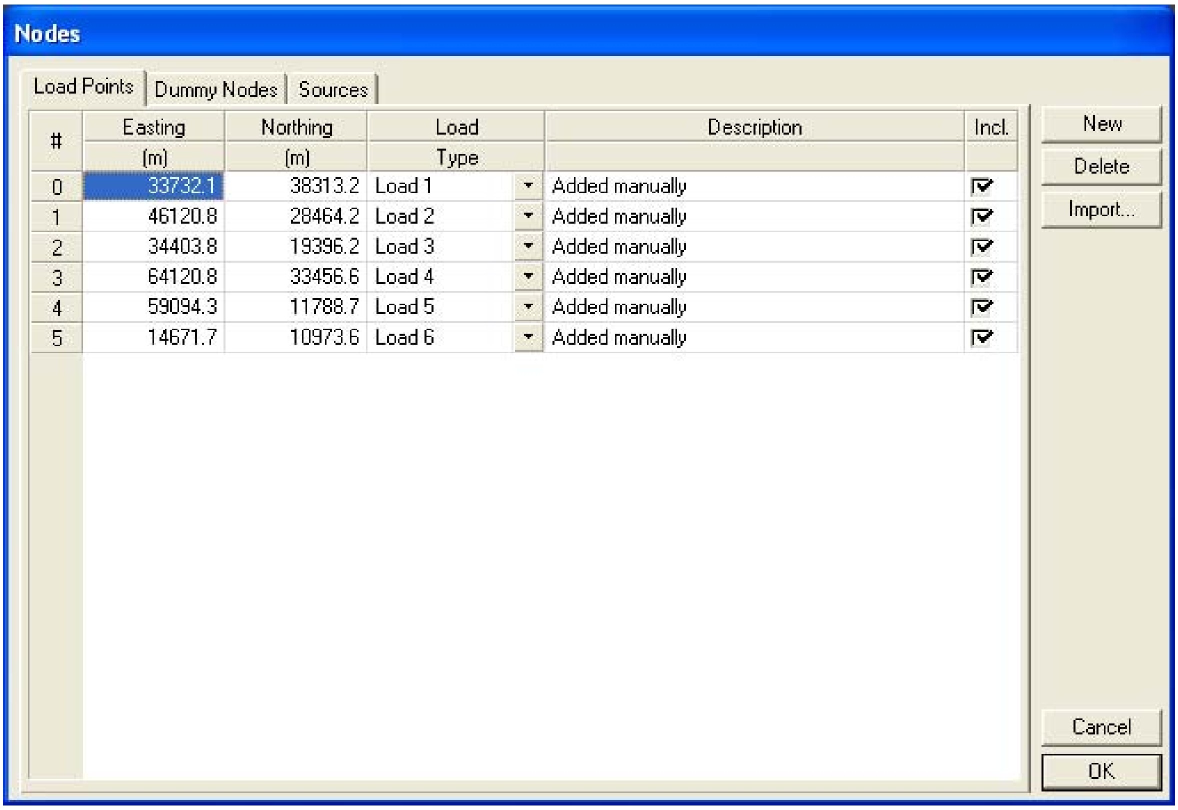
The *monthly electricity fee*, in *$/month*, is also required and it can be different for the on grid and off grid. The required input data for different load types are presented in figure 18.




| Type | Description | Color | On-Grid Load (kWh/d) | On-Grid Fee ($/month) | Off-Grid Load (kWh/d) | Off-Grid Fee ($/month) |
|---|---|---|---|---|---|---|
| 0 | Load 1 | ... | 786.000 | 1651.00 | 786.000 | 1651.00 |
| 1 | Load 2 | ... | 751.000 | 1576.00 | 751.000 | 1576.00 |
| 2 | Load 3 | ... | 1077.000 | 2261.00 | 1077.000 | 2261.00 |
| 3 | Load 4 | ... | 2353.000 | 4942.00 | 2353.000 | 4942.00 |
| 4 | Load 5 | ... | 726.000 | 1525.00 | 726.000 | 1525.00 |
| 5 | Load 6 | ... | 1027.000 | 2158.00 | 1027.000 | 2158.00 |

**Figure 18**: The required input data for different load types

The load point locations depend on coordinator system and the detailed input data is presented in figure 19.

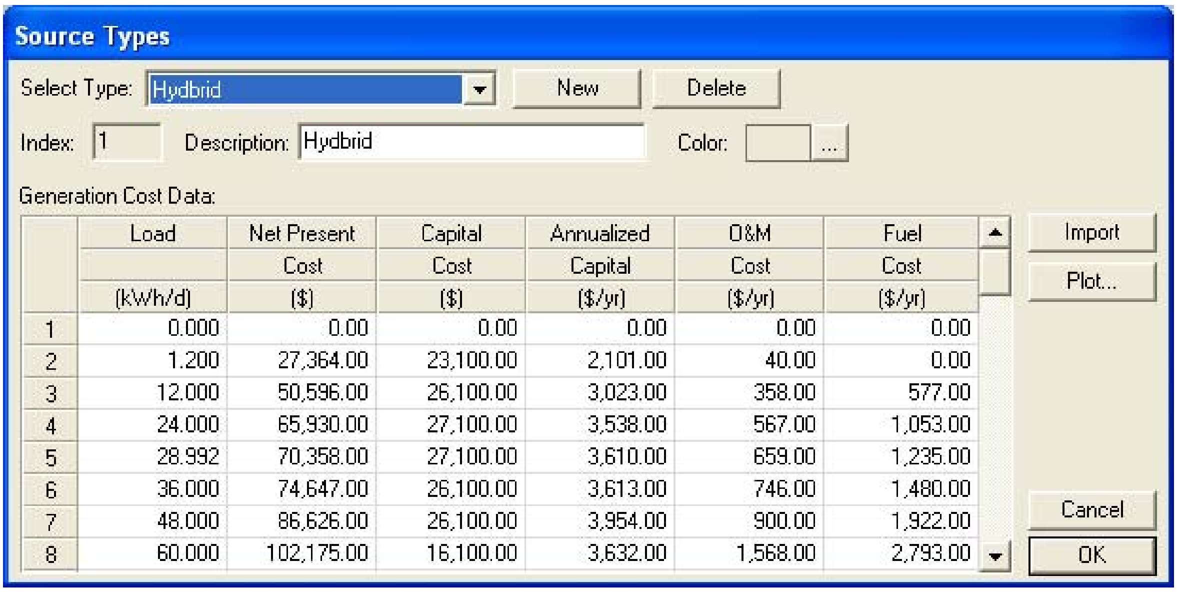



| # | Easting (m) | Northing (m) | Load Type | Description | Incl. |
|---|---|---|---|---|---|
| 0 | 33732.1 | 38313.2 | Load 1 | Added manually | ☑ |
| 1 | 46120.8 | 28464.2 | Load 2 | Added manually | ☑ |
| 2 | 34403.8 | 19396.2 | Load 3 | Added manually | ☑ |
| 3 | 64120.8 | 33456.6 | Load 4 | Added manually | ☑ |
| 4 | 59094.3 | 11788.7 | Load 5 | Added manually | ☑ |
| 5 | 14671.7 | 10973.6 | Load 6 | Added manually | ☑ |

**Figure 19**: Input data for load point location

### 7.2 Input data for source types

In the current Vipor, only ten source candidates are allowed for analysis. For each, <u>*Net present cost ($)*</u>, <u>*capital cost ($)*</u>, <u>*annualized capital ($/year)*</u>, <u>*O&M ($/year)*</u> and <u>*Fuel cost ($/year)*</u> are required as the input data. A detailed illustration for one source type is presented in figure 20.




| | Load (kWh/d) | Net Present Cost ($) | Capital Cost ($) | Annualized Capital ($/yr) | O&M Cost ($/yr) | Fuel Cost ($/yr) |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 1.200 | 27,364.00 | 23,100.00 | 2,101.00 | 40.00 | 0.00 |
| 3 | 12.000 | 50,596.00 | 26,100.00 | 3,023.00 | 358.00 | 577.00 |
| 4 | 24.000 | 65,930.00 | 27,100.00 | 3,538.00 | 567.00 | 1,053.00 |
| 5 | 28.992 | 70,358.00 | 27,100.00 | 3,610.00 | 659.00 | 1,235.00 |
| 6 | 36.000 | 74,647.00 | 26,100.00 | 3,613.00 | 746.00 | 1,480.00 |
| 7 | 48.000 | 86,626.00 | 26,100.00 | 3,954.00 | 900.00 | 1,922.00 |
| 8 | 60.000 | 102,175.00 | 16,100.00 | 3,632.00 | 1,568.00 | 2,793.00 |

**Figure 20**: Input data for source types

Source point locations also depend on coordinator system and detailed input data with load point location is presented in figure 21.

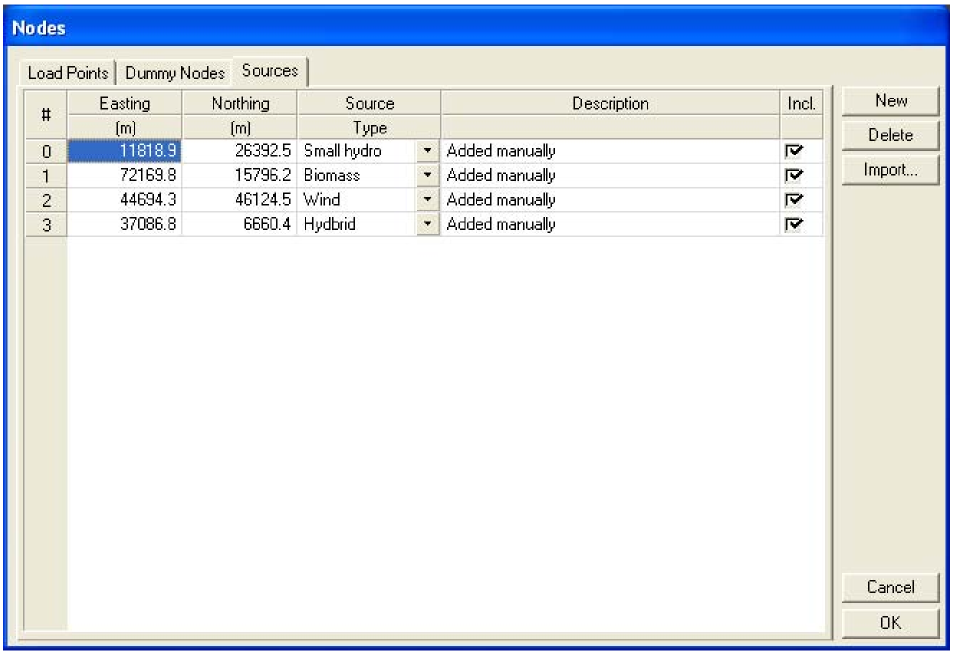



**Figure 21**: Input data for source location

### 7.3 Other input data

Terrain considerations are usually important in determining the optimal layout of a distribution network. In ViPOR, terrain is included in the analysis by defining a terrain grid of a particular resolution and then assigning a terrain cost multiplier to each grid cell. Generally, terrain types have been identified such as water (extremely expensive), forest (moderately expensive), grassland (less expensive than forest), and the area along an existing trail or road (the least expensive). An illustration is presented in figure 22.

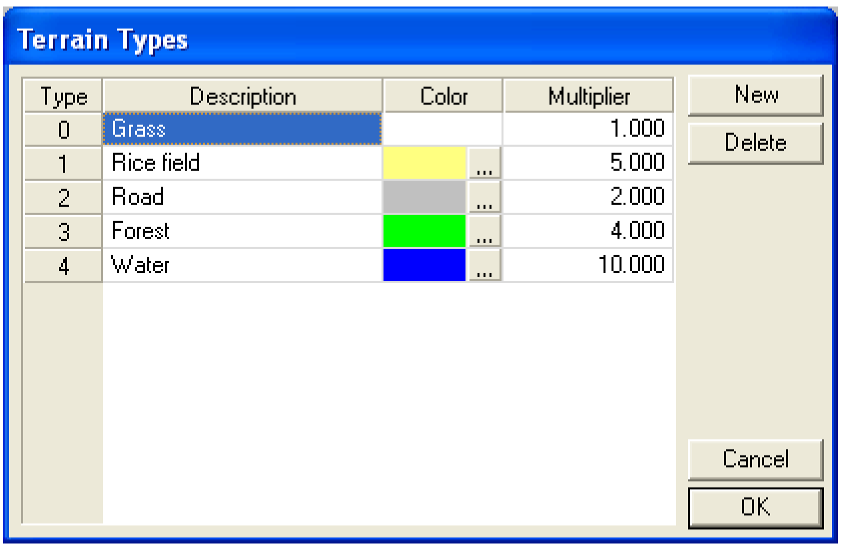



**Figure 22**: Input data for terrain types

In Vipor software, linear features are simply collections of points connected by lines, and so the expected format is one point on each line. The appropriate format of a point depends on the coordinate system used, as detailed in figure 23.

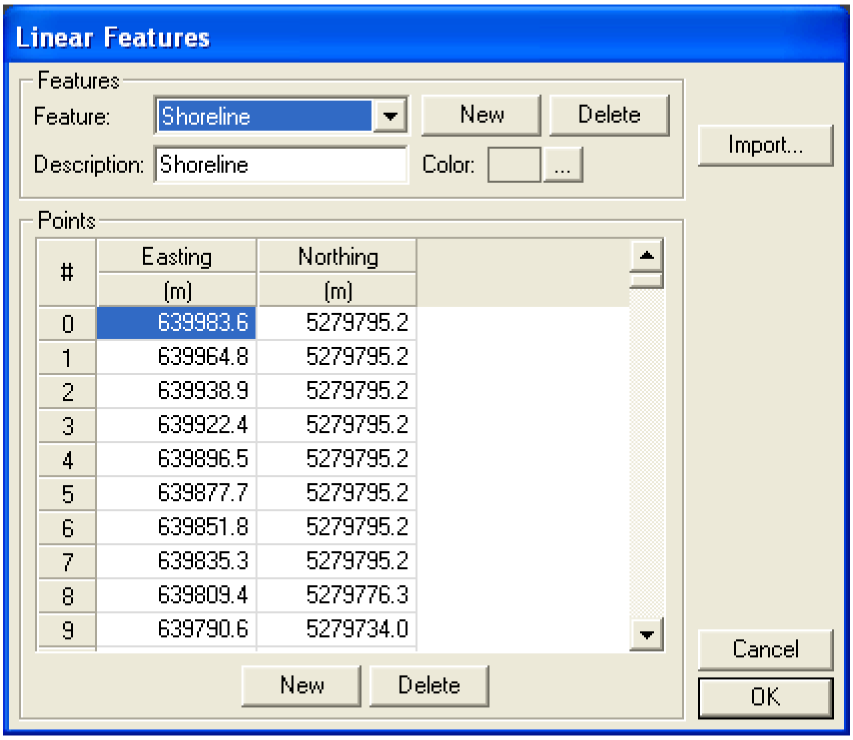
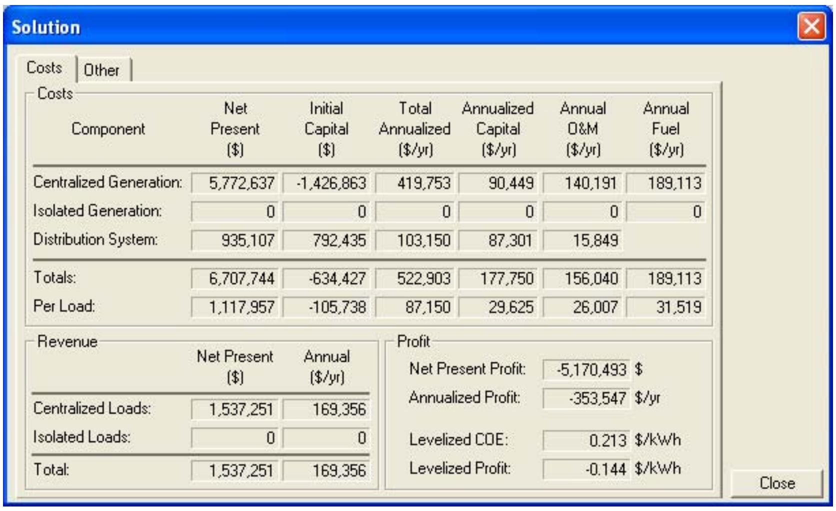



**Figure 23**: Input data for linear features

### 7.4 Output templates

The optimal configuration network will be obtained and separated into mixed or all centralized or isolated option. In each option, the total cost will be separated in terms of generation costs and distribution costs, and the costs per load are also calculated. Furthermore, for each option, a cost break down of the configuration will be presented in terms of <u>*net present cost ($)*</u>, <u>*capital cost ($)*</u>, <u>*annualized capital ($/year)*</u>, <u>*O&M ($/year)*</u> and <u>*Fuel cost ($/year)*</u>. An illustration for an output is presented in figure 24.



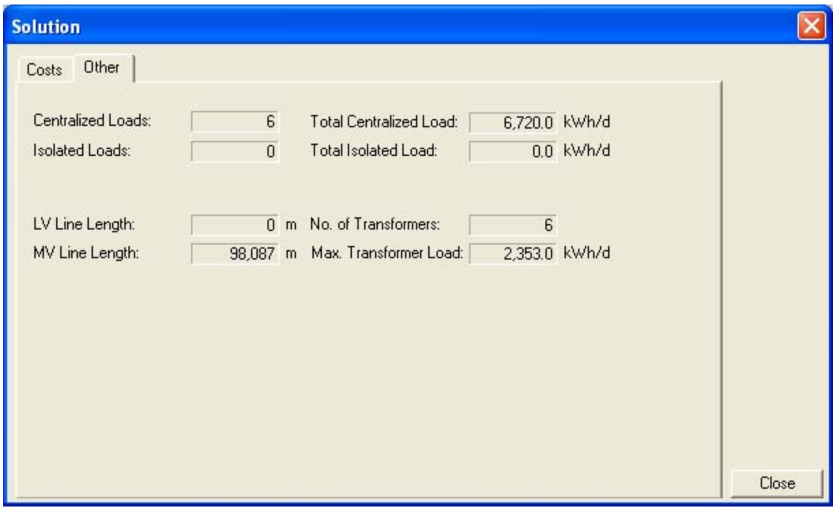



**Figure 24**: Output template for optimal configuration network

The total cost for each level of load, load points report, transformers report and sources report is presented in table 1, table 2, table 3 and table 4, respectively.

| Load (kWh/day) | Total Cost ($) | Gen. Cost ($) | Dist. Cost ($) | Isolated Cost ($) |
|---|---|---|---|---|
| 0 | 17492818 | 0 | 0 | 17492818 |
| 751 | 16482310 | 618387.75 | 326149.5 | 15537773 |
| 786 | 16334220 | 650421.5 | 237122.05 | 15446676 |
| 2539 | 13559898 | 2267909 | 408699.28 | 10883290 |
| 3104 | 12727801 | 2771971 | 542752.25 | 9413078 |
| … | … | … | … | … |
| 5934 | 7934978 | 5104654 | 784182.19 | 2046141.9 |
| 5969 | 8025023.5 | 5136198 | 933780.81 | 1955044.6 |
| 5994 | 7981200.5 | 5157444.5 | 933780.81 | 1889975.3 |
| 6720 | 6707743.5 | 5772636.5 | 935107.13 | 0 |

**Table 1**: Total cost for each level of load

Load Points

| Number | Type | Description | Load size (kWh/d) | Wire Run (m) | Depth (m) |
|---|---|---|---|---|---|
| 0 | Load 1 | Added manually | 786 | 0 | 0 |
| 1 | Load 2 | Added manually | 751 | 0 | 0 |
| 2 | Load 3 | Added manually | 1077 | 0 | 0 |
| 3 | Load 4 | Added manually | 2353 | 0 | 0 |
| 4 | Load 5 | Added manually | 726 | 0 | 0 |
| 5 | Load 6 | Added manually | 1027 | 0 | 0 |

Only distribution has been considered in the case study.

**Table 2**: Load points report

Transformers

| Type | Number | Load (kWh/d) | Wire Run (m) |
|---|---|---|---|
| Load | 0 | 786 | 15,827 |
| Load | 1 | 751 | 18,680 |
| Load | 2 | 1,077 | 14,816 |
| Load | 3 | 2,353 | 19,408 |
| Load | 4 | 726 | 13,676 |
| Load | 5 | 1,027 | 15,681 |

**Table 3**: Transformers report

Sources

Sources types have been chosen

| Number | Description | Load (kWh/d) |
|---|---|---|
| 0 | Added manually | 1,027 |
| 1 | Added manually | 5,693 |
| 2 | Added manually | 0 |
| 3 | Added manually | 0 |

**Table 4**: Sources report

## II. A CASE STUDY BY USING POWERWORLD SIMULATOR SOFTWARE

This document gives details of the input/output template of "power flow" or "load flow" software module.

The input/output template is explained through an example of a 6 nodes test system. There are various programs available (free) for solving load flow problems. However, POWERWORLD Simulator (PWS) from Power World Corporation seems to be more attractive in terms of user friendliness and visual display options. Demonstration PWS software with some limitation on number of nodes is available free at "http://www.powerworld.com/downloads.html". This document is prepared based on the POWERWORLD Simulator software.

**PURPOSE:** The main aim of the software is to run load flow and calculate voltage drops and losses to see whether there is any serious violation such as voltages and power losses.

**INPUT:** Network configuration, including loads, sources, line and transformers parameters information.

**OUTPUT:** Voltage and Angle at various loads, voltage drops and losses along various lines.

### 2.1 Test System

Figure 1 shows single line diagram of a sample rural electrification network of a province, which could be an output of the ViPOR or similar software for network optimization. The main aim of the load flow is to see the various electrification alternative plans that obtained form network optimization software meets various regulations, including voltage drop and real power losses. If it does not meet the regulations, remedial measures can be employed in various alternative scenarios.

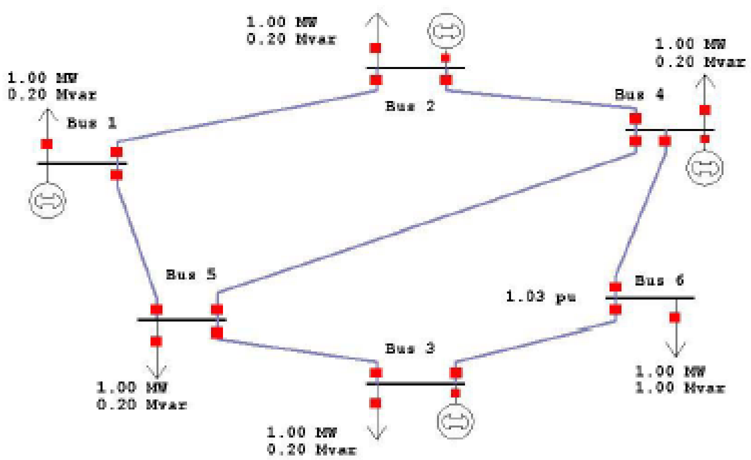



**Figure 1**: Single line diagram of provincial rural electrification network

In this example, there are 6 nodes (BUS), including four generating plants. Generators are located at Bus 1, Bus 2, Bus 3 and Bus 4. All the nodes have loads and the values of real and reactive power loads are displayed in the diagram and are also tabulated in table 1, in the input data section. The system has a total real and reactive load of 6 MW and 1.4 Mvar, respectively. The system has seven transmission lines and no transformers.

## 2.2 Input Data

Input data required for the load flow solutions are summarized in tables 1 to 3. The load data in table 1 can be obtained from load forecasting software. It should be noted that in load forecasting module, reactive power load should be estimated at each load point by assuming certain value of power factor at each load group. The reactive power load is an important input in the load flow simulation. Given a load value of X MW with a power factor of cosφ, the reactive power load and the MVA load can be calculated using the equations (1) and (2), respectively. Typical Power factor values can be assumed based on different load groups.

Reactive Power Load (Y)

$$Y = X \tan \phi \qquad (1)$$

MVA Load (Z)

$$Z = \frac{X}{Cos \phi} \qquad (2)$$

The other input data for load flow simulation is the voltage level, which will be an output of the network optimization software such as ViPOR. In table 1, column 1 corresponds to serial number, and column 2 corresponds to the name of each node. In the real system, each node can be represented by the village name for an easy identification. Voltage level of each node is given in column 3 and the real and reactive power loads are given in columns 4 and 5, respectively. Column 6, the last column represents the total MVA load of the system, which can be calculated by equation (3).

$$Z = \sqrt{X^2 + Y^2} \qquad (3)$$

**Table 1:** Input (Load Data)

| Number | Name | V level kV | X (MW) | Y (MVar) | Z (MVA) |
|---|---|---|---|---|---|
| 1 | One | 22 | 1 | 0.2 | 1.02 |
| 2 | Two | 22 | 1 | 0.2 | 1.02 |
| 3 | Three | 22 | 1 | 0.2 | 1.02 |
| 4 | Four | 22 | 1 | 0.2 | 1.02 |
| 5 | Five | 22 | 1 | 0.5 | 1.12 |
| 6 | Six | 22 | 1 | 0.1 | 1.00 |

The other important information needed for load flow solutions are generation or "source" or data (table 2). For this, information like minimum and minimum real and reactive power generation capability of various generators in the network should be specified. In the case of wind power plant option the reactive power generation is zero since wind power generation option uses induction machines for generating electricity. If the reactive power support from other machines is difficult to obtain to support the wind turbines in the network, capacitors can be added at the wind turbine location.

In table 2, column 2 corresponds to name of various generation nodes. Columns 3 and 4 represents the real and reactive power generations. Minimum and maximum real power generations of various power plants are given in column 7 and 8, respectively.

**Table 2:** Input (Generation and Source Data)

| Number | Name | Gen MW | Gen Mvar | Set Volt | Min MW | Max MW | Min Mvar | Min Mvar |
|---|---|---|---|---|---|---|---|---|
| 1 | One | 0.41 | -4.93 | 1.02 | 1 | 5 | -99999 | 99999 |
| 2 | Two | 2 | 2 | 1.04 | 1 | 2.5 | -1 | 2 |
| 3 | Three | 0.6 | -1 | 1.01 | 1 | 2.5 | -1 | 2 |
| 4 | Four | 3 | 2 | 1.03 | 1 | 2.5 | -1 | 2 |

The line and transformer data are also needed for the load flow simulation. The minimum information required on transmission lines and transformers is given in table 3. Columns 2 and 3 correspond to name of the "From node" where the transmission line is originating from and to name of "To node" where the line ends, respectively. Columns R (resistance), X (series reactance) and B (shunt reactance) correspond to transmission line parameters.

**Table 3:** Input (Line and Transformer Data)

| From Number | From Name | To Number | To Name | Circuit | Xfrmr | R | X | B |
|---|---|---|---|---|---|---|---|---|
| 1 | One | 2 | Two | 1 | No | 0.04 | 0.08 | 0.002 |
| 1 | One | 5 | Five | 1 | No | 0.04 | 0.08 | 0.002 |
| 2 | Two | 4 | Four | 1 | No | 0.04 | 0.08 | 0.002 |
| 3 | Three | 5 | Five | 1 | No | 0.04 | 0.08 | 0.002 |
| 3 | Three | 6 | Six | 1 | No | 0.04 | 0.08 | 0.002 |
| 5 | Five | 4 | Four | 1 | No | 0.04 | 0.08 | 0.002 |
| 6 | Six | 4 | Four | 1 | No | 0.04 | 0.08 | 0.02 |

## 2.3 Building a Network for Simulation

In order to build a power distribution network for simulation, one has to work in the "edit mode". Input data such as generators, transformers, transmission lines, loads and other compensation devices can be inserted using the "Insert" menu. Inserting any element in the network will open up a small window for that particular element where all the data related to the element have to be input.

Once the network is built completely, the program can be switched to run mode and the simulation of power flow can be started.

## 2.4 Building a Network for Simulation

Figure 2 shows the single line diagram of the sample network obtained by running the power flow program. Various outputs from the power flow solution can be displayed in the one line diagram and the output can also be extracted in the form of Excel sheets. The various outputs that could be displayed in the network include voltage magnitudes at various nodes, real and reactive power generation at source nodes, line flows etc. ore details of output are discussed in the next section.

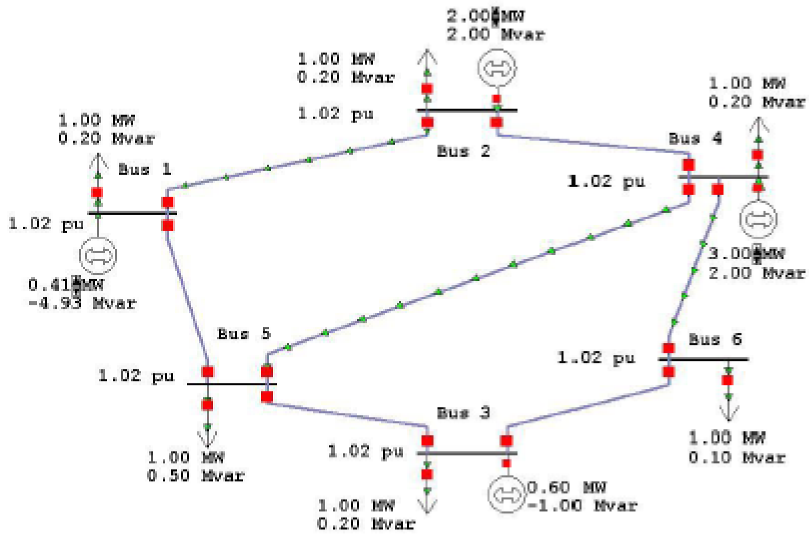



**Figure 2:** Single line diagram of the provincial rural electrification network, after load flow run

### 2.5 Building a Network for Simulation

In addition to the displayed output in the single line diagram, most of the output can be exported into Excel sheets as shown in Tables 4 and 5.

Table 4 gives a summary of voltage magnitude, phase angle, real, reactive power loads, and real and reactive power generation at various generation nodes. These results can be analyzed further to see if there is any violation of allowable voltage limits.

In this particular example, as can be seen from column 4 in table 4, none of the voltages has gone below or above the acceptable limit of ± 5 percent from the nominal value of 1.00p.u. (1.00p.u corresponds to 22kV). Total generation required to supply all the loads in the network is 6.1MW and -1.93Mvar. The negative reactive generation means that the network is generating reactive power due to the shunt capacitance of transmission line and this often happen in the lightly loaded system conditions.

**Table 4**: Output (Generations and Voltage Information at Various Nodes)

| Number | Name | Nom kV | PU Volt | Volt (kV) | Angle (Deg) | Load MW | Load Mvar | Gen MW | Gen Mvar |
|---|---|---|---|---|---|---|---|---|---|
| 1 | One | 22 | 1.02 | 22.44 | 0 | 1 | 0.2 | 0.41 | -4.93 |
| 2 | Two | 22 | 1.02264 | 22.498 | -0.03 | 1 | 0.2 | 2 | 2 |
| 3 | Three | 22 | 1.0216 | 22.475 | -0.07 | 1 | 0.2 | 0.6 | -1 |
| 4 | Four | 22 | 1.02331 | 22.513 | -0.05 | 1 | 0.2 | 3 | 2 |
| 5 | Five | 22 | 1.02146 | 22.472 | -0.06 | 1 | 0.5 | | |
| 6 | Six | 22 | 1.02267 | 22.499 | -0.1 | 1 | 0.1 | | |

Table 5 shows some outputs related to transmission lines, including real, reactive power flows, %NVA line loading, real and reactive power losses. In this example, there is no serious violation of voltage, line losses or line flow limits. However, the Mvar losses are negative because of the reasons give in the previous section.

**Table 5:** Output (Line Power Flow and Losses)

| From Number | From Name | To Number | To Name | From MW | From Mvar | From MVA | % of MVA Limit (Max) | MW Loss | Mvar Loss |
|---|---|---|---|---|---|---|---|---|---|
| 1 | One | 2 | Two | -0.9 | -3 | 3.2 | 3.2 | 0 | -0.2 |
| 1 | One | 5 | Five | 0.3 | -2.1 | 2.1 | 2.1 | 0 | -0.21 |
| 2 | Two | 4 | Four | 0.1 | -1 | 1 | 1 | 0 | -0.21 |
| 3 | Three | 5 | Five | -0.3 | 0.2 | 0.3 | 0.5 | 0 | -0.21 |
| 3 | Three | 6 | Six | -0.1 | -1.4 | 1.4 | 1.4 | 0 | -0.21 |
| 5 | Five | 4 | Four | -1 | -2 | 2.2 | 2.2 | 0 | -0.21 |
| 6 | Six | 4 | Four | -1.1 | -1.3 | 1.7 | 1.7 | 0 | -2.09 |